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Table of Contents

Clean Sky 2 "Thematic Topics" Special Session (PART I) 18

LEAFINNOX: A novel low-NOx, low-soot aviation combustor concept based on MILD combustion principles 18

CHAIRLIFT: Compact Helical Arranged combustoRs with lean LIFTed flames 18

Impact of stationary and transient factors on the NOx formation in stimulated flames 19

Progress and first results in the study of the pilot-IA collaboration in SPO 19

Socio-Technical Simulation Model to identify PF-PM supporting tools requirements in a SPO framework 20

Clean Sky 2 "Thematic Topics" Special Session (PART II) 20

HARVIS project: Human Aircraft Roadmap for Virtual Intelligent System 20

Highly iterative concept development for requirement-compliant air taxis 21

Production-based description of air taxi archetypes by function-based, constitutive components and a bill of materials 22

UNIFIER19: From TLAR to a winner of a concurrent conceptual design competition 22

The impact of propulsive architecture on the design of a 19-passenger hybrid-electric aircraft 23

Clean Sky 2 "Thematic Topics" Special Session (PART III) 24

Recent Achievements in the Design of Ultra High Aspect Ratio Wings of Environmentally Friendly Aircraft 24

Aerodynamic Analysis of a scaled UHBR Fan 25

The UHBR Fan ECL-5 CATANA - An open-test-case for aerodynamics, aeroelastics and aeroacoustics 26

The VENUS project: Investigation of Distributed Propulsion Noise and its Mitigation through Wind Tunnel Experiments and Numerical Simulations 26

SINATRA: Seeding-free, non-intrusive aero engine distortion measurements – Project updates 27

Clean Sky 2 "Thematic Topics" Special Session (PART IV) 28

CleanSky2 SOLIFLY - Developing structural batteries towards aeronautic application 29

MW-class HTS electric motor for regional aircraft propulsion 29

DCADE - Diamond Converter and Arc fault DEtection for high-altitude operations 30

Credible Hybrid Electric Aircraft – CHYLA project overview and objectives 30

An Overview of the Scalability Investigation of hybrid Electric concepts for Next-generation Aircraft (SIENA) project 31

The preliminary design of a Low Transonic Fan made of composite material, test article of an innovative WT test campaign to measure aerodynamic, aeroelastic and aeroacoustics advances in UHBR Turbofan engines 31

Design of Hybrid-Electric Small Air Transports 32
Clean Sky 2 "Technology Evaluator" Special Session (PART I) 35
Clean Sky 2 Technology Evaluator Mission Level Introduction 35
Environmental Impacts of CS2 Technologies for Next Large Passenger Aircraft 36
Clea Sky 2 - Regional Aircraft 37
Improvement of European thin haul mobility: the role of small Green commuter aircraft 38
Clean Sky 2 "Technology Evaluator" Special Session (PART II) 39
Low Sweep Business Jet 2035 Mission Level Assessment Results 39
The NGCTR (Next Generation Civil Tilt-Rotor): faster, farther, cleaner 40
Airport-level assessments in Clean Sky 2 TE (CLAIRPORT / GREENPORT2050) 41
Design Evaluation and Performance Assessment of Fast Rotorcraft Concepts for 2050 41
Results on ATS level assessments (ac) 42
Overall Air Transport System Vehicle Scenarios (OASyS) – Commercial Supersonic, Business Supersonic, and Urban Air Mobility Forecasts 42
Clean Sky 2 "Technology Evaluator" Special Session (PART III) 43
TeDiMo - Developing a diffusion model for prediction of technology propagation into the aviation market 43
GLIMPSE2050: Regulations & Policies 43
Review of novel propulsion technologies for sustainable aviation from TRANSCEND 44
Review of alternative fuels for sustainable aviation from TRANSCEND 44
GLOWOPT: Development of climate functions for aircraft design 45
Reducing emissions through fleet and flight network optimisation – the Clean Sky project REIVON 45
Aerodynamic Analysis & Design (PART I) 47
Development of the ritz polynomial method for solving aeroelasticity problems 47
Numerical analysis of cyclorotor aerodynamic properties in hovering state 47
Ground effect aerodynamics of twin fuselage aircraft 48
Experimental Investigation of the Performance and Flow Field of a Propeller in both Propulsive and Regenerative Conditions 48
A CFD/experimental comparative database to feed a predictive model for ground vortex characteristics 51
Aerodynamic Analysis & Design (PART II) 52
An accurate RANS-based transition prediction approach (part I) 52
An accurate RANS-based transition prediction approach (part II) 52
Cross-effect between realistic aerodynamic loads and blade deformation on VTOL propellers 53

Relying on Dynamically Morphing Blades to Increase the Efficiency of a Cycloidal Rotor 54
Preliminary design of a small-scale, fixed-wing BWB UAV supporting a Cooperative-Intelligent Transport System for highway traffic-monitoring 54
Aerodynamic assessment of the use of tubercles and wing fences on a fixed-wing, tactical Blended-Wing-Body UAV platform 55
Aerodynamic Analysis & Design (PART III) 55
Limitations of modern hybrid RANS-LES models for transitional flows at low Reynolds numbers and acoustics 55
Multifidelity constrained bayesian optimization, application to drone design 56
Benchmark of different aerodynamic solvers on wing aero-propulsive interactions 56
Open source CFD methodology for preliminary aircraft design analysis 56
Multi-fidelity weight analyses for high aspect ratio strut-braced wings preliminary design 57
Junction flow and nacelle wing interaction on a pusher motorized sailplane configuration 57
ARTEM project (PART I) 58
Noise Reduction Technologies for Future Aircraft Concepts – an introduction to the H2020 project "ARTEM" 58
Slanted Septum Core and Multiple Folded Cavity Liner concepts for broadband sound absorption: A Numerical and experimental evaluation 58
Implementation of a Zero Massflow Liner: From concept to prototype 59
Innovative liner concept using friction powder for increasing of broadband noise absorption. Applications for broadband noise absorption in fan duct, reduction of jet noise reflected by wing pressure side and noise reduction in aircraft cabin 59
A novel active acoustic liner based on corona discharge 60
Innovative liners based on optimized metasurfaces 60
ARTEM project (PART II) 61
A comprehensive and consistent design-to-noise study of high-lift profiles and their noise reduction potential 61
Reducing trailing edge noise with the application of finlets on NACA aerofoils 62
Installed jet noise of elliptical nozzles 62
Plasma based active noise control of an excited jet interacting with a plate 62
Numerical analysis of fan noise for the NOVA boundary-layer ingestion configuration 63
Mid-fidelity aeroacoustic modelling and measurements of pusher and tractor generic Distributed Electric Propulsion systems 63
ARTEM project (PART III) 64
Parametric investigation of aeroacoustic installation effects in a Distributed Electric Propulsion system 64

Prediction of Fan Tone Radiation Scattered by A Cylindrical Fuselage 66
Diffraction of sound radiated from a cylindrical duct in the application to the problem of engine noise shielding 67
RDO of a regional transport with distributed, hybrid gas-electric propulsion under low-noise constraints 67
Aeroacoustic assessment of a blended wing configuration with distributed electred propellers 68
Junction flow and nacelle wing interaction on a pusher motorized sailplane configuration 68
FUTPRINT50 project 69
System Architectures for the Thermal Management of HEA – FUTPRINT 50 69
Hybrid-Electric Architectures and Their Influence on Aircraft Design 69
A reduced battery system model and sizing algorithm for future hybrid electric airplanes architectures studies 69
Application of Probabilistic principles to Set-Based Design for the optimisation of a hybrid-electric propulsion gas turbine 70
Graphene Technology for Design Efficiency of the Solar Hybrid Electrical Cryoplane and Airships 70
Optimal Cryogenic System for Hybrid Electric Propulsion Aircraft/Airship with LH2 and High Temperature Superconductor 71
IMOTHEP European project: a holistic approach to hybrid electric propulsion 71
FUTPRINT50 Academy (Part I) 71
Development, modelling and analysis of the thermal management system for a hybrid electric propulsion system of regional aircraft 71
FUTPRINT50 Academy (Part II) 72
A preliminary study into the impact of electrification on the sizing requirements and performance of a turbofan engine 72
High speed flows technologies for future aviation and space programs 72
Demonstrator for Technologies Validation (DTV) GNC design in-flight testing 72
Reactive model based on hydrogen peroxide engine at INCAS Supersonic Wind Tunnel for single stage to orbit studies 73
Exploring methods for supersonic ramp intake optimization with RANS cross checking 73
Sonic Boom Evaluation from Blowbown Wind Tunnel Data 74
Bionic Structures for Comfort and Safety of Future Civil Aircrafts 75
Investigation of non-regular grids for lattice fuselage barrels for increase of comfort 75
Optimization method of composite truss rod structure with advanced reliability 75
Algorithm of searching of design loading cases of airframe of perspective civil aircraft 76

Novel unidirectional CFRP aircraft lattice fuselage LVI protection with the use of foamed thermoplastic 76
Human Factors 77
Support Team Assignment for Base Maintenance of Aircraft Fleet: a Case Study 77
How much workload is workload? A human neurophysiological and affective - cognitive performance measurement methodology for Air Traffic Controllers 77
Usability studies for workload assessment in remotely piloted aircraft systems 78
ecoDESIGN and Sustainable Productivity (PART I) 80
ecoDESIGN and Sustainable Productivity 80
ecoDESIGN in Next Generation Aircraft Fuselage 80
ECO-CLIP: circular economy from factory waste material towards aircraft structural components 80
Sustainable management of End of Life of Aircraft Composite Structures 80
Replacement of Hard Chrome Plating on Steel 81
ecoDESIGN and Sustainable Productivity (PART II) 81
Assessment of the impact of material selection on aviation sustainability 81
Key environmental indicators for the aircraft manufacturing industry 83
DIGESTAIR – a novel anaerobic digester solution in air transport for on board safe and efficient waste management: first results 83
Project GENESIS – Gauging the environmental sustainability of electric and hybrid aircraft 84
Validation of the zonal model for an Environmentally Friendly Aircraft Cargo Fire Protection System with containerized load 84
ecoDESIGN and Sustainable Productivity (PART III) 85
Life Cycle Inventories for Engine Blisk LCA 85
Environmental analysis of blisk manufacturing 85
Industrialization of CFRP Re-Use and Recycling 86
Innovative test methodology for shelf-life extension of carbon fibre prepregs 86
New Intelligent Semi-Products based on recycled carbon fibre 86
2D-material based devices for innovation in Aviation & Space: from modeling to experimental results 88
The effect of fabrication tolerances on the high-frequency performance of Graphene-Field Effect Transistors 88
Electro-thermal modeling and characterization of Graphene Nano-Platelets films for de-icing applications 88
Graphene-based analogue phase shifters for phased array antennas in aerospace/aeronautical applications 89

On a new generation of sensors for Aerospace applications: optimization of preparation methodology and preliminary tests 89
Cubesat satellite patch antenna designed with 3D printable materials: a numerical analysis 92
Design of self-responsive composites for aeronautical applications (PART I) 94
Role of Graphene-based Nanoparticles on the Resistance of Aeronautical Epoxy Coatings to Sunlight and Corrosion 94
Development of Epoxy Resin Composites with De-Icing Properties 95
Aircraft De-Icing Strategies based on Recent Developments in the Nanotechnology Field 95
The role of POSS symmetry in polymer matrix dispersion 96
Biocompatible hybrid materials synthesized via sol-gel for aerospace applications 96
Innovative self-responsive composites for aeronautical applications through Sol-Gel chemistry 96
Design of self-responsive composites for aeronautical applications (PART II) 98
Multifunctionality of supramolecular self-healing aeronautical nanocomposites 98
Self-Healing Certification Challenge for Advanced Structures in Aeronautics 99
Thermal profiling of self-healing process simulating flight conditions. A solid-state NMR study. 100
Self-healing composites material via hydrogen bonding interactions 101
Multi-material design & function integration of advanced sensors & actuators in composites 101
A digital-based design methodology for the optimization of high-performance multi-material structures 101
Intrinsic interfaces between additively manufactured metal and composite structures for use in electric propulsion engines 102
Geometric features of carbon-based nanomaterials for advanced sensing in composites 102
Air Traffic Management (ATM) & Airports (PART I) 103
Analysis of vulnerability of ATM to weather phenomena 103
Machine Learning classification techniques applied to static air traffic conflict detection 103
Drone safe-landing with real-time route optimization 104
Safety Performance Functions to predict Separation Minima Infringements in en-route airspace 104
Dynamic sector characterisation model with the application of machine learning techniques 105
Cross-border Free Route Airspace concept and its impact on flight efficiency improvement 106
A performance-oriented path planning algorithm for unmanned aerial vehicles based on bit-coded flight maneuvers 107
Air Traffic Management (ATM) & Airports (PART II) 107
Regulatory Framework on the UAM Operational Concepts of the ASSURED-UAM Project 107
Managing Airport Capacity and Demand: an Economic Approach 108

Acoustic impact of Capodichino airport by the use of the AEDT software 109
Protecting Aviation Safety Against Cybersecurity Threats 109
Reduction the turbulence impact on an aircraft in the flight planning process 110
Influence of airspace avoidance due to political and safety issues on flight efficiency and environment 110
Non-destructive testing of aerospace components / Optimising Design for Inspection 111
Structural Health Monitoring of Multi-layered CFRP Panel Using Ultrasonic Guided Waves 111
Finite Element Modeling and Analysis of Representative Wing Structure for Structural Health Monitoring Puposes 112
Monitoring ice in fuel tanks and on aircraft fuselages by means of acoustic emission 112
Sigmoidal sensing devices for simplified data interpretation and enhanced robustness in Structural Health Monitoring of aircraft 113
Sensitivity analysis of non-destructive technique for determination of material properties in reinforced laminated composite plate 113
Damage Detection in Aircraft Structural Components Using Acoustic Technologies 114
A Semi-supervised Deep Learning Method for Helicopter Anomaly Detection 115
Next generation multifunctional and intelligent airframe & engine parts: manufacturing, maintenance, recycling: DOMMINIO, SUSTAINair, MORPHO joint session 117
DOMMINIO: Digital Method for Improved Manufacturing of Next-Generation Multifunctional Airframe Parts 117
SUSTAINair: SUSTAINablility increase of lightweight, multifunctional and intelligent airframe and engine parts 117
SLOWD project 119
Flexible Aircraft Wings with Fuel Slosh Effects 119
Experiments and scaling effects in the context of a SDOF vertical sloshing problem 119
Computing Aircraft Fuel Slosh Induced Dissipation via a Volume-of-Fluid Formulation 120
Nonlinear sloshing integrated aeroelastic analyses of a research wing prototype 120
Statistical analysis of sloshing-induced dissipative energy across a range of Froude numbers 120
Prediction of energy dissipation in violent 3D sloshing flows by Smoothed Particle Hydrodynamics 121
Smoothed particle hydrodynamics based reduced order model for sloshing analysis 121
Space Technologies (Part I) 123
HERA Mission LIDAR Mechanical and Optical Design 123
Comparison of thermal protection systems for reusable microlaunchers 123
CubeSat satellite patch antenna designed with 3D printable materials: a numerical analysis 124

Space Technologies (Part II) 125
PERIOD – PERASPERA In-Orbit Demonstration toward the transition into the in-space services, assembly and manufacturing paradigm 125
Fully Modular Robotic Arm Architecture Utilizing Novel Multifunctional Space Interface 126
Achieving Payload and AIT Flexibility by Separating Satellite Bus and Payload Unit 126
Structural Design of a reusable microlauncher first stage 127
Presentation of the MoonFibre Project: Recent Developments 128
R&D Research in the Field of Aeronautics & Air Transport: ACACIA, ClimOP, GREAT, ALTERNATE Joint Session 129
ACACIA: Developing improved understanding on aviation's climate impact 129
Non-CO2 Impacts of Aviation 130
Occurrences of natural and contrail cirrus and their microphysical properties observed from in-situ measurements 130
ClimOP Project – Climate assessment of innovative mitigation strategies towards operational improvements in aviation 131
The analysis of NOx-ozone effects from optimised air-traffic using algorithmic climate change functions 132
Remotely Piloted Aircraft Systems: SESAR Joint session of INVIRCAT, URClearED, CORUS-XUAM, PJ13 & SAFELAND projects 133
INVIRCAT – A concept of operations to efficiently integrate IFR RPAS into the TMA 133
URClearED – A well clear concept for integration of certified RPAS in airspace classes D-G 133
CORUS-XUAM: tackling the airspace integration challenges of Urban Air Mobility 134
The ERICA project: another step toward the integration of RPAS into the civil airspace 135
SAFELAND: managing in-flight incapacitation in single pilot operations 135
Innovative applications of drones: Drones4Safety, Labyrinth, 5D-AeroSafe & RAPID joint session 136
EU project Labyrinth (Unmanned Traffic Management 4D Path Planning Technologies for Drone Safety and Security in Transport EU project Labyrinth 136
Towards Validation of Drone Embedded “Sense and Detect” Hazard Perception 137
Inspection Drones for Ensuring Safety in Transport Infrastructures 138
Applications offered by 5D-AeroSafe project for airports and waterways safety 138
Hybrid Electric Flight: PART I - Distributed propulsion 139
Wing structural model for electric distributed propulsion GA/Regional aircraft 139
Structural and aerodynamic analysis of wing distributed electric propulsion for potential wing replacement of conventional aircraft 139
Energy consumption and environmental impact of urban air mobility 140

Aeroelastic assessment of distributed electric propulsion wings 140
Evaluation of the prospects of distributed electric and hybrid propulsion systems utilization on commuter aircraft 141
Design of near-zero emission aircraft based on refined aerodynamic model and structural analysis 141
Hybrid Electric Flight: PART II - Hybrid electric powertrains 142
Optimal sizing of hybrid electric propulsion system for eVTOL 142
Comprehensive studies of the characteristics of a hybrid propulsion system 142
First Principle Model of an Electric ECS Pack 142
An optimized strategy for the Power Management Unit on a More Electric Aircraft 143
Certification Gap Analysis for Distributed Electric Propulsion Airplane in EASA CS-23 category 143
Layout and Testing of Serial Hybrid Electric Powertrain for Light Twin Demonstrator Platform with Jet Fuel and Hydrogen Fuel Cell Application 144
Aircraft Testing 145
A motorized and remotely controlled Horizontal Tailplane for efficient WT testing 145
Static Structural Behaviour of Composite Beam for Carrying Electric Propulsion Systems 145
Vibration testing and modal analysis of the e-Genius-Mod 146
Gappy pod methodology applied to select the worst design limit load conditions for the wing of a civil tilt-rotor 146
Investigation of the impact of a particle foam insulation on frost buildup on the aircraft structure 147
Development of an innovative noise generation system for turboprop aircraft fuselage testing ... 147
JETSCREEN project 148
JETSCREEN project: Achievements towards fueling the future of aviation 148
The impact of fuel chemical composition on the products of incomplete combustion in an APU gas turbine engine 148
Development of a JETSCREEN model for the prediction of Seal Swell in Sustainable Aviation Fuels 149
Development of a JETSCREEN model for the prediction of Thermal Stability in Sustainable Aviation Fuels 149
Kinetic modeling of jet fuel combustion, from fuel characterization to pollutants formation 150
Using machine learning to predict the quantity of a fuel sorbed into a polymer 151
Aircraft Design 152
Fully automated piping in an Airbus A320 landing gear bay using graph-based design languages . 152
Creation of Innovative Concepts in Aerospace based on the Morphological Approach 153

Parametric Studies on Tank Integration for Hydrogen Jet Engines 153
Spectral project - application of FAST-OAD code to the conceptual design of hydrogen fueled commercial aircraft 154
Conceptual design of a fixed wing hybrid UAV UUV platform 154
Flight Testing of Wing Tip Propellers - Review of the Flight Test Results 155
Regional jet retrofitting through multidisciplinary aircraft design 155
Advanced Manufacturing Technology for Aeronautics (PART I) 156
Design of composite aircraft flight control surfaces supported by virtual allowables approach: prediction of hybrid-laminate mechanical behaviour in manufacturing variability contest 156
Development of innovative technologies for manufacturing of certified narrow body aircraft composite flap 156
Numerical and experimental investigation into laser-metal-deposition based additive manufacturing with difficult-to-machine materials 157
Compressive properties of additively manufactured PETG composites reinforced with different fibres 157
PADICTON – Part distortion prediction, design for minimized distortion, additive manufactured polymer aerospace parts 158
Prediction of thermo-mechanic effects through numerical simulation of induction heating of thermoplastic composites 158
Principle and strategy of 'Design for Recycling' for energy harvesters 159
Advanced Manufacturing Technology for Aeronautics (PART II) 159
Innovative tooling and end-effectors for multifunctional thermoplastic fuselage components welding 159
Fabrication of micro-components through Micro-FAST 160
ELADINE: sensor monitoring and numerical model approach for composite material wing box shape distorsions prediction 160
Digital Image Correlation enhanced three point bending material test system 161
Process and energy efficiency in aeronautic production through smart industry implementation 161
Optimization of the induction welding process through the integration of a thermal camera 162
Development a high precision hybrid machining processes for superhydrophobic on epoxy painting materials adhering to an aluminum alloy 162
Advanced Manufacturing Technology for Aeronautics (PART III) 163
Design methods and manufacturing techniques applicable for constructing dynamically scaled airplane models 163
Particle foam molded cores in a one-shot resin infusion process for high-rate production of wing moveables 164

Friction stir welding trade-off studies on a tilt rotor nacelle primary structure 165
Simulating the Induction Welding Process of thermoplastic composite materials for aircraft structures 165
Evaluation of nitrogen permeability properties of thermoplastic composite materials for the production of next generation aircraft pressure vessels 167
STRATOFLY project 168
Main achievements of the H2020 STRATOFLY PROJECT 168
Large eddy simulation of the STRATOFLY small scale flight experiment 168
Computational Evaluations of Emissions Indexes Released by the STRATOFLY Air-Breathing Combined Propulsive System 169
Aerodynamic Characterization of the Hypersonic Civil Aircraft STRATOFLY-MR3 169
The Climate Impact of Hypersonic Transport 170
Integrated subsystems design for the STRATOFLY MR3 vehicle 170
Recent advances on developing civil supersonic aircrafts 172
Bionic structure and new capabilities to provide safety and high level of comfort for the new generation of supersonic passenger aircrafts 172
Effect of nozzle geometry on acoustic characteristics of isolated and installed turbulent jets 172
Supersonic Platform Specifications for SENECA Project 173
Goals, tasks and technic concept of Russian flight civil supersonic jet technology demonstrator .. 174
Development of computer code and calculation of the propagation of sonic boom to the ground in a real atmosphere 174
Design solutions synthesis at advanced supersonic passenger aircraft preliminary aerodynamic design under parametric epistemic uncertainty conditions 174
MORE&LESS Academy 176
LTO noise prediction methodology for SST aircraft conceptual design 176
Mission analysis activities for the conceptual design of high-speed transportation systems 176
AeroTermO: Implementation of Genetic Algorithms for Supersonic Airfoil Optimization 177
GreenHawk3: mach 3 biofuel supersonic business jet 178
Design of supersonic and hybrid engine based advanced rocket (SHAR) 178
EPIC SRC projects joint session: iFACT, NEMESIS, GIESEPP, EDDA 180
iodine Fed Advanced Cusp Field Thruster - iFACT 180
Key design and operation factors for high performance of C12A7: e-based cathodes 180
Performance comparison of LaB6 and C12A7: e-ceramics for space EP cathodes 181
GIESEPP – Gridded Ion Engine Standardized Electric Propulsion Platforms: Going Green in Space 181
Direct-Drive Architecture for Solar Electric Propulsion 181

Systems / Prognostics / Safety (PART I) 183
Model-based prognosis for spalling identification in a flight EMA with differential ball-screws 183
Model validation for a transient ECS failure case in a business jet mock-up 183
Real Estate Advisory Drone (READ): system for autonomous indoor space appraisals, based on Computer Vision and Visual Inertial Odometry techniques 184
UAV-based high resolution image processing for hydro-geomorphological high-risk area monitoring 184
Enabling In-Flight Connectivity with the new Generation of Electronically Steered Antennas 185
Fault-tolerant control via four-leg converter of a full-electric propulsion system for lightweight fixed-wing UAVs 185
Systems / Prognostics / Safety (PART II) 186
Vibration based SHM analysis for an unmanned rotor vehicle 186
Simulation of runway irregularities in a landing gear test rig 186
The thermal control system of NASA's Curiosity rover: a case study 187
Analytical Design of Conventional and Electrical Aircraft Environmental Control Systems 187
Digital twins for prognostics of electro-hydraulic actuators: novel simplified fluid dynamic models for aerospace valves 188
A novel model-based metaheuristic method for prognostics of aerospace electromechanical actuators equipped with PMSM 188
New active monitoring techniques for asymmetry control of flap actuation systems 189
Small Air Transport (SAT) Technologies (PART I) 190
Cost Optimized Avionics System - Navigation Solution for Small Aircraft Transportation Segment 190
Enabling SAT single pilot operations: Tactical Separation System design advancements in the COAST Project 190
Design Advancements for an Integrated Mission Management System for Small Air Transport vehicles in the COAST project 191
Latest developments in AWAS: the Advanced Weather Awareness System in the COAST Project . 192
Experimental verification of the emergency destination definition in Flight Reconfiguration System in the COAST project 192
Cost-Optimized Avionics System - Surveillance Solution with Radar for Small Aircraft Transportation Segment 193
Small Air Transport (SAT) Technologies (PART II) 194
Derivation of top-level aircraft requirements for small aircraft transport by modelling demand in Europe 194
Ground and flight tests of the composite engine nacelle developed in the SAT-AM (Clean Sky 2) project 194

CFD wind tunnel assessment on the case-study of the MOTHIF blown flap 194
Flight Control 196
Automatic approach with the usage of runway light systems 196
Comparison of selected algorithms for estimating the angle of attack of a transport airplane - flight simulations 196
Take-off phase control algorithm for general aviation light aircraft 197
Unmanned helicopter flight control actuator specification through mission profile analysis 197
From sensors to onboard systems 198
The TecALSens Project: New solutions for load sensors in aeronautics 198
Flight test verification of automatic stabilisation system using aircraft trimming surfaces 199
Onboard computer controlling the flight stabilisation system with the use of trimmers 199
Optimal flight trajectory synthesis for an anti-collision maneouvre performed within environment of moving obstacles 200
Impact of sensors excellence on the accuracy of tactical guided missiles 200
The impact of sensor errors on flight stability 200
MAHEPA project (PART I) 202
Flying hybrid with the MAHEPA project: challenges, achievements and future scenarios 202
Hybrid-electric power-train modelling for airplane performance analysis and sizing 202
Conceptual studies of hybrid-electric passenger airplanes 202
Impact of Distributed Propulsion on the Design of a Hybrid Electric Aircraft 203
Optimal power management and mission profile for a Hybrid Aircraft 203
Electrical machines: design principles and main aspects 204
MAHEPA project (PART II) 204
Development, Testing and Integration of a new Power Management Control and Delivery Module for a Hybrid Electric Aircraft 204
Exhaust Emission Measurements Applicable to the Hybrid Panthera: Emission Mapping for the EU project MAHEPA 205
Safe, redundant and efficient Hydrogen Fuel Cell System powertrain for electric aircraft applications 205
How to fly hybrid-electric: MAHEPA flight test experience 206
Ground infrastructure investments for operation of hybrid-electric aircraft 206
Strategy for hybrid-electric short-haul air transportation 206
AIRPOXY project 208
AIRPOXY: Thermoformable, repairable and bondable smart epoxy based composites for aero structures 208

Design of high performance 3R vitrimers and 3R adhesives for Aerospace industry: Development, Applications and Future trends 208
Bonding strategies for dynamic 3R-resin in functionalized composites surfaces made by the SQRTM process 209
Manufacturing, thermoforming and mechanical characterization of 3R-composites 210
Evaluation of repair efficiency on 3R polymers & composites using mechanical and NDE tests 211
Numerical Analysis & Virtual Testing of aircraft structures 212
Numerical parametric study of the laser-shock paint stripping on aerospace aluminum substrates 212
Towards simulation of disassembly of bonded composite parts using the laser shock technique .. 212
Numerical structural analysis of composite nose landing gear for UAV 213
Virtual test approach of titanium/composite repair in service, installed on certified narrow body aircraft composite structure flap 213
Analysis of the application of fuselage skin reinforcements with beam element representations in flexible full aircraft models for ditching simulations 213
Automatic tool-based pre-processing of generic structural models for water impact simulations in the aircraft pre-design 214
Novel approaches on aeronautical composite materials 216
Development of a novel hybrid thermoplastic material and holistic assessment of its application potential 216
Influence of polymer indicator coating thickness on damage tolerance and residual strength of composite material 217
Influence of preloading cyclic bending on the residual strength and stiffness of a composite material 217
Ballistic impact response of reinforced honeycomb sandwich panels 217
Determination and Validation of Low Velocity Impact Behavior of GLARE for Different Energy Levels and Specimen Thicknesses 218
Effect of Temperature on Low Velocity Impact Behavior of GLARE Material 218
European Policy Actions in the Field of Aviation & Space 220
The Learn & Fly Project: Increasing Students Interest in STEM Through Aeronautics 220
Policy actions within the aerospace projects developments. Particular case: RoRCraft fuselage manufacturing for RACER Demonstrator 220
Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM - Outline of H2020 CSA Project 221
InnEO'Space PhD: Preparing Young Researchers for a successful career on Earth Observation applications 222

ENABLEH2 project 223
Enabling Cryogenic Hydrogen-based CO2-free Air Transport (ENABLEH2) 223
Heat Management Opportunities in Hydrogen Fuelled Gas Turbine Engines 223
Advances in numerical and experimental research of hydrogen micromix low emissions combustion systems 224
Modelling studies of the hazards posed by liquid hydrogen use in civil aviation 224
Understanding infrastructure and operational challenges generated by alternative energy aircraft 225
Enabling Cryogenic Hydrogen-Based CO2-free air transport: Technology Evaluation and Road Map to Accelerate Entry into Service 225
Propulsion (PART I) 227
Health Monitoring, Fault Diagnostics and Failure Prediction for Fuel Cells in Aviation 227
Initial Assessment of a Fuel Cell – Gas Turbine Hybrid Propulsion Concept 227
Revamping of a high-pressure centrifugal compressor stage - a numerical case study 228
Study of cavitation phenomena in a directional spool valve by means of Chaos Theory 228
Analysis of working fluids applicable for high-temperature loop heat pipe applications 229
Piston Engine Modelling for Hydrogen Fueled Composite Cycle Engines 229
Propulsion (PART II) 230
Specific Aspects in Numerical Simulation of Complex Processes in Gas Turbine Engine Bearing Chamber 230
Full electric and Hybrid powertrain: the AI challenge and the real environmental choice 231
Ventilation Analysis of Simplified Engine Nacelle for Pusher Configuration Aircraft 231
Development of a combined Artificial Neural Network & Principal COmponent Analysis technique for Engine Health Monitoring 232
Development of plasma assisted actuators for re-ignition of aeroengine under high altitude conditions 232
Model-based dynamic performance simulation of a microturbine 233
Trade-off studies between NOx and CO2 to evaluate the future development strategies for aircraft engine 234
AI and future scenarios in aviation 235
Integrated approaches of Machine Learning and engine data to evaluate spare parts request for aircraft engines 235
A Hybrid Approach of Machine Learning and Expert Knowledge for Projection of Aircraft Operability 235
GRETEL: sustainable aircraft technologies for green Turboprop configuration 237

GRETEL lifts up: sustainable solutions for rapid integration of new technologies 237
An efficient optimization scheme for the preliminary sizing of composite aircraft wings 237
Instrumentation and Ground Testing of a Composite Elastic Wing Wind Tunnel Model 238
An efficient optimization scheme for the preliminary sizing of composite aircraft wings 238
Manufacturing, Assembly and Integration of a Large Scale Composite Wing Wind Tunnel Model and the Design and Implementation of an associated Measurement System 239
HYFLEXFUEL project 241
The HyFlexFuel project: A perspective to flexible production of sustainable jet fuel from a broad feedstock base 241
Quantification of European biomass potentials and identification of preference regions for sustainable aviation fuel production 242
From biocrude to sustainable aviation fuel components: challenges, successes and perspectives 242
System design and performance evaluation of jet fuel production by hydrothermal liquefaction . 243
The JETSCREEN fuel prescreening process to support development of innovative Sustainable Aviation Fuels 243

Clean Sky 2 "Thematic Topics" Special Session (PART I)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

LEAFINNOX: A novel low-NOx, low-soot aviation combustor concept based on MILD combustion principles

***Prof. Epaminondas Mastorakos (University of Cambridge)**, P. M. de Oliveira, I. El Helou, L. Miniero, P. Khushboo, N. Noiray, G. De Falco, A. D'Anna, D. Fredrich, A. Giusti*

Novel low-NOx, low-soot combustion concepts are needed to ensure environmentally-friendly aeroengines. In this project, the Lean Azimuthal Flame combustion concept, which is based on MILD combustion principles, has been studied for various liquid fuels from the perspective of flame stability, emissions, and fundamental structure. The results from modelling and experiment demonstrate the mixing and combustion mechanisms present in the burner, delineating the reasons why both NOx and soot can be kept at low levels simultaneously. The structure of the kerosene LEAF flame and implications for future developments are discussed.

CHAIRLIFT: Compact Helical Arranged combustoRs with lean LIFTed flames

***Dr. Antonio Andreini (University of Florence),** L. Langone, R. Koch, S. Hoffmann, S. Harth, M. Shamma, M. G. De Giorgi, S. Bonuso*

The thematic topic project CHAiRLIFT aims at verifying a novel combustion chamber concept for ultra-lean low NOx operations in next-generation aeroengines operated with kerosene-like liquid fuels so as to fully address Clean Sky 2 targeted objectives in terms of NOx by 2050 (i.e. ACARE Flightpath 2050). The new combustor architecture is based on the combination of two specific concepts: the adoption of lean lifted flames stabilized by “low swirl” air-spray nozzles and the arrangement of the burners with a circumferential inclination of their axis inside the annular chamber (Shot Helical Combustor, SHC). The use of lifted flames permits to reach a high level of fuel-air premixing so as to allow actual lean operations of the reaction with a reduced risk of flashback and thermo-acoustics instability. The use of helical arrangement of the lifted spray flames allows to limit the overall combustor length and to extend the lean blow out limits of the system. In the first part of the project fundamental studies have been carried out to investigate, by the means of experimental tests and high fidelity CFD, the stabilization process of the lifted flames, the aerodynamics of the SHC and the lean blow out limits of the first proposed concept with 45°-degree inclination in comparison to conventional not inclined arrangement. To support the numerical investigations, an advanced liquid film atomization model is being developed which is capable to describe the droplet formation and tracking at early stage of the atomization process. A sensitivity to burner inclination has been conducted suggesting a new configuration for a second test campaign with reduced tilting angle of the burners. In parallel, a revolutionary method to further improve flame stability is under investigation by dedicated experiments leveraging the use of nano-pulsed plasma discharge coupled to real-time flame detector based on ion probe sensor: this strategy will allow operating with even leaner mixture targeting further NOx reduction capabilities.

Impact of stationary and transient factors on the NOx formation in stimulated flames

Mr. Dmytro A. Dolmatov (National Aerospace University KhAI), *A.V. Kukurudza, S.V. Epifanov, S.M. Nyzhnyk*

The article contains the results of numerical and physical researches of atmospheric and high-pressure hydrocarbon-air and hydrocarbon-air-oxygen flames, affected by modulated discharge (arc, high frequency spark and corona types). The influence of such factors as flow speed oscillations and unevenness, small blunt bodies, discharge parameters and its changing, oxygen injecting and its position etc. has been studied. According to obtained results, the both high-temperature and highspeed mechanisms of NO formation in primary and secondary combustion zones can be accelerated or suppressed by discharge free electrons with specific energy. The key free radicals and ions concentration fields can be shifted in favor of NOx-suppression electrochemical mechanisms by low energy discharge(s) in the zones with relatively rich concentration of alkyl radicals. The results of numerical simulation also shows that high temperature zone with specific combination of short-live intermediate species concentrations during interaction with stimulating discharge(s) can produce significant amount of abnormal radicals, involved into NOx generation-suppression electrochemical mechanisms.

Progress and first results in the study of the pilot-IA collaboration in SPO

Mr. Charles-Alban Dormoy (CATIE), *J-M. Andre, T. Letouze, T. Hentati*

As part of the Clean Sky 2 program funded by Horizon 2020, Co2Team (Cognitive Collaboration for Teaming) is proposing a pilot assistance system based on artificial intelligence (AI) and more specifically cognitive computing (CCT). The use case studied includes the most accident-prone phases of flight. The flight scenario involves a high workload, a strong degradation of situational awareness (SA), and time pressure. The objective is to determine what level of AI is needed to assist pilots and collaborate effectively to enable good decision making and maintain good SA and mental representation (MR). Three hypotheses were formulated:

1. An evolved assistance (CCT) with explanation is more helpful than a simple one for SPO.
2. SPO is safer with a proactive assistant rather than an on-request assistant
3. A SPO cannot be managed safely without assistance in a legacy cockpit

To test these hypotheses, four modalities were tested on the scenario. In the first modality, the pilot is alone in the cockpit of the A320 and has no assistance (SPO). In the second modality, the pilot can be assisted by an AI but only “on request”, in the manner of commercial intelligent voice assistants such as Siri, Google Home or Alexa. If the pilot does not consider it necessary to be assisted, the assistant does not offer help. The third modality is based on a proactive AI. The pilot can request it and the AI can intervene by itself to support the pilot, on performance calculations, monitoring of the avionics, etc. In this modality, voice exchanges are more natural than in modality 2. In addition, the AI has a multi-modal augmented reality system that allows information to be displayed in the cockpit in addition to voice assistance. However, this modality 3 does not provide any explanation or details to the information provided to the pilot (e.g. for a landing performance calculation, the AI only gives the result without giving the information considered nor the detail of the result factored or not). In the fourth and last modality, the AI, here called CCT, is in its most accomplished form. It can be solicited, can be proactive and combines all the functionalities of modality 3. The difference is that it also provides explanations and/or justifications with the information provided. This version, in addition to offering information at key

moments for a good decision-making, aims at maintaining a good SA and a good MR without cognitively overloading the pilot. This should allow a good DM with a stronger involvement and understanding of the pilot and a better confidence in the assistance system. The experimental phase is still in progress and the results will be known in July 2021. The first results indicate that hypotheses 2 and 3 are verified. Co2Team is in line with the vision of Horizon Europe's.

Socio-Technical Simulation Model to identify PF-PM supporting tools requirements in a SPO framework

Dr. Miguel Angel Piera Eroles (Universitat Autònoma de Barcelona)

The coexistence of different tasks in the aircraft flight deck to be performed under tight time constraints has been a driver of automation by modernizing the cockpit with new supporting tools to lessen the pilot flying (PF) workload. Analogous to the airside, also the ATC control work position (CWP) has been modernized with new functionalities to better support their monitoring and decision-making actions.

The different SPO architectures ranging from the displacement of the second pilot to the ground, to the replacement of the second pilot with on-board automation requires a deep analysis of the PF actions when they are sequenced as part of a procedure or when the same action is performed as a concurrent task that coexist with other pending task that pilot need to perform according to changing dynamic priorities and time limits. In this context, a socio-technical simulation model can be seen as a requirement to better understand the impact on the WL of the actions that can be performed concurrently and how knowledge-based actions interfere with one another. An important outcome of the ST model is the analysis of the PF degraded mode due to pending memory items that affects PF performance.

The implemented ST in E-PILOTS model extends data-driven predictions with a knowledge-based approach to identify not only the supporting tools to reduce the mental task-load of most critical tasks, but also to identify the different PF tasks in which extra research could contribute to mitigate WL variability and maintain PF workload below certain threshold, to pave the way down for the SPO. The socio-technical simulation model in E-PILOTS project formalizes the different tasks during approach, providing valuable information to optimize PF workload by reducing it to just below the level where it has an adverse effect on performance. It has been used the FRAM (Functional Resonance Analysis Method) formalism to specify the WL and SA during the approach phase to provide a better understanding of PF cognitive state evolution, and identify those skill-rule-knowledge task that pilots must perform that could be improved by means of cognitive computing applications and maintain PF WL below a certain threshold in SPO while improving his SA. The presentation will illustrate achieved results with the ST simulator validated with a Flight Simulator during an approach phase whose complexity is driven by different sources of interruptions that force PF to generate memory items affecting its performance.

Clean Sky 2 "Thematic Topics" Special Session (PART II)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

HARVIS project: Human Aircraft Roadmap for Virtual Intelligent System

Mr. Alexandre Duchevet (Ecole Nationale de l'Aviation Civile), *Ms. Carmen BEJARANO*

HARVIS project (Human Aircraft Roadmap for Virtual Intelligent System) main aim is to identify how cognitive computing algorithms implemented in a digital assistant can support pilots in dealing with complex decision-making scenarios. Two AI assistant concepts were selected based on their potential to

support pilot's decisions and in managing peak workload during certain events. The two concepts considered in the project are: (1) Non-stabilized approach assistant and (2) Aircraft dynamic rerouting assistant. The Non-stabilized approach assistant aims to support pilots for approach stabilization and go around decision-making. The assistant algorithm for go-around prediction was developed using an online survey platform in order to collect feedback. On this platform, professional pilots were asked to evaluate final approach scenarios, giving a difficulty rating all along the scenario and their opinions on the necessity to perform a go-around. The Aircraft dynamic rerouting assistant aims to support pilots in anticipating possible route variations and providing different trajectory options in case of emergency. It can help pilots to better manage peak workload situations by providing the best options for diversion and relevant information about each alternative based on the selected criteria and in useful time. Both assistant concepts were selected and refined using an iterative approach based on advisory board meetings with experts from different operational backgrounds and workshops with professional pilots. The feedback and inputs collected so far highlight the importance to balance between the transparency of the information processed by the AI assistant and the quantity of information provided to pilots so that they understand assistant outputs while not being overloaded by too much information during critical phases. The two assistant concepts will be integrated into a single demonstration platform in order to validate the operational benefits of AI based systems in future cockpit for single pilot operations.

Highly iterative concept development for requirement-compliant air taxis

G. Schuh, ***Mr. Maximilian Spangenberg (e.SAT GmbH),*** *T. Meyer-Hollatz*

The increasing demand for individual mobility worldwide is leading to the development of new forms of mobility. Individual air mobility (e.g. air taxis) could be an innovative approach to meet this increasing demand. To successfully realise such innovative approaches, interested companies must know the technical, economic and ecological requirements of all relevant stakeholders and integrate them in their air taxi developments. Based on these diverse requirements, a resilient air taxi concept must first be created that describes the essential characteristics of future air taxis and enables a well-founded assessment. In practice, however, it is often difficult for companies to outline such a concept in the requirements phase and then develop it consistently and highly iteratively in the conceptual design phase. To face this challenge, a process has been set up which creates a deep link between the requirements and concept development phase to assure the development of requirementcompliant air taxis in an agile mannor. The process is divided into two parts. The first part connects the market analysis, requirements definition and concept creation, thus linking the requirements and concept development phase. It is based on a double diamond model consisting of two phases. In contrast, the second part is focusing on the pre-development until the end of the concept development phase by adapting the SCRUM process to derive a sound air taxi concept. Both parts are executed in a highly iterative manner to reflect the significant amount of uncertainty at this early process stages. First, the requirements for an air taxi are collected from various sources such as legal requirements, market requirements, and technical requirements. Since missing requirements lead to expensive rework in the subsequent phases, searching broadly and exploring the entire problem space in iterations is essential1 . The requirements are then defined and operationalised. Finally, a prioritisation is established to focus on the critical assumptions and problem statements in the following phases. Secondly, the problem statement consisting of top-level specifications and prioritised development goals is the origin of the ideation phase. At the end of the ideation phase, an array of technically feasible air taxi concepts is developed. To do so, the air taxi is subdivided in its core functions. For each function, the design team must develop one or more solutions that are then evaluated

on a functional base. Following the concept of a morphological analysis, the solutions per function are combined into multiple concepts. Each concept is then transferred in a minimum viable model to evaluate its performance. Based on the performance and development goals, a ranking is established to select the best concept. In the second part, development questions to set up a sound concept are answered in SCRUM design sprints. The development questions are derived from the prioritised development goals. Each design sprint leads to a concept increment, either a minimum viable product when facing the customer or a technical prototype if its purpose originates from a technical background. Finally, the new design process for air taxis is validated by comparing it with the actually followed design process of the Silent Air Taxi, a piloted five-seater aircraft currently being developed by German start-up e.SAT GmbH.

Production-based description of air taxi archetypes by function-based, constitutive components and a bill of materials

Mr. Maximilian Spangenberg (e.SAT GmbH), *Günther Schuh, Marc Kreins*

Urban- and Regional Air Mobility (UAM/ RAM) offers innovative solutions to meet the growing demand for individual mobility, as established transport modes are reaching their capacity and infrastructure limits. More than 100 design concepts for so called 'air taxis' are currently being developed to address the markets for urban and regional air mobility. According to an UAM study by Frost & Sullivan, air taxis will enter the market in 2022 and will expand with a compound annual growth rate of about 46% to more than 430,000 operational units by 2040. 1 For the successful development of such concepts, the companies involved must be familiar with the technical and economic specifications of relevant stakeholders and include them in the early design process. Those design phases are crucial, as costs for subsequent changes increase with the progress of the development. In order to identify any specification failures at an early stage, it is necessary to visualize the technical design progress of air taxis to prepare a product success in the best possible way. An often-neglected aspect for the product success is the early production preparation. The goal of this paper is the development of a model that makes it possible to define the constituent technical components of various air taxi archetypes, to describe them as a function of the design process, and to include in them into a bill of materials. Aviation experts such as Finger2 and Brown3 already classified the leading types of air taxis based on their market requirements for UAM. This paper reviews and extends these types by RAM concepts and describes their specified characteristics. First, air taxi archetypes are defined and validated based on existing use cases and literatures. These types can be clearly defined by their formative and descriptive components. Second, these components are determined and described from a technical and economical perspective by applying a function-based approach to assure a close link to the technical development tasks. Third, a bill of materials is defined, which systematically covers and characterizes the relevant specification parameters such as weight and performance for further detailing phases of the design process. The bill of materials is set-up in a flexible manner to reflect technical and economic uncertainty in the early development phases of air taxis. Finally, the model is validated by comparing it to the components and bill of material of the "Silent Air Taxi", a piloted five-seater aircraft, currently being developed by the German startup e.SAT GmbH.

UNIFIER19: From TLAR to a winner of a concurrent conceptual design competition

Mr. David Eržen (Pipistrel Vertical Solutions d.o.o.), *Fabrizio Oliviero, Lorenzo Trainelli*

One of the major challenges in the implementation of Europe's Flightpath 2050 vision, that envisages that virtually all EU citizens shall reach any continental destination in less than four hours, door to door, by the year 2050, is to provide enhanced mobility solutions to regions without adequate transport infrastructure.

Those regions may share common disadvantageous topographical characteristics that prevent building ground infrastructure or were simply left out of the investment strategy in the past due to low population density. Regardless of the reason, substantial financial investments would be required to establish an effective regular ground transport network (highways, fast railway, …) to meet the 2050 plan and the environmental implications of such network will not be negligible. UNIFIER19 investigates a new aircraft concept for passenger and cargo transportation on short and very-short haul routes, that would provide communities with a new mobility solution by exploiting existing, sparse, and underused small airport network and without overwhelming investment burdens for new ground infrastructures. In addition, this aircraft would provide a zero-emission environmental footprint, thanks to its hybrid fuel-cell/battery propulsion system. An exhaustive market research was performed on Belgium, Italy and Latvia territory, representing high-, mid-and low-ground transportation density regions in Europe respectively. The research was focused on two mobility services: the microfeeder and the miniliner. The microfeeder service is intended as a hub-to-spoke air transportation service, used to feed major airports from smaller cities or open country territories, whether the miniliner service would provide an inter-city connection. The market study findings became a basepoint for top level aircraft requirements (TLAR), which were upgraded with 2025 technological assumptions. An interesting result from market study that indicated an average block range of 350 km (one hop) resulted in a specific multi-hop mission requirement which also eliminated the need of refueling infrastructure on all small airports in the network. The next step was a down-selection from all possible combinations of airframe configurations and hybrid electric architectures that were considered potentially beneficial by considering technological complexity and functional compatibility between aircraft building blocks. The most promising configurations were sized in one of two independent conceptual design loops and subsequently cross-checked by the other design loop. This approach not only provides cross-validation of the conceptual design loops but also ensures that results from each loop's component, albeit implementing different tools, predict similar values. Finally, a winning design was selected based on noise emissions evaluation, production and operating cost analysis and qualitative structural, manufacturability and certifiability assessment. Due to its liquid hydrogen powertrain system and distributed electric propulsion configuration, the design will enable establishing a quiet and green enhanced mobility service with minimal ground infrastructure investment.

The impact of propulsive architecture on the design of a 19-passenger hybrid-electric aircraft

Mr. Christos P. Nasoulis (Aristotle University of Thessaloniki - A.U.Th.), *Giorgos Protopapadakis, Vasilis G. Gkoutzamanis, Anestis I. Kalfas*

The electrification of aircraft is an on-going endeavor, currently examined intensively in the general aviation class. However, for the commuter class, the component selection for the hybrid-electric propulsion architecture is instrumental, to fully exploit the electrification benefit. Within this work, a comparison of two 19-seater aircraft with different hybrid-electric propulsive components is made, using an in-house aircraft conceptual design tool. The first aircraft is based on two parallel-hybrid turboprop engines and cruises at low altitude and Mach number speeds. On the other hand, the second aircraft has two series/parallel-hybrid jet engines and operates at both higher altitude and Mach numbers. A design space exploration is performed where different degrees of hybridization and batteries specific energy are considered, to define the technological requirements for each architecture. The evaluation of the propulsive architectures is based on block fuel reduction, overall mission duration, direct operating costs and total environmental impact from each propulsion system. The results aim to quantify the benefits of each configuration and determine the one with the closest entry into service.

Clean Sky 2 "Thematic Topics" Special Session (PART III)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

Recent Achievements in the Design of Ultra High Aspect Ratio Wings of Environmentally Friendly Aircraft

Prof. Sergio Ricci (Politecnico di Milano)

There is a world-wide need for improved fuel-efficient and environmentally friendly aircraft designs; however, the rate of improvement in performance of conventional aircraft configurations (via improved aerodynamics, composite structures and better engines) is reducing to a marginal level. Consequently, there is a need to explore the benefits of novel aircraft architectures to provide a step-change in fuel efficiency; this need has been identified by ICAO, FLIGHTPATH2050 and CLEANSKY2 initiatives in Europe and also NASA, with challenging goals set for reductions in CO2, NOx and noise by the year 2050. May 2020, the CS2-U-HARWARD project started, in response to the call JTI-CS2-2019-CFP10-THT-07: Ultra-High Aspect ratio wings, aiming at the use of innovative aerodynamic and aeroelastic designs in a multi-fidelity multi-disciplinary optimal design approach to facilitate the development of Ultra-High aspect ratio wings for medium and large transport aircraft. After one year of the activity, it is the right time to discuss about the preliminary results obtained. The design activities foreseen in the project range from the conceptual up to the high-fidelity level and are managed by three teams focusing on different aircraft configurations. Team 1, composed by Politecnico di Milano and IBK, is focused on traditional cantilever wing configurations. Team 2, composed by ONERA and ISAE, is focused on the Strut-Braced Wing configuration. Finally, Team 3 represented by University of Bristol, is mainly focused on folding wing tip configuration. The first year activity was focused on the setup of the medium fidelity tools to be used to explore the differentconfigurations and to performs a comparison of the capabilities of the different tools used by three teams. For the comparison purpose, a common test case has been selected, i.e. the A320-like aircraft available in the CeRAS open data base. Then a special attention has been devoted to the selection of the Reference Aircraft to be used to compare the final performances obtained by the new configurations. The definition of the Reference Aircraft is based on two different aspects: the mission to be completed by the aircraft, which often relies on some market segments in the aeronautics industry: regional, short-medium range, long range, and the technology level and detailed features to be implemented on this reference aircraft. Since no market segment was explicitly specified in the U-HARWARD targets, an extended analysis has been conducted to choose the most relevant mission definition, both from the benefits we can expect for a future commercialized aircraft, and from the more general lessons we could derive with the studies conducted in U-HARWARD. The decision was to investigate the extended Short Medium Range segment (SMR, meaning ~200 PAX, Design Range < 4000 NM, M~0.78) which is the one of the A321, to combine the demonstration of high benefits in this “middle of the market” segment, and the possible transposition to smaller (eg. SMR and even regional) or bigger aircraft. Finally, once the segment is chosen, there are 3 possible choices for the reference aircraft:

- An existing, currently flying aircraft, with known geometry and features,
- A redesigned aircraft upon chosen TLAR,
- A projected aircraft with technology improvements associated with some target EIS (eg. 2035 in most CS2 studies).

Aerodynamic Analysis of a scaled UHBR Fan

Mr. Nunzio Natale (Dream Innovation srl.), *T. Eggers, J. Friedrichs, S. Russo*

In the frame of the CA3ViAR Clean Sky 2 (Composite fan Aerodynamic, Aeroelastic, and Aeroacoustic Validation Rig) CfP project[1], the main objective is to design a low-speed (low-transonic) fan typical of a future large aircraft UHBR engine, in terms of aerodynamic shaping as well as structural design and analysis to make sure the test article experiences aerodynamic and aeroelastic instabilities in an expected way during WT operations. Eventually, open access to all the produced models will be provided, with the objective to establish an "open test-case" for the whole European scientific community, unique in the engine fans landscape. Dream innovation provided support to Technische Universität Braunschweig which was in charge of the aerodynamic design performing 3D CFD for all the intermediate designs developed within the iterative design loop. This paper will focus on the aerodynamic analysis of the preliminary fan stage design which resulted from the design loop. In particular, detailed CFD results will be presented giving a complete overview of the machine performance at design point and off-design. The results are obtained using ANSYS CFX Version 2019 R3. The aerodynamic design process is set to provide the dimensions and characteristics of the fan stage, as well as the shape of the blades. It starts with an engine cycle analysis, the resulting thermodynamically based dimensions of a full-sized engine are scaled to the final rig dimensions. Meridional and 3D blade design are then performed. CFD simulations have to be carried out to ensure the design actually met the performance requirements. To achieve high-fidelity CFD results, a high-resolution mesh with low-Reynolds configurations is set up. Based on the airfoil sections a volume model is created within NUMECA AutoGrid5 to mesh the fan stage. The two-equation k-ω SST model has been used to perform the CFD calculations in the preliminary design stage. This model allows to achieve a reasonable robustness and accuracy, for the planned CFD analyses, with limited computational costs. High-accurate CFD computations require a mesh with right characteristics in order to achieve valuable results. In particular, considering the turbulence model chosen the dimensionless wall distance y+ plays a key role. This parameter was chosen to be y+ = 1 at the blade, hub and shroud walls as required by the model. The required mesh density was determined using the grid convergence index (GCI) to ensure mesh independent results. Steady-state calculations are considered in this preliminary design phase because a fully unsteady approach would be excessively time-consuming for the amount of intermediate designs points to analyse. Moreover, the steady state approach is accurate enough to predict the overall performance. The interface between the rotating fan domain and the stationary OGV domain is modelled with a mixing plane approach. For the preliminary design, the rotor-stator interaction will not be investigated. Results in terms of performance map (efficiency and pressure ratio) and detailed flow-field show the required final target in terms of aerodynamic performance (established in the preliminary design phase and based on the state-of-the-art transonic rotors for modern UHBR engines performance) has been met for this design, which makes it possible to use this aeroshape to perform the aeroelastic and structural analyses. The point at which the CFD last converged is treated as the surge limit of the fan stage for a preliminary estimate. The design is also checked for a sufficient stall margin (SM), proving this performance parameter is satisfactory for the produced aeroshape.

[1] https://cordis.europa.eu/project/id/864256

The UHBR Fan ECL-5 CATANA - An open-test-case for aerodynamics, aeroelastics and aeroacoustics

Mr. Christoph Brandstetter (École Centrale de Lyon), *Xavier Ottavy*

Application of composite rotors enables disruptive design possibilities but demands for a fundamental understanding of the dynamic behaviour to ensure robust design and safe operation. Sensitivity to multi-physical resonance between aerodynamic, structure-dynamic and acoustic phenomena is amplified in modern low speed fan designs for UHBR application. Very thin blades, which are required to maintain high efficiency at transonic flow conditions, are flexible and prone to vibrations. As a result, aeroelastic and aeroacoustic problems increasingly set the stability limit. Test cases of representative geometries without industrial restrictions are a key element of an open scientific culture but currently non-existent in the turbomachinery community. The most commonly used test cases in computational fluid dynamics (e.g. NASA Rotor37/67; TUD Rotor 1 etc.) were designed over two decades ago, and their aeroelastic characteristics are not representative of modern turbomachinery. Also, available experiments have not been conducted with a focus on coupling-phenomena and hence did not comprise multi-physical instrumentation. In order to provide a multi-physical validation benchmark representative of near-future UHBR fan concepts, the open-test-case fan stage ECL5 has been developed at Ecole Centrale de Lyon. Design intention was to develop a geometry with high efficiency and a wide stability range that can be realized using layered carbon fibre composites. The final design iteration of the fan stage is currently fabricated and will be experimentally tested within the European CleanSky-2 project CATANA (Composite Aeroelastics and Aeroacoustics, catana.ec-lyon.fr). In this publication, the test case is introduced with details on geometry, methodology and aerodynamic design of the whole stage as well as a study on structure dynamics and aeromechanical stability. An analysis of the calculated aerodynamic performance with a focus on critical flow structures like tip-leakage flow, radial flow migration and flow separations is presented. Furthermore, details on the experimental campaign comprising multi-physical instrumentation anticipated for 2021 are given to highlight the research focus.

The VENUS project: Investigation of Distributed Propulsion Noise and its Mitigation through Wind Tunnel Experiments and Numerical Simulations

Prof. Roberto Camussi (Università Roma Tre), *A. Di Marco, A. Visingardi, A. Pagano, N. Paletta, L. Flamini, R. Pasta, F. Rusconi*

Distributed Electric Propulsion (DEP), is one of the propulsion configurations that, taking advantage from the Distributed Propulsion concept, is believed to exploit the benefits of electrical engines to drastically reduce fuel consumption and emissions. In the framework of the topic JTI-CS2-2018-CFP10-THT-08, the proposal VENUS will have the objective to understand the physics behind the aeroacoustics of DEP through a deep theoretical, experimental and numerical study. Appropriate numerical procedures for DEP noise assessment will be set-up and experimental data-set obtained in dedicated wind tunnel tests, will be used both as experimental DEP noise validation reference and for providing support to the identification of the main parameters affecting DEP noise. Technologies for DEP noise reduction will be studied as well and tested experimentally. From the technical standpoint, the VENUS consortium will support the model design, manufacturing and integration by realizing a representative test article for WT parametric aeroacoustic tests, able to allow for configuration changes, in terms of engine-wing and engine-engine installation configurations, and to test the selected noise mitigation technologies. The consortium will develop methods and tools enabling a concurrent aerodynamic and aeroacoustic design

of DEP configuration aircraft. The final step will consist in the experimental-numerical assessment of the numerical models. As a practical achievement, the study will support the design of a new regional aircraft configuration, in terms of wing and engines' installation, to target a DEP which is optimized in terms of aerodynamic and aeroacoustic performance. It is pointed out that all the produced models, data and documents will be open access for other institutions, with the objective to establish an "open test-case" for the whole European scientific community, unique in the aircraft design landscape. The presentation will provide an upgrade about the activity of the project after about one and a half years of activity.

SINATRA: Seeding-free, non-intrusive aero engine distortion measurements – Project updates

Dr. Pavlos Zachos (Cranfield University), *Jonas Steinbock, Michael Dues, Peter Gunterman, Ingo Röhle, Ulrich Doll, Joni Baikie, Nicholas Lawson*

Reducing the environmental impact of future aircraft architectures is a goal of the aerospace research community[2]. In the last decade there has been a notable focus on the development of new aircraft designs with reduced emissions and the noise footprint. Several of the proposed configurations feature a closer integration of the aero-engine into the fuselage[3] with Blended-Wing-Body (BWB) or Boundary Layer Ingestion (BLI) architectures showing notable benefits in terms of flight efficiency[4]. Convoluted intakes, often used for aircraft engine integration, generate unsteady flow distortion[5] which can affect the propulsion system performance[6] and its aerodynamic and mechanical stability[7]. Better understanding of the unsteady distortion aerodynamics is a key requirement for the development of these novel aircraft configurations and require support of numerical means, ground test facilities as well as in-flight testing capabilities. Current practice for aero-engine testing and safety certification relies on only a few intrusive measurements of pressure and temperature (at a low temporal frequency) to quantify the flow distortion levels that the engine face is presented with by the intake. Although unsteady flow distortion has been historically identified as a key detrimental factor to an aero-engine's stability, the relatively low maturity of advanced flow measurement methods in combination with the high risk of integrating complex measurement systems into engine test facilities have prevented the measurement of richer instantaneous data. As a result, the understanding of flow distortions that lead to engine stall events remains a key requirement. This becomes even more critical as industry is moving towards an era of strongly closely coupled aircraft configurations. Given the known limitations of currently used methods (low spatial and temporal resolution, intrusive instruments that interact with the flow), existing technologies are inadequate to sufficiently reduce the risk on the development of future systems. Non-intrusive laser-based solutions such as Particle Image Velocimetry (PIV) or Doppler Global Velocimetry (DGV) can overcome this difficulty. However, such techniques require the use of particles to seed the flow, which comes with a number of caveats including the requirement of uniform seeding distribution across the

[2] ACARE, "Flightpath 2050," 2011

[3] Epstein, A. H., "Aeropropulsion for Commercial Aviation in the Twenty-First Century and Research Directions Needed," AIAA Journal, vol. 52, 2014, pp. 901–911, doi: 10.2514/1.J052713.

[4] Okonkwo, P., and Smith, H., "Review of evolving trends in blended wing body aircraft design," Progress in Aerospace Sciences, vol. 82, 2016, doi: 10.1016/j.paerosci.2015.12.002.

[5] Cousins, W. T., "History, philosophy, physics, and future directions of aircraft propulsion system / inlet integration," Proceedings of the ASME Turbo Expo, Vienna, ASME, 2004, pp. 305–320.

[6] Melick, H. C., J., "Analysis of inlet flow distortion and turbulence effects on compressor stability," NASA-CR-114577, TR-2-57110/3R-3071, Dallas, 1973.

[7] Im, H., and Zha, G., "Investigation of Flow Instability Mechanism Causing Compressor Rotor-Blade Nonsynchronous Vibration," AIAA Journal, vol. 52, Jul. 2014, pp. 2019–2031, doi: 10.2514/1.J052781.

measurement plane and the installation of seeding rakes within the intake sub-system which are notably challenging in airborne measurements. A promising technology to overcome the above challenges is Filtered Rayleigh Scattering (FRS)[8][9]. Due to its potential to offer spatial and temporal resolution as extensively as PIV methods, it allows even highly dynamic flow distortions generated by the geometry of the complex intakes to be clearly understood. Depending on the application, the FRS technology can be used with a continuous wave (CW) laser to provide time averaged data which allows simplified steady state flows distributions to be calculated, or when used with a high-powered pulsed laser to provide instantaneous distortion data which better reflects the underpinning unsteady nature of the flow. In this context SINATRA's objectives are defined as follows aiming to further mature the FRS technology.

1. Develop and validate up to TRL4 an FRS measurement system prototype, using a CW laser, for time averaged distortion measurements (synchronous total pressure and velocity). Integrate this prototype onto an complex intake test rig setup with representative complex distorted flows to create a demonstrator that will show the potential of FRS technology to be used for ground and in-flight distortion measurements. #
2. Upgrade the above prototype, to demonstrate an FRS measurement system working with a pulsed laser thus showing the capability of the technology to measure instantaneous distortions on a fundamental unsteady flow up to TRL3.
3. Provide a ground test inlet distortion facility that will be available to the whole European aeronautical, industrial & scientific community. This will enable a wide range of non-intrusive flow measurements representative of future aeronautic system and novel propulsion systems to be explored.
4. Use the experimental data from the time average FRS measurements to characterise the distorted flows that are pertinent to advanced closely coupled propulsion systems by means of conventional and/or novel distortion descriptors.

In terms of expected impact, SINATRA provides the opportunity to investigate and develop the applicability of FRS technology for the measurement of distorted complex flows which although focused for the purposes of the project on inlet flows can be also useful to various aspects of turbomachinery, both aeronautical and otherwise. Furthermore, it allows the FRS technology to be assessed to a level similar to other non-intrusive technologies currently better mastered within academia and industry such as S-PIV or DGV. The ambition of this project is to lift the steady FRS technique to a higher TRL in order to meet challenging requirements towards system integration, robustness and automation imposed by BLI representative flow configurations. This will lay the foundations for the transition of the technology into a commercially available product. An FRS measurement system demonstrator at a bespoke aero-engine distortion facility will provide a very useful test facility for European organisation for future development of non-intrusive measurement systems in propulsion integration applications.

Clean Sky 2 "Thematic Topics" Special Session (PART IV)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

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CleanSky2 SOLIFLY - Developing structural batteries towards aeronautic application

Dr. Helmut Kühnelt (AIT Austrian Institute Of Technology), *Alexander Beutl, Frederic Laurin, Alexander Bismarck, Sebastian Willrodt, Michele Guida, Fulvio Roman**o***

Radical innovations for all aircraft systems and subsystems are needed for realizing future carbon neutral aircraft, at first in the regional aircraft segment with Hybrid Electric Aircraft (HEA) to be delivered after 2035. Electrical energy storage is one key element here, demanding safe, energy dense, lightweight technologies. Combining load bearing with energy storage capabilities is a promising way to minimise the detrimental impact of battery weight on the aircraft. However, despite the various concepts developed in recent years, the viability of this solution has been demonstrated at material or coupon level only, leaving many open questions concerning its effective applicability for structural elements of a size relevant to the effective implementation into the airframe. Within the CleanSky2 project SOLIFLY "Semi-SOlid-state LI-ion Batteries FunctionalLY Integrated in Composite Structures for Next Generation Hybrid Electric Airliners" (2021-2023) the AIT Austrian Institute of Technology, the aeronautics research centers ONERA and CIRA, the Universities of Vienna and Naples, and the SME CUSTOMCELLS Itzehoe, will be conducting research to develop further structural batteries towards aeronautic applications. Based on a non-conventional semi-solid-state formulation suitable for Li-ion structural batteries, two different scalable battery cell concepts are to be developed further and combined: on the one hand, so-called Coated Carbon Fibres (CCF/carbon fibres coated with active material), which intrinsically store energy, and, on the other hand, thin battery cells that are installed into the carbon composite structure (Reinforced Multilayer Stack/RMS). Functional integration of the formulation will be optimized, first at the cell level and subsequently scaling up the cell concepts, on a representative aerospace-grade component, here a stiffened panel, to demonstrate the electrochemical and mechanical properties of the developed structural battery technology. A further aspect that SOLIFLY focuses on is to closely link technological development to the actual needs of the aviation industry. To ensure this, the expectations and specifications of the aircraft manufacturers are incorporated into the design process from the very beginning, taking into account airworthiness and production requirements. A technology roadmap and a technology readiness level scale-up strategy are project outcomes which ensure that the inherently scalable processes can actually be industrialized. The talk will present the concept of SOLIFLY and the progress achieved in the first phase of the project including the outcome of a first industrial workshop.

MW-class HTS electric motor for regional aircraft propulsion

Dr. Marco Satrústegui (CEIT)

First, a detailed description of the HIVOMOT project, its consortium and its main goals are disposed. An analysis on the state of the art on electric aircraft propulsion is given, which provides information on the design guidelines that have been taken in recent years, as well as the different projects and studies that are planned for the medium-term future. Thanks to this framework, geometric and performance requirements for a MW-class HTS electric motor are defined together with the objectives to be met. In addition, a superconducting motor design module is implemented in Matlab and FEMM, which helps to develop the selected motor efficiently, rapidly and accurately. Finally, the conclusions from evaluating different motor topologies are summarised.

DCADE - Diamond Converter and Arc fault DEtection for high-altitude operations

Mr. Antonio L. Rodriguez-Vazquez (Skylife Enginnering)

The increasing demand for clean aviation is pushing the industry towards the all-electrical aircraft, with cero emissions. The green deal of the European Commission is a clear high-level example of the commitment that all the countries all over the world should have. Recent advances in the last few decades in power semiconductors is moving the industry to the electrical propulsion, where the generation and electrical consumers are connected together in a small weak electrical grid. The amount of power to be managed by the electrical system is expected to be increasing in the following decade from a few Megawatts to power small aircraft to several tens of MWs to power long haul aircrafts. The evolution of aircraft electrical power management system to higher power is critical in the next few years to reach the objective of a future clean sky program. In this context, the overall objective of DCADE is the evaluation of potential technologies and components of electrical systems for aeronautic applications that will allow higher voltage converters while maintaining the power density and arc detection techniques that will increase the reliability and safety of high altitude, high power, high voltage A/C distribution systems. The project is divided in 3 working packages. WP1 and WP2 will focus on comparing state of the art SiC semiconductor technology for power converters with promising Diamond semiconductor technology. This technology will allow higher voltages, higher temperatures and lower losses compared to SiC, which results in higher power density. The purpose of WP3 is to evaluate the ability of an AI (neural network combined with a reflectometry algorithm) to detect an arc fault and to locate it in an aircraft distribution network. It will be done by performing four tasks to evaluate the IA solution: firstly, to create a database necessary to carry out the learning of the neural network. This database will contain the arc fault voltage and current signals measured at various locations in the aircraft distribution network. Secondly, to define the most suitable neural network architecture among the different possible architectures. Then, to do the learning of the neural network from the signal database. Thirdly, make an electronic board (target) to integrate the neural network and the reflectometer algorithm. Finally, the electronic board with the neural network will be evaluated in real conditions by calculating the detection and false detection rates and the ability of the solution to determine the position of the arc in the network.

Credible Hybrid Electric Aircraft – CHYLA project overview and objectives

Dr. Maurice F M Hoogreef (Delft University of Technology), *A Elham, B F Santos, M Henke, R Mallwitz, M Steen and J Friedrichs*

Research initiatives in hybrid-electric/sustainable aviation typically address only a single vehicle or single vehicle class. However, it can be expected that for novel propulsion and energy solutions to reach a sufficient maturity level an approach not too different from the early days of aviation could be followed: starting small to prove a technology and gradually scaling it up to larger and larger classes of vehicles. Therefore, it is important to sketch a landscape of technologies and identify areas suitable for scaling, as well as limitations or challenges for development. The CHYLA project aims to contribute to the overall research and development in sustainable aviation by providing exactly this; an overview of scaling opportunities, challenges and limitations of key radical technologies where the credibility of underlying technology assumptions is an explicit factor in developing such a landscape. In CHYLA we introduce the concept of “credible aircraft design”, which refers to the influence of the uncertainty in the assumptions behind the design to quantify how realisable, or in other words, how credible, is the design. Since technical

work on the project has just started, the article will present a general overview of the CHYLA scope, approach and objectives.

An Overview of the Scalability Investigation of hybrid Electric concepts for Next-generation Aircraft (SIENA) project

Ms. Ana Garcia Garriga (Collins Aerospace Applied Research and Technology), *Giusi Quartarone, Serena Iovino, Lorenzo Trainelli, Alberto Rolando, Constanza Mariani, Mauro Mancini*

This paper presents an overview of a project called "Scalability Investigation of hybrid Electric concepts for Next-generation Aircraft" (SIENA). This is a collaborative project being developed under the European Union Clean Sky 2 Program Thematic Topics. The aviation industry has committed to a set of ambitious goals to reduce fuel burn, emissions and noise by 2050, including reducing global net aviation carbon emissions by 50% by the year. To help achieve these goals, new radical aircraft (A/C) system architectures, like new hybrid-electric propulsion systems, have to be designed in a way that are not only technically feasible but also operationally and economically viable. However, a number of technology challenges persist and combinations of Hybrid-Electric Propulsion (HEP) technologies with novel technologies, such as complex aero-propulsive couplings, novel thermal management technologies and non-drop-in fuels (such as hydrogen, or liquid natural gas) are being considered. The multitude of promising technologies, and the way they can be combined and integrated in A/C, results in a very large number of design options. Consequently, the research and industrial community is largely focusing on designing solutions for specific aircraft and operational concepts, resulting in multiple configurations developed in parallel. SIENA introduces an innovative notion of scalable-by-design aircraft concepts by performing an automated and exhaustive design space exploration and systematic analysis of novel technologies, and their integration in new vehicle architectures. The project will focus on the development of a systematic methodology to review the feasibility of integrating different technologies in novel aircraft architectures in such a way that they can be scaled-up from smaller to larger passenger aircraft. These technologies will include key innovations such as HEP and the integration of non-drop-in fuels and will be considered for five different vehicle classes, from general aviation aircraft, through regional, commuter, to short- and long-range passenger aircraft. The performance of the different technologies will be assessed against classic aircraft performance requirements, as well as studying the economic, regulatory, and operational impact of such technologies and their viability in the aviation industry. The generated breakthroughs and findings from the project will guide upcoming projects under the Horizon Europe program. The presentation will outline the technical development program, the challenges being addressed and the potential benefits that the approach presented can bring to the aerospace industry.

The preliminary design of a Low Transonic Fan made of composite material, test article of an innovative WT test campaign to measure aerodynamic, aeroelastic and aeroacoustics advances in UHBR Turbofan engines

Dr. Nicola Paletta (IBK Innovation GmbH & CO KG), *Flüh J., Lindemann J., Seume J., Gößling J., Friedrichs J., Eggers T., Russo S., Natale N., Vlachos D., Mazarakos D., Baltopoulos A., Vavouliotis A.*

In the last decades, airplane operators and manufacturers have been continuously investing in new technologies for more efficient and less polluting aircraft, aiming for positive economic and ecological impacts. Recent advances in Ultra High Bypass Ratio (UHBR) engines are the result of a big effort in the development of more efficient Turbofan engines, as a response to the need to increase the propulsive

efficiency, through reduction of the difference between engine outlet velocity and flight velocity, considered one of the major contributors to the reduction of fuel consumption and emissions.

UHBR propulsors require larger fans, posing significant challenges from aerodynamic and structural points of view. The higher engine-BPR does increase the required operating range of the fan by moving Take-Off and Approach closer to the part power limit of the fan and therefore reducing its stall-margin and increasing the flutter risk. In parallel, the increased fan diameter is driving the intake design, with significant implications on drag and airflow inlet distortion at the Aerodynamic Interface Plane (AIP) during off-design and cross-wind. Beside these increased aerodynamic requirements, the fan itself has to be reduced in weight, thus requiring the application of lighter and stiffer materials, such as Carbon Fibre Reinforced Polymers (CFRP) instead of more conventional titanium alloys, providing more design degrees of freedom in terms of "customized" stiffness and inertia distributions along the blade-span. This implies the need of developing more reliable and accurate methods for aerodynamic, aeroacoustic and aeroelastic design of engine fans. The ambition of the CA3ViAR project is to design an Open-Test-Case Fan that experiences instability mechanisms which are representative for UHBR fans of civil aircrafts, and to perform a comprehensive experimental investigation to measure aerodynamic, aeroelastic and aero-acoustic performance in a wide range of operational conditions. Experimental tests will be performed in the Propulsion-Test-Facility (PTF) of the Institut für Flugantriebe und Strömungsmachinen (IFAS) of Braunschweig, Germany. The objective of this work is to present the preliminary design of the Low Transonic Fan (LTF) to be used as test article, whose main requirement is to be operated in conditions of aerodynamic and/ or aeroelastic instability during wind tunnel operations, in a safe and controlled way. More in particular, the consolidated aerodynamic design of hub profile, fan and stator blades is presented along with trade-off analysis on blade-tip gap and rotor axial position. The strategy adopted to drive the structural design is presented and discussed. One of the aims is to target an optimal fan rotor stability map, evaluated by means of high-fidelity flutter analysis taking into account acoustic reflection at the intake for different intake length, aerodynamic viscosity and compressibility effects, enabling tests close to the instability and at the same time ensuring a sufficient level of safety inside the WT. On the other hand, dynamic and stress analyses complement the structural design to comply with strength requirements and define a Campbell diagram compatible with design conditions and desired testing points. The preliminary mechanical design of composite blades and rotor hub has been also completed, complying with the main requirement of ensuring the proper stiffness and strength according to structural and aeroelastic analysis, and implementing all the design features to lower the structural damping as much as possible. Indeed, further aeroelastic analysis aimed at assessing the impact of the rotor mistuning in terms of deviations in the natural frequencies of the blades on the aeroelastic performance demonstrated that a very low structural damping is required to enable reaching unstable conditions in the WT. The rotor instrumentation is also presented, together with the studies to embed sensors in the composite blades, complemented by manufacturing trials and demonstration tests. Preliminary analyses aimed at characterizing the aeroacoustic performance for different lengths of the intake complete the overview on the LTF preliminary design.

Design of Hybrid-Electric Small Air Transports

Mr. Francesco Orefice (Università degli Studi di Napoli Federico II), *Valerio Marciello, Fabrizio Nicolosi, Qinyin Zhang, Guido Wortmann, Jonathan Menu, Vincenzo Cusati*

The challenges of (hybrid) electric aircraft: The increasing perception of the environmental impact of technological progress has moved aviation market to new ecological requirements, other than speed and

payload capacity, the purely economic driving factors of the past century. Direct emissions from aviation account for about 3% of the European Union's (EU) total greenhouse gas emissions and more than 2% of global emissions[10]. The contribution of aircraft emissions to climate change has been established in literature[11], as well as the environmental cost of those pollutants. Among the others, noise can be considered the dominant part of that cost, since it is almost the 75% of the total cost[12]. From this point of view, the design of new concepts integrating hybrid power sources and highly efficient propulsive system is a crucial aspect of the future aviation. The rapid expansion of the sector caused by globalisation, liberalisation, combined with current technologies and the appearance of the low fares business models, increased the severity of aviation impact on the climate change in the last decade. However, integrating aviation into discouraging policies will have negligible impacts both on future market growth and emissions, as stated in Ref. [13] [14] [15], where the aviation activity growth rate has been fixed at 2.5% and the fuel efficiency improvements per year has been fixed at 1%. The growth rate proposed is conservative if compared with other studies that did not account the current status of aviation segment. Large Air Transports are the main responsible of aviation emissions due to airlines activity, except for noise emissions[16], often related to fleets composed by old aircraft. For this reason and anticipating the renewing of the fleets, some industrial projects are pushing on the reduction of emission introducing new enabling technologies: ultra-high-by-pass ratio, electric propulsive systems, energy supply and combustion with Hydrogen, and many others. On the other hand, the interest in general aviation market has been renewed by the increment of domestic flight and, at the same time, by the possibility of a rapid entrance in service of new hybrid technologies[17]. At the same time, hybrid-electric propulsive systems have opened the path to the possible introduction of air transports in urban context thanks to reduced noise and pollutants. This is the market segment filled by Personal Air Vehicles and Small Air Transports (SAT). In particular, the SAT's market segment has been investigated by the ELICA (ELectric Innovative Commuter Aircraft) project to fulfil market demand of future concepts. The conceptual design chain discussed in the present work and its application have been developed in the framework of the aforementioned project. The reliability of results presented in literature about hybrid-electric concepts is strongly dependent on the assumptions made by authors. Thus, the aim of the present work is supporting the discussion of conceptual design methods for hybrid-electric concepts with the support of industrial partners that can orient the design

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choices with well educated guesses or reliable data, as well as with the enhancement of methodologies themselves. **II. Conceptual Design Chain:** The conceptual design aims to choose a single optimal aircraft configuration, which fulfills the TLAR (Top-Level Aircraft Requirements) and aviation regulations requirements. In case of a hybrid-electric aircraft, it is important to explore different powertrain operating modes with the mission profile to maximize the efficiency of the air transport. The conceptual design workflow is divided in three main modules: pre-design, sizing, and analysis. Such investigation may be included in an optimization loop targeting, for instance, minimum weight penalties, reduced emissions, and minimized direct operating cost (DOC). The preliminary design process moves from the statistical definition of the main geometrical characteristics depending on top-level requirements. It is a necessary step to have a baseline when designing a completely new aircraft and compare trends at early stages of the design process, when no details about geometry are available. The following step is the sizing process, which starts after fixing the characteristics of the propulsive architecture in terms of components, hybridization parameters, and operating modes. The evaluation of aviation regulation constraints and mission requirements yield to the choice of the sizing point, that is the combination of wing loading W/S and power loading W/P. From this point performance, modifying the input parameters, trends relating aircraft characteristics in terms of mass and energetic requirements can be link to the powertrain architecture chosen to investigate the potential benefits and limits. The last step is the analysis of the energetic requirements and flight performance, which is a crucial step to verify the compliance with aviation regulations and TLAR, and to optimize the aircraft. The present work is focused on this last step requiring enhanced methods to perform flight simulation, weight refinement and further optimization (Figure 1). The integration of industrial feedback and contributions at this level make the difference of this work with respect to literature studies. An accurate choice of the objective functions and design constraints can be applied at this level to optimize the platforms chosen during the previous steps of the design process. The top-level aircraft requirements provided in the framework of the ELICA project have been applied to the design chain discussed in previous works of the same authors[18] [19] [20]. [21] Additional constraints to the technological level targeting years 2025 and 2035 as possible entrance in service have been fixed by Rolls-Royce driving the weight estimation loop to reliable results. The approach to the failure analysis related the estimation of one-engine inoperative (OEI) performance have been enhanced thanks to the contribution of Siemens. Details about the enhancement of the analysis methods will be briefly discussed in the present section and detailed in the final presentation. The environmental impact of hybrid-electric propulsion is often directly related to fuel saving percentages along the operative life and the evaluation of the pollutants strongly depend on the accuracy of the flight mission information. A simulation-based analysis would be preferable for the scope, even if it can be realized only characterizing each single step of the whole flight mission of an aircraft by its aerodynamics and propulsive features. Therefore, all the aspects defining the aircraft state at each step, such as Mach number, altitude, throttle setting, acceleration, rate of climb, etc., must be determined to simulate the flight history. The amount of information required to perform the detailed simulation analysis requires first-hand data by powertrain

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manufacturer that, for the present work, have been collected thanks to the partnership with Rolls-Royce. Efficiencies of each element of powerplant model and technological levels in general, foreseen for the target entrance in service, are fundamental for the refinement of the concept. On the one hand, the powerplant model is related to equations strongly dependent on the target architecture and efficiencies; on the other hand, the weight estimation of the power system depends on the technological level in terms of specific power and energy. The powertrain architecture is often preliminary designed aiming for the minimum weight or the maximum propulsive efficiency, without accounting for redundancies or fault tolerant alternatives, often left to further refinement in a later design stage or at higher technological readiness level (TRL). The contribution of Siemens to the safety of the modelled architecture has been integrated as a constraint of the design chain being discussed. In the present work, as an example of the applied design chain, the chosen configuration includes eight distributed electric propellers and two inboard propellers directly connected to the shaft of the thermal engine. The battery packaging has been defined to optimize the safety margin in case of failure of one thermal engine or battery pack. The scientific community is progressively moving towards higher TRLs and this process is raising the need to perform high-fidelity flight mission analysis. A reliable fidelity level can be achieved by estimating, step by step, the energetic consumption, in terms of fuel and electric energy, and the aero-propulsive interaction effects. The methodologies presented are integrated in a MATLAB based toolbox. Analysis activity is an iterative process that aims to estimate aircraft performance, whose geometric and aerodynamic characteristics are determined during a previous step of the design loop.

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Clean Sky 2 "Technology Evaluator" Special Session (PART I)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

Clean Sky 2 Technology Evaluator Mission Level Introduction

Dr. Thomas Zill (DLR)

This brief presentation will provide an overview of the activities on Mission Level towards the first global assessment of the Clean Sky 2 Technology Evaluator and will serve the introduction into the session dedicated to the Mission Level. The overall approach of the assessment on Mission Level will be presented, see Fig. 1.

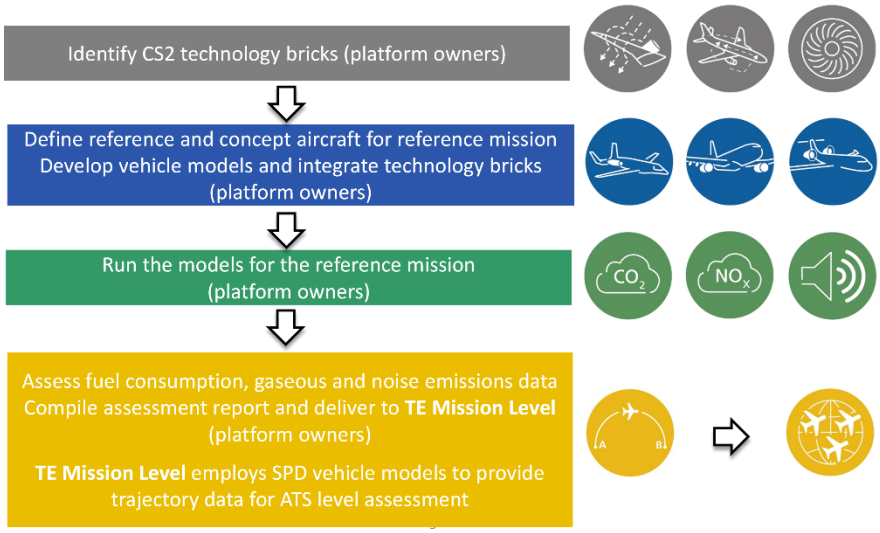


Figure 1: Methodology of Mission Level assessment

For the evaluation of the environmental benefits, with respect to the high-level of objectives of Clean Sky 2, various concept aircraft and their respective reference vehicle have been defined. The concept aircraft serve as the platform to integrate the novel Clean Sky 2 technology developments. An overview of these concept models, each of which is tailored to serve specific market segments, will be given. Mission Level is tasked with the evaluation of the environmental impact of these concept models, assessing their performance with regard to the reduction of total fuel burn as well as gaseous and noise emissions. The aggregated results of these performance indicators, which show that substantial progress towards the programme's environmental targets has been achieved, will be shown and discussed, before handing over to the individual platform owner's presentation for more detailed insights into the concept models.

Environmental Impacts of CS2 Technologies for Next Large Passenger Aircraft

Dr. Pierre Arbez (Airbus)

The Clean Sky 2 Joint Undertaking is committed to alleviating environmental impacts of aeronautics and fostering the competitive advantage of the aeronautical industry and supply chain in Europe. In particular, Clean Sky 2 has set-out an ambitious objective to reduce from 2014 state-of-the-art, CO2, NOx, and noise emissions by respectively 20% for new aircraft entering into service in the 2030-2035 period and by 30% for the most innovative concepts joining the fleet after 2035. This objective assumes a global fleet forecast to grow in accordance with a worldwide air passenger traffic increasing in the coming decades by 4 to 5% per year, considering that approximately 50% of flying vehicles might carry major Clean Sky 2 technologies by 2050. In order to evaluate the environmental impacts and benefits of the most efficient combination of technologies integrated on new aircraft/rotorcraft concepts, the Technology Evaluator (TE) had been created as an integral part of the Clean Sky programme. It will enable quantification of Clean Sky's contribution to the ACARE Flight Path 2050 environmental objectives, particularly on CO2, NOx and noise reductions. To do so, assessments of the new concept aircraft being developed will be performed at three levels, at mission, airport and air transport system levels. They will be carried out using specific Clean Sky tools enabling Partners to build a global evaluation of the environmental benefits of the programme. Among the various concepts addressed in Clean Sky 2, Airbus develops advanced Large Passenger Aircraft (LPA) planned to enter into service either in the period 2030-2035 or after 2035. These new innovative

aircraft configurations implement the new Clean Sky 2 technologies to specifically address short-middle range and long-range flight missions. This abstract aims at introducing the overview of the environmental targets for LPA concepts, their underlying key enabling technologies, evaluated and compared with reference 2014 technologies considering design criteria like weight saving, fuel saving, maintenance or production improvement, overall aircraft system improvement and noise reduction. These technologies are implemented into virtual aircraft models that enable the prediction of the performances of these newly equipped concepts along defined flights. Their benefits and impacts will be evaluated and then presented accordingly to the final 'mission level' assessment handled for the Technology Evaluator.

Clea Sky 2 - Regional Aircraft

Mr. Giovanni Cerino (Leonardo)

Future market of Civil Passenger Aircraft will have an important portion composed by Regional Aircraft. This aircraft category, that will include passenger class up to 120-130, will be employed on typical short routes (from 200 nm up to 500 nm). It's reasonable to foresee for the next decades, that the regional fleet will increase and it will represent a relevant percentage of global air transport. Therefore, it's suitable to develop and implement advanced new technologies oriented to reduce the environmental impact in terms of fuel/pollution and perceived noise very important for those airports close to massive residential areas. In order to obtain significant environmental benefits, it's necessary to study technological improvements in any part of the aircraft starting from the power plant that represents the relevant part of pollution and noise generation. In order to limit such undesired effects is necessary to improve, at first of all, technologies pertinent to engine components (i.e. combustion chamber, compressor, ecc.) but also all other airframe aspects in order to limit required power from the engine: Aerodynamic – cruise/climb efficiency increasing essentially depending on aerodynamic design oriented to obtain minimum drag. Other fuel reduction amount can be obtained also from stall speed optimization that allow to reduce wing surface that's positive in terms of environmental impact. On board systems electrification – in general pneumatic system removal induces a better engine efficiency. Therefore, the technical choice is to adopt electrical air conditioning systems but, in general, to electrify whole systems architecture (i.e. very advantageous also to eliminate hydraulic fluids very detrimental for environment in disposal phase).

Structures – to optimize structural configuration and to adopt new materials in order to reduce weight and also to optimize production processes and so on.

Trajectories – optimization of flight path around airport area in order to reduce fuel but also to reduce perceived noise annoyance on population.

Within Clean Sky 2 REG IADP two different regional platforms have been studied by Leonardo Aircraft and its Core Partners:

- 90 seats – turboprop powered – Range: 1200 nm, Mach: 0,56
- 130 seats fast turboprop powered - Range: 1600 nm, Mach: 0,62

The environmental impact reduction has been calculated respect to following Reference aircraft representative of 2014 year regional aircraft technological level:

- 90 seats class: Re-sized ATR72 Aircraft. It's a virtual 90 seats turboprop aircraft with same ATR72-600 technological level (no 90 seats turboprop civil platform in service on 2014).
- 130 seats class: Airbus A220-300. Since on 2014 there were no turboprop a/c of this size, the most advanced platform, from technical point of view, has been selected.

Environmental Impact of CS2 Technologies in the Regional MultiMission aircraft Configuration

Mr. Luis Benítez Montañés (Airbus Defence and Space SAU), *Pilar César Rubio*

Airbus Defence and Space, former CASA, works in Clean Sky 2 program in a set of technologies focused on the Regional Multi-mission aircraft configuration. These technologies cover multiple aspects of the aircraft design, manufacturing and operation like innovative materials, systems architectures towards a more electrical aircraft, affordable flight control system devoted to control multiple control surfaces in the wing and new manufacturing and assembly processes. The first assessment of the technology evaluation has been recently done and the impacts on the Clean Sky 2 environmental targets has been done: evaluation of emissions (fuel consumption, CO2 and NOx) and noise reduction in take-off and landing. The session will explain the principal conclusions of the environmental impact of these technologies focusing in the peculiarities of the future Regional Multi-mission aircraft configuration.

Improvement of European thin haul mobility: the role of small Green commuter aircraft

Mr. Diego Giuseppe Romano (Piaggio Aero Industries S.p.A. in A.S.)*, Gianvito Apuleo*

In the last years transportation demand has grown up as consequence of the increase in leisure, and business for both heavily travelled routes (between major cities) and thin routes (between remote areas, and remote areas with major cities). In parallel, aviation sustainability issues have become more and more important, being aviation pollution an important source of global environmental pollution. Moreover, several States, as well as private Companies travelling for business, have introduced bans and/or special taxes on short flights covering distances that could be travelled by train in less than 3 hours. These regulations have a major impact on short haul thin routes, which could be covered by small air transport (up to 19 seats). Thus, dedicated research and technology innovation effort has been put in place over the last years to develop eco-friendly, and economically viable, aircraft able to answer sustainability needs, market demand, and cost-effectiveness. In particular, in the framework of Horizon2020, EU (European Union) has funded the Clean Sky 2 SAT (Small Air Transport) TA (Transverse Activity) initiative, whose main goal is to address technology innovations to reduce environmental impact as well as operational cost of small commuters, ensuring improved levels of operational safety. SAT TA is a Project with an overall budget of about 68 mln€, including small aircraft OEMs (Original Equipment Manufacturers), major aircraft suppliers, SMEs (Small and Medium Enterprises), research centres and academia (more than 80 Partners involved). The research activity has focused on the following main technology streams:

1) New generation turboprop engine with reduced fuel consumption, emissions, noise and maintenance costs for 19 seats aircraft.
2) More electric digital systems including:
    a. Affordable fly-by-wire architecture for small aircraft (CS23 certification rules).
    b. More electric systems replacing pneumatic and hydraulic aircraft systems (high voltage EPGDS - Electrical Power Generation and Distribution System -, hybrid de-ice system, landing gear and brakes).
    c. Advanced avionics for small aircraft, to reduce pilot workload, paving single pilot operations for 19 seats.
3) Affordable airframe structures including:
    a. Low cost composite wing box and engine nacelle using OoA (Out of Autoclave) technology, LRI (Liquid Resin Infusion) and automated deposition process.
    b. Affordable small aircraft manufacturing of metallic fuselage by means of FSW (Friction Stir Welding) and LMD (Laser Metal Deposition).
    c. Advanced cabin comfort with new interiors materials and more comfortable seats.

To address the abovementioned technologies, two different platforms have been designed: a Reference and a Green aircraft. Reference aircraft is a virtual aircraft designed considering 2014 technologies with an existing engine assuring requested take-off power. Green aircraft is designed integrating the technologies developed within Clean Sky 2. Preliminary integration studies of the proposed technologies show an encouraging reduction of emissions (up to 20% CO2 reduction, and 29% NOx reduction for the design mission) and operational costs of small aircraft.

Clean Sky 2 "Technology Evaluator" Special Session (PART II)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

Low Sweep Business Jet 2035 Mission Level Assessment Results

Mr. Jérôme Lery (Dassault Aviation), *Jean Le Gall*

This paper will present two business jets models that have been elaborated by Dassault Aviation and submitted by the Airframe ITD to Clean Sky TE2:

- BJ reference aircraft, which represents a state of the art, classical business jet from 2000;
- Low Sweep Business Jet (LSBJ) conceptual aircraft, which represents what could be a 2035 business jet (*) with new technologies for the airframe, systems and propulsion, in order to:
    - Increase overall cruise efficiency by a better L/D, weight decrease and fuel specific consumption decrease;
    - Decrease the community noise levels.

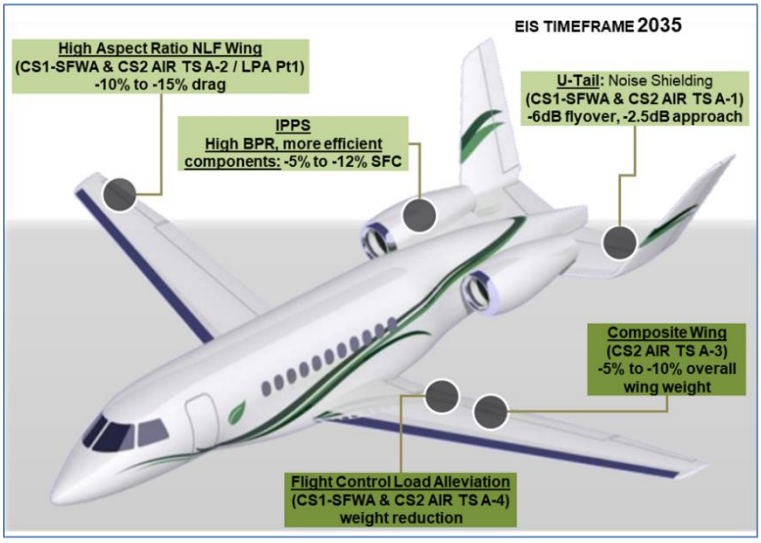
(*): many technologies have sufficient maturity for 2025-2030 EIS, progress on noise and CO2 in the 15-20% class would be possible by then. Firstly, the Top-Level A/C Requirements and overall aircraft design will be presented, and secondly, mission Level Assessment results from TE2 first assessment will be detailed. The LSBJ2035 conceptual aircraft permits a gain up to 30% on emissions, partly due to the engine technologies. Laminarity is one of the key technologies that enable the observed gain. It is easier to achieve on a business jet thanks to the small size of the aircraft and its ability to flight at high altitude. Even if the empty weight does not decrease, it is important to note that the key feature of a composite wing is to permit the design of higher aspect ratio without large decrease of the sweep angle, thus permitting an acceptable cruise speed and a better overall cruise efficiency. Additionally, the LSBJ2035 conceptual aircraft offers 40% to 50% reduction of noise foot print area. The selected technology inputs come from technology streams developed under both Clean Sky 1 (Smart Fixed-Wing Aircraft) and CS2 research since 2015, having reached a sufficient maturity level (>TRL3) already in 2018, see table below.

Integrated technology	**Coming from**	**Main Benefit**	**Expected benefit over conventional technology**
High aspect ratio Natural Laminar Flow wing	CS SFWA CS2 AIR TS A-2 LPA WP 1.4.6	Drag reduction	10% to 15% of drag reduction, depending of laminarity extension and feasible aspect ratio
Noise shielding Tail Plane	CS SFWA CS2 AIR TS A-1	Noise Shielding	Reduction up 6 dB on fly over, 2.5 dB on approach
Composite wing	CS2 AIR TS A-3	Wing weight reduction	5% to 10% of overall wing weight reduction – enables more

Integrated technology	Coming from	Main Benefit	Expected benefit over conventional technology
			aggressive wing planform (sweep angle + aspect ratio)
Flight control load alleviation	CS SFWA CS2 AIR TS A-4	Weight reduction	Composite wing weight takes into account load alleviation
IPPS: High BPR, more efficient components	Internal Research	SFC reduction	SFC reduction by 5% to 12% due to BPR increase and component efficiency improvement

Integrated technologies and expected benefits for the business jet concept

2900 nm (5370 km) - Mach 0.78 - 12 PAX – MTOW 18.8 t



Ref. BJ2000 – Falcon 2000 like
2900 nm - Mach 0.75 – 12 PAX – MTOW 19.8 t

Benefits vs Platforms	BJ 2035 Concept July 2018		
PERFORMANCE	SFC	Mass (tons)	Drag
Aerodynamics High & Low speeds	-	↗	↘↘
Structure	-	↘	-
Systems	-	-	-
Improvements for noise	-	↗	↗
Engine	↘↘	-	↗
Total Performance	-5% to -12%	-1.0 t	-10 to -15%

Total IMPACTS avg %Reduction vs Ref 2014	CO_2	NO_x	NOISE
	-17.5% to -31.5%	-15% to -28%	Take-Off and Landing Footprint Area -42%

The NGCTR (Next Generation Civil Tilt-Rotor): faster, farther, cleaner

Mr. Giorgio Vicenzotti (Leonardo)

In response to numerous environmental and societal pressures, the aviation sector is embarking upon a period of unprecedented technological change that has the potential to revolutionize transport mobility. Leonardo Helicopters Division (LHD) responded to the CS2 challenge by proposing the Next Generation Civil Tilt Rotor (NGCTR), with the purpose of increasing performance and operational capability over current tilt-rotor configurations. It envisions a substantial increase in productivity and operational capability for various civil missions and public service scenarios, thanks to a cruise speed in the order of 280 kts – about twice the typical helicopter speeds and closer to that of a turboprop aircraft – and a maximum operating range of about 1,000 nautical miles (1,850 km). This aircraft will have dimensions comparable to those of a helicopter and will operate in all weather conditions and comfort level similar to those of an airliner thanks to its pressurized cabin and very high maximum ceiling (25,000 ft), that of an aircraft. This will allow to expand the opportunities to ensure people's mobility and freight transportation, reaching remote geographical areas that today helicopters and airplanes cannot reach

easily. This will be achieved by minimizing the environmental impact through reduced emissions (CO2, NOx, noise) and without the need to create large and expensive infrastructures. Also the impact on search&rescue (SAR) operations of this new mean of transportation has been addressed. The advantage of the fast rotorcraft enhanced capabilities is twofold: to cover in a shorter time the actual helicopters coverage area and to extend the actual coverage area capabilities. The latter can be translated into a fleet substitution rate, that is assessing the number of conceptual vehicles required to serve the same SAR coverage area of a reference/existing fleet.

Airport-level assessments in Clean Sky 2 TE (CLAIRPORT / GREENPORT2050)

Mr. Michel van Eenige (Royal Netherlands Aerospace Centre NLR)

Capitalising on the success of the Clean Sky Programme (2008-2016), the Clean Sky 2 Programme aims to make a substantial contribution to the ACARE 2050 environmental and mobility goals by accelerating the introduction of innovative aircraft technologies in the timeframe 2025-2035. Cross-positioned within the Clean Sky 2 Programme, the Technology Evaluator (TE) is a dedicated evaluation platform. It has the key role of assessing the environmental impact of the technologies developed in this programme and their level of success towards the ACARE 2050 environmental and mobility goals. This assessment is conducted at three levels: aircraft, airport and air-transport system level. The presentation will focus on assessments at airport level. The objective of these assessments is to quantify the environmental impact at airport level up to 2050 of technologies developed in the Clean Sky 2 Programme. This impact includes noise on the ground and the population exposed to noise, as well as emissions and their contribution to air quality. For this purpose, air traffic at and around a set of representative European airports is simulated for two flight schedules. The first is a flight schedule with reference aircraft, and the other is the same flight schedule with Clean Sky 2 aircraft (i.e. aircraft equipped with Clean Sky 2 technologies) replacing their reference. Based on this simulated air traffic, noise and emissions in the vicinity of the airport are calculated to enable a comparison between the environmental performance of the two air traffic scenarios. With the first Clean Sky 2 TE assessment at airport level completed in the CLAIRPORT project and the preparation of the second (and expanded one) in the GREENPORT2050 project in progress, the presentation will provide an overview of the assessment approach and its results emerging from this first assessment as well as an outlook to the second (and final) assessment.

Design Evaluation and Performance Assessment of Fast Rotorcraft Concepts for 2050

Dr. Devaiah Nalianda (Cranfield University), *Calum Scullion, Vassilios Pachidis, Alf Junior, Gianluigi Misté, Jos Stevens, Edward Rademaker, Stefan van 't Hoff, Nico van Oosten, Luis Meliveo*

Strategic Research & Innovation Agenda (SRIA) goals have been set up for the European aviation industry to ensure future environmental sustainability, while meeting society's needs for fast efficient transportation. As a part of these goals, Clean Sky 2 proposes to introduce a number of concept aircraft and rotorcraft to replace reference technology counterparts at different time scales (2015/2020/2035/2050). In this context, "Fast" rotorcraft are set to play a key role as an enabling technology, in contributing to and achieving ambitious environmental objectives and future targets. In order to ensure the realisation of these objectives of the European aviation industry, it is also necessary to assess and evaluate the environmental and socio-economic impact of these new technologies in that time scale. This paper will therefore describe such assessments for Fast rotorcraft concepts, which are currently being undertaken as part of the CS2 project DEPART2050 (Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050). Based on the requirements of the Technology Evaluator, the project is currently undertaking performance assessments of simulated advanced tilt-rotor and compound rotorcraft configurations. The assessments are being undertaken at the airport and Air Traffic System (ATS) levels and include quantification of potential environmental (emissions and noise) and

mobility (connectivity and productivity) improvements that may be accrued through replacement of reference technology over the designated time scales. The focus of the presentation will be to firstly introduce the technical activities being undertaken within project DEPART2050. It will further provide an overview of the modelling methodologies being followed within the project to simulate reference and fast rotorcraft concepts. Hence, this will include a description of the physics-based models and the modelling framework employed to assess performance, environmental and mobility improvements. The presentation will finally include an illustrative case study, wherein utilising the defined methodology and framework, mission results for a generic fast rotorcraft concept, obtained for realistic four-dimensional operational scenarios will be discussed in comparison with a reference state-of-the-art technology. Assessments of perceived improvements in performance, emissions, mobility and cost benefits, arising from the introduction of the configuration within the future fast rotorcraft fleets will be presented.

Results on ATS level assessments (ac)

Mr. Alf Junior (DLR), *Wolfgang Grimme, Marc Gelhausen*

The Clean Sky 2 (CS2) Technology Evaluator (TE) is a platform to monitor and assess the environmental and socio-economic impacts of the technological improvements and aircraft innovations arising from all CS2 activities. The TE specifically quantifies the expected improvements of the aviation sector in future scenarios in comparison to reference scenarios and via impact assessments, which are performed on three different levels, i.e. mission level, airport level, and air transport system (ATS) level. While on the mission and airport level only environmental impacts (CO2, NOx and noise emissions) are covered, the ATS level includes also socio-economic impacts like connectivity, job creation, gross-domestic product and competitiveness. The presentation will focus on the outcomes of the 1st TE assessment at ATS level. Global aircraft fleet forecasts up to 2035 and scenarios up to 2050 with and without Clean Sky 2 technology aircraft included, have been developed with the aim to quantify the environmental impacts (CO2 and NOx). For this purpose, a realistic insertion of new technology into the future aircraft fleet has been modelled based on the current generation aircraft life time. Taking the year 2014 as a basis and considering the air traffic growth until 2050, reference and Clean Sky aircraft fleets have been compared to quantify the Clean Sky technology effect and providing an environmental “footprint” of future air transport.

Overall Air Transport System Vehicle Scenarios (OASyS) – Commercial Supersonic, Business Supersonic, and Urban Air Mobility Forecasts

Mr. Jiajie (Terry) Wen (Georgia Tech-CNRS UMI), *Turab A. Zaidi, and Dimitri N. Mavris*

nic transport (SST), supersonic business jets (SSBJ), and urban air mobility (UAM) vehicles is on increasing attention today. The EU CS2-sponsored OASyS (Overall Air Transport System Vehicle Scenarios) project forecasted future scenarios for these vehicles in the 2035-2050 timeframe. The project encompassed a one-year effort concluding in September 2020 and included several publications across the three areas of study. The OASyS demand estimates can then be used to quantify the potential environmental impact from operating the aforementioned types of vehicles. The outcome is a set of scenarios that will inform the CS2 Technology Evaluator, and will help stakeholders to understand the impact of UAM and civil supersonic operations in the context of the global air transportation system. The SST research concluded that operations can be quantified from a value-added perspective (faster than subsonic airliners). The size and breadth of an SST network depend heavily on noise regulations and the quantification of premium-class passengers switching to SST services. A very large SST network is not expected, but the results show that demand could exist for a sizeable network under certain conditions, if suitable scenario assumptions are utilized. Additionally, the SST network emissions will most likely be small compared to the current subsonic baseline network. The SSBJ analysis concluded that the SSBJ network characteristics would be

comparable to subsonic business aviation in all major aspects. Compared to supersonic commercial aviation, business aviation would have the same order of magnitude in terms of daily flights and one order of magnitude higher in terms of the number of routes served. It was also noted that when the time-saving requirement is very low, the added benefit of low-boom full supersonic overland flight is not significant. The UAM work found that operations would be based on mobility patterns and framework developments influencing mobility in cities. This study concludes that strong market demand exists for a range of UAM ticket costs and vertiport densities. It is noteworthy that the cruise speed of UAM vehicles may not have a significant effect on UAM demand. However, infrastructure and fleet size influence waiting times, and this has a substantial impact on UAM demand estimates across the investigated scenarios.

Clean Sky 2 "Technology Evaluator" Special Session (PART III)

Session Chair : Dr. Jean-Francois Brouckaert, Clean Sky Joint Undertaking

TeDiMo - Developing a diffusion model for prediction of technology propagation into the aviation market

Ms. Lis Weilandt (Institute of Aerospace Systems, RWTH Aachen University), *Xueying Liu, Eike Stumpf, Reinhard Madlener*

The air transport system of today is facing substantial global challenges that can only be met by research and development of innovative technologies. This, however, is time consuming and expensive and in any case associated with economic risk for technology providers. Hence, to avoid malinvestment, it is essential to properly estimate the chances of success of respective technologies. The main objective of the project TeDiMo (Technology Diffusion Model) was therefore to establish a technology diffusion model in the context of the Technology Evaluator that enables the investigation of the propagation of new technologies developed in Clean Sky 2. To that end, relevant stakeholders of the air transport system have been identified and mechanisms driving technology diffusion have been worked out and parameterized. On that basis, two different approaches for diffusion modelling have been explored: An epidemic approach and an agent-based approach. In addition to a comprehensive set of data about available aircraft and operative airlines, the agent-based model requires information on annual demand and discard rates per aircraft category. The model functionality is based on an aircraft score algorithm that rates aircraft performance capabilities based on airline needs and then distributes overall aircraft demand among aircraft models according to a set of decision rules. Since the agent-based approach offers a wider range of application and extensibility, it is chosen over the epidemic model for further investigations. When simulating the diffusion of new technologies into the market, it is essential to know the influence of these new technologies on the diffusion parameters elaborated before. Hence, an impact assessment of Clean Sky 2 technologies was conducted to prepare the application of the prior developed diffusion model to a world fleet scenario including Clean Sky 2 aircraft concepts. Application of the diffusion model shows plausible results, expected model sensitivity in response to changes of model inputs such as demand and discard rates and the score algorithm gives reasonable score variations depending on changes to different aircraft performance parameters. Thus, the developed model is ready to contribute to informed decision making within future technology development and selection processes.

GLIMPSE2050: Regulations & Policies

Kinanthi Sutopo, ***Mr. Michel van Eenige (Royal Netherlands Aerospace Centre NLR)***

Capitalising on the success of the Clean Sky Programme (2008-2016), the Clean Sky 2 Programme aims to make a substantial contribution to the ACARE 2050 environmental and mobility goals by accelerating the introduction of innovative aircraft technologies in the timeframe 2025-2035. Cross-positioned within the

Clean Sky 2 Programme, the Technology Evaluator (TE) is a dedicated evaluation platform. It has the key role of assessing the environmental impact of the technologies developed in this programme and their level of success towards the ACARE 2050 environmental and mobility goals. GLIMPSE2050 is a Clean Sky 2 TE project. It expands the aircraft technology-oriented focus of the Clean Sky 2 Programme by evaluating at global level the potential effects up to 2050 of regulations and policies that are currently discussed and potentially introduced until 2040 to reduce the environmental impact of aviation. Herewith, it estimates which environmental reductions can be achieved by these regulations and policies in addition to those brought by Clean Sky 2 technologies. More specifically, GLIMPSE2050 compares the environmental performance of two scenarios. The first scenario is a projection of the air transport system up to 2050 based on autonomous economic, demographical and technological developments but without the regulations and policies. The second scenario is the same projection of the air transport system up to 2050, but with the selected regulations and policies introduced. The presentation will provide an overview of GLIMPSE2050. It will address the approach to select the regulations and policies and to carry out the assessments as well as present selected results.

Review of novel propulsion technologies for sustainable aviation from TRANSCEND

Mr. Johan Kos ((Royal Netherlands Aerospace Centre NLR)), *Jaap van Muijden, Alte I. de Boer, Oscar Kogenhop, Edward R. Rademaker*

Novel propulsion technologies and alternative fuels are key technologies for reducing the environmental impact of aviation and its impact on climate change. The TRANSCEND (Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains) project in the Clean Sky 2 Technology Evaluator evaluates the potential contribution of these technologies to FlightPath 2050 and related zero net emission goals for the period 2035-2050. The technologies evaluated are complementary to the propulsion (and aircraft) technologies developed in Clean Sky 2 and evaluated in its Technology Evaluator. In addition, TRANSCEND prepares roadmaps for selected promising novel propulsion and alternative fuels towards their full-scale entry-into-service in the period 2035-2050. This presentation introduces the TRANSCEND project and reviews novel propulsion technologies both for aircraft powered by sustainable replacements of kerosene and for aircraft powered by hydrogen. The review focuses on the identification of the technologies, their preliminary evaluation for different classes of aircraft, and their allocation to classes of aircraft. Four categories of novel propulsion have been reviewed: gas-turbine based propulsion (both for drop-in and for non-drop-in energy sources), electric propulsion, and hybrid-electric propulsion. Based on these categories, a number of classes of propulsion concepts with numerous underlying novel propulsion technologies will be presented for potential aircraft application before 2050, allocated to aircraft seat classes. In the complementary presentation by John Posada Duque the review of the alternative fuels for sustainable aviation is presented.

Review of alternative fuels for sustainable aviation from TRANSCEND

Mr. John Posada (TU Delft, Department of Biotechnology), *Inna Stepchuk, Elisabeth van der Sman, Mar Palmeros-Parada, Patricia Osseweijer*

The TRANSCEND project (as part of the Clean Sky 2 Technology Evaluator) aims to develop roadmaps for full scale entry-into-service of selected propulsion technologies and alternative fuels in the period 2035-2050, in line the emission target of FlightPath-2050 for the period 2035-2050. In this work we present the selection of six sustainable aviation fuels (SAFs) that will be included in TRANSCEND road-mapping. The full context of TRANSCEND and its findings for promising propulsion technologies are introduced in the complementary presentation: “Review of novel propulsion technologies for sustainable aviation from TRANSCEND” by Johan Kos. The reviewed SAFs included bio-based fuels and e-fuels as drop-in SAFs, and non-drop-in energy sources (here hydrogen).

As part of the literature review, 19 groups of production technologies for SAF were initially identified, from which 5 technologies were discarded in the screening process due to either potential limitations on scalability or it very early technological development stage (i.e. very low Technology Readiness Levels). Subsequently, the 14 remaining technologies were comparatively analyzed for both their unitary production costs (i.e. costs per unit of usable energy [€/MJ]) and unitary greenhouse gas (GHG) emissions (i.e. CO2-eq. per unit of usable energy [CO2-eq./MJ]). As a result, five promising SAF production routes were pre-selected for further discussion with experts in a workshop; and at the end of the session six SAFs were selected for further evaluation in the roadmap, they are: hydroprocessed esters and fatty acids (HEFA), Fisher-Tropsch process (FT), fast pyrolysis (FP), Alcohol to Jet (ATJ), power-to-liquid (PtL) for e-fuel via Fisher-Tropsch, and alkaline electrolysis (AE) for hydrogen. Finally, the data collected on the life cycle GHG emissions, for most the relevant alternative energy sources and production routes, were used to develop an open Microsoft Excel based tool (the "Ecological Balance Sheet") to quickly estimate a range of expected GHG emissions and the potential emissions savings of a production chain (based on similar systems already reported in literature).

GLOWOPT: Development of climate functions for aircraft design

Ms. Kathrin Deck ((TU Delft), *Volker Grewe, Feijia Yin, Irene Dedoussi, Roelof Vos, Pieter-Jan Proesmans, Florian Linke, Kaushik Radhakrishnan, Malte Niklaß, Benjamin Lührs*

Aviation ensures mobility for both passengers and goods. It is important as a transport sector for connections on and between continents. Nevertheless, aviation also contributes to anthropogenic climate change. The effects are usually divided in CO2 and non-CO2 effects and therefore not only CO2 emissions but also other emissions (e.g., NOx , water vapour or soot) and contrails are covered. To reduce the effects of aviation's climate impact, several mitigation options are applied. One approach are climate change functions, which will be addressed here. The concept of climate change functions was used in previous projects, e.g. REACT4C, WeCare, ATM4E. The goal of these functions was to optimize the aircraft routes regarding the calculated climate impact. Climate change functions measure the climate impact per unit emission for a specific day, which considers the current meteorological conditions. Climate change functions were previously used to optimize the aircraft routings. The concept should now be applied for the optimization of the aircraft design as well since the promising concept is currently missing for the application of aircraft design optimization. The climate functions for aircraft design will connect the aircraft design with the climate impact of various emission in order to be able to optimize the aircraft design. For the calculation of the functions, it is necessary to define a specific application. This application results from a combination of aircraft design parameters. Aircraft design parameters can be for example flight altitude, climb rate, speed or range. Based on a resulting emission inventory, the temperature response can be calculated with the model "AirClim". This model calculates with the input, first, the radiative forcing and based on that the temperature change. The final development step is the verification of the climate functions.

Reducing emissions through fleet and flight network optimisation – the Clean Sky project REIVON

Dr. Thomas Rötger (ENVISA), *Gabriel Casas, Hans Dorries, Ling Lim, Bethan Owen, André van Velzen, Florian Linke, Benjamin Lührs, Kaushik Radhakrishnan*

The Clean Sky 2 Technology project REIVON investigates to what extent the CO2 emissions of global aviation can be reduced via an aircraft size/range optimised fleet and flight network. For the latter, two main approaches are investigated, namely splitting long-haul flights into shorter legs and reducing flight frequencies on busy routes to the necessary minimum using larger aircraft. In addition, REIVON analyses potential measures to establish an air transport system with optimised aircraft, flight network and frequencies, and assesses its impact on stakeholders (passengers, aircraft manufacturers, airlines, airports

and airport neighbours). So far, a general impact assessment methodology and the necessary models, tools, metrics and global aviation forecast data have been gathered and agreed. Currently, optimised alternatives to the current air transport system are being elaborated and fuel use and CO2 emissions for the baseline and alternative cases are being computed.

Aerodynamic Analysis & Design (PART I)

Session Chair : Prof. Konstantinos Kontis, University of Glasgow, UK

Development of the ritz polynomial method for solving aeroelasticity problems

V.V. Chedrik, K.A. Balunov, A.V. Chedrik, ***Mr. Anton. Kuznetsov (Central Aerohydrodynamic Institute - TsAGI),*** *S.A. Tuktarov*

Aeroelasticity problems are usually related with broad parametric studies. Firstly, it is due to the uncertainty in the scheme parameters at the design and development stages. Secondly, it is necessary to ensure margins of aeroelastic stability by many structural and flow parameters. The use of the Ritz method significantly reduces time to create mathematical models and allows to consider several designs with acceptable accuracy. In computational TsAGI software KC-M and ARGON, a modern version of the Ritz polynomial method is implemented to calculate the aeroelasticity characteristics of aircraft to be developed. Further improvements of the method and the integration of new algorithms and codes are currently an important and actual problem in aeroelasticity.

Numerical analysis of cyclorotor aerodynamic properties in hovering state

Mr. Shawn Cogan (University of Stuttgart), *Louis Gagnon*

Cyclorotors employ cyclically pitched axial rotor blades to create an extremely maneuverable propulsion system. The pitch angle throughout one rotation is defined so that the resulting blade angle of attack follows a prescribed function that generates lift. The lift and drag produced is also affected by curvilinear flow, dynamic stall, and induced velocities, all of which affect the resulting angle of attack. These factors form complex relationships that are difficult to model analytically, making it hard to predict a cyclorotor's performance. Here, a numerical model is presented which can be used to predict thrust and power draw of different cyclorotor configurations. Parameters include airfoil, number of rotor blades, rotational velocity, pivot function, fluid properties and Reynold's number. The numerical model builds on previously implemented approximations but focuses on time-efficient calculations so that many configurations may be calculated in an iterative process. In each iteration the parameters can be adjusted according to machine learning or other metaheuristic optimization algorithms to determine an optimal configuration.

Design challenges of cryogenic regional turboprop aerodynamic layout

Mr. E. A. Pigusov (Central Aerohydrodynamic Institute - TsAGI), *A.A. Krutov, E.S. Perchenkov, Yu.N. Chernavskih, V.I. Chernousov*

The use of cryogenic fuel (liquid hydrogen, liquefied natural gas) in aircraft will radically reduce harmful emissions into the atmosphere, as well as reduce fuel consumption. In aviation, for reasons of minimizing the volume and weight of fuel tanks, hydrogen and liquefied natural gas must be stored in liquid form, in a state of strong cooling. Both gases in the liquid state have several times less weight compared to kerosene, which could allow reducing the aircraft take-off weight or increasing a payload. But the introduction of cryogenic fuel on transport category aircraft requires solving the problems of its storage on board. For the storage of cryogenic fuel, special tanks with minimal heat flows (spherical or cylindrical) with effective thermal insulation are required, which must be located outside of the estimated area of uncontained aircraft engine debris. An important task when placing such tanks in the layout of the aircraft is to reduce their harmful effect on the aerodynamic characteristics. This paper is discussed the results of study on aerodynamic layout of the cryogenic regional turboprop with a low level of environmental impact. A modification of a regional twin-engine turboprop for operation on cryogenic fuel is considered. The problems and features of the placement of the fuel tank for cryogenic fuel are shown. The results of

experimental studies of the aerodynamics of an aircraft model with a cryogenic tank and the results of the calculation of flight performance with various types of fuel are presented.

Ground effect aerodynamics of twin fuselage aircraft

Mr. E. A. Pigusov (Central Aerohydrodynamic Institute - TsAGI), *V.I. Chernousov, A.A. Krutov, P.V. Savin*

The paper presents experimental study results of ground effect influence on the aerodynamic characteristics of a twin fuselage transport airplane (TFTA) in a low-speed wind tunnel. The aerodynamic configuration has the two fuselages distributed under high-wing, and a "TT"–shaped tail. Aerodynamic model of TFTA was produced in 1:20 scale. The TFTA model consists of two fuselages, wing, empennage and external tank. The TFTA model has no wing high lift devices, flight control surfaces (elevator, rudder, ailerons, spoilers), landing gears and engine nacelles. A fixed rigid screen (ground plate) was used to simulate a runway surface. Test data were obtained at the flow velocity V=50 m/s and Reynolds number of Re= 1 mil based on the mean aerodynamic chord (MAC). Angles of attack (AoA) were ranged from -6° to +20° and sideslip angles from -20° to +20° when tests were performed without the ground plate. Near the ground plate, the AoA range was restricted to prevent contact between model rear fuselage and ground plate. The tests were performed for following model heights above the ground plate: h/b≈0.7 (main landing gears contacting the runway), 1.0 and 1.3, where h – height from the trailing edge of centerwing to ground plate, b – MAC. The analysis includes studying the ground effect on the longitudinal, lateral and directional aerodynamic characteristics and horizontal tail effectiveness. The effect of installing an external cryogenic fuel tank under the wing between the fuselages of the model was considered too. The obtained data shows the typical behavior of the aerodynamic characteristics near the ground plate for aircraft model with high-wing and high placed horizontal tail. Ground proximity significantly increases the maximum lift-to-drag ratio and slightly changes the longitudinal moment characteristics. Horizontal tail effectiveness is maintained for all tailplane angles near the ground plate. The longitudinal, lateral and directional stability of the TFTA model is maintained in all considered modes near the ground plate.

Experimental Investigation of the Performance and Flow Field of a Propeller in both Propulsive and Regenerative Conditions

Mr. Robert Nederlof (Delft University of Technology), *D. Ragni, T. Sinnige*

The distributed propeller concepts and associated electrification of aviation bring new opportunities to use the propellers in an efficiency-enhancing manner. Similar to regenerative braking in (hybrid-)electric cars, propellers can be used to recover part of the potential and kinetic energy during flight phases where no energy input is needed. The use of propellers as an energy recuperation system will result in a completely different flow field around the propeller blades, where the slipstream velocities will be markedly different than the propulsive case. Furthermore, the operation in off-design conditions will have a negative effect on the blade loading, since the positively cambered airfoils will be prone to separation at the negative angles of attack associated with the regenerative operation. The flow separation on the blades becomes very significant at the higher regenerative conditions and hence limits the regenerative capabilities of the propeller. To characterize the change in performance, blade loading and slipstream flow field when using the propeller in regenerative conditions, an isolated propeller experiment was performed in the Low-Speed Low-Turbulence Tunnel at Delft University of Technology. The experiment was done using a three-bladed version of an original six-bladed propeller which is representative of a turboprop aircraft. Three blades were removed from the original propeller to limit power requirements in propulsive and regenerative regimes while keeping a representative blade loading condition. The loads of the propeller were measured using an internal load cell and an external balance, to be able to separate the interaction effects between propeller slipstream and support structure. For the analysis of the flow field, stereoscopic PIV and a 5-hole pressure probe were used. Figure 1 displays a photograph of the test setup.

The wind tunnel experiment was also used to generate an extensive dataset for validation of low-order tools for the prediction of aerodynamic loading on the propeller in the regenerative condition.

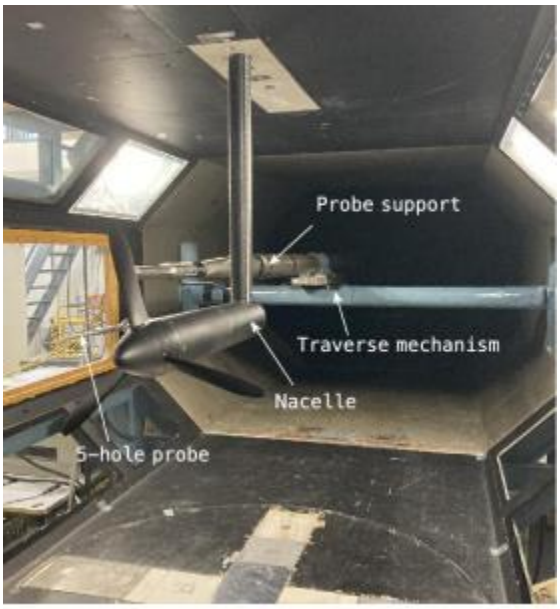
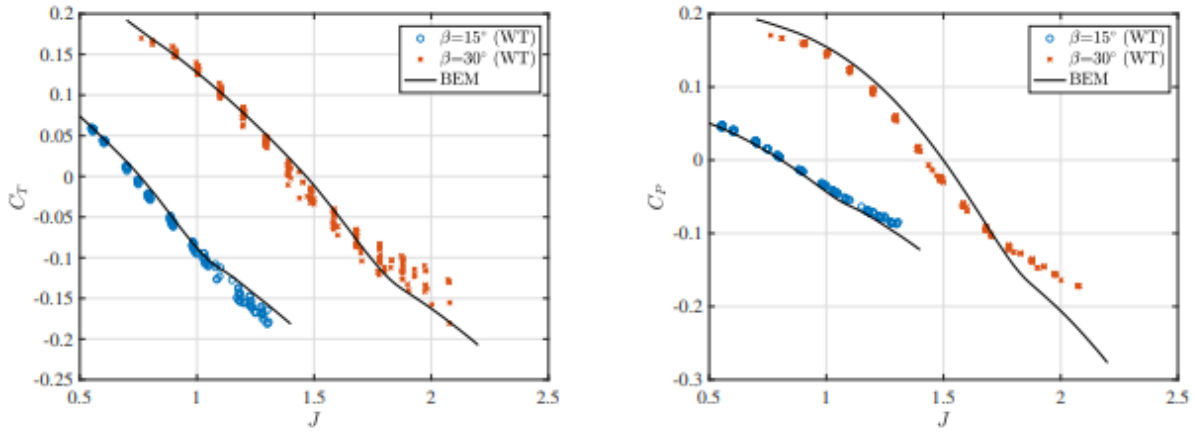


Figure 1: Propeller setup in the Low Turbulence Tunnel

In Figure 2, the thrust and power data of the propeller, measured by the internal load cell, is shown for two pitch settings, namely for 15◦ and 30◦, defined at 70% of the propeller radius. In Figure 2, the wind tunnel (WT) results are compared with the analysis results of a conventional implementation of the blade element momentum (BEM) method. These results were obtained by varying the rotational speed of the propeller, while keeping the tunnel speed fixed to 30 m/s. The thrust coefficient and power coefficient are shown versus the advance ratio in Figure 2a and 2b respectively. The wind tunnel results are presented as individual markers corresponding to the individual data points recorded in the experiment. The scatter at low thrust is due to the effect of variations of the load-cell temperature during operation of the electric motor during the test. By randomizing the order of the measurement points within runs and by sufficient repetition, the impact of the resulting measurement error on the overall performance trend was minimized. The final paper will include response-surface models and an assessment of the uncertainty of the experimental data.



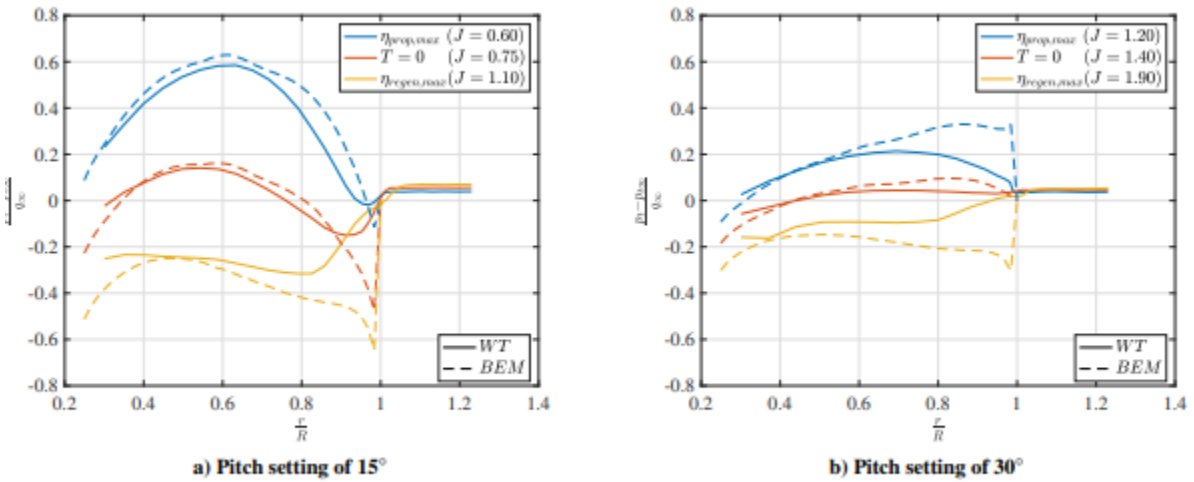
a) Thrust coefficient versus advance ratio

b) Power coefficient versus advance ratio

Fig. 2 Comparison between wind tunnel and BEM performance data for a pitch setting of 15° and 30° at V_∞=30 m/s

As shown in Figure 2, the BEM method is able to predict the propulsive regime reasonably accurately compared to the wind tunnel data, while for the regenerative regime, the difference between the two starts to become larger. This divergence between wind tunnel data and the BEM analysis results becomes clearer when analyzing the. The over-prediction in regenerative performance is attributed to the relatively low Reynolds number at these advance ratios. Especially, for the pitch setting of 30◦, the regenerative

conditions are achieved at much lower rotational speeds, compared to the pitch setting of 15◦. The sharp change in slope at around an advance ratio of 1.75 is due to the large negative angles of attack on the blade that led to stall. The stall is not well modeled by the BEM method, resulting in the large offset with the experimental data. The lack of accurate BEM modeling at negative angles of attack and low Reynolds numbers is confirmed by the total pressure data behind the blades. These data were obtained by traversing the 5-hole pressure probe in lateral direction at the vertical position of the propeller axis, at multiple longitudinal positions downstream of the propeller plane. In Figure 3, the total pressure distribution is shown for the 5-hole probe measurements at 0.15 downstream of the propeller planes, which was the closest possible position to the blades. This total pressure distribution is representative of the loading distribution on the propeller blades. The total pressure coefficient downstream of the blades is shown for three different advance ratios, which are the point close to the maximum efficiency in the propulsive regime, the point close to zero thrust and the point close to maximum regenerative efficiency. The latter is defined as the ratio between the recuperated power and the total kinetic power available in the free stream.



a) Pitch setting of 15° b) Pitch setting of 30°

Fig. 3 Comparison between wind tunnel and BEM total pressure distribution along the blade

For the cases of maximum propulsive efficiency and zero thrust at a pitch setting of 15◦, the BEM method can accurately model the blade loading. The total pressure calculated by the BEM method shows a sudden jump, due to the tip correction applied in the method. However, at the regenerative condition, the large negative angles of attack result in large separation regions on the blade, leading to a rather flat loading distribution, where the BEM over-predicts the regenerative performance. For the pitch setting of 30◦, where the same three mentioned conditions are achieved at lower rotational speeds and thus lower Reynolds numbers, the blade loading is already off in the propulsive regime. For the other two points, the loading is also much different than the BEM prediction. The final paper will include a more detailed investigation of the propeller loading, and additional quantitative assessment of the slipstream flow field, including the PIV data. This will increase the understanding of the propeller performance in regenerative conditions, and it will help to prepare for future studies of propeller-wing interaction phenomena in such regenerative conditions.

A CFD/experimental comparative database to feed a predictive model for ground vortex characteristics

Mr. Fabien Dupuy (Capgemini Engineering), *Rita Mendonca, E Costa, Sylvain Raynal, Vincent Camenen, Jean-Paul Bouchet, Sébastien Courtine*

This study focuses on the analysis of vortex formation and ingestion by aircraft engines in ground operations. This phenomenon arises under specific combinations of wind direction and velocity and inlet air speed, generating engine vibrations and leading to suction of damaging abrasive particles; thus, its characterization in early design stages is crucial. The framework of this investigation is the InVIGO project, part of Clean Sky 2 and funded by European Union's Horizon 2020 research and innovation program under grant agreement No 864288. This project combines Wind Tunnel (WT) test results with Hybrid RANS/LES (Scale Adaptive Simulations method) numerical simulations performed in the WT geometry to provide a comprehensive characterization of vortex ingestion and a powerful database to develop a predictive model for vortex characteristics using Data Analytics. This model will be used during early engine tests to characterize vortex properties using only conventional "light instrumentation" (pressure rakes with a low level of intrusiveness, generally used to capture large flow separation regions). The combination of data from WT test campaigns + CFD simulations allows not only covering a larger number of vortex configurations (thus creating a richer database), but also a deeper analysis of the obtained data in reference planes of interest: inside the nacelle (where it is more challenging to set up instrumentation) or in the immediate vicinity of the nacelle (in planes where Stereo Particle Image Velocimetry, PIV, is performed experimentally). A matrix of several test points covering different combinations of ground clearance, intake speeds and wind velocity values was prepared for CFD simulations and WT campaigns. The test section (6x5x12 m) contains the nacelle connected to a suction pipe and positioned above an adjustable raised floor (for ground clearance modifications). Cameras are positioned on a vertical system to carry out Stereo-PIV measurements in 3 reference planes. Additionally, pressure probes are placed on the nacelle lip and pressure rakes in the fan plane. Unsteady simulations are performed with Ansys Fluent using a SAS formulation, and with a slightly degraded CAD geometry (pressure rakes within the intake were removed as they require fine grids in the corresponding regions). Vortex characteristics are extracted periodically, both for WT results (2 horizontal planes + 1 vertical plane) and simulations (same reference planes, with the addition of the fan plane). The first objective of Data Analytics is to transpose characteristics of the experimental vortex into fan plane data. The overall coherence between WT and CFD results is analysed in the vertical PIV plane. Results showed very good agreement between the data obtained in CFD simulations and in the experimental test campaigns, with a matching of vortex detection for 23 out of the 24 analysed cases. Flow fields and vortex characteristics determined numerically were also found to be similar to the ones obtained experimentally. Namely, for the cases in which a vortex was identified, average equivalent vortex radius and tangential velocity $V\theta$ were found to be comparable. Vortex characteristics prediction was investigated with data analytics through the use of multi-layer perceptron. It was found that average vortex radius and circulation are well predicted using only the information from the vertical PIV plane. Other characteristics, and specifically standard deviation values, are best predicted when the upper horizontal plane is included. Future work will include a deeper analysis of the data obtained during a second experimental test campaign. The available database size will double by means of new simulations and tests. The model for vortex reconstruction in the fan plane will be built, along with the final predictive model for the characteristics of vortices arising under different combinations of the relevant input macro-parameters (ground clearance, intake speed, and wind velocity).

Aerodynamic Analysis & Design (PART II)

Session Chair : Prof. Konstantinos Kontis, University of Glasgow, UK

An accurate RANS-based transition prediction approach (part I)

Serena Russo, Vincenzo Citro, ***Mr. Nunzio Natale (DREAM INNOVATION Srl),*** *Flavio Giannetti*

Abstract—We present a numerical procedure to improve the performance of the classical Reynolds-Averaged Navier-Stokes approach for transitional flows by introducing a transition prediction tool in the RANS code. A black-box procedure able to estimate first the boundary layer quantities (starting from the pressure distribution) and then to compute the linear evolution of the fluctuations has been included in an existing RANS code. Thanks to the coupling to the eN method, the transition location is predicted and periodically imposed during the RANS computations. The natural laminar flow technology is one of the most interesting solution to improve the aircraft performance of the future green aircrafts since it allows to reduce the total aircraft drag of more than 5%. Transition prediction from laminar to turbulent flow, however, is a critical key point in the correct estimation of the friction drag, leading edge separation and boundary layer thickness. Stall mechanisms are also affected by the correct prediction of the transition location because only in this case it could be captured: the achievement of a good agreement with experiments is impossible without correct information about the transition. In the authors experience, existing Reynolds-Averaged Navier-Stokes (RANS) approaches could suffer of inadequateness in the capability of turbulence models to predict the transition with the accuracy required for aeronautical applications in cruise and, especially, in high-lift conditions. The approach proposed in this paper to predict the transition location and the laminar flow extension is based on a numerical framework based on the coupling between a high-fidelity, Reynolds–Averaged Navier–Stokes (RANS) tool and Linear Stability Equations[22] [23]. According to this method, boundary layer equations are written in conical formulation[24] and the solution of RANS equations and transition onset is obtained through an eN method based on the PSE calculations. The validation of the present approach has been achieved by comparing the numerical results against the experimental data documented in the ETRIOLLA project[25]. The scope of the ETRIOLLA project was the design of an aeroelastic wind tunnel model tested in the ONERA S1MA wind tunnel. The flight shape of the wing has been designed within the Clean Sky GRA (Green Regional Aircraft) programme with the purpose to allow for natural laminar flow on a large part of the upper side of the wing leading to reduce drag and increase efficiency.

An accurate RANS-based transition prediction approach (part II)

Mr. Flavio Giannetti (Universita' degli Studi di Salerno), *Serena Russo, Nunzio Natale, Vincenzo Citro*

We present a CFD analysis of a wind tunnel model of the new laminar turbo-prop aircraft designed in the frame of the European Clean Sky 2 programme. The analysis has been performed by using an improved Reynolds-Averaged Navier-Stokes (RANS) approach able to simulate transitional flows[26].

[22] A. Krumbein, eN transition prediction for 3D wing configurations using database methods and a local, linear stability code, Aerospace Science and Technology 12 (2008) 592-598;

[23] S. Russo et al., The use of RANS approach for predicting transition, Aerotecnica Missili & Spazio 97 (3), 145-152

[24] T. Cebeci and J. Cousteix, Modeling and Computation of Boundary-Layer Flows Book, 1999.

[25] https://cordis.europa.eu/project/id/323460

[26] S. Russo et al., An accurate RANS-based transition prediction approach (part I), 11th EASN International Conference on "Innovation in Aviation & Space to the Satisfaction of the European Citizens" 2021

This work is carried out within ESTRO Clean Sky 2 CfP project[27], in the framework of the Innovative Aircraft Demonstrator Platforms (IADP) "Regional" of the "Clean Sky" 2 Programme, whose goal was to develop an innovative future green regional aircraft configuration based on several new technologies able to match the very demanding and challenging objectives ACARE 2020. A laminar wing for the innovative turbo-prop aircraft has been designed in the Regional IADP platform and ESTRO is aimed to evaluate the wing performance both numerically and experimentally. In this phase of the project, numerical investigations are under analysis to prepare the wind tunnel test campaign and the wind tunnel model setup. However, the aerodynamic wing performance is strongly affected by the capability to correctly simulate the transition from laminar to turbulent flow. In fact, transition influences friction drag, leading edge separation and boundary layer thickness with relevant consequences on the estimation of on aerodynamic features. In particular, stall mechanisms could be captured only if the role of the transition is completely clarified: the achievement of a good agreement with experiments is not possible without correct information about the transition. The work presents the numerical results of the aerodynamic performance of a scaled model of the innovative laminar turboprop A/C wing by using a CFD approach that includes the transition prediction. Numerical results will be compared by considering two different procedures: a) CFD analyses in which the transition location is imposed and b) CFD analyses in which the position of the transition is evaluated. The prediction of the transition location and the laminar flow extension is based on a numerical framework based on the coupling between a high-fidelity RANS tool and Linear Stability Equations (LNS)[28] [29][3][4]. According to this method, boundary layer equations are written in conical formulation[30] and the solution of RANS equations and transition onset is obtained through an eN method based on the LNS calculations.

Cross-effect between realistic aerodynamic loads and blade deformation on VTOL propellers

Mr. Sylvain Raynal (CapGemini), *G. Millot, S. Anselmetti*

This study concerns propeller calculations and blade deformation in the framework of Vertical Take-Off and Landing (VTOL) vehicles. An electric-VTOL geometry is designed by CAPGEMINI as future urban mobility solutions. It relies on a decoupled-propulsive architecture comprising 8 dual-rotor lifters and 2 ducted single-rotor pushers with constant blade pitch. Knowing each propeller performance during a full flight mission allows sizing the electrical components. However, accurately predicting these performances is a huge challenge for multiples reasons:

- Non-uniform inflow for lifters during horizontal flight (beneath self-lift velocity)
- Airframe wake for pushers due to boundary layer ingestion (BLI) integration type
- High aerodynamic and centrifugal forces resulting in deformed blade

CFD simulations including the entire airframe but without blades were conducted. Blade effect was imposed by coupling CFD with an external code for blade aerodynamics. Using the resulting radial and azimuthal blade force distribution allows the prediction of blade deformation under realistic flow field. This paper specifically presents these deformations and their impact on propeller performances. This study relies on three main parts. The blade performance calculation is based a python code called DragOnFly. It uses Blade Element Momentum Theory to deduce, among many characteristics, propeller lift, drag and blade twist torque. This method also allows radial (along the blade span) and azimuthal splitting to deal with changing angle of attack, variable airfoil (HAM-STD series until 30% blade span and EPPLER 850 series after) and heterogeneous upstream flow. DragOnFly is connected to the CFD solver,

[27] https://cordis.europa.eu/project/id/831809

[28] A. Krumbein, eN transition prediction for 3D wing configurations using database methods and a local, linear stability code, Aerospace Science and Technology 12 (2008) 592-598

[29] S. Russo et al., The use of RANS approach for predicting transition, Aerotecnica Missili & Spazio 97 (3), 145-152

[30] T. Cebeci and J. Cousteix, Modeling and Computation of Boundary-Layer Flows Book, 1999.

namely Ansys Fluent, used to perform RANS calculation around the airframe. During DragOnFly aerodynamic calculation, mechanical deformation can be included, based on a 1D mechanical model. This model, which includes aerodynamic and centrifugal loads, was derived from 2D mechanical calculations performed with MSC.Nastran. The Young modulus of the 1D model was adapted to match deformations predicted with 2D models. Cruise mission point was investigated. An iterative coupling between CFD simulation and DragOnFly calculation was performed without mechanical deformation. Once converged, the aerodynamic load was extracted to analyze the resulting azimuthal variability of mechanical deformation, assuming independent azimuthal behaviour. The upstream velocity field showed large variability underlining boundary layer ingestion (BLI) effect. Results showed a significant impact on twist angle decrease, although lower in the region impacted by BLI effect. This translates into a strong thrust deficiency. This region also shows the lowest blade tip clearance due to maximum blade radial deformation, still lower than 0.1% blade span. The comparison between all these results and those obtained with theoretical uniform inflow indicate that using uniform inflow give an appropriate intermediate estimation, without capturing all the fluctuations. Future work will directly implement mechanical deformation during CFD/DragOnFly convergence process.

Relying on Dynamically Morphing Blades to Increase the Efficiency of a Cycloidal Rotor

Ms. Doudou Huang (University of Stuttgart), *Louis Gagnon*

The curvature of the airfoil has a significant effect on the aerodynamic performance of cycloidal rotor system. This paper aims to improve the aerodynamic performance of the cycloidal rotor system by using dynamically morphing blades in a CFD model. In this paper, three different camber morphing concepts (leading edge deflection, trailing edge deformation and cambered NACA profile) have been applied to a baseline 2-bladed system with rotating and pitching NACA0015 aerofoils. Then, based on these three camber concepts, a series of URANS 2D numerical simulation were conducted for blades with different morphing degrees using OpenFOAM. The simulation results verified that the local blade flow condition could be optimized and thus significant improvement in thrust and higher efficiency could be achieved by properly tuning the morphing control.

Preliminary design of a small-scale, fixed-wing BWB UAV supporting a Cooperative-Intelligent Transport System for highway traffic-monitoring

Stylianos Dimitriou, ***Mr. Stavros Kapsalis (Center for Interdisciplinary Research and Innovation, Aristotle University of Thessaloniki),*** *Thomas Dimopoulos, Dimitrios Mitridis, Konstantinos Pouchias, Pericles Panagiotou, Kyros Yakinthos*

The current work presents the preliminary design procedure of a small-scale, fixed-wing Unmanned Aerial Vehicle (UAV), incorporating the novel Blended-Wing-Body (BWB) layout configuration. The UAV is designed to support a Cooperative-Intelligent Transport System (C-ITS), for monitoring traffic conditions at large national highways. The developed UAV-ITS is expected to improve the transportation of both passengers and cargo shipments, by offering traffic details and providing warnings for emergency situations, such as accidents. More specifically, the UAV mission requirements dictate a short takeoff and landing runway, loiter and maximum velocities equal to 130 and 160 km/h respectively, 6-hour endurance and a gross takeoff weight (GTOW) up to 25kg. The UAV design procedure emphasizes on both aerodynamic and stability behavior, aiming to a high aerodynamic efficiency. This is achieved by selecting the appropriate airfoil sections, as well as the key geometrical characteristics such as quarter-chord sweep, aspect ratio, wing twist and wingspan. Moreover, the design is supported by Computational Fluid Dynamics (CFD) analyses, to determine the aerodynamic and stability coefficients. Following the CFD modeling, the performance parameters of the platform are estimated and the engine-propeller system is

selected with the use of in-house sizing tools. Furthermore, an internal layout study is conducted to integrate the payload, the avionics, the electronics and engine components and determine the center of gravity. Finally, the overall UAV design concludes to an optimum configuration of the UAV-ITS, satisfying all the aerodynamic, stability and mission requirements.

Aerodynamic assessment of the use of tubercles and wing fences on a fixed-wing, tactical Blended-Wing-Body UAV platform

Mr. Charalampos Papadopoulos (Laboratory of Fluid Mechanics and Turbomachinery Aristotle University of Thessaloniki), *Sophia Ioannidou, Pericles Panagiotou, Kyros Yakinthos*

In this work, a study on the impact of passive flow control techniques on an fixed-wing, tactical Blended-Wing-Body (BWB) Unmanned Aerial Vehicle (UAV) is presented. The novel BWB layout smoothly integrates the wing into the fuselage (center body), creating an aerodynamically superior platform. However, the lack of a dedicated horizontal stabilizer creates the need for sweeping the wing aftwards, so that the longitudinal stability constraints are addressed. This in turn causes spanwise flow to appear on the wing, reducing the efficiency at high angles of attack and increasing the risk of premature stall and pitch break. In an attempt to contain those adverse effects, two passive flow control techniques are implemented in this study, namely the wing fences and the tubercles. Wing fences are vanes or airfoils attached vertically to the lifting surface and are one of the oldest flow control techniques used in aerospace applications to stop the spanwise flow. When properly designed, they have the potential of completely stopping the spanwise flow. On the other hand, tubercles are sinusoidal modifications of the leading edge of the wing. This is a novel flow control technique, with the original concept inspired from the characteristic flipper of the humpback whale (Megaptera Novaeangliae). Each bump creates a set of counter-rotating vortices that acts as a virtual fence and stops the spanwise flow. The results from this assessment show that flow control techniques can potentially improve the lift distribution and increase the maximum coefficient of lift of a BWB UAV. This means that a considerable benefit can be achieved in terms of aerodynamic efficiency and that there is motivation for further investigating those techniques.

Aerodynamic Analysis & Design (PART III)

Session Chair : Prof. Konstantinos Kontis, University of Glasgow, UK

Limitations of modern hybrid RANS-LES models for transitional flows at low Reynolds numbers and acoustics

Mr. Adam Sieradzki (Łukasiewicz Research Network – Institute of Aviation), *Witold Klimczyk, Paweł Kękuś-Kumor*

Reynolds Averaged Navier-Stokes/Large Eddy Simulation (RANS/LES) hybrid methods have been developed significantly in recent years. They gained popularity due to the possibility of obtaining a scale-resolved solution of the flow field, without an unfeasible increase in the computational cost, as in the case of LES or Direct Navier-Stokes (DNS) simulations. Solving turbulent scales is often necessary for many engineering topics related to intrinsically unsteady phenomena like aeroacoustics. However, hybrid methods also have limitations linked to the “grey-area” problem of unphysical switching between RANS and LES formulations, that can e.g. affect the modeling accuracy of the laminar-turbulent transition. This paper aims to analyze the problem based on the results of low Reynolds number NACA0012 simulations, performed with the use of Stress-Blended Eddy Simulation (SBES) and Wall-Modeled LES (WMLES) models, which represent different branches of hybrid methods. The obtained characteristics of the boundary layer transition region were compared with an XFOIL solution. Calculation of the intensity of

aeroacoustic sources revealed the importance of proper modeling of the transition in terms of acoustics. Numerically obtained pressure fluctuations in the turbulent boundary layer were also compared with results of semi-empirical models available in the literature. On this basis, the possibility of predicting turbulent boundary layer - trailing edge noise was assessed. The culmination of the work was the comparison of the calculated sound pressure levels, generated by the flow around NACA0012 airfoil, with the experimental data.

Multifidelity constrained bayesian optimization, application to drone design

Rémy Charayron (ISAE Supaéro / ONERA), *Thierry Lefèbvre, Nathalie Bartoli, Joseph Morlier*

In aeronautics, the first design stages usually involve to solve a constrained multi-disciplinary optimization problem. The bayesian optimization strategy is a way to solve such a complex system. This approach requires to evaluate the objective function and the constraints many times. Evaluations are generally performed using numerical models that can be computationally expensive. To alleviate the overall optimization cost we can use variable information sources to make the evaluations. Typically, we used to deal with cheap low-fidelity models to explore the design space and expensive high-fidelity models for exploitation. In the following work, we compare two bayesian optimization methods on an aerostructural drone design constrained optimization problem: a mono-fidelity approach and its multi-fidelity counterpart. The multi-fidelity mode allowed to divide the computation cost by 1.6 compared to the mono-fidelity one. A good correlation and a large cost ratio between fidelity levels are key levers for the multi-fidelity strategy to be efficient. Three main areas of work are planned for the future: add a third level of fidelity, add new disciplines to the multi-disciplinary model and adapt the method to multi-objective optimization.

Benchmark of different aerodynamic solvers on wing aero-propulsive interactions

Dr. Danilo Ciliberti (University of Naples "Federico II"), *Emmanuel Benard, Fabrizio Nicolosi*

Distributed electric propulsion is a fertile research topic aiming to increase the wing aerodynamic efficiency by distributing the thrust over the wing span. The blowing due to distributed propulsors shall increase the wing lift coefficient for a given planform area and flight speed. This should bring several advantages as wing area, drag, and structural weight reduction, which in turn reduce fuel consumption, allowing airplanes to fly more efficiently. However, there are no consolidated preliminary design methods to size a distributed propulsion system. Numerical analysis is then performed at early stage, where many design variables have not been fixed yet. Therefore, the design space is vast and exploring all the possible combinations is unfeasible. For instance, low-fidelity methods (VLM, panel codes) have a low computational time, but usually they do not account for flow separation and hence they are unable to predict the wing maximum lift. Conversely, high-fidelity codes (CFD) provide more realistic results, but a single drag polar sweep can last days. This work provides a benchmark of different aerodynamic solvers for a typical regional turboprop wing with flaps and distributed propulsion, to better understand the limits of each software in the prediction of aero-propulsive effects.

Open source CFD methodology for preliminary aircraft design analysis

Mr. Juan Alonso Verges (ISAE-SUPAERO), *Mayur Oak, Martin Delavenne, Emmanuel Benard*

Taking as a point of departure the design characteristics of the FAST-OAD: Future AircraftSizing Tool - Overall Aircraft Design framework, a new computational methodology based on Euler CFD simulations is proposed to expand FAST's capabilities and to integrate surrogate modeling techniques. The objective is then to build a complementary preliminary design solution that provides valuable aerodynamic results for new aircraft geometries. This methodology will be entirely based on open-source software in order to make its implementation as accessible and straightforward as possible. Its different stages are therefore

the geometry generation and pre-processing by linking FAST-OAD with OpenVSP and GMSH, following with the SU2 Euler solver for the CFD simulation and finishing with the post-processing with Paraview. In this paper, we present a new python application that integrates all this entire methodology into a highly automated and user-friendly tool. Hence, the main philosophy of this tool is to connect all the programs involved in a CFD Euler analysis of a full-scale aircraft geometry throughout the same script to obtain automatically a wide variety of results such as aerodynamic curves, global coefficients or flow variable's fields and figures. Moreover, this tool is meant to be fast, intuitive and not very demanding in terms of computational cost. Validation with respect to reference aircraft configurations like CRM and CERAS are provided. Last this computational tool is applied to the improvement and expansion of simulation's results using surrogate modelling techniques.

Multi-fidelity weight analyses for high aspect ratio strut-braced wings preliminary design

Mr. Martin Delavenne (ISAE-SUPAERO), *Emmanuel Benard, Sébastien Defoort, Christophe David, Nicolo Fabbiane, Jean-Sébastien Schotte, Guillaume Arnoult, Gérald Carrier*

In the wake of "flygskam" movement that emerged in Sweden a couple of years ago many voices recently raised to denounce the environmental footprint of aviation. Even if the real impact of the sector could appear rather limited the critics reveal the necessity to propose cleaner aircraft to both meet public expectations and environmental goals. Because the classical wing-tube configuration seems to have reached its limits, disruptive designs must be considered. Among the perspectives to reduce emissions, high-aspect ratio wings represent a promising path to be explored within the European CleanSky2 project U-HARWARD. Indeed, substantial diminution of induced drag are expected from those new configurations resulting in fewer fuel consumption. To achieve high-aspect ratio without compromising the structural weight strut can be introduced. They allow for an alleviation of the bending moment at the wing root and therefore lighter structures. However, the consideration of those new wings configuration at early design stages is not straightforward and new methods have to be introduced. In this paper, we present three different fidelity approaches to tackle with (ultra) high-aspect ratio strut-braced wings sizing and weight estimates in preliminary design context. Already existing analytical formulations for the wings are extended, intermediate fidelity aero-structural coupling has been developed and high-fidelity structural representation are considered. Depending on the maturity of the concept these methods could be used to explore the design space, to refine the optimum or to analyse the final concept. Validation with respect to reference configurations is provided. Then the methods are applied to the analysis of strut-braced wings.

Junction flow and nacelle wing interaction on a pusher motorized sailplane configuration

Mr. Risshi Jain (ISAE-SUPAERO), *Emmanuel Benard, Erwin Ricky Gowree*

Flow interactions at junctions such as the wing and fuselage like bodies are contributors towards the interference drag over an aircraft and can make a significant part of the total drag. This comes from strong horseshoe vortex formations originating from inflection in boundary layer velocity profile and potential corner separation. This study investigates a potential interference drag reduction technique by the use of a shallow cavity wrapped around the foot of the body in interaction with the base surface, a flat plate and then an airfoil. This technique is applied to the specific challenge of pusher integration on a motorized sailplane configuration. The investigation by means of RANS CFD simulations is carried in two phases where a combination of a pylon and a simplified nacelle is first designed for minimal form drag, followed by junction optimization based on the shallow cavity strategy to reduce the interference drag. The elliptically shaped cavity is found to effectively reduce drag and improve the performance envelope of the motorized sailplane in gliding mode.

ARTEM project (PART I)

Session Chair : Dr. Karsten Knobloch DLR, Germany

Noise Reduction Technologies for Future Aircraft Concepts – an introduction to the H2020 project "ARTEM"

Dr. Karsten Knobloch (DLR), *Ralf Burgmayer, Eric Manoha, Francesco Adamo*

With ARTEM (Aircraft noise Reduction Technologies and related Environmental iMpact), a technology development project was started in December 2017 (funded by the EC under grant number 769350) in order to increase the technology readiness level (TRL) of innovative noise reduction technologies for future low-noise aircraft configurations. Future aircrafts, anticipated to be introduced between 2035 and 2050, might have different configurations than the current tube-and-wing design with underwing–mounting of the engines. For 2035, the tube-and-wing layout could persist while the engine integration may differ, e.g. being semi-buried in the fuselage. For the 2050 time frame, blended wing-body aircrafts with very high bypass ratio (BPR≥16) may power long-range aircrafts, while regional aircrafts might exhibit hybrid propulsion systems or distributed electric propulsion system. Acoustic interaction effects related to the complex integration of air craft components like the propulsion system, high-lift devices, and landing gear are expected to contribute significantly to the overall noise signature of future aircraft configurations. The accurate prediction of those effects with tools of different fidelity – from low order analytical or semi-empirical to high fidelity numerical simulations – is required for the different design phases of new aircraft configurations. The selection and application of appropriate tools in benchmark exercises and subsequent optimization work of different noise reduction means is one of the main topics of ARTEM. A further core area is the development for innovative devices (liners, meta-materials) for the reduction of radiated noise. The trend towards larger propulsion systems implies the need to reduce low-frequency noise and broad band noise effectively while being restricted by tight geometrical dimensions. Passive and active concepts have been investigated and have reached a TRL 3 to 4 depending on actual technology. The output of these two major activities is fed into an extensive assessment task which explores the capabilities of the noise reduction means on different platforms: an industry-supported assessment reveals expected short-/mid-term benefits and may suggest accelerated development of promising concepts. Applicable technologies are also incorporated into a noise prediction exercise performed for the concepts BOLT and REBEL which have been defined in order to resemble main properties of blended-wing body aircraft configurations. Here, also shielding effects of the airframe are considered. This presentation introduces the H2020 project ARTEM by giving an overview of the project and the interconnections between individual contributions. Major results of the technical progress of the project partners are presented in subsequent individual presentations which form together a comprehensive overview of topics and achievements of this project. Beside some on-going work in the assessment part, most activities in the technology development have been finalized or will end soon with ARTEM expected to deliver its final outputs by May 2022.

Slanted Septum Core and Multiple Folded Cavity Liner concepts for broadband sound absorption: A Numerical and experimental evaluation

Mr. Suresh Palani (University of Southampton), *Paul Murray, Alan McAlpine, and Christoph Richter*

The primary objective of this paper is to report a detailed evaluation of two novel liner concepts, a Slanted Septum Core (SSC) and a Multiple FOlded CAvity Liner (MultiFOCAL), for aero-engine applications, under both high sound pressure levels and grazing flow (Figure 1). In-duct insertion loss predictions are made for the novel liners for downstream and upstream sound propagation, with the results compared with

that of optimised conventional Single Degree-of-Freedom (SDOF) perforate liners for the downstream case, and optimised SDOF linear liners for the upstream case. A numerical model of the flow duct test facility is developed using the commercial finite element code, COMSOL Multiphysics. This model is used to predict the liner insertion loss in the flow duct test facility. A multi-modal broadband sound source is used, utilising the assumption of uncorrelated modes with equal energy per mode. Initially, the acoustic properties of the novel liner concepts were predicted, without grazing flow, using a normal incidence impedance test set-up numerical model for high sound pressure level (SPL) pure tone excitations. Also, normal incidence acoustic impedance measurements were made to validate the preliminary pure tone predictions, and to evaluate the fundamental no flow characteristics of the SSC and MultiFOCAL configurations at high SPLs (Figure 2). Subsequently, impedance predictions, including mean flow adjustments, were used to define the lined boundary condition in the grazing flow propagation model, and the wall impedance was then iterated for the maximum insertion loss for each novel liner configuration. Ultimately, the optimised novel liners will be manufactured and tested in the flow duct facility at the Netherlands Aerospace Centre (Royal NLR). Consequently, all of the simulations in this paper are based on a grazing flow test set-up that is representative of the NLR facility. For downstream sound propagation, a simple Convected Wave Equation model with the standard Ingard–Myers boundary condition is shown to be sufficient to predict the liner attenuation accurately. For upstream sound propagation, predictions and measurements for a SDOF linear liner highlight the need to account for boundary-layer refraction in the numerical modelling. As a result, the refraction effect due to the mean flow boundary layer is modelled using a Linearised Euler Equation solver. For validation, the insertion loss of a Single-Degree-of-Freedom (SDOF) liner, with a linear layer facing sheet, is predicted for downstream and upstream multi-modal sound propagation. Predictions are for zero flow and for Mach 0.3 and 0.5, for frequencies between 100 and 6000 Hz, with a frequency step of 100 Hz.

Implementation of a Zero Massflow Liner: From concept to prototype

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Modern aeroengine designs necessitate new damping concepts due to changed noise emission characteristics, reduced installation space and an enhanced requirement for primary air through the burner. Hence, the available secondary air, used for damping in bias flow liners is reduced. Within the scope of the project ARTEM (Aircraft noise Reduction Technologies and related Environmental iMpact) new liner technologies are developed and evaluated. The Zero Massflow Liner (ZML) concept applies an additional high sound pressure acoustic source to the liner cavity to alter the linings impedance and maximize the damping characteristics of the liner. The underlying physical effect responsible for the change of impedance is flow separation at the facing sheet of the liner. Compared to conventional bias flow liners the net mass flow is zero, since a harmonic flow is applied. A semi empirical model, describing the change of impedance due to the additional sound source, in combination with a numerical simulation is used for prototyping. Thereby, the acoustic actuation in the cavity and the geometric parameters of the liner are adjusted to approach a desired dissipation behavior and thus an optimum impedance over varying Mach numbers. Consequential, the prototype is studied experimentally at the liner flow facility of the German Aerospace Center DUCT-R. The measurements are compared to the results of the simulation and the concept is evaluated in hindsight of practicability and efficiency.

Innovative liner concept using friction powder for increasing of broadband noise absorption. Applications for broadband noise absorption in fan duct, reduction of jet noise reflected by wing pressure side and noise reduction in aircraft cabin

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This paper presents paper research related by influence of friction powders on enlarging the absorption band of acoustic liners used for reduction of tonal noise in fan duct of aero-engines. Experiments done in COMOTI using fine powders (granules) made of various light-weight materials which were introduced in the honeycomb cells of SDOF liners at 33%, 66% and 100% of height shown an considerable broadening of absorbed band of frequencies without a significant decreasing of absorption at resonance frequency. In COMOTI the measurements were done using Kundt tubes. Although the phenomenon is general being present at any type of powder, it was observed that for some powders the absorption is higher than for others. On the other hand, it was observed that % of honeycomb height filling with powder is also important, this percent depending however by the nature of the powder material. Experiments done in grazing flow at CNRS-Le Mans University shown that the phenomenon is also present with high intensity and depends by the nature of powder material. The best results were obtained for the cork powder for the honeycomb filling with powder at 66% of height. For this material the broadening of the transmission loss well was maximum. This phenomenon could be explained by apparition of multiple frictions between powder granules which are taking place at very low scale consuming the noise power in a broader band of frequencies. The friction additionally contributes to noise power reduction by air lamination and by Helmholtz resonator effect, in this case existing multiple resonance height values. The friction between the particles of powder seems to have a major influence because the best absorption was obtained for powders with a large distribution of particles' dimensions while for particles with a small dimensional distribution (expanded polyester balls) the transmission loss well broadening was smaller. The friction powders technology is simple and can be easily be adapted to the existing manufacturing technology for acoustic liners with small manufacturing costs. This feature is conferred by the fact that powders can be easily poured in the honeycombs at the required height. The friction powder technology can be applied not only for the fan duct. It can be applied for reduction of jet noise reflected by pressure side of wing and cabin noise reduction.

A novel active acoustic liner based on corona discharge

***Dr. Stanislav Sergeev (EPFL)**, Hervé Lissek*

This work presents the development and evaluation of the novel active acoustic liner based on the plasma discharge. The controlled transducer operates on the principle of the atmospheric corona discharge in a wire-to-mesh geometry which covers the liner area. A simple robust design and the absence of moving parts in the liner due to the actuator construction favors this approach compared to other existing active liner concepts. The noise is reduced by adjusting the liner acoustic impedance to the optimal for sound absorption in the duct. The impedance control strategy with the use of corona discharge actuator is described. The liner prototype consisting of several active cells is designed and tested experimentally in the flow duct under grazing incidence. The liner performance is examined for cases of tonal noise, broadband excitation and in the presence of the mean flow. The achieved impedance leads to a broadband sound attenuation in the duct which reveals the potential of the corona discharge actuator technology to be a serious alternative to the conventional electrodynamic transducers in active noise control systems.

Innovative liners based on optimized metasurfaces

***Prof. Umberto Iemma (Roma Tre University)**, Lorenzo Burghignoli, Giorgio Palma*

The evolution of aeronautic propulsion is leading towards turbofans with High and Ultra High Bypass Ratios, characterized by larger fans and shorter nacelles or even distributed open rotor configurations for innovative aircraft. Therefore, the research on new efficient acoustic linings for engine noise reduction is always extremely active, chasing the targets set by the international authorities. Metasurfaces are considered a promising breakthrough technology for designing innovative aeroacoustic treatments in

aeronautics, capable to achieve their effects with subwavelength thicknesses. The current work presents numerical results for metamaterial linings based on phase gradient metasurfaces. The linings are modelled as equivalent metafluids in FEM simulations, and a Simulation Based Design Optimization is adopted for evaluating optimal parameters. Two case studies are presented, an innovative nacelle intake lining and an unconventional body surface treatment for a BWB with distributed propulsion. Numerical simulations show that metafluid-based devices are promising candidates for a new generation of low noise technologies for community noise alleviation in aeronautics.

ARTEM project (PART II)

Session Chair : Dr. Karsten Knobloch DLR, Germany

A comprehensive and consistent design-to-noise study of high-lift profiles and their noise reduction potential

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The optimal design of future transport aircraft has to comply with further tightened environmental requirements. Therefore, the usage of mature design tools is mandatory that provide on the one hand side a prediction capability for the effect of even subtle design variations. On the other hand, predictions with short turnaround time of the order of 100 CPUh are necessary to enable a sufficient resolution of the design space at acceptable numerical effort. For aerodynamic analysis with Computational Fluid Dynamics (CFD), Reynolds Averaged Navier-Stokes Simulations (RANS) has matured as a state-of-the-art simulation tool in industry that provides the crucial short turnaround times and sufficient reliability of results. However, up to date no useful acoustic metric could be derived from the RANS flow variables that could be further utilized for aeroacoustics driven design (design-to-noise). Scale resolving simulation tools, on the other hand, require a simulation effort far beyond 100 CPUh and are of limited use if a large set of variants has to be studied. In some predecessor work Computational Aeroacoustics (CAA) simulation with vortex sound sources derived from RANS deduced synthetic turbulence has demonstrated a feasible way to model broadband noise spectra for problems such as trailing edge noise or high-lift slat noise. Successful simulations revealed that i) major noise source characteristics can be deduced from a space-time stochastic realization of synthetic turbulence and that ii) CAA turnaround times are comparable to that of RANS. Hence, the approach has some potential to bridge the current prediction gap by providing sufficiently efficient a meaningful acoustic metric from RANS turbulence data. In this work a 2-D design study has been carried out using 5 different high-lift profiles to demonstrate the applicability of the approach for design-to-noise applications. CAA and CFD simulations have been conducted using 3 different velocities (40m/s, 50m/s, and 61.5m/s). Acoustic results (narrow band spectra) and time averaged aerodynamic characteristics (cp-distribution) of the 2-D design study have been cross-compared for the F16 reference high-lift profile with a scale resolving approach. Good agreement for both data sets could be demonstrated. With the Very Long Chord Slat (VLCS) variant a geometry intended to lower the noise emissions of the F16 reference profile has been studied. Two novel Krüger flap designs have been evaluated concerning their noise reduction trends.

Meaningful noise trends and clear noise reduction potentials could be identified. Conventional slat noise is found to scale with the fourth power of Mach number. For the F16 reference profile a gap/overlap slat setting variation study has been performed. The gap variation study revealed clearer noise reduction potential yielding about 3dB overall sound pressure level (OASPL) reduction towards the ground. The VLCS yields an OASPL noise reduction potential of up to 6dB towards the ground, as was found in previous experimental studies. The Krüger flap designs yield the clearest noise reduction potential. For the first considered Krüger design, OASPL noise reduction yields on average 6dB over the entire lower polar arc

range. A second aerodynamically optimized Krüger design, however significantly loses part of the noise reduction potential, thus indicating the importance of an holistic approach towards high-lift design that incorporates besides aerodynamic also aeroacoustics characteristics.

Reducing trailing edge noise with the application of finlets on NACA aerofoils

Mr. Felix W Gstrein (University of Bristol), *Bin Zang, Yannick Mayer, Mahdi Azarpeyvand*

Finlet surface treatments are a passive control method aiming to reduce the trailing edge noise emission of lifting devices. The method has received increasing attention recently due to its vast potential to effectively reduce noise over a range of frequencies. The present experimental work investigates the noise reduction performance of different finlet treatments applied on a NACA 0012 and a NACA 65-410 aerofoil, as shown in Fig. 1. The selection of different finlet types is based on the findings of previous studies and covers the parameter ranges over which the finlet treatments have been found to show the largest favourable impact on the unsteady aerodynamic loading and hence the radiated noise of lifting devices. Considering the fundamental parameters, such as finlet height, length, position with respect to the aerofoil trailing edge, and the spacing between two adjacent finlet walls, the parameters optimal for reducing the aerofoil trailing edge noise have been identified under the present experimental conditions. The far-field sound pressure level results confirm the ability of the selected finlets to reduce the trailing edge noise by up to 6 dB in the frequency range between 500 Hz and 4000 Hz (see Fig. 2). To better understand the effects of the finlets on the near-field aerodynamic characteristics of the aerofoils, the unsteady surface pressure loading on each aerofoil and particularly at the trailing edge is examined. A variation of the finlet spacing, position and length shows that the related noise reduction effects are independent of the Reynolds number range considered in the present study. Moreover, an optimal ratio between the finlet height and the boundary layer thickness over the aerofoil is identified. The findings from this experiment will provide a useful guide for the optimisation of the finlet treatments for the NACA aerofoils at the given conditions.

Installed jet noise of elliptical nozzles

Mr. Anderson Proenca (University of Southampton)*, Jack Lawrence*

This paper presents an experimental investigation into the aeroacoustics of two elliptical jet nozzles installed close to a wing model. Flow field data is obtained using hot-wire anemometry. The unsteady velocity data is analysed to provide information about 1) the changes in boundary conditions at the nozzle exit, 2) the jet spreading rate compared to a round jet baseline, and 3) the turbulence properties of the jet plume. The hydrodynamic and acoustic pressure fields of all nozzles are measured using independent free-field microphone arrays and wall-pressure transducers flush-mounted on the wing model's surface. Results of the far pressure field suggest that, although the jet mixing noise increases substantially with decreasing ellipticity, the elliptical jet nozzles are seen to provide a slight acoustic reduction of the jet-surface installation noise source. The unsteady velocity and unsteady near pressure field data indicates that the acoustic benefit is due to 1) changes in the turbulence flow field close to the trailing edge of the wing, and 2) modification of the azimuthal modes in the jet near-field. Further details will be provided in the presentation and in the final manuscript.

Plasma based active noise control of an excited jet interacting with a plate

Dr. Georgy Faranosov (Central Aerohydrodynamic Institute - TsAGI), *Victor Kopiev, Oleg Bychkov, Vladimir Kopiev, Ivan Moralev, Pavel Kazansky*

The possibility of controlling jet-wing interaction noise by plasma actuators is demonstrated for a tone excited jet. The idea of installation noise control consists in the assumption that it is linearly related to the instability waves evolving in the jet shear layer and scattered by the plate trailing edge. Tonal excitation

of the jet is used to amplify instability waves at a certain frequency and thus to facilitate the problem of their control. Jet excitation is implemented by a loudspeaker installed in the settling chamber. The control action is introduced by a high frequency dielectric barrier discharge (HF DBD) plasma actuator with a ring-like electrode mounted on the inner surface of the nozzle close to the nozzle edge. Both the acoustic excitation and the plasma actuator generate axisymmetric fluctuations in the jet flow. It is demonstrated that installation noise can be significantly suppressed if the plasma actuator generates instability wave with the amplitude equal to that of the excited by the loudspeaker, but in antiphase to it, and vice versa, if these instability waves are in phase, installation noise increases by about 6 dB. The effect of control is most pronounced at sideline and upstream directions of observation where installation noise dominates the acoustic signal radiated by the loudspeaker out of the nozzle. The effect of control is shown to be similar for jet Mach number range from 0.4 to 0.6. The results support the hypotheses that low-frequency jet-wing installation noise is generated by the large-scale structures scattered on the trailing edge, and can be controlled in a linear framework. The suppression of jet instability wave, excited at a certain frequency, directly leads to the reduction of installation noise. These results are quite promising and show the potential of such a technique for installation noise mitigation. Preliminary ideas for the implementation of this concept for unexcited jets are described. The work has been partially supported by the Russian Ministry of Industry and Trade, project “ORINOCO-2” as a part of the European Union's Horizon 2020 project ARTEM, grant No 769350 (development of plasma actuators and control strategy) and by the Russian Science Foundation, project 19-71-10064 (development of the procedure of instability wave detection in the near-field).

Numerical analysis of fan noise for the NOVA boundary-layer ingestion configuration

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BLI embedded propulsion systems might be subject to inlet flow distortions and ingestion of turbulence at the fan plane which can impact both broadband and tonal fan noise. In this work, the analysis is performed on a modified version of the Low-Noise NASA SDT fan-stage integrated into the ONERA NOVA fuselage in order to reproduce the NOVA BLI configuration. The numerical flow solution is obtained with the high-fidelity CFD/CAA solver Simulia PowerFLOW® while the acoustic far-field is computed by using the Ffowcs-Williams & Hawkings integral solution applied to a permeable surface. All simulations are performed for an operating condition representative of take-off with power cut-back. Installation effects due to the BLI configuration are quantified by comparison with an isolated configuration of the modified Low-Noise SDT fan-stage at the same operating condition. It is found that the BLI fan stage, which is not optimal, is characterized by strong azimuthal fan blade loading unsteadiness, less axisymmetric and coherent rotor wake tangential velocity variations, and higher levels of in-plane velocity fluctuations compared to the isolated engine. This resulted in no distinct tonal components and higher broadband levels in the far-field noise spectra, as well as in an increment of cumulative noise levels up to 18 EPNdB. This study, which represents the first high-fidelity CFD/CAA simulation of a full-scale aircraft geometry comprehensive of a BLI fan/OGV, provides a clear understanding of the change of the noise sources in BLI integrated.

Mid-fidelity aeroacoustic modelling and measurements of pusher and tractor generic Distributed Electric Propulsion systems

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Two Distributed Electrical Propulsion configurations were studied experimentally and numerically to analyse aeroacoustic installation effects, within the scope of H2020 EC project ARTEM. The mock-up has a scale 1:3 with respect to the full-scale model and consists of a wing featuring 17 % thick airfoil and up

to three propellers positioned either in front of the wing, referred as tractor configuration, or above the wing, referred as pusher configuration. Wind tunnel tests were conducted in a closed wind tunnel test section, where aero-propulsive performance was evaluated on a balance, and acoustic tests were done using a circular microphone array, allowing to highlight the dominant aeroacoustic sources. The simulation methodology includes both the tonal and broadband noise prediction due to the propeller self-noise and the viscous interactions between the blade wakes with the airframe, including scattering effects due to the wing and to the closed test section. The main purpose of this work is to demonstrate how well can mid-fidelity methods, recently developed within this project, capture the dominant aeroacoustic sources. Preliminary comparisons of experimental and numerical data indicate good agreement between the data and will be further advanced for the final presentation.

ARTEM project (PART III)

Session Chair : Dr. Karsten Knobloch DLR, Germany

Parametric investigation of aeroacoustic installation effects in a Distributed Electric Propulsion system

Mr. Julien Christophe (von Karman Institute for Fluid Dynamics), *J. Dominique, Y. C. Kucukosman, C. Schram, A. Hajczak, J. Drofelnik, M. Andrejašič*

Electric and hybrid Distributed Electric Propulsion (DEP) solutions have become an increasingly attractive option for the aviation industry[31], and have been thoroughly studied in terms of aerodynamics, emissions and costs[32] [33] [34] [35], but more scarcely investigated in terms of noise emissions. Several studies[36] [37] indicate that DEP architectures offer promising perspectives for noise reduction and appear as a viable solution for delivering the strict mid-to-long term environmental goals set by governmental agencies. Although the noise prediction capabilities have demonstrated their potential in such DEP applications[38] [39], there are still remaining possibilities for the optimisation of the configuration main parameters, as for example the

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propeller locations along the chord of the main wing and the relative clocking angle in case of multi-propellers configurations, which are expected to induce a reduction of the noise footprint by acoustic shielding and destructive interferences, respectively. The present study proposes a parametric study for DEP configurations main parameters using fast low-order noise prediction methods in order to identify potential configurations leading to a substantial reduction of the noise radiated towards the observer. The considered noise mechanisms and corresponding methodologies are here described.

- The prediction of tonal self-noise emitted by the propeller(s) is achieved by a three-steps simulation chain described as follows. First, the aerodynamic sectional blade loading is obtained by using a lifting-line method coupled with a free-wake model. These sectional loads are then converted to a pressure distribution over the blade surface following an empirical distribution. Secondly, this pressure distribution is given as an input to a Ffowcs-Williams & Hawkings solver that provides the direct acoustic disturbances at the listeners positions, the incident pressure field as well as its normal gradient on the neighbouring scattering surfaces (here, the wing) in the Fourier domain, at the harmonics of the blade passing frequency. Lastly, a Boundary Element Method solver based on the Brakhage-Werner formulation[40] [41] is used to obtain the total field at the listeners positions. The assessment of this methodology with respect to experiments carried out in INCAS aerodynamic facility is presented in an accompanying paper
- The prediction of the broadband self-noise, due to the scattering at the trailing edge of both suction and pressure side boundary-layers, relies on a strip approach in which the blade noise is the sum of the acoustic fields generated by strips dividing the blade in the spanwise direction. The blade is cut at iso-radius cuts, for which the flow around the blade section is obtained from two-dimensional Reynolds-Averaged Navier-Stokes (RANS) computations at the considered strips. The trailing-edge boundary-layer profiles are then extracted and wall-pressure models[42] are used to compute the wall-pressure spectrum near the trailing-edge. Together with geometrical blade parameters, this is the primary input to Amiet's theory[43] for trailing-edge noise. In order to take into account possible acoustic scattering effects on the main wing, this theory is coupled with Acoustic Transfer Vectors (ATV) obtained from a FEM computation.
- The viscous tonal wake interaction noise, due to the interaction of the propeller wake with the main wing in tractor configurations or due to the wake of the supporting pylon re-ingested by the propeller in pusher configuration relies also on the strip approach described above. The main input parameter for the method is the wake velocity deficit that can be obtained from the same two-dimensional computations mentioned above. From this, the upwash velocity component can be Fourier decomposed at the blade passing harmonics. This constitutes the main input for the Amiet's model for tonal wake interaction noise[44] that can be also coupled with the classical FEM models to take into account acoustic scattering effects. Two configurations are proposed in the present study, that have been experimentally and numerically analysed within the scope of the H2020 EC project ARTEM. The mock-up has a scale 1:3 with respect to the full-scale model and

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consists of a wing featuring 17% thick airfoil and up to three propellers positioned either in front of the wing, referred as tractor configuration, or above the wing, referred as pusher configuration. For these configurations, the two following parameter investigations are proposed:

- Variation of the propeller position relative to the main wing for a single propeller. This also includes separation distances that cannot be reached in the accompanying experiments for which the wake interaction noise might be dominant. An example of the noise radiation patterns obtained for the first blade-passing frequency of a single propeller located at different positions along the chord of the main wing is shown in Fig. 1.
- Variation of the clocking angle between different propellers to analyse its effect on the radiated tonal noise. This also includes the study of the possible acoustic benefit of changing the rotational direction of some propellers relative to the others (clockwise versus counter-clockwise).

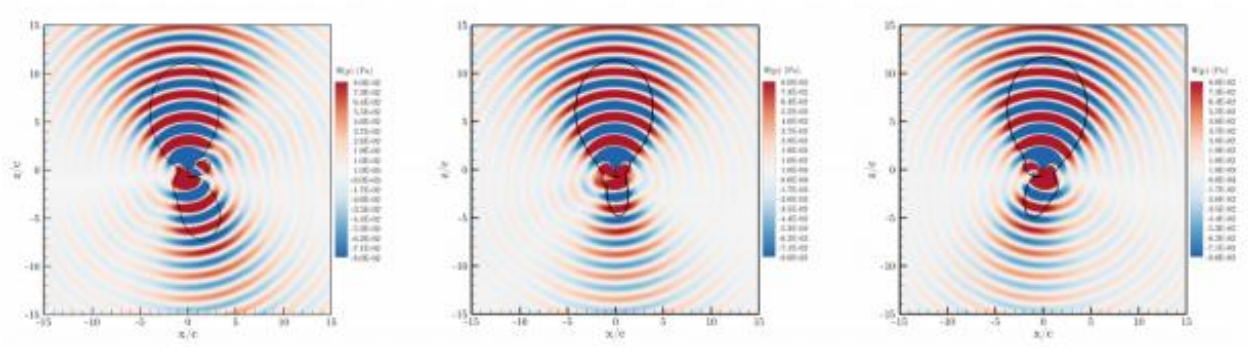

Figure 1: Real part of the scattered complex pressure emitted at the blade-passing frequency of a single propeller located at the leading-edge (left), mid-chord (center), and trailing-edge (right) of the main wing.

The comparison between the different configurations are analysed in terms of noise frequency spectrum radiated to a predefined observer position and directivity in the far-field.

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Prediction of Fan Tone Radiation Scattered by A Cylindrical Fuselage

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The aim of this paper is to present a theoretical prediction method of the scattering of fan tone radiation from a turbofan inlet duct by the airframe fuselage. The fan tone noise is modelled by an acoustic disc source that represents the sound field at the inlet duct termination. Adjacent to the source is a cylindrical fuselage that scatters the fan tone radiation. The prediction method is valid for upstream sound radiation. The acoustic pressure on the cylindrical fuselage is affected by refraction of the sound as it propagates through the fuselage boundary layer. This effect known as boundary layer shielding is more prominent forward of the turbofan, since the fan tone noise radiated from the inlet duct is propagating upstream. In all similar previous work, numerical methods have been used to calculate the sound propagation through the fuselage boundary layer. In this paper, an asymptotic approach is used to model sound propagation through a boundary layer which is modelled by a thin linear shear velocity profile. This formulation leads to both near- and far-field solutions of the scattered pressure field expressed in terms of a Fourier series. The Fourier coefficients can be expressed in analytic form for the far-field solution, and in terms of an inverse Fourier transform integral for the near-field solution. Consequently, the scattered pressure field can be computed very quickly, thus providing a fast and efficient prediction method. A realistic fuselage

turbulent boundary layer does not resemble a linear shear layer. Nevertheless, it is shown that the effect of acoustic shielding by a turbulent boundary layer can be modelled by taking a liner shear profile with a shape factor that matches the shape factor for a realistic turbulent profile. Comparison with numerical results using realistic boundary layer profiles shows good agreement, demonstrating that the method is applicable for realistic problems of fan tone radiation scattered by a fuselage. Illustrative results are included to investigate how boundary layer shielding is predicted to be affected by the frequency of the sound and the thickness of the fuselage boundary layer.

Diffraction of sound radiated from a cylindrical duct in the application to the problem of engine noise shielding

Dr. Stanislav Denisov (Central Aerohydrodynamic Institute - TsAGI), *Nikolay Ostrikov, Victor Kopiev*

Aircraft power plant noise reduction is one of the main tasks of modern aviation acoustics. It successful solution will reduce the acoustic impact on the environment, as well as increase the competitiveness of new engine generation models and aircraft equipped with them. One of the main aviation engine noise sources is the fan noise radiated from the inlet duct. This noise source is acoustically noncompact and has a complex structure characterized by the presence of a large number of radial and azimuthal modes propagating in the duct. As known, besides of sound-absorbing structures, one of the most promising methods of fan noise reduction is the shielding effect for the engine installed above the airframe or the aircraft wing. This report is devoted to the study of the interaction between the shielding screen and various azimuthal modes radiated from a circular cylindrical channel. In this work presented the results of computational and experimental studies of rotating azimuthal modes shielding by a rectangular screen. To adjust and generate individual azimuthal modes, a 48 microphone array of microphones and acoustical drivers were used, which ensure high accuracy and stability in all modes used in the experiments. Here we consider different tonal frequencies and azimuthal mode numbers; measurements are carried out for different screen positions, as well as without a screen. Based on the Geometrical Theory of Diffraction and the Kirchhoff theory it has been developed an approach for the shielding efficiency calculation of rotating azimuthal modes radiated from a circular cylindrical channel. Comparison between calculated and experimental dependences showed good agreement, which indicates the correctness of the calculation approach and the accuracy of the experiments. Obtained results analysis presented in this work allows to conclude that the shielding efficiency is highly sensitive to the position of the screen, which leads to the appearance both amplification and noise reduction regions in the geometrical shadow zone, and these regions depend on the frequency and number of the azimuthal harmonic. This work was supported by the Ministry of science and higher education of the Russian Federation under the agreement No 075-11-2018-178 (unique identifier of the agreement RFMEFI62818X0011) as a part of the European Union‘s Horizon 2020 project ARTEM, grant No 769350.

RDO of a regional transport with distributed, hybrid gas-electric propulsion under low-noise constraints

Prof. Umberto Iemma (Roma Tre University)*, Francesco Centracchio, Monica Rossetti*

The paper reports the conceptual design process performed in the project ARTEM (Aircraft noise Reduction Technologies and related Environmental iMpact, id. 769350) on the regional aircraft with distributed electric propulsion using hybrid gas-electric technology. The context is the development of breakthrough solutions to guarantee the sustainable growth of the commercial aviation in the 2050 operational scenario, taking into account the foreseen evolution of technology and market demand. The target mission has been identified as a typical short-range operation (maximum range around 900 nm) with cruise Mach number M=0.5. To accomplish the task, the Blended-Wing-Body (BWB) concept has been selected. The reasons underlying the choice are basically related to environmental benefits expected

in terms of community noise and local air quality. In addition, the favorable ratio between internal volume and overall dimension makes easy possible an increase of the payload with respect to a tube-and-wing concept of the same external size. The design process stated with the definition of the initial layout from scratch, taking into account the basic constraints on payload and dimensions. Then, the hybrid propulsion system has been integrated into the initial design to achieve the initial weight estimate. Through a multi-objective optimization, the basic layout has been improved in terms of MTOW (-7%) and aerodynamic efficiency (+28%). Particular attention has been paid to the optimization of the distributed propulsion, with the development of innovative, adaptive metamodeling techniques for the aerodynamic and aeroacoustic assessment of the propellers array. Stochastic radial-basis-functions and artificial neural networks were used in the derivation of the surrogate models, also taking into account the uncertainties related to the mid-/long-term evolution of the relevant technologies.

Aeroacoustic assessment of a blended wing configuration with distributed electred propellers

Barbarino Mattia, ***Mr. Adamo Francesco P. (CIRA)****, Visingardi Antonio*

Distributed Electric Propulsion systems feature the novel concepts of utilizing electrically-driven propulsors which are only connected electrically to energy sources or power-generating device. As a result, propulsor can be placed, sized and operated with greater flexibility to leverage the synergistic benefits of aero-propulsive coupling and provide improved performance over more traditional designs. An example of such concepts is represented by REBEL (REgional Blended Wing body Electric-propelled): it is a disruptive concept developed and designed in the framework of the ARTEM european project; it corresponds to a Blended Wing body equipped with an electric propulsions system. The analysis here developed focus the attention on a set of parameters affecting the propulsion system, as the number of the propellers, the relative position, phasing and sense of rotation among them, in order to see the aerodynamic and aeroacoustic effects that these parameters variation produce. The aerodynamic analysis has been performed via an unsteady, free-wake panel code based on the Boundary Element Method for multibody configuration whereas the acoustic signature of each configuration has been investigated by using a FW-H approach and the sound radiation and the scattering properties of the REBEL configuration has been evaluated by using a BEM solver. As final results, acoustic footprints on airport areas have been generated, using dedicated trajectories for airport flight conditions, using noise hemispheres and analytical propagation tools for getting a complete noise assessment.

Junction flow and nacelle wing interaction on a pusher motorized sailplane configuration

Mr. Risshi Jain (ISAE Supaero), *Emmanuel Benard, Erwin Ricky Gowree*

Flow interactions at junctions such as the wing and fuselage like bodies are contributors towards the interference drag over an aircraft and can make a significant part of the total drag. This comes from strong horseshoe vortex formations originating from inflection in boundary layer velocity profile and potential corner separation. This study investigates a potential interference drag reduction technique by the use of a shallow cavity wrapped around the foot of the body in interaction with the base surface, a flat plate and then an airfoil. This technique is applied to the specific challenge of pusher integration on a motorized sailplane configuration. The investigation by means of RANS CFD simulations is carried in two phases where a combination of a pylon and a simplified nacelle is first designed for minimal form drag, followed by junction optimization based on the shallow cavity strategy to reduce the interference drag. The elliptically shaped cavity is found to effectively reduce drag and improve the performance envelope of the motorized sailplane in gliding mode.

FUTPRINT50 project

Session Chair : Prof. Andreas Strohmayer, University of Stuttgart, Germany

System Architectures for the Thermal Management of HEA – FUTPRINT 50

Ricardo Gandolfi, ***Dr. Ricardo Reis (Embraer Portugal),*** *Walter Affonso Jr., Carlos Roberto Ilário da Silva1, Renata Tenorio Tavares, Timoleon Kipouros, Panagiotis Laskaridis, Andrei Chekin, Aleksey V. Kukovinec, Yury Ravikovich5, Nikolay Ivanov, Leonid Ponyaev, Dmitry Holobtsev*

Electric and Hybrid-Electric Aircraft (HEA) propulsion system designs shall bring challenges at aircraft and systems level, mainly propulsion, electric and thermal management systems (TMS). The electrification of the propulsion system relies on large and high-power electrical equipment (e.g., electrical motors, converters, power electronics, batteries, and others) that dissipate heat at a rate at least one order of magnitude higher than conventional propulsion aircraft systems. As a result, high impacts on weight, drag and power consumption of the TMS/cooling systems at the aircraft level are expected. This paper proposes potential approaches for systems architectures that will perform the thermal management of future Electric and HEA. For each architecture, relevant aspects such as its integration to aircraft, safety, operational and maintenance impacts, certification, technologies readiness level (TRL) and the latest research works are analysed. A quantitative comparison of the several architectures is also proposed considering weight, volume, electric power consumption, pneumatic air flow and cooling air flow per cooling effect.

Hybrid-Electric Architectures and Their Influence on Aircraft Design

Dominik Eisenhut, ***Mr. Nicolas Moebs (University of Stuttgart),*** *Jonas Mangold*

Rising awareness for climate change and initiatives to reach climate neutrality are emerging worldwide. One driver of emissions is the transport sector and with it the aviation industry. Aviation shall be cleaner, more environmentally friendly and contribute its share to the overarching goal. A hybrid-electric regional aircraft is a promising option to achieve this. Such an aircraft can fulfil the need for faster travel in rural areas where other options like high-speed trains are not feasible. The goal of the Horizon 2020-project FUTPRINT50 is to accelerate the technology development to enable entry into service of such an aircraft in 2035/40. The presentation will give insight in the current status of the FUTPRINT50 project. This will cover the main work packages and put them in general context of the project. It contains an overlook of the overall aircraft design and also includes the key technologies closely investigated in this project: energy storage, energy harvesting and thermal management. Main focus of the presentation will be on the selected hybrid-electric architectures that are investigated in the course of the project. Different powertrain architectures and their synergetic effects on the overall mission will be discussed and analysed. Furthermore, their influence on the aircraft design will be addressed with the help of results created in parametric analyses during the initial sizing. This includes first estimations of mass and flight performance as well as the impact of essential safety aspects on the overall aircraft design.

A reduced battery system model and sizing algorithm for future hybrid electric airplanes architectures studies

Dr. Boris Berseneff (CEA, France), *Sébastien Fiette, Anh-Linh Bui Van*

The path to climate-friendly aviation is a difficult way that needs to be traveled fast. A considerable and immediate drop of fossil fuels consumption is necessary to respect the Paris Agreement. Hybrid-electric and full-electric aircraft are part of the solution but developing a reliable and profitable hybrid-electric regional aircraft is a complex task. The European research project FUTPRINT50 aims at developing

methods and tools to help to achieve this goal. The battery system is one of the key elements of aircraft electric architectures as it stores energy for propulsion and auxiliary systems. Among other challenges, optimal sizing (including mass, electric performances and aging) and safety are the two most difficult aspects to overcome. Herein, we propose a battery sizing tool which, for a given power solicitation, optimizes battery systems sizing including all above cited parameters. Based on a reduced battery cell model, this tool is fast enough to be run in a high-level general optimization at aircraft level. The reduced battery cell model is built up using, either a reference cell model (fixed chemistry, format and specifications) parameterized by testing, or a parametric cell model based on physical modeling (possibility to tune several chemistry parameters). Integrating a response surface of cell voltage, the reduced model is tuned thanks to a large set of dynamic simulation. This model is then used to run an optimal battery sizing, finally taking into account performance targets (mass, volume, voltage, power), aging and safety.

Application of Probabilistic principles to Set-Based Design for the optimisation of a hybrid-electric propulsion gas turbine

Mr. Andrea Spinelli (Cranfield University), *Luchien Anderson, Hossein Balaghi Enalou, Bahareh Zaghari, Timoleon Kipouros, Panagiotis Laskaridis*

Current research in hybrid and electric aircraft propulsion has outlined the higher complexity in design than traditional propulsion. Despite this awareness, current design methodologies rely on aircraft-level analysis and do not deal with technological uncertainty, which is the major limitation for developing hybrid-electric propulsion. We present a methodology for exploring the design space using the principles of Set-Based Design, which incorporates probabilistic assessment of requirements and multidisciplinary optimisation with uncertainty. The framework can explore every design parameter combination using a provided performance model of the system under design and evaluate the probability of satisfying a minimum required figure of merit. This process allows to quickly discard configurations incapable of meeting the goals of the optimiser. A multidisciplinary optimizer then is used to obtain the best point in each surviving configuration, together with their uncertainty. This information is used to discard more undesirable configurations and build a set of Pareto optimal solutions. We demonstrate an early implementation of the framework on designing a variable geometry gas turbine with a boosted fan stage. An electric motor is mounted on the fan shaft and powered by a battery in a hybrid-electric architecture. We obtain a map of variable geometry settings to optimise the specific fuel consumption of the engine under surge margin and turbine entry temperature constraints, and overall recover the uninstalled engine efficiency.

Graphene Technology for Design Efficiency of the Solar Hybrid Electrical Cryoplane and Airships

Prof. L Ponyaev (MAI), *M Kuprikov, R Domjan*

The problems of implementing graphene technologies in design research on complex low weight solutions are relevant for the development of high stress composite construction with solar nanofilm energy storage devices for hybrid electric cryogenic aircraft (as the LH2 hydrogen cryoplanes) and airships (disk shaped LTA MAI thermoplanes). Optimal design is directly related to the higher specific performance of liquid hydrogen-based fuel systems and cryo-cooling systems, taking into account the use of new graphene-based materials and thin flexible solar cells, which is considered for the SOLARSTRATOS and MAI projects or for any projects of hybrid electric aircraft/airships and their propulsion. The design analysis of improving the design capabilities of graphene technologies with its unique strength, electrical superconductive, gas tightness and low mass in the component modification of hybrid electric propulsion (HEP) of aircraft is carried out. Optimization of design solutions using combined graphene and film solar cells can lighten the weight of fuel tanks with liquefied hydrogen at high internal pressures and

simultaneously include in the cryo cooling systems of electric motors-generators and batteries with solar energy charging, which increases the efficiency of on-board electrical systems and reduces the initial energy level and allows for improved energy efficiency and reduced weight costs in the design studies of the FUTPRINT50 program.

Optimal Cryogenic System for Hybrid Electric Propulsion Aircraft/Airship with LH2 and High Temperature Superconductor

Mr. Yu Ravikovich (MAI), *L Ponyaev, D Holoptsev, R Domjan*

The complex analysis for research and development (R&D) of the technical appearance and calculation of the technical characteristics of the new hybrid electric propulsion aircraft/airship (HEPA) with LH2 and High Temperature Superconductor (HTS) cryo cooling system (CCS) may be use to the cooperation any R&D process by FUTPRINT50 EC Program. The new design synthesis of the optimal Cryogenic Refrigerator Cooling System on the basis of the reverse Brayton cycle with the use of turbomachines with the main design diagrams of the use the cryogenic systems of the cryogenic capacity and low temperature level for the calculation of created using test thermodynamic models of individual circuit elements, taking into account the efficiency of each element, hydraulic losses in the paths of all system elements: the calculation of hydraulic losses in the channel element, thermal management of exchangers of the regenerative type with turbocharger and turbo expander calculation. The using on line the small light wireless sensor-detector or solar energy components basing on the Seebeck-Peltier effect will be more efficiency with new graphene construction. The experimental development of a two-stage electric compressor and turbo expander was including the tests of the cryogenic cooling system of the CCS LAB demonstrator.

IMOTHEP European project: a holistic approach to hybrid electric propulsion

Mr. Philippe Novelli (ONERA), *S. Defoort, N. Tantot, D. Zimmer, J. Lopez, R. Biaujaud, Ch. Lochot, G. Troiano*

Commercial aviation is seeking new technologies to reduce its greenhouse gas emissions. Accordingly, IMOTHEP's top-level objective is to assess the actual potential offered by hybrid electric propulsion (HEP), a promising option to achieve a step increase in aircraft efficiency. IMOTHEP performs an in-depth investigation of electric technologies for hybrid electric aircraft in close connexion with advanced aircraft configurations and innovative propulsion architectures. It explores a range of aircraft configurations for regional and short medium range missions, which provides the specification for the technological investigation of the various components of the hybrid propulsion chain. From the performance evaluation, the project will identify key enablers and technology gaps for HEP development, as well as required tools, infrastructures and regulatory adaptations. A final sector wide roadmap for HEP maturation will assemble all the outcomes of the project.

FUTPRINT50 Academy (Part I)

Session Chair : Prof. Andreas Strohmayer, University of Stuttgart, Germany

Development, modelling and analysis of the thermal management system for a hybrid electric propulsion system of regional aircraft

Karlan Pillay, ***Mr. Hossein Balaghi Enalou (Cranfield University),*** *Panagiotis Laskaridis*

The turn of the decade has given conventional methods of aircraft propulsion a short and finite timeline. An extreme paradigm shift is currently on the horizon to reduce the impact of aviation. One of the viable

options put forward is the usage of electric architectures in aircraft propulsion systems. The expectation is that these electrical systems would be integrated into regional aircraft in a stepwise fashion until development enables sustainable all-electric aircraft. The implications of electrification include a reduction in fuel and an increase in the number of heat sources. With the current thermal management systems at the limit of operation, research studies need to be undertaken to determine the new methods of managing the heat loads and ensuring that components operate within the design limits and optimum efficiency. This paper aims at developing a simulation tool of the thermal management system that can be used to determine the size of the heat exchangers for different hybrid-electric architectures. The study will use a propellor-driven, regional aircraft as a baseline, to which different hybrid-electric architectures will be modelled and simulated over a mission profile. The thermal management system model will be integrated into these architectures to which the simulations are carried out. The best performing hybrid electric and thermal management system architecture will be chosen, also providing the size characteristics for the heat exchangers. The study carried out would provide a simulation software which can not only be used on regional aircraft but expand to other regional aircraft or larger commercial aircraft to determine the thermal management system requirements and the overall proof of concept.

FutPrInt50 Academy (Part II)

Session Chair : Prof. Andreas Strohmayer, University of Stuttgart, Germany

A preliminary study into the impact of electrification on the sizing requirements and performance of a turbofan engine

Katerina Antoniou, ***Mr. Hossein Balaghi Enalou (Cranfield University),*** *Panagiotis Laskaridis*

The ever-increasing pressure towards aviation to decrease emissions has resulted in exploration of novel electrification concepts. In this direction, the trend lies towards electrifying the engine through hybrid electric propulsion architectures. Current study focuses on the impact that electrification strategies on sizing of a twin spool turbofan engine. To investigate the effect of electrification strategies on an engine, first a valid engine model is established. Flight segments in which electric power is usually applied includes take-off, climb and cruise. Through different SFC decrease strategies, the impact of electrification on the overall engine performance is studied in terms of SFC and surge limit of the low-pressure compressor. In this framework, different resizing strategies for an engine core are studied. The components of the resized engine are designed and compared against the baseline ones to observe the impact of electrification on turbomachinery design in a preliminary level.

High speed flows technologies for future aviation and space programs

Session Chair : Dr. Catalin Nae, INCAS, Romania

Demonstrator for Technologies Validation (DTV) GNC design in-flight testing

Ms. Ana-Maria Neculaescu (INCAS), *Tudorel-Petronel AFILIPOAE, Adrian TOADER, Hans STRAUCH, Stephane DUSSY*

INCAS is developing in-house a reusable testing platform, called DTV – Demonstrator for Technologies Validation, an on-going project in collaboration with the European Space Agency, Future Launchers Preparatory Program (FLPP). The platform is currently in the tether testing phase and an acceptance flight is expected in 2021 at INCAS facility in Măneciu Prahova, which is INCAS main testing facility for space-related applications. In the frame of the project, a Flight Simulator was developed at INCAS containing a high-fidelity Plant model, guidance profiles and control strategies for the reusable vehicle. The aim of this

paper is to present the full control strategy developed by INCAS for DTV vehicle. A controller which is divided in a vertical, lateral and roll control channels will be described in detail. A comparison between simulations and measurements during flight testing campaigns in tether setup will be presented and assessed. The real flight data confirms that the adopted control methodology and strategy is suitable for the control of a reusable testing platform for space applications.

Reactive model based on hydrogen peroxide engine at INCAS Supersonic Wind Tunnel for single stage to orbit studies

Mr. Corneliu Stoica (INCAS), *Alexandru MARIN, Emanuel TRANDAFIR, Alexandru PANA, Alexandru NICA, Sorin DEFTA, Ionut BUNESCU, Gilbert STOICAN, Dumitru CURT*

A key point for different space missions, including satellite lunching and future space tourism, is the fuel consumption, which is linked to the propulsion system optimization. From the information related to actual aeronautical programs for supersonic jets and from published flight measurements of space launchers (Ariane5 and VEGA), it was concluded that currently used approach (CFD and wind tunnel testing) underestimates the base pressure and hence overestimates the vehicle drag. This is mainly due to the influence of the plume temperature on the complex flow field surrounding the base region, leading also to a large uncertainty in the heat loads and fluctuating loads on the nozzle. As a result from current investigations on the capabilities in Europe with respect to the active models simulations for space applications, INCAS has identified a real need for a facility able to provide this very specific capability for improved predictions. Traditionally INCAS supersonic wind tunnel, as many other wind tunnels, used cold plumes to simulate the jet-on conditions in tests, for flight ranging from transonic to supersonic conditions. This paper describes the work on the last development program aimed to enhance INCAS Supersonic Wind Tunnel testing capability by introducing hot plume testing capability under similitude conditions for space vehicles. This capability is based on a dedicated supply system for hydrogen peroxide, used as a mono-propellant for the rocket engine system simulator, to be used complementary with the existing cold air supply system for jet simulations. Following this goal, we introduce a generic calibration model for base drag evaluation under similitude criteria. The built wind tunnel model is using a generic launcher configuration installed on a dedicated support, including a peroxide engine simulator able to simulate hot plume interactions in transonic and supersonic regimes and a secondary air flux. During testing it is possible to measure the global loads and pressure surface measurements using specific instrumentation of the model, contributing to the development of a set of scaling parameters and similitude factors for active rocket engines simulations in wind tunnels. The proposed approach goal is to improve the knowledge related to interaction between rocket exhaust plumes and the base region leading to an optimized launcher design. The basic work performed was taking into account the need for the new supply system to be qualified with respect to safety procedures needed for standard usage in wind tunnel tests at INCAS. Also, as a result from the test campaign, one engine testing rig was developed, able to measure the hydrogen peroxide engines parameters before they are installed on the wind tunnel model.

Exploring methods for supersonic ramp intake optimization with RANS cross checking

Dr. Mihai-Victor Pricop (INCAS), *Mihăiță-Gilbert STOICAN, Dumitru PEPELEA, Mihai Leonida NICULESCU*

Several optimization routines are used for configurations like planar ramp intakes. The ramps consist of two and three segments, whose lengths are optimized together with their angles. The optimization algorithms are constrained Differential Evolution, Ant Colony, NLP (Nelder-Mead), all handling free form constraints and bounds. To properly assess the optimization process, families of ramps are optimized across a range of Mach number from supersonic to hypersonic. Pressure recovery performance for a Mach range provides the consistency level of the optimization process. Furthermore, several ramps are computed at the respective regimes with a RANS code, to enable more in dept comparisons. Optimal

ramps are then configured for off-design cases using the same optimizers, with a modified formulation: frozen segment lengths, variable angles only. Besides the ideal gas model baseline, real gas elements are used in the form of temperature dependent enthalpy, to enable more comparisons.

Sonic Boom Evaluation from Blowbown Wind Tunnel Data

Dr. Catalin Nae (INCAS), *Dumitru Pepelea*

Wind tunnel models can be designed to produce booms with shaped signatures near the aircraft, but it has not been demonstrated, by analysis or experiment, that a shaped signature will persist to the ground during the flight in a real atmosphere. Non-linear effects in the near field noticeably disturb the flow in the middle and far-fields. Therefore, the choice of the low sonic boom configuration should be supported by the experimental investigations delivering reliable information for the CFD methods.

INCAS has initiated an original methodology for sonic boom characterization, possible to be implemented in blowdown wind tunnels (e.g. INCAS Supersonic Wind Tunnel up to TRL 4) and possible to be adapted for large industrial wind tunnels. Research is on-going to establish a credible scientific foundation for designing supersonic aircraft with low sonic booms and to develop improved experimental evaluation tools in relevant environment at higher TRL. The overall technology for the sonic boom evaluation is based on the correlation between 3 types of information, provided by dedicated models and sensing technologies:

- CFD analysis and far-field extrapolations using state-of-the-art high-performance codes;
- Rotating Kulite pressure sensing matrix (INCAS patent) for dynamic pressure information under the model (near-field sonic boom N-wave);
- Digital Schlieren images analysis (including post-processing using Abel inverse transformation)

A dedicated sonic boom wind tunnel test campaign has been conducted on a reference model in INCAS SWT. The primary purpose of the test is to determine whether the sharp pressure peaks in the sonic boom signature could be measured while using the rotating Kulite matrix, instead of the move/pause mode of operation used in earlier sonic boom tests using dedicated transverse probes. Measured sonic boom signatures are compared with numerical results from CFD analysis. Zhilin model is used to propagate the computed near field sonic body signatures to the ground. The small variations in the ground signatures and in the loudness levels, generated by model, are assessed with respect to the ground signature and their sensitivity to the turbulent modeling. The loudness level at the ground is evaluated also, as it is the case for the standard deviation. Finally, N-wave characterization is delivered for the reference configuration for both close-field and far-field sonic boom regions.

Bionic Structures for Comfort and Safety of Future Civil Aircrafts

Session Chair : Dr. Alexander Shanygin, Central Aerohydrodynamic Institute (TsAGI), Russia

Investigation of non-regular grids for lattice fuselage barrels for increase of comfort

***Dr. Alexander Shanygin (TsAGI, Russia, Zhukovsky**), I. Kondakov, E. Dubovikov, M. Levchenkov*

Configurations of currently designing perspective supersonic passenger aircrafts (SPA) have a number of specific features as compared to the ones of subsonic passenger aircrafts. These features lead to sufficient increase of complexity of their airframes. At those requirements of safety and comfort give additional constraints of SPA structure, connected with more complex flight regimes. Up-to-date requirements on noise and sonic boom make the task of searching rational structure layout for SPA even more difficult and form new constraints on the structure. Experience of development of the new generation of structures for subsonic passenger aircrafts shows that development of airframes based on bionic principles, formulated in TsAGI, as a result of international and domestic projects, give new opportunities not only in weight saving, but also in additional increase of safety and comfort for passengers. This is reached due to interaction of the main parts of bionic structure (stiff grid of unidirectional composite ribs and system of protective elements). In the present work results of numerical investigations for searching of rational bionic structure of a hypothetic SPA, having low supersonic speed with almost no heating, are presented. It is shown, that in frame of bionic layout due to selection of rational grid structure and using positive synergy effect of grid-protection interaction, higher level of safety and comfort in cabin including decreased level of thermal/noise insulation, increased size of windows and lower shake in turbulence can be provided without weight penalty. The report is prepared in the implementation of the program for the creation and development of the World-Class Research Center “Supersonic” for 2020-2050 funded by the Ministry of Science and Higher Education of the Russian Federation (Grant agreement of December, 8, 2020 № 075-11-2020-023).

Optimization method of composite truss rod structure with advanced reliability

***Dr. Andrey Chernov (TsAGI, Russia, Zhukovsky),** E. Dubovikov, D. Fomin, I. Mareskin*

To improve the safety and reliability of load-bearing composite aircraft structures, the possibilities of using unconventional structure layouts are currently being considered. One of these promising structures is a truss rod structure based on hybrid metal-composite rod load-bearing elements, which has a high weight efficiency. The reliability of such a structure is ensured by an impact protection system for the rod elements. The paper proposes a technique for optimizing composite truss rod structures with impact protection, taking into account the synergistic interaction of the load-bearing structure of rod elements and elements of the protection system. The optimization problem is solved on the basis of a genetic algorithm using a two-level parametric strength FEM model of the structure. The FEM model of the first level simulates a truss structure using 1D finite elements (FE) of the rod and beam type. As a result of the FEM analysis, the force factors acting on each load-bearing element are determined for a detailed strength analysis. The FEM model of the second level simulates individual rod element using two layers of 2D bending FEs, connected to each other by rigid MPC (multi point contact) elements. One layer simulates the load-bearing part of the rod element, the second layer simulates the protection system. Using this model, the analysis of stress/strain state is carried out and the strength, global and local stability margins of each rod element are determined. In this work, optimization studies of a truss composite structure for the wing load-bearing section are carried out and the potential of this type of composite structure in comparison with the traditional one in increasing the reliability of the structure while ensuring high weight efficiency is shown.

The report is prepared in the implementation of the Russian Foundation of Basic Research (RFBR) grant № 19-29-13046.

Algorithm of searching of design loading cases of airframe of perspective civil aircraft

Mr. Dmitrii Vedernikov (TsAGI, Russia, Zhukovsky), *Y. Mirgorodsky, S. Belikov*

Determination of the critical loading parameters during the interaction of the structure with the aerodynamic flow is one of the most time-consuming stages of the preliminary design procedure for the airframe of a passenger aircraft. The correct solution to this problem largely depends on both the weight efficiency and reliability parameters of the aircraft, and the comfort of passengers when flying in turbulent air. Additional difficulties in determining the loading parameters arise for unconventional structures with structural anisotropy. Analysis of the loading factors acting on the airframe structure requires a large number of computational studies using numerical strength and aerodynamic models. In order to reduce the complexity of determining the critical loading parameters, this paper proposes a fast and reliable algorithm for searching critical loading cases based on the following principles:

- global parameterization of strength FEM and load aerodynamic models
- parametric discretization of the space of allowable flight modes
- full automation of the computational procedure
- iterative narrowing of the range of potential critical loading cases in the Max-Height-Mass (M-H-M) space.

This paper presents a description of the proposed algorithm, as well as the results of validation studies for a number of unconventional designs, including perspective supersonic aircraft and regional aircraft. It is shown that the using of the algorithm makes it possible to reduce the calculation time for finding critical loading factors by at least 10 times while maintaining the same calculation accuracy. The report is prepared in the implementation of the program for the creation and development of the World-Class Research Center “Supersonic” for 2020-2050 funded by the Ministry of Science and Higher Education of the Russian Federation (Grant agreement of December, 8, 2020 № 075-11-2020-023).

Novel unidirectional CFRP aircraft lattice fuselage LVI protection with the use of foamed thermoplastic

Prof. Sergei Sapozhnikov (TsAGI, Russia, Zhukovsky), *I. Kondakov*

In this work the novel design of the load-bearing aircraft lattice fuselage frame made of unidirectional carbon fibre rods is considered and the problems of low-velocity impact (LVI) protection of this type of structures is investigated. It is shown that a thin, aerodynamic shell and the load-bearing lattice frame should be separated by a protective layer of foamed thermoplastic capable of absorbing the impact energy without damaging the unidirectional CFRP grid. Based on the finite element analysis, numerical models have been developed to assess the strength of the grid made of unidirectional CFRP during local impact (explicit dynamics, large displacement, plasticity and fracture). There were found rational mechanical behavior and minimal thickness of the protective layer to absorb the impact energy of up to 50 Joules without damage to a business-class aircraft's lattice CFRP fuselage frame. The results of numerical analysis were compared with experimental studies of the impact on fragments of the unidirectional specimens of the grid and their residual compressive strength and good correlation between numerical and experimental data was shown. The report is prepared in the implementation of the program for the creation and development of the World-Class Research Center “Supersonic” for 2020-2050 funded by the Ministry of Science and Higher Education of the Russian Federation (Grant agreement of December, 8, 2020 № 075-11-2020-023).

Human Factors

Session Chair : Prof. Luis Santos, ISEC Lisboa, Spain

Support Team Assignment for Base Maintenance of Aircraft Fleet: a Case Study

*Duarte Pereira, Isaias Gomes, Prof**. Rui Melicio (ICT, University of Evora; IDMEC, Instituto Superior Técnico),** Victor Mendes*

This paper presents a case study of practical application for the problem of planning base maintenance of a mix of aircraft fleets. The case study is a mathematical programming problem written as a minimization problem. The cost function is the sum of cost due to technicians assigned to the maintenance of aircraft with the daily operation cost due to facilities, and with the revenue opportunity cost due to aircraft downtime. This problem is a contribution to perform the correct maintenance, which is of extreme importance for favouring the profits of airline companies. The formulation follows a model of pure linear integer programming solved by the pyomo library calling the GLPK, and for comparison, solved by solvers in the Scipy library as a nonlinear programming problem, relaxing the decision variables to continuous ones. The purpose of the comparison is a discussion about the results and the limitation of using solvers for nonlinear programming problems to address the planning of base maintenance of the aircraft fleet.

How much workload is workload? A human neurophysiological and affective - cognitive performance measurement methodology for Air Traffic Controllers

***Mrs. María Zamarreño Suárez (Universidad Politécnica de Madrid),** Rosa M Arnaldo Valdés, Francisco Pérez Moreno, Raquel Delgado-Aguilera Jurado, Patricia María López de Frutos, Víctor Fernando Gómez Comendador*

1. **Introduction:** Air Traffic Controllers (ATCOs) play a fundamental role in the safe and efficient management of flights. In order to perform their work properly, they need to be able to cope with stressful situations that demand a rapid decision-making process. In the realization of their tasks, the human factor aspect cannot be overlooked. For this reason, it would be of great interest to make use of an ATCO neurophysiological and affective - cognitive performance methodology that would make it possible to detect the moment at which an ATCO is about to be overloaded or with too little workload. These two factors can both degrade the quality of the ATCO's actions. Such a methodology could only be valid if supported by experimental data. Previous studies in the field of human factors applied to ATCOs tend to present certain limitations. Firstly, the difficulty of using air traffic controllers or professionals having ATC training as study subjects. In addition, in cases where the above condition is met, the number of subjects is usually too reduced, which implies certain limitations when drawing conclusions based on the measurements recorded. This study, carried out in collaboration with CRIDA, proposes to solve both limitations referred, as it poses the development of a methodology on the basis of a simulation platform and a large group of air traffic controller students.
2. **Discussion:** For the development of the experimental data collection campaign, Eurcontrol's ESCAPE and Skysoft's SkySim simulation platforms, as well as the ROSE exercise editor are available. In addition, for the measurement of human factor metrics, GP3 eye-tracking equipment, commercialized by Gazepoint, is used to obtain data such as, for example, the number of blinks or the number of fixations of the student during the simulations. To complete the set of devices used, Emotiv's Insight equipment is available, to obtain encephalographic data (with an outstanding interest nowadays, as part of the industry 4.0). As this data is collected, affective-cognitive parameters are obtained as well as raw data captured by the electrodes. In both cases, the referred equipment is low-cost, which offers the advantage of an easy implementation and the additional possibility of extending the methodology

to other simulation platforms and further scenarios. All the equipment mentioned above is used to carry out simulations with a group of controller students. The exercise programme is evolutionary, and the difficulty of the exercises increases progressively. This programme has been specially designed for this project. Each of the students simulates the corresponding exercises and their human factor metrics are registered.

3. **Conclusion:** Using the above technical means and following the full completion of the exercise programme by the controller students, a large volume of visual tracking and encephalographic data is available, as well as information about the amount of workload perceived by the students. From the analysis of this preliminary experimental data, two fundamental questions can be answered: i) can the use of this platform be validated as a means of obtaining the desired methodology? and ii) what are the thresholds for detecting an overload and an underload in the performance of the ATCOs, based on their physiological and affective-cognitive human factors metrics?

Usability studies for workload assessment in remotely piloted aircraft systems

Ms. Antonio Esposito (Kore University of Enna), *Paolo Buono, Fabrizio Balducci, Andrea Alaimo and Calogero Orlando*

The transition from manual systems to systems in which the levels of automation, management, and control can be adapted to the workload level is the basis of an ergonomic development that places humans as a part of the system and not simply as a user. It is, therefore, necessary to properly investigate the relationship between workload and human-computer interaction. Workload overload can often lead to reduced accuracy in operations and errors and reduced situational awareness. The same effects can arise under conditions of too low a workload [1]. In order to improve the performance, it is necessary to give the proper settlement between automation and operator workload level. There are several measurement methods of workload and situational awareness, the most common and easy to use of which are indirect measurements based on questionnaires [2]. Indirect or subjective measurement provides a description of the workload level as it appears to the operator while performing a task; however, the reliability of such measurements can be compromised by the operator's perceptions. In addition, these techniques fail to measure changes in workload levels over time. Indirect measurements are distinguished from direct measurements based on physiological parameters. Today, direct or objective measurements are based on heart rate (HR), heart rate variability (HRV) [3], respiratory rate, electroencephalogram, pupil size, and eye movements or eye blink rate [4]. On the other hand, physiological measurements can use the body's physical reactions to objectively estimate the amount of mental workload associated with a task operation [5, 6]. The aim of this work is the workload evaluation of pilots that perform remotely fly operations wearing physiological sensors useful to gather objective data. During the experimental campaign, we involved certified drone pilots; thus, the experiment does not take into account the learning phase. Six tasks with different difficulty levels were formulated to perform specific functions of piloting. The first task is fully automated, and the pilot must define a flight envelope and monitor that the drone is performing its activities correctly. The other five tasks are manual, and the pilot must manually drive the drone according to the provided instructions. The fully automated flight can be considered the baseline for the user's physiologic response compared to the other test results. The baseline makes the results independent from the specific subject. The six tasks are described in the following. They are ordered by complexity, from the lowest to the highest complex task.

(i) Fully automated flight: define a flight envelope on waypoints and check that the drone performs the mission correctly

(ii) Take-off and Hovering: take altitude up to about 10 meters for a few seconds and then descend

(iii) Straight flight: proceed straight at constant altitude for 30 meters and go back to the starting position by turning (use of the inverted controls)

(iv) Diagonal and Angle curves: from a low altitude made a diagonal climb of 45°, draw a rectangle in flight and then make a diagonal descent of 45°

(v) Curves: fly to the agreed point, circle around it and return to the starting point

(vi) Precision Landing: land the drone at a designated point

To gather information on the strategies implemented in the task execution and on the difficulties encountered during the test, usability techniques have been exploited by highlighting the strengths and weaknesses of the piloting systems used to pilot drones that may affect the overall performances. The analysis of the results allowed us to isolate problems related to the usability of the piloting interfaces used, while the analysis of the physiological measures highlighted their usefulness in the evaluation of the workload level of a pilot during the fly tasks. Through the Thinking Aloud techniques [7] it was possible to evaluate the user interface of two remote piloting applications, the former is a simulator, and the latter is the User Interface to control a real drone. Furthermore, measurements like execution time and success rate were collected for each task while user satisfaction has been evaluated through NPS [?] and SUS questionnaires [8]. The "Cognitive Walkthrough" technique [9] was used to compare the drone management and piloting experience carried out with the two piloting systems. Other evaluation techniques that were used are the heuristic evaluation [10] and the Modified Cooper Harper for Unmanned Vehicles Display (MCH-UVD) [11], this one is specific for UAV displays. The relationship between direct physiological measurements and indirect workload measurements can provide reliable and useful data to monitor a pilot's workload. The preliminary results obtained for Remotely Piloted Aircraft Systems (RPAS) together with the analysis of the signals and their appropriate processing can support the development of a technology that can adapt the automation levels, of a complex system such as RPAS, in order to balance the operator's workload. Such adaptation can include Artificial Intelligent (AI) components that are triggered according to a given situation. An emergent field, that focuses on the problem of user control versus AI control is HCAI [12].

ecoDESIGN and Sustainable Productivity (PART I)

Session Chair : Mr. Torsten Moll, Fraunhofer-Gesellschaft, Germany

ecoDESIGN and Sustainable Productivity

Mr. Torsten Moll (Fraunhofer-Gesellschaft), *Rainer Schweppe*

The European aeronautics industry has a large environmental and socio-economic relevance. Its sustainability, productivity and competitiveness will strongly depend on the innovation steps to make economic value and ecologic value come together. Looking at aviation as circular economy, all life cycle phases must be considered closing the loop from end-of-life to material production. Sustainability of materials, processes and resources, efficient manufacturing, lifetime services and the end-of-life challenge will drive the competitive value in the context of environmental services. The presentation provides an overview about the ecoDESIGN Transversal Activity in the Clean Sky 2 programme. This includes an outlook on selected activity domains and demonstrations in scope.

ecoDESIGN in Next Generation Aircraft Fuselage

Ralf Herrmann, Piet-Christof Wölcken, Marta Solares-Canal, ***Mr. Torsten Moll (Fraunhofer-Gesellschaft)****, Carl-Christoph Höhne, Corinna Lätsch*

Sustainability and competitiveness of next generation large scale aircraft structures will strongly depend on their environmental footprint along the full life cycle. This particularly includes design, materials processes and resources, manufacturing and production, lifetime services as well as recycling and end-of-life for disruptive concepts and innovation. This presentation provides an overview about the implementation of ecoDESIGN approaches in the Multi Functional Fuselage Demonstrator as part of the Clean Sky 2 and it introduces into several more detailed presentations on linked projects which will be presented separately as part of the EASN Conference Session on ecoDESIGN and Sustainable Productivity.

ECO-CLIP: circular economy from factory waste material towards aircraft structural components

Mrs. Raquel Travieso Puente (AIMEN Technology Center), *C Martín-Pérez, N González-Castro, E Rodríguez-Senín, J Vidal-Navarro, G Vicente and S L Veldman*

This paper discusses the development of short fibre frame clips and system brackets partly made from recycling CF/LMPAEK factory waste composites employing two technologies (injection molding and 3D-printing). The project will develop and validate fused deposition modeling (FDM) as cost-efficient process to manufacture system brackets using the novel formulation of recycled composite as ra material. Energy directors for ultrasonic welding is presented for successful joining of the clips to the fuselage avoiding fasteners. The parts will be assembled into the lower half of the multifunctional fuselage demonstrator. The results were developed within ECO-CLIP project, which aims to: (1) assess technical aspects of material recyclability and (2) assess the economic and environmental validity of the technology.

Sustainable management of End of Life of Aircraft Composite Structures

Mr. Alejandro Marques Paola (Aitiip Centro Tecnologico)

I would like to introduce HELACS Project. HELACS (JTI-CS2-2020-CFP11-LPA-02-36) is a Clean Sky 2 project within the scope of Horizon 2020 Framework Program.

This project will properly include the European Industry necessities when the current dismantling and recycling processes will be improved to properly manage CFRP components, now and in the future, by transferring innovative technologies and systems in two main pillars:

- Flexible and Portable Robotic Platform with machine learning capabilities and dedicated tools for CFRP cutting and debonding (i. Hydro-jet cutting tool for any CFRP and ii. Resistance welding [bonding/debonding] tool for thermoplastic CFRP, new comers in the aeronautic sector)
- Recycling and valorisation technologies based on optimised pyrolysis processes for improving carbon fibre recycling yield and sizing formulation for improving carbon fibre functionalities (sizing agents for mechanically enhancing of recycled carbon fibres and sizing agents for enabling debonding capabilities in carbon fibres for thermoplastic CFRP (debonding via ultrasounds or induction heating technologies)

HELACS project is based on previous results of end of life aircraft management projects, the review of recommendations and standards for aircraft disassembly and aircraft materials recycling (such as the developed for the Aircraft Fleet Recycling Association - AFRA) and the experience and support of the biggest Maintenance, Repair and Overhaul (MRO) entity in Europe, Teruel Airport (PLATA), to implement a cost-competitive and energy efficient solution for dismantling and recycling Carbon Fibre Reinforced Polymer (CFRP) components.

Replacement of Hard Chrome Plating on Steel

A. Albolino, V. Derosa, ***Mr. Ali Bahwan Al Mukhaini (Leonardo – Società per azioni)***

Hard Chrome Plating is a key process which treats components for enhanced hardness, durability and corrosion resistance. While the technology is proven, it is extremely energy inefficient, and incorporates the use Cr(VI), an extremely hazardous chemical which poses risks to both the handler and the environment, which also increases disposal costs, and the total embodied emissions of the process, due to these concerns it is important to assess alternative technologies to achieve the required performance. Thermal Spraying technology namely High Velocity Oxygen Fuel (HVOF) is an appealing substitute, which could satisfy requirements, while increasing energy efficiency and eliminating the use of Cr(VI). The merits of HVOF compared to Hard Chrome Plating in the treatment of steel pins were explored, with a focus on the reduction of toxic waste, energy usage and costs, and conformity to REACh regulations. Life Cycle Inventories and flow charts were produced for each technology, and a Life Cycle Analysis study was performed comparing both technologies. The materials used, energy expenditure, emissions produced and waste materials at each stage of the process were evaluated. The data was gathered through measurements where possible, and theoretical calculations coupled with estimations were employed when necessary. It was then processed into relevant normalised indicator groups. It was found that the switch to HVOF would decrease the Energy Demand, water pollution and Eco-toxicity, aligning it better with regulation. However, significantly more dust was produced in the process when compared to Hard Chrome Plating, causing an increased hazard on Human Respiratory Health. Certain aspects such as waste stream management were not considered in the model, and thus further detailing will be required for a more comprehensive understanding. Nevertheless, the LCA suggests that HVOF is an attractive alternative to Hard Chrome Plating, which is not only more energy efficient but is significantly more environmentally friendly and confirmative to regulations.

ecoDESIGN and Sustainable Productivity (PART II)

Session Chair : Mr. Torsten Moll, Fraunhofer-Gesellschaft, Germany

Assessment of the impact of material selection on aviation sustainability

Dr. Dionysios Markatos (University of Patras), *Spiros Pantelakis*

Emissions in the aviation industry are of increasing concern among the governments, policymakers and the flying public, as environmental issues such as climate change and global warming pose great

sustainability challenges for the aviation industry[45]. The European Union and the aviation industry have agreed to reach a 75% reduction in CO2 emissions per passenger kilometer by 2050[46]. Therefore, it is crucial to consider sustainable approaches and solutions when it comes to future aircraft applications. Towards this direction, hydrogen has emerged as a potential aviation fuel of the future[47]. The current work aims to contribute to the understanding of the impact of the material selection on aviation sustainability, from the economic and environmental point of view, under the scope of a hydrogen-fueled aircraft. The potential emissions savings from the extensive use of composites in the state-of-the-art aircrafts have been proved[48]; however, hydrogen implementation in future aircrafts and its associated effects on the emissions, as well as the aircraft structure and configuration, urges the need to re-examine the impact of the material selection on aviation sustainability, taking into account the principles and objectives of circular economy. In the above framework, the impact associated with all life-cycle phases of a component (either constructed from CFRP or aluminum) has been assessed. To enable material comparison, a typical weight saving of 20% is used as the basis for comparison between a component made either from CFRP or an aluminum alloy [4], and the associated values are expressed as per-equivalent mass. As expected, the greenhouse gas emissions (GHG) avoidance deriving from the use of CFRP instead of aluminum (either virgin or recycled ones), when hydrogen fuel instead of kerosene is implemented, is significantly lower, especially when hydrogen fuel from renewable sources is used. However, it should be noted that the impact of other non-CO2 pollutants caused by H2 burn must be also considered; in this direction, reliable models to assess the overall impact on the climate, under a comprehensive life-cycle study, are required. Furthermore, the costs emerging from the replacement of aluminum with CFRP (either recycled or virgin ones) are considerably higher (for the aluminum) when hydrogen is used instead of kerosene; this is owed to the significantly high cost of hydrogen, despite its high fuel efficiency, compared to kerosene. Subsequently, to assess the above in a holistic view and towards circular aviation objectives, a flexible formula based on simple mathematical equations is introduced, with the aim of aiding future material selection for aircraft-related applications. The proposed model offers a trade-off between three relevant dimensions of sustainability, i.e., environmental, cost, and technology performance (quality); the latter is interpreted in the current study as the quality-dependent reuse impact of an aircraft material after its EoL (End of Life). Implementation of the above approach, demonstrated that the overall impact of material selection and resulting weight, through all life phases of the material (including EoL), is lower when hydrogen is implemented; however, it remains significant. It is also noticeable, that considering a hydrogen-fueled future aircraft with net zero emissions as well as a high maturity level of advanced alloys for implementing them in aviation applications, a small window for the utilization of such alloys as primary aviation materials (e.g. nano-crystalline materials) may (re)-open. Finally, the current work underlines the need to harmonize existing life-cycle analysis (LCA) methods into an integrated modeling and assessment approach that considers the specifications of upcoming technological developments in aviation.

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Key environmental indicators for the aircraft manufacturing industry

Mrs. Eleonore Pierrat (Technical University of Denmark), *Rupcic Lea, Laurent Alexis, Hauschild Michael*

Global aviation contributes significantly to environmental problems, such as climate change, noise, or air pollution, mainly due to aircraft operations. Aircraft manufacturing represents between 1% and 3.5% of the life cycle emissions. Understanding the disaggregated contributions of the aircraft manufacturing value chain to environmental impacts is essential for reducing those impacts, but remains challenging due to aircraft complexity and the lack of public data. Besides, other key environmental issues, such as water use and waste generation, are rarely addressed in scientific literature. Here we contribute to bridge this knowledge gap by mapping the energy requirements, the carbon footprint, and the water withdrawals of the aircraft industry from cradle-to-gate, i.e. covering extraction of resources, production of materials and manufacturing of the aircraft. The mapping is based on environmental reports of top 100 manufacturing companies covering 84% of the market and complemented by information from environmental databases. We found that airframers and engine manufacturers are the largest contributors to the environmental impacts of the sector. The engine production carries a disproportionate share of the environmental burden with 31% of the carbon footprint and 32% of the water withdrawal, while representing less than 15% of the aircraft weight. This is mainly due to the higher environmental intensities associated with titanium alloy production and engine manufacturing. Moreover, titanium machining appears highly resource intensive, as the buy-to-fly ratio for this material is approx. 10:1 and the recycling rate is low with approx. 15%, possibly due to the intricate geometry of some engine components e.g. bladed integrated disks. Our results therefore call for two main ways to reduce environmental impacts in the aircraft manufacturing. First, airframers should focus on reducing the environmental impacts by design, as they control a significant part of the supply chain. Secondly, engine manufacturers should seek to optimize the material efficiency to reduce the use of primary resources and the associated environmental impacts.

DIGESTAIR – a novel anaerobic digester solution in air transport for on board safe and efficient waste management: first results

Mr. Enrique Aymerich (CEIT), *Jon García-Aguirre, Tamara Fernández-Arévalo, Héctor Lacasta-Gonzalo, Juan-Miguel González-Herrero*

Waste production in commercial aircrafts accounts for 0.3 – 3 kg of waste/traveler where food waste and packing waste of galleys represent 40% of total waste. Currently, the organic waste management of commercial flights is subjected to non-sustainable practices and restrictions (i.e. the animal by-product regulation 2009). Within the framework of Clean Sky 2.0, DIGESTAIR project (GA-832012) evaluates the implementation of an anaerobic digestion (AD) prototype that will enable the treatment of the organic waste that is generated on board in commercial flights, namely sewage from lavatories, food waste and packing water (biodegradable plastics). The waste management solution includes an AD prototype, with a pretreatment process (pasteurization unit) that enables to hygienize the organic waste before the AD process, which operates under low retention times, i.e. 4 – 5 days. In order to construct and design the AD prototype, laboratory tests have been performed, where specific aspects related to the biodegradation of the sole waste streams, different waste stream mixtures and pretreatment processes were evaluated. In addition, an AD model has been developed which enables to analyse different scenarios at different retention times. The designed AD prototype includes a storage tank with an integrated waste trituration unit, a pasteurization unit and a methanogenic unit of 100 L (Figure 1). An external ceramic membrane has been included to optimize the AD process. The AD prototype has been automatized, with the integration of a PLC and Scada software. AD tests are on-going to be made with the on-board waste streams, to validate the prototype. The Figure 2 shows a 3D view of the AD concept in an

Airbus A350 fuselage. The experimental results have been used to calibrate a simulation tool. This tool will consider all the special conditions that will take place in short, medium and long-distance flights, such as time of operation when flying, pressure and temperature into the aircraft environment, and the evolution of organic load. Moreover, the simulation tool will add value to the DIGESTAIR project and it will support decision making to push the technology progress as regards the following: (i) redesign of the ADP for optimisation and technical realisation in aircraft environment, and (ii) the evaluation of the transferability of the DIGESTAIR approach to novel scenarios such as ship transport.

Project GENESIS – Gauging the environmental sustainability of electric and hybrid aircraft

Dr. Alexis Laurent (Technical University of Denmark)

In a global context, where societies need to move towards more environmental sustainability, the aviation sector has an important role to play. Transition to reduce its environmental footprint, i.e. the impacts on ecosystems, human health and natural resources stemming from activities in the entire value chain of aircraft, has become high on political and industrial agenda. This transition must go hand in hand with the technological transformation of aircraft systems, moving away from the conventional use of fossils-based fuels to alternative energy sources, like biofuels, hydrogen or electricity via batteries. Recently-launched project GENESIS, which is part of the Clean Sky 2 programme, contributes to this effort with a purpose to develop a technology and sustainability roadmap for transitioning towards environmentally sustainable and competitive electric and hybrid aircraft systems. Regional class, 50 pax aircraft are considered as a focus point, and several powertrain technology alternatives are explored, including conventional, batteries, fuel cells and hybrid combinations of them, all with three-time perspectives over the period 2020-2050. Building on the multidisciplinary and complementary expertise of its consortium members, GENESIS specifically aims to (i) develop a conceptual design, associated with technology requirements, for 50 pax regional class electric/hybrid aircraft; (ii) perform technology foresight analyses on the key elements of the aircraft system; and (iii) build life cycle inventories for each relevant technology processes within the aircraft life cycle (from resource extraction, through manufacturing and use, up to end-of-life), and use them to perform prospective life cycle assessment quantifying potential environmental impacts of future aircraft system configurations and potential scenarios. Outcomes from these will feed into the development of the technological and sustainability roadmap for future regional class electric A/C development, and thus contribute to steer future initiatives within academia, industry and authorities to transition to innovative, competitive and sustainable aviation.

Validation of the zonal model for an Environmentally Friendly Aircraft Cargo Fire Protection System with containerized load

Arnav Pathak, Marie Pschirer, Max Kienberger, ***Dr. Victor Norrefeldt (Fraunhofer IBP)***

Within the CleanSky2 Environmentally Friendly Aircraft Cargo Fire Protection System, a simulation model for the local distribution of nitrogen as extinguishing agent and residual oxygen concentration has been developed. While the model has undergone thorough validation for the unloaded cargo bay, its performance in the loaded cargo bay is still to be proven. For this, the cargo bay in the Fraunhofer Flight Test Facility has been equipped with geometrically equivalent LD3 container elements to replicate the flow blockage for the fire suppression system. Test were conducted and the local distribution of residual oxygen was measured. The test data is used to validate the zonal model predicting the local distribution of agents in the cargo hold.

ecoDESIGN and Sustainable Productivity (PART III)

Session Chair : Mr. Torsten Moll, Fraunhofer-Gesellschaft, Germany

Life Cycle Inventories for Engine Blisk LCA

Mr. Kilian Fricke (Fraunhofer Gesellschaft), *Thomas Bergs, Philipp Ganser, Sascha Gierlings, Joana Albano*

The aviation industry has been growing continuously over the past decades. To ensure sustaina-bility and competitiveness for aviation industry, a full understanding of the environmental im-pacts is required, not only during use phase but along the entire life cycle including Materials, Processes and Resources, Manufacturing and Production, Lifetime Services as well as Reuse, End-of-Life and Recycling. Core engine components, for example integral rotors (Blisks), are comprised of high value metallic alloys that require complex and resource consuming manufac-turing processes. The presentation and full paper will introduce an approach for Life-Cycle-Inventory data acqui-sition during Blisk manufacturing as basis for a Life-Cycle-Assessment (LCA) according to ISO 14040. A particular focus will be set on the data quality and confidence level with regard to measuring, acquisition and analysis of in- and output flows within the chain of Blisk manufac-turing. This includes the stages of material generation, forming processes, heat treatments, ma-chining, surface treatments and quality assurance. A particular focus is drawn to selected varia-tions on mechanical machining processes. On this basis, first results of an LCA for Blisk-manufacturing will be presented.

The work is part of the Clean Sky 2 ecoDESIGN Transversal activity and Engines ITD.

Environmental analysis of blisk manufacturing

Ms. Lea Rupcic (Technical University of Denmark), *Eleonore Pierrat, Kilian Fricke, Torsten Moll, Michael Zwicky Hauschild, Alexis Laurent*

Engine manufacturers have been reported to be the second-largest contributors to the aircraft manufacturing industry concerning carbon footprint, energy requirement, and water consumption. A large part of the impacts is likely to be traced to the production of blisks (integrated bladed rotors) due to manufacturing challenges. Complex geometry, small tolerance, and efforts per part are relatively high compared to other engine subsystems. The required highly resistant materials, such as titanium alloys, are usually machined from a solid piece of material with large material loss, down to 20% of the material input only being used in the final product in some situations. In this context, how large are the environmental impacts associated with blisk manufacturing, and where can reduction potentials be? Here, we investigate the implications of the high share of wasted materials and assess the environmental impacts with the functional unit defined as manufacturing of a functional high-pressure compressor blisk made of Ti–6Al–4V alloy in 220 mm tip radius and final weight of 3.7 kg for an average cycle time of 107h in a research laboratory in Germany. We use the life cycle assessment (LCA) methodology and material flow analysis. Primary data were collected from pilot-scale manufacturing of a blisk used in an aircraft engine, made of conventionally cased titanium alloy, subsequently milled. The system life cycle was modeled using GaBi LCA software and additional data from the ecoinvent LCI database was used for modelling background processes. ReCiPe 2016 life cycle impact assessment methodology was used to quantify a large variety of potential environmental impacts. The climate change impacts per functional unit were found to amount to 3.6 tCO_2e in a scenario without recycling titanium scraps during production processes. Manufacturing scored higher impacts relative to material generation for several environmental impact categories such as toxicity of chemical releases on the environment and human health, eutrophication, metal depletion, land use, and ionizing radiation. In categories related to fossil fuel consumption, such as climate change, material generation has a greater impact due to the associated high

energy requirements. Moreover, explored scenarios for waste management of manufacturing waste showed that significant impact reductions could be achieved, depending on the recycling rates for titanium scraps. These findings demonstrate that the development of scrap recycling for specialized titanium alloy may be an efficient way to reduce the environmental impacts associated with blisk manufacturing. This can contribute to lowering the impacts associated with engine manufacturing and help to move towards sustainable aviation.

Industrialization of CFRP Re-Use and Recycling

Mr. Jannis Ginter (Fraunhofer Institute of Chemical Technology)

The use of carbon fibre reinforced polymers (CFRP) for lightweight components in aviation is steadily increasing and lots of achievements have been reached for the design and manufacturing of CFRP in the past. However, there still is a large potential to increase sustainability of CFRP across the full life cycle and in particular with regard to circular lifecycle approaches. In comparison e.g. to metallic parts, the recycling processes of CFRP during production and at their end-of-life is more complex. Industrial implementation of recycling technologies and end-of life solutions is required to realize more sustainable concepts than just the incineration of high value material and avoid landfill. This presentation and the related paper provide an approach to implement a full-scale supply chain of recycled carbon fibre (rCF) for an aviation industry case example. The holistic concept covers all involved processes from cured and non-cured manufacturing scraps of virgin carbon fibre thermoset material via recycling processes to a full demonstrator part made of recycled carbon fibre material. It also includes the collection of life cycle inventories (LCI) to quantify the environmental benefits by life cycle assessment (LCA).

Innovative test methodology for shelf-life extension of carbon fibre prepregs

Mr. Constance Amaré (Universite de Bordeaux), *Olivier Mantaux, Arnaud Gillet, Matthieu Pedros, Eric Lacoste*

The aerospace industry makes extensive use of composite materials in the form of fibre fabrics pre-impregnated with thermosetting resin, called prepregs. In order to minimize the resin polymerization before curing, prepregs must be stored at -18°C (0°F). A period close to 1 year is defined by the manufacturers, corresponding to the maximum storage time at -18°C (0°F) in a sealed bag. Although manufacturers try to minimize offcuts and time out of the freezer, it is estimated that 30 to 40% of the roll is not used (Pannkoke, Oethe, & Busse, 1998). Today, recertification of expired materials is still complex and expensive, therefore it is generally chosen to send them to landfill. The purpose of this work is to correlate physicochemical measurements with the loss of their mechanical performance. This work is carried out within the framework of the European project MANIFICA dealing with the recycling of carbon fibres. Processability, physicochemical and mechanical tests were performed in order to point out and measure the aging effects. This study was illustrated by testings on unidirectional Hexcel carbon/epoxy prepreg M21/34%/UD194/IMA-12K. Three different expiry dates of this material were studied and the properties were compared. It was shown that the main observed degradation was the processability of the prepreg while mechanical performance declines shortly after the expiry date. This study could lead to a simpler and more objective measurement of the actual expiry rate of prepregs, which could be useful to speed up recertification procedures or to propose new scenarios to extend the shelf-life of expired prepregs.

New Intelligent Semi-Products based on recycled carbon fibre

Ms. Alexandre Faure (Université de Bordeaux), *Olivier Mantaux, Arnaud Gillet, Gilles Cazaurang*

The carbon fibre recycling industry is not yet able to operate at full capacity. This lack of potential is a repercussion of the few semi-products containing recycled carbon fibres available on the market.

Moreover, only poor mechanical properties can be expected today from recycled carbon fibres composites. The MANIFICA project, based on steam thermolysis technology of carbon composite waste from the aeronautic industry, aims at producing new semi-products of highly-aligned recycled carbon fibres. In the first part we will introduce the I2M-Université de Bordeaux re-alignment process (MANIFICA project) able to produce continuous tapes containing long discontinuous fibres with a very good alignment. Benefits from this process are (i) to prevent any fibre breakage and guaranty 50 to 250 mm fibre length and (ii) to highly-align fibres (90% at ±10°). Therefore, composites based on these semi-products acquire high mechanical properties (stiffness and strength). In the second part, several semi products based on realigned-fibres tapes we will be presented. Appropriate manufacturing processes will be introduced and potential semi-structural applications will be proposed as a function of the semi-products. This will demonstrate that high performance products can be targeted with recycled carbon fibres, thanks to the development of these intelligent semi-products. We believe that the use of this competitve novel range of semi-products will enable to open new markets for recycled carbon fibres. Thus, it shall lead the carbon fibre recycling sector in reaching industrial maturity.

2D-material based devices for innovation in Aviation & Space: from modeling to experimental results

Session Chair : Prof. Patrizia Lamberti, University of Salerno, Italy & Dr. Polina Kuzhir, University of Eastern Finland, Finland

The effect of fabrication tolerances on the high-frequency performance of Graphene-Field Effect Transistors

Mrs. Monica La Mura (University of Salerno), *Patrizia Lamberti, Vincenzo Tucci*

High-frequency electronics has been historically driven by telecommunications and defense applications for aviation and aerospace. Electronic research for aeronautics includes the development of pushing-edge radiofrequency (RF) devices and circuits for high-frequency communications, such as antennas, transmitters and receivers, modulators and demodulators, filters, shields, power and signal amplifiers, mixers, oscillators. Despite the advances in CMOS-based RF circuits, unsolved issues related to losses and noise have determined the rise of III-V compound semiconductors technology. Devices based on III-V semiconductors such as GaAs, InP, and GaN, made great achievements in high-frequency applications, mainly thanks to the higher electron mobility of these compound materials. Nevertheless, their lower thermal conductivity limits the device density in comparison to CMOS technology-based ICs. Meanwhile, graphene has already proven to have extreme electron mobility and thermal conductivity, and the issues related to its zero-bandgap (that prevent graphene-based devices from turning off completely) are of secondary importance in analog RF electronics. In addition, RF circuits can take advantage of the ambipolarity of the GFET's current, which enables a strong reduction in the transistor count, favoring additional miniaturization capabilities. The inherent tolerance to radiation also makes graphene electronics interesting for the aerospace field. For these reasons, graphene is more promising than established technologies for the development of breakthrough electronics for RF applications. The RF performance of an amplifier can be assessed by computing several figures of merit. Voltage gain capabilities are strictly related to the amplifier's transconductance, gm, and output conductance, gds, which we presented in a previous work. To provide an important measure of the amplifier's high-frequency capabilities, depending on the applications, the cut-off frequency, fT, and the maximum oscillation frequency, fMAX, are usually computed. In particular, fT represents the maximum operating frequency to deliver a current gain, and fMAX represents the maximum frequency at which the amplifier is capable to deliver power and provide stable oscillations. In this work, we perform a tolerance analysis of a GFET Common-Source amplifier, originally proposed in [1] as the first high-frequency voltage amplifier obtained by using large-area CVD-grown graphene. The device performance is assessed by means of circuit simulations, designed according to a full factorial Design of Experiments, and performed using a large-signal charge-based compact model of a GFET described in [2]. The Advanced Design System® (Keysight Technologies, Inc.) simulation environment is used by varying channel width, W, the channel length, L, and the top oxide thickness, tox, in order to investigate the impact of geometry variations caused by fabrication process-related tolerances. Following the study presented in [3], where we discussed the impact of tolerances on the device gm and gds, the impact of the same variations is here reported on the high-frequency performance described in terms of fT and fMAX.

Electro-thermal modeling and characterization of Graphene Nano-Platelets films for de-icing applications

Prof. Antonio Maffucci (University of Cassino and Southern Lazio - Dep. DIEI), *F. Bertocchi, S. Chiodini, F. Cristiano, G. Giovinco, K. Lahbacha, S. Sibilia, G. Trezza*

This paper provides a study of the electro-thermal properties of commercial films, made by pressed Graphene Nano-Platelets (GNPs), in view of their use as heaters in an innovative de-icing system. The equivalent electrical resistivity and thermal conductivity are studied by means of models and experimental characterization.

Graphene-based analogue phase shifters for phased array antennas in aerospace/aeronautical applications

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Beamforming is a technique consisting of controlling the direction of the main lobe of a radiating system, e.g., an antenna array. The steering control can be done by changing the phase of the signal inputting each antenna, e.g., by the use of a phase shifter. This technique constitutes the basis of the so-called phased arrays and has recently received vast interest for 5G, radars, satellites and beyond communication systems due to the reduction in power consumption and overall improvement of the signal-to-noise ratio, among other advantages. However, the development of high-performing RF applications for aerospace and aeronautical applications is challenging due to the harsh operation conditions. In this regard, the last 2020 NASA Technology Taxonomy included into the taxonomy area "TX5.2 Radio Frequency" fields such as (i) the development of innovative RF technologies, (ii) the enhancement of the power-efficiency of communications and (iii) the design of innovative antennas. For such objectives, graphene is frequently proposed as a candidate due to its high radiation and corrosion resistance, temperature tolerance, flexibility and mainly because it results a promising material for high-frequency applications due to its intrinsic superior carrier mobility and ultra-high carrier saturation velocity. Taking all the aforementioned, we have explored the use of graphene-based devices such as graphene field-effect transistors (GFETs) and metal-insulator-graphene (MIG) varactors as building blocks for bias-controlled analogue phase shifters taking advantage of the possibility of tuning the graphene quantum capacitance thanks to graphene low density of states around the Dirac point. We have opted for designing the operating frequency within the S-band of the spectrum, which is used for aeronautical purposes.

On a new generation of sensors for Aerospace applications: optimization of preparation methodology and preliminary tests

Mr. M. Froio (Università degli Studi di Roma Tor Vergata, Dipartimento di Scienze e Tecnologie Chimiche), *F. Micciulla, A. Cataldo, C. Cencetti, R. Cossi, S. Bellucci*

In the previous work, we showed our preliminary studies on the alcoholic drinks as a new class of medium to exfoliate expanded graphite and disperse Graphene NanoPlatles(GNPS) into the solution. Following the paper of GEORGE H. REAZIN et al on extensive chemical analyses of stored whiskies in a charred oak barrel, we tried to identify some compound of these alcoholic solution which could support the exfoliation of graphite. We prepared a hydroalcoholic solution of these elements, and we performed the exfoliation. In order to obtain the optimum in terms of exfoliation and stabilization of the dispersion, a Design of Experiment was applied. The analyses showed a reduction of GNPs dimensions (lateral size and thickness) and a different homogeneity of suspension with this water - alcoholic solution and GNPs. We have found an acceptable rate of efficiency, figure 1.

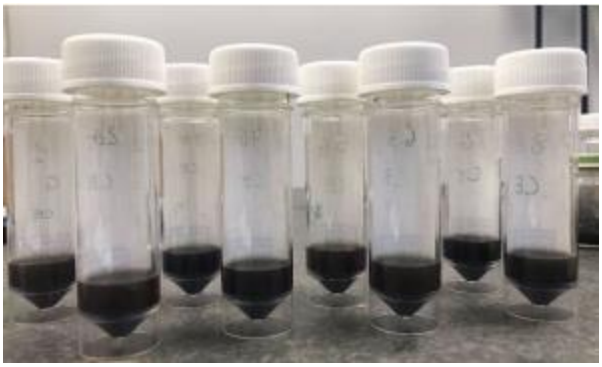

Figure 1: Homogenous GNPs dispersions

The Expanded graphite used in our studies is synthesized by means of exfoliation process into Next Group's Laboratory at Frascati National Laboratories – INFN. Following a low cost and green process which uses commercial intercalated graphite and very short time to expand the graphite, a quite small amount of residual material is detectable. We used a special istrument, PR-1 Nano - Premixer of THINKY Corporation, designed to highly reproduce the dispersion of nano-materials such as CNTs, while operating safely by keeping the sample in an enclosed container. The dual-sonic technology (patented) rotates the container at a high speed while ultrasound irradiates from the bottom and side of the ultrasonic bath. The rotation of the container at an angle of 45° causes convection in the materials, and thus ultrasonic irradiates the entire sample, figure 2.

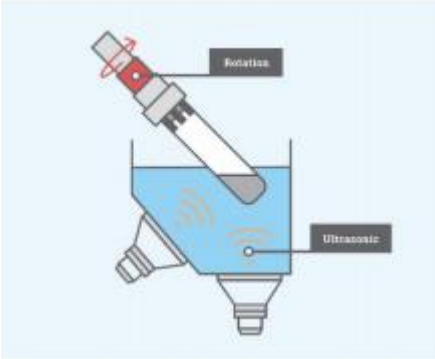

Figure 2: PR1 operating principle

Several experiments were done to determine the optimal hydroalcoholic solution composition for the exfoliation process, as demonstrated by Raman spectra.

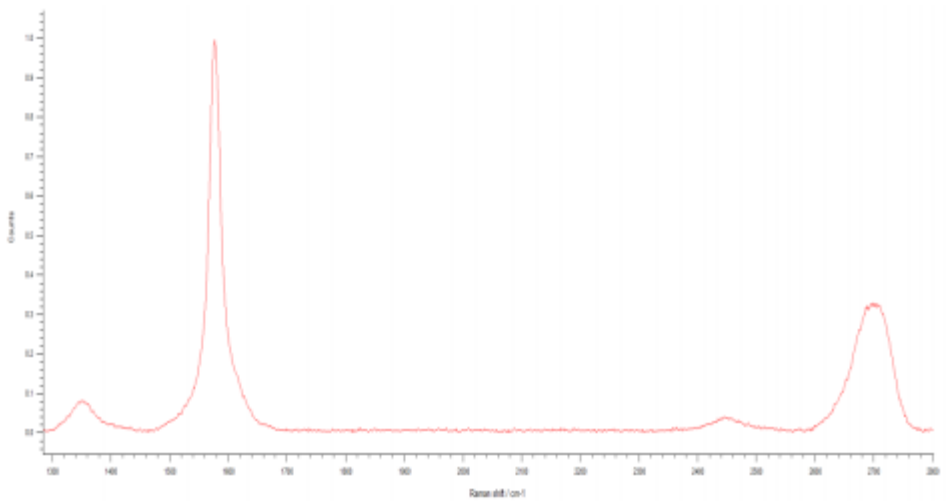

Figure 3: Raman Spectrum of GNPs

In figure 3, the spectrum shows that there is an average layer number of 3-4, and this can be deduced from the symmetry of the 2D peak at 2759 cm-1 . The peak at 1350 cm-1 is very small indicating that there are few structural defects in the geometry. The stability of the different suspensions was tested by the analytical centrifuge LUMiSizer which measures instantaneously the extinction of transmitted light across the full length of the samples using the STEPTechnology (Space and Time Extintion Profiles). The enhanced optical system of the LUMiSizer enables to detect particles and droplets velocity distributions for creaming and sedimentation phenomena and performs particle sizing (ISO 13318- 2). We were encouraged from the achieved results with GNPs, so we tried to exfoliate MoS2 using the same procedure and medium. We discovered that number of layers strongly depends on the time of sonication. GNPs'exfolation is less dependency from this parameter. It was possible to obtain 5- 6 layers of MoS2, after 90 minutes of sonication into PR-1. Figure 4.

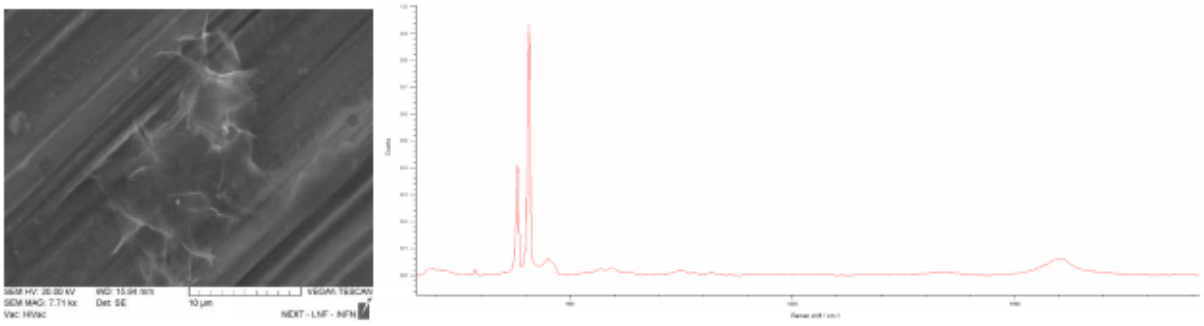

Figure 4: Scanning Electron Microscope Image and Raman Spectra of MoS_2

Using the material that we made by ultrasound sonication, we realized a humidity sensor. It is one of the most used devices for humidity monitoring, fundamental for comfort of the passengers during the flight. Nowadays the achievement of a comfortable environment in aircraft cabins is a factor of paramount importance in air travel business competition; on the other hand, the need of reducing the propulsion fuel cost has driven the airline companies to adopt air handling systems that may reduce the levels of thermal comfort and air quality inside the cabins of commercial airliners. The usually monitored parameters are temperature, relative humidity and carbon dioxide concentration. We dropped a GNPs suspension and a

MoS2 suspension on a mask of interdigital circuit and measured the impedance when the humidity changed, in the AC regime figure 6.

Figure 6: a picture of the interdigital circuit with GNPs and MoS2 on the top.

The preliminary measurements were encouraging: it was possible to see a change in impedance slope. This implies a change in the conductivity of the composite. It is a positive moisture detection mechanism which is interpreted through the Grotthuss' mechanism. It is very promising for future investigations: the humidity sensor can be further characterized, investigating different humidity percentages, defining response times, recovery times and other parameters.

Cubesat satellite patch antenna designed with 3D printable materials: a numerical analysis

Prof. Erika Pittella (Pegaso University), *Livio D'Alvia, Emanuele Piuzzi*

The aim of this work is to present a compact patch antenna system compatible with any CubeSat satellite structures designed using 3D printable materials. Nanosatellites are revolutionizing the space industry, enabling the access to the space with a significant reduction of costs for satellite industries and a shorter design development time with respect to large satellites. Moreover, using additive manufacturing it is possible to build customized system components, designing the inner part, also with complex geometry, without material wasting. Furthermore, 3D printing lets to go from production to consumption straight, having a great effect on the supply chain. Generally, CubeSats count on VHF/UHF communication systems with deployable monopole or dipole antennas for low bit-rate uplink and downlink. Instead, S-band is among the favourite choices for high bit rates, as the range 2400–2450 MHz is one of the international amateur satellite frequency ranges allocated by the International Telecommunication Union (ITU). An S-band printed patch antenna system is designed in this paper, considering the overall size (10×10 cm2) and weight constraints imposed by the CubeSat standard[49]. The antenna system is simulated with Microwave Studio (MWS) by Computer Simulation Technology (CST), using as substrate the polylactic acid, or polylactide (PLA), a thermoplastic polyester, a widely used plastic filament material in 3D printing. PLA is produced from renewable resources making it biodegradable and recyclable. Moreover, this material has dielectric properties similar to conventional material used to manufacture microwave components, with the great advantages deriving from 3D printing. For this preliminary study, a reconfigurable antenna system operating at 2450 MHz is considered. In particular, it consists of rectangular patches that, properly excited, allow to achieve different radiation pattern shapes. This characteristic makes this type of antenna useful for a wide range of different applications, satisfying requirements related to a mission with a single design[50]. First, considering the geometrical constraints, a rectangular patch geometry is simulated within the CAD considering PLA as substrate material. With such a substrate, the dimensions of a single patch

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have been computed first analytically, and then they have been optimized with MWS to achieve the best matching (S11 < -10 dB@ at 2450 MHz). Then, in a second phase, four identical patches are simulated, changing the phase of the feeding signals achieving different radiation patterns and different polarization of the antenna. As future development, using the PLA filament (Filoalfa©) for the substrate and conductive filaments[51] [52] for the metallic part, the antenna system prototype will be manufactured and tested using a 3D printer, as for example the Raise3D Pro2 dual extruder printer[53].

[51] https://www.multi3dllc.com

[52] Y. Xie, S. Ye, C. Reyes, P. Sithikong, B.-I. Popa, B. J. Wiley, S.A. Cummer, "Microwave Metamaterials Made by Fused Deposition 3D Printing of a Highly Conductive Copper-Based Filament", Applied Physics Letters, May 1, 2017.

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Role of Graphene-based Nanoparticles on the Resistance of Aeronautical Epoxy Coatings to Sunlight and Corrosion

Prof. Marialuigia Raimondo (University of Salerno), *Vito Speranza, Roberto Pantani, Carlo Naddeo, Liberata Guadagno*

Recently, the effectiveness of graphene nanoplatelets (GNPs), dispersed in low quantity in a waterborne epoxy resin, in enhancing the coating anticorrosive properties and strongly contrasting its photooxidative degradation has been demonstrated [1-2]. It is well known that epoxy-based coatings are vulnerable to ultraviolet (UV) damage and their durability can be greatly decreased in outdoor environments. In this work, we aim to focus on the exceptional ability of GNPs incorporated in the epoxy films, at different weight percentages, in increasing the photooxidative resistance of polymeric films, thus consequently determining a strong decrease of the mechanical damages caused by UV irradiation. The effects of UV light on the morphology and mechanical properties of the solidified nanofilled epoxy films are investigated by Atomic Force Microscopy (AFM), in the acquisition mode "HarmoniX". This work highlights the possibility of extending traditional AFM imaging with a technique, which is sensitive to the punctual changes in the mechanical properties of the surface film, providing information on the heterogeneity of multiphase polymeric systems. The polyharmonic response varies with modifying local mechanical properties. It is worth noting that, by coupling the AFM phase maps with the AFM modulus maps, morphologies and distribution of crystalline aggregates (for both unfilled and GNP filled samples) can be simply identified. In this work, in order to supply pertinent information on the local changes caused by the photooxidative degradation, a comparison of the material properties on located regions, before and after UV irradiation, is shown. In particular, AFM microscopy, in the acquisition mode "HarmoniX", has allowed studying both qualitative and quantitative nanometric-resolved maps of the mechanical properties, highlighting that the incorporation of low percentages, between 0.1 and 1.0 wt%, of graphene nanoplatelets (GNPs) in the polymeric film causes a significant increase in the mechanical stability of the irradiated films. The advantageous effect increases progressively as the GNP percentage increases. In particular, films (30 ± 1.5 µm thick) unloaded and loaded with GNPs have been subjected to accelerated photo-oxidative degradation by exposing them to 550 hours of UV irradiance, reproducing the ultraviolet (295–380 nm) component of solar radiation at the earth surface. Films without GNPs have proven to be very sensitive to UV treatment. Figure 1 shows for the sample 1GNPs (550): (a) the AFM phase map image; (b) the AFM image of the DMT modulus map and (c) the profile of the value of the elastic modulus. For this sample, as expected, the profile of the value of the elastic modulus is more uniform with respect to that detected for the sample 0GNP. In this case, the effect of the UV irradiation does not cause a decrease in the elastic modulus. It seems that, a slight increase is detected on the region characterized by higher values in modulus. This is most likely due to the effect of UV irradiation on the thin layer of polymer matrix covering the nanoparticles. The UV irradiation consumes part of the polymer on the GNP nanoparticles; it cannot penetrate beneath them, preventing the polymer matrix from further damages.

Development of Epoxy Resin Composites with De-Icing Properties

Mr. Luigi Vertuccio (University of Salerno), *Fabiana Foglia, Roberto Pantani, Liberata Guadagno*

The use of epoxy resin-based composites began in the last century with the first applications in the field of aeronautical, mechanical and naval engineering. Recently, the remarkable properties of these materials, and the decrease of the production cost, are also advantageously exploited in the restoration and structural adaptation of reinforced concrete elements or in masonry. Carbon Fibers Reinforced Polymers (CFRPs) have been employed in civil engineering for the realization of assembled structures, such as bridges and footbridges, offshore structures, and the construction of experimental buildings. This paper focuses on the design of structural resins which can be easily activated for the anti/deicing function. In particular, the efficiency of the Joule effect in the heating of nanomaterials has been analysed for three different types of nanocomposites containing incorporated MWCNTs and two different grades of expanded graphite. These nanomaterials can be used for the impregnation of GFRPs or CFRPs or in the form of coating. The employed graphites strongly differ among them on the aspect ratio. The performed tests highlight that this last parameter significantly affects the achieved value of temperature for higher values of applied power. The resin containing MWCNTs has proven to be the best performing system both in terms of applied voltages and maximum temperature achieved by the sample. Expanded graphites, instead, can be advantageously applied to maintain low the viscosity of the nanomaterials during the processing stages.

Aircraft De-Icing Strategies based on Recent Developments in the Nanotechnology Field

Mrs. Fabiana Foglia (University of Salerno), *R. Pantani, I. Guadagno, L. Vertuccio*

Ice formation/growth on the leading edge of aircraft wings is to be avoided because it negatively affects flying safety and greenhouse gas emissions in the earth's atmosphere. Ice on aircraft surfaces modifies the smooth flow of air, decreasing lift, increasing the mechanical resistance determined by the contact of the aircraft with the air and determining a decrease in the stability. Current strategies to avoid ice formation and its growth are based on the use of hot air from engines or sprayable chemicals In recent years the employment of electro-thermal devices has been received more attention[54] [55] [56]. In this work, it is proposed an innovative method to perform the de-icing, by the use of an electro-thermal film heater. The film heater is produced by a green film-casting process using a biodegradable polymer as a matrix, loaded with two different types of commercially available expanded graphite. This film heater is 200 microns thick; this allows it to be directly placed between the plies of the composite material. Thanks to the addition of high percentages of filler, the films are electrically conductive, so the Joule effect has been exploited for the de-icing. The heating tests indicate the feasibility of this strategy. High efficiencies in the de-icing performance are obtained by applying low voltages in the range of 0-10 V, considering the capability of the onboard battery. Furthermore, it is found that the aspect ratio influences the heating performance. Specifically, a higher value in the expansion of the graphite nanoplatelets allows for obtaining better performance in the heating efficiency.

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The role of POSS symmetry in polymer matrix dispersion

Mr. Ignazio Blanco (University of Catania "Luigi Vanvitelli"), *Francesco Agatino Bottino*

Despite their first discovery, dated 1946, the use of polyhedral oligomeric silsesquioxanes (POSSs) as reinforcement for polymeric material has taken hold starting from '80. Their characteristics, a nano-sized cage structures, linked with their hybrid (inorganic–organic) nature allow the modification of these molecules according to the particular needs of the host polymer. By combining the low weight and processability of traditional polymers with the property enhancements derived by the inclusion of POSS molecules the resultant nanocomposite can act as self-passivating/self-healing membranes that will dramatically increase the lifetime of orbiting bodies. POSSs may be considered as a nano form of silica, and in their most common form they are comprised of a cubic cage of eight silicon corner atoms and twelve oxygen edge atoms (Figure 1), where each of the eight silicon atoms may carry one of an extremely wide range of functional groups (R), generating hundreds of possible compounds. The aim of this work was to design different POSS structure by changing some of the corner groups and investigate if and how much the symmetry/asymmetry of the POSS structure influences the dispersion in the polymer matric and thus affect the thermal and mechanical properties of the obtained nanocomposites.

Biocompatible hybrid materials synthesized via sol-gel for aerospace applications

Prof. Michelina Catauro (University of Campania "Luigi Vanvitelli"), *Flavia Bollino, Ferdinando Papale*

The health of astronauts, during space flight, is threatened by bone loss induced by microgravity, mainly attributed to an imbalance in the bone remodeling process. In the present work, the response to the microgravity of bone cells has been studied using the SAOS-2 cell line grown under the condition of weightlessness, simulated by means of a Random Positioning Machine (RPM). Cell viability after 72 h of rotation has been evaluated by means of WST-8 assay and compared to that of control cells. Although no significant difference between the two cell groups has been observed in terms of viability, F-actin staining showed that microgravity environment induces cell apoptosis and altered F-actin organization. To investigate the possibility of hindering the trend of the cells towards the death, after 72 h of rotation the cells have been seeded onto biocompatible ZrO2/PCL hybrid coatings, previously obtained using a sol-gel dip coating procedure. WST-8 assay, carried out after 24 h, showed that the materials are able to inhibit the pro-apoptotic effect of microgravity on cells.

Innovative self-responsive composites for aeronautical applications through Sol-Gel chemistry

Mr. Aurelio Bifulco (Università degli Studi di Napoli Federico II)*, Jessica Passaro, Claudio Imparato, Francesco Branda, Antonio Aronne*

Sol-Gel chemistry is a "bottom-up" synthesis route that starting from simple molecules allows to obtain films, particles (also nano), fibers, gels and bulk materials both glassy than crystalline. Silicatic materials are generally obtained from the following Si precursors: tetramethoxysilane (TMOS) or tetraethoxysilane (TEOS). The chemistry is based on the very well-known hydrolysis and polycondensation reactions. In alkaline environment monodisperse silica particles may be easily obtained with sizes from a few nanometers till micron ("Stöber" method). The above reminded reactions occur at room temperature allowing matching their formation with polymer chemistry. In the "in situ" strategy, nanoparticles are produced in the presence of a monomer before polymerization is promoted. In this communication a series of innovative self-responsive materials for aeronautical applications produced by the research group using the Sol-Gel chemistry will be shown.

Stöber particles were used to produce innovative sound absorbers through an eco-friendly electrospinning process, using suspension of Stöber particles in ethanol solutions of polyvinylpirrolidone, PVP[57]. The process allowed to produce sound absorbers with reduced thickness and excellent sound-absorption properties in the low and medium frequency range (250–1600 Hz) for which human sensitivity is high and traditional materials struggle to match (see Fig. 2), that also pass the fire tests which are mandatory in many engineering areas. The mats were composed of PVP and Stöber silica particles (see Fig. 3). The high density of surface silanols groups of Stöber particles assured high compatibility with PVP. The Stöber particles were decisive to dimensionally stabilize the mats upon thermal treatments that conferred water resistance while determining the self-extinguishing property of the material. Silica-epoxy nanocomposites were obtained through polymerization of "in situ" generated silica charged Bisphenol A diglycidyl ether (DGEBA) with the aid of a cycloaliphatic hardener, more ecofriendly but with much greater problems of flammability of the final product with respect to usual aromatic hardeners[58] [59] [60]. Transparent composites with a very fine distribution of silica particles were obtained (see Figs. 4 and 5). UL 94-V0 rating was successfully achieved (self-extinguishing behavior) through addition of DOPO-based flame-retardants and melamine. The presence of finely dispersed silica (only 2 wt%) proved to be crucial to assure no melt dripping. As it is known recently natural fiber-reinforced polymer composites exhibited a significant interest growth as far as fundamental research and their industrial applications are considered, because being not expensive, fully or partially recyclable and also biodegradable. Sol-Gel chemistry of inexpensive waterglass solutions was exploited[61] as a new, simple and ecofriendly chemical approach for promoting the formation of a silica-based coating on hemp fabrics able to act as a thermal shield and to protect the latter from heat sources (see Fig. 6). When combining hemp surface treatment and Ammonium Polyphosphate (APP) addition (15 wt%) to epoxy, a remarkable decrease of the Heat Release Rate (HRR), Total Heat Release (THR), Total Smoke Release (TSR) and Specific Extinction Area (SEA) (respectively by 83%, 35%, 45% and 44%) as compared to untreated hemp/epoxy composites was recorded. The coating overcame "washing tests" thanks to the formation of –C–O–Si– covalent bonds with the cellulosic substrate so as proved though Fourier Transform Infrared (FTIR) and solid-state Nuclear Magnetic Resonance (NMR). With the aid of the so many silanes available on the market the silica coating may also allow easy functionalization for the tailoring of the interface. Finally nanostructured wrinkled silica colloidal particles may be obtained when hydrolysis and polycondensation of TEOS is performed in emulsion cyclohexane/aqueous solution of urea and cetylpyridinium bromide (CPB) in the presence of iso-

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propanol (see Fig. 7)[62]. A biomimicking hierarchically structured coating upon a surface may be obtained by depositing Janus nano-structured wrinkled colloidal particles (see Fig. 8). The morphology of the surface is thus ruled by different scales: the size of the wrinkles (few tens of nanometer), particle radius (several hundreds of nanometers) and interparticle distance. A glass microscope slide was covered by drop casting the particles, obtaining super-hydrophobic features of the surface characterized by a high-water contact angle (149°) and, more interestingly, by a very low water contact angle hysteresis (CAH = 2°) and roll-off angle (ROA = 1.8°). Finally, Sol-Gel chemistry proved to be important in the production of innovative materials for relevant aeronautical applications like sound absorbers and hydrophobic (possibly self-anti-icing) materials. Sol-Gel chemistry proved to play an outstanding role in improving fire behavior and obtaining self-extinguishing composites and biocomposites. As it is well known this is a relevant issue determining the applicability of a material particularly in the transport industries.

Design of self-responsive composites for aeronautical applications (PART II)

Session Chair Prof. Liberata Guadagno & Prof. Roberto Pantani, University of Salerno, Italy

Multifunctionality of supramolecular self-healing aeronautical nanocomposites

Mrs. Elisa Calabrese (University of Salerno), *Marialuigia Raimondo, Liberata Guadagno*

All materials are sensitive to damages. In the case of structural polymers, this usually makes the material unusable. The real challenge in the field of composite materials, suitably designed for structural applications (aircrafts, ships, wind turbine blades, automotive, etc.), consists in achieving specific targets such as: 1) weight reduction - to maximize the performance; 2) control of pollution during the manufacturing process of the materials and their use in service; 3) low consumption of fuel and resources; 4) reduction of the manufacturing and operating costs. Various criticalities, such as the absence of electrical and thermal conductivities and the poor impact damage resistance, severely limit the use of thermosetting resins for aeronautical applications, thus compromising their structural stability over time. An important step forward to contribute to the spread of use of structural composites can be reached by designing smart materials having autonomous damage-repair functionality and other specific functions integrated in the material structures. Commonly, self-healing polymeric materials can be divided into two different groups based on the approach chosen to impart self-healing functionality to the polymer. Based on this classification intrinsic or extrinsic systems can be developed. Extrinsic systems are often based on the microencapsulation concept. Recent extrinsic systems involve the use of a ruthenium initiator for Ring-Opening Metathesis Polymerization (ROMP), characterized by high thermal and chemical stability, able to preserve its own catalytic action in a very reactive[63] [64].

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A very promising way to develop an intrinsic healing system is based on the supramolecular chemistry[65], which has a great influence on the overall mechanical properties of the final material. Usually, the supramolecular systems are characterized by repeatable and autonomous self-healing capability, but they have been developed for applications where no high mechanical performance of load-bearing materials is required. Supramolecular self-healing systems include dynamic covalent bonds and non-covalent interactions. In order to develop structural composites, which guarantee high mechanical performance and multifunctional properties, hybrid materials or nanomaterials have been functionalized with hydrogen bonding moieties able to activate supramolecular self-healing mechanisms and introduce additional functionalities[66] [67] [68] [69]. This work proposes an interesting strategy based on supramolecular chemistry with the aim of creating self-healing multifunctional materials for structural application in aeronautics and other fields, where high mechanical performance is required (Figure 1). In particular, the authors propose the use of molecules employed as self-healing fillers, having functional groups able to act both as hydrogen bonding donors and acceptors, to add into a toughened epoxy resin in combination with pristine Multiwall Carbon Nanotubes (MWCNTs) aimed at activating self-healing mechanisms and simultaneously conferring electrical conductivity to the resulting nanocomposites. **Acknowledgements:** This research has been funded with support from the European Union (Horizon 2020–G.A. EU Project 760940-MASTRO).

Self-Healing Certification Challenge for Advanced Structures in Aeronautics

Mr. Raffaele Longo (University of Salerno), *Giuseppina Barra, Liberata Guadagno*

Innovation and continuous development of cutting-edge materials find robust interest of companies for using avantgarde technologies. Material research is widening toward mainly two directions: the improvement of the existing functionalities and the development of new functionalities of the materials. However, widespread applicability of materials with new functionalities and their marketing requires also efforts towards the creation and implementation of technical standards and measurement techniques. Standardization is an important stage in the development of any new material and it is based on the consensus of stakeholders including end users, businesses, standards organizations and governments. The main function of standards is to define the qualities and technical properties of a material to ensure consistency across different manufacturers and industries. It is important to assure that a product is genuine, safe and will perform in the way it is expected. For new materials standardization will also enable easier communication between producers and consumers.

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In this context, the current paper shows the activities performed within MASTRO Project – H2020, focusing on the possible strategies to reach the standardization of innovative materials in aeronautic field. In MASTRO Project self-healing, de-icing, self-sensing and self-curing materials, obtained using nanocomposite technologies, have been widely studied and tested to understand their usability in a significant environment. The purpose of the standardization activity in MASTRO project is to explore the possibility of transferring the results of research into one or more standards. The first step is to understand the research results which have not necessarily a need to be transposed into standards, and those that potentially will provide valuable support to new or existing standards through, for example, the validation of test methods or product and /or process. The second part of this activity was the identification of needs and opportunities for standardization in the eventuality partners have developed specific procedure or protocols to overcome particular issues, which were not reported in literature. Generally, in this process, the applicability of the possible standard to other bodies (research groups both academic and from industries) was considered. The use of some innovative functionalities developed in MASTRO project, such as those related to self-healing materials, has not been yet regulated with any of the available standards. For these materials, standardization needs and opportunities have been identified in order to enable their widespread use. The preparation of a New Work Item Proposal on this kind of functionalities (with all relevant documentation that can help for the procedure) is in progress. Figure 1 shows the followed approach and the applied strategy to rationalize data regarding available standard, standard needs and opportunities of the developed materials for the evaluation of possible Standardization Processes. The used algorithm for the rationalization of the information is based on the readiness level of the technology and on the relevance to improve the safety of the material.

Thermal profiling of self-healing process simulating flight conditions. A solid-state NMR study.

Mr. Savvas Orfanidis (NCSR Demokritos), *M. Raimondo, L. Guadagno, A.S. Paipetis, M. Fardis, G. Papavasilliou*

The self-healing polymer composites have gained increasing research interest over the past several decades and the technological interest of the most demanding industries such as aerospace, automotive and ship building industries. This study focused on the development of a thermal scanning of the self-healing progress in order to determine the thermal behavior of the self-healing agent during the thermal fatigue of a flight. The examined structure of this scenario is a protective coating (Aerowave 3003 epoxy primer) with dispersed self-healing microcapsules and catalyst Curing Solution 6007. The enclosure of the self-healing microcapsules is a mixture of an epoxy part, a diluent and a chromophore (DGEBA+ BDE+ Solvent Red 242). Our approach is to mapping the polymerization reactions during the self-healing process in real time the T2 relaxation time simulating the thermal cycles and visualizing the results in polymerization heat maps and observe the activation temperature of the self-healing process, evaluate the end of polymerization after the thermal fatigue and finally simulate the thermal path of a flight and compare the polymerization time of a static temperature scanning versus the thermal cycle. The self-healing system was tested in different temperatures (-50oC to 60oC), those temperatures were chosen due to operation environment of aerospace applications in order to understand the behavior of the self-healing process.

Self-healing composites material via hydrogen bonding interactions

Ms. Annaluisa Mariconda (University of Basilicata), *Russo Simona, Calabrese Elisa, Raimondo Marialuigia, Guadagno Liberata, Longo Pasquale*

The development of self-healing composites materials for structural applications[70] [71] offers considerable benefits: maintenance costs reduction and overcoming difficulties connected to damage diagnosis and repair. Depending on the self-repair mechanism, they are classified into two types: extrinsic self-healing and intrinsic self-healing. They involve covalent bonds, weak non-covalent interactions or a combination of both, based on reversible mechanism. Even when the materials seem to be at rest, a large number of covalent and/or non-covalent bonds are forming and breaking in dynamic equilibrium state. Thus, the self-healing process can be very efficient because much interaction may combine[72]. Our research group is studying the possibility to have composite materials with efficient self-healing ability through hydrogen-bonding interactions. The copolymer poly(PEGMA-co-UPy)[73], with various percentages of PEGMA and HEMA-Upy, can be blended with epoxy resins, for applications in the aeronautical field. This copolymer poly (PEGMA-co-UPy) confers self-healing properties to the resulting composite materials, thanks to the reversibility of hydrogen bond interactions among the polymer chains.

Multi-material design & function integration of advanced sensors & actuators in composites

Session Chair : Dr. Angelos Filippatos, TU Dresden, Germany

A digital-based design methodology for the optimization of high-performance multi-material structures

Mr. Willi Werner Zschiebsch (HTWK Leipzig), *Angelos Filippatos, Robert Böhm*

A central process in composite lightweight engineering is the design of different fibre-reinforced parts. Some sub-processes such as the construction and numerical failure analysis as well as certain parts of the design process itself can be significantly improved using modern software tools. This often means that a compromise between optimization and increasing development costs must be found in order to balance structural complexity, number of design iteration loops and subsequent changes in the requirements. We introduce a computer-driven automation process for a multi-domain, parameter-driven design optimization. The proposed concept was built around the idea that the methodology can be used with different software tools that are already in operation in the design process of lightweight structures and therefore allows an easy implementation in already existing development chains. The developed process was successfully applied to different design scenarios, for example for designing GFRP rotors with respect to their structural dynamics performance. The results show promising time savings during the design phase and allow to quickly adapt the design to subsequent changes in the optimization goal.

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Intrinsic interfaces between additively manufactured metal and composite structures for use in electric propulsion engines

Mr. Martin Pohl (ILK, TU Dresden), *Richard Grothe, Sebastian Spitzer, Christian Weidermann, Maik Gude*

For electric aviation drive systems engines with significantly increased power density are required. Combining the technologies of additive manufacturing of metals with the technologies of fiber reinforced composites enables hybrid structures with same or increased functionality and lower mass. Rotors or housings in hybrid design have interfaces to adjacent structures are classically made of metal. Areas for remote load transmission or with increasing distance to the rotation axis are made of fiber composite. The interfaces between the two materials required for such a hybrid metal-fiber composite design can be specifically adjusted to the functions to be fulfilled, the resulting loads and the induced stresses by using the increased degrees of freedom of additive and composite manufacturing. However, the large number of degrees of freedom of the material and the geometry leads to great challenges for engineers in the development of such structures. Within the scope of this publication, an approach for the function-oriented design of a metal-fiber composite rotor for an aviation electric motor is proposed (global design). A design and pre-dimensioning method for the intrinsic interface between the materials is presented (local design).

Geometric features of carbon-based nanomaterials for advanced sensing in composites

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Electrically conductive polymer-based nanocomposites have been widely exploited owing to their potential in several demanding applications. Advanced sensing applications are emerging both on flexible substrates for the prediction, detection and monitoring of human body motions, and on carbon fibre reinforced polymer (CFRP) composites for the monitoring of infrastructure damage and structural health. Since percolating networks that can be formed by surrounding carbon fibres with carbon nanomaterials, are susceptible to sense external mechanical stimuli, reduced graphene oxide (rGO) or carbon nanofibers (CNFs) were investigated in this work, as promising in-situ strain sensors. The piezoresistive behavior of epoxy-based nanocomposites was monitored by measuring the electrical resistance change during quasi-static tensile experiments. A different response was systematically observed for nanoreinforcements having different geometric features, e. g. one-dimensional tubular CNFs and two-dimensional layered rGO. The DC electrical resistance of nanocomposites containing rGO increases monotonically until the ultimate failure (Figure 1a). On the other hand, in CNFs nanocomposites the electrical resistance increases until a certain strain, followed by an increase of conductivity promoted by the formation of alternative conductive networks through the connection of neighboring CNFs (Figure 1b). This study also showed that these nanocomposites are potential materials for the manufacturing of CFRP composites with both tunable sensitivity and strain range.

Air Traffic Management (ATM) & Airports (PART I)

Session Chair : Prof. Octavian Thor Pleter, University Politehnica of Bucharest, Romania

Analysis of vulnerability of ATM to weather phenomena

Dr. Vittorio Di Vito (CIRA), *Edoardo Bucchignani, Roberto Valentino Montaquila, Giovanni Cerasuolo, Myriam Montesarchio, Alessandra Lucia Zollo, Davide Cinquegrana*

Weather conditions and Air Traffic Management (ATM) operations are strongly related, due to the relevant influence that the observed and forecasted weather conditions into assigned airspace have on the operational conditions that are therefore possible for such airspace. In the framework of the SESAR JU funded project CREATE (Innovative operations and climate and weather models to improve ATM resilience and reduce impacts), therefore, a dedicated study has been carried out in order to investigate the relation between weather and ATM. Such study both investigated the consequences that adverse weather conditions can have on ATM and, on the other side, addressed the currently and future available tools that can support ATM in the prediction and management of weather conditions from the aeronautical operations point of view. In this paper, the results of such literature study are outlined. More in details, in the paper first the main outcomes of the study are summarized, in terms of identification of the most relevant weather phenomena that affect the ATM operations, indication of their main impacts on them in terms of operational disruptions and, finally, identification of the associated level of severity. In particular, the above indicated aspects are addressed by taking into specific consideration the enroute and the TMA (Terminal Maneuvering Area) flight phases and, for each of them, the main affecting weather phenomena and the main affected operations are identified. Then, in the paper the results of the study are summarized about the identification of the most relevant meteo tools that are expressed by state-of-the-art technologies to support the ATM operations in order to properly take into account the weather conditions in a precise and timely manner. This study addresses both the review of available and perspective tools for weather reporting and of the available and perspective numerical models supporting ATM in terms of weather models and air quality models.

Machine Learning classification techniques applied to static air traffic conflict detection

Dr. Javier Pérez-Castán (Universidad Politécnica de Madrid), *Tomislav Radisic, Thomas Feuerle, J. Bowen-Varela, L. Pérez-Sanz, L. Serrano-Mira*

This article evaluates the application of Machine Learning (ML) classification techniques applied to air-traffic conflict detection. The methodology develops a static approach in which the conflict detection prediction is performed when an aircraft pierces into the airspace. Conflict detection does not evaluate separation infringements but a Situation of Interest (SI). An aircraft pair constitutes an SI when is expected to cross with a longitudinal separation lower than 10 Nautical Miles (NM) and a vertical separation lower than 1000 feet (ft). Therefore, the ML predictor classifies aircraft pairs between SI or No SI pairs. Air traffic information is extracted from OpenSky that provides ADS-B trajectories. ADS-B trajectories do not offer enough situations to be evaluated. Hence, the authors performed simulations varying the entry time of the trajectories to the airspace within the same time period. The methodology was applied to a portion of Switzerland airspace, and simulations provided a 5% rate of SI samples. Cost-sensitive techniques were used to handle the strong imbalance of the database. Two experiments were performed: the Pure model considered the whole database, and the Hybrid model considered aircraft pairs that intersect longitudinally lower than 20 NM and vertically lower than 1000 ft. The Hybrid model provided the best

results achieving 72% recall, representing the success rate of Missed alerts and 82% accuracy, which means the whole predictions' success rate.

Drone safe-landing with real-time route optimization

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Current UAV technology has led to an exponential growth in the potential applications of drones in both the military and the civilian fields. Therefore, drone missions must be subject to regulations that ensure safety in operations, especially in Urban Air Mobility tasks. Nevertheless, unpredictable conditions may lead drones to dangerous routes, e.g. flying over assemblies of people. To address this issue, we propose a technological solution to give a drone the ability to detect people and/or crowds in the territory below it, and, consequently, to automatically re-route itself to avoid people. To minimize the risk of impact with people during an emergency landing, this process is carried out in real-time by moving the drone to a safe area as quickly as possible. The proposed technological solution is based on the interplay of a number of software components that run on the drone and are interfaced with a minimal number of sensors. Components are loosely coupled and communicate through a publish/subscribe messaging pattern. Starting from an initial flight-plan optimized on the ground station in accordance with the mission objectives, the flying drone continuously acquires images and telemetry from its sensors. This information is then filtered by a decision module so that the most relevant images are geo-referenced and fed into a detection module based on a lightweight deep neural network for people detection. The output of the detection module is a set of geo-referenced bounding boxes that are further used by an optimization algorithm to define a new set of waypoints that re-route the drone to a safe location. Preliminary results in simulated environments showed that the proposed solution for route optimization is promising both in terms of effectiveness and efficiency, so that it could be applied to Mini/Micro UAVs with medium-sized computational capabilities.

Safety Performance Functions to predict Separation Minima Infringements in en-route airspace

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1. **Introduction:** One of the challenges facing Europe is to achieve an effective, intelligent, sustainable and safe air transport system. Among the areas of greatest concern to the aviation industry today, particularly due to the expected growth in traffic and the depletion of the current ATM system, is the occurrence of loss of separation between aircraft in airspace, which could lead to a specific category of accidents: Mid Air Collisions (MAC). This is the origin of the FARO project, saFety And Resilience guidelines for aviatiOn, funded by the European Union in the SESAR 2020 programme, which addresses the development of predictive safety models to assess the impact of new automation solutions on safety and resilience.
2. **Discussion:** The aim of this project is to establish a systematic framework for characterizing the safety of air routes, in terms of loss of separation between aircraft, based on the definition of models known as Safety Performance Functions (SPF). These must be adapted to the particularities of the airspace, as well as considering the intrinsic characteristics of this airspace, such as the routes and sectors

involved, aircraft traffic and its evolution, and airspace management. Such models, once developed, calibrated and validated, could be extended to other key performance areas in air traffic management, such as capacity, efficiency, etc.

The proposed methodology aims to derive a model capable of characterizing and predicting the occurrence of Separation Minima Infringements (SMI) between en-route aircraft. Techniques with high predictive capacity have been chosen, which allow integrating knowledge modeling with data inference, and which have proven useful for estimating low probability events: Bayesian Networks (BN). Developing a Bayesian Network model for a problem as complex as the prediction of SMIs is not easy. It has been necessary to establish a conceptual framework that integrates the current knowledge available on the causality and precursors of SMIs with the hindsight derived from the analysis of the type of data available in the project, in particular those that reflect the ATCO interventions. The conceptual framework that supports the proposed BN model considers the general scenario of aircraft evolution and focuses on the analysis of the Closest Point of Approach (CPA), for any possible pair of aircraft in an air traffic sector, and on the understanding and quantification of the process that leads to said CPA.

To translate the conceptual framework into a set of causal subnetworks, the concepts of the ATM barrier model and event trees are incorporated. The ATM barrier model explicitly presents the progression of the incident and can be used as a "live" model to prevent future breaches of separation or to intervene in an incident to stop its development.

The principles of event tree analysis are employed to effectively translate this barrier model into a causal network representation. The event tree provides a top-down logic modeling technique for success and failure that explores responses through a single initiating event. It establishes a way to evaluate the probabilities of results and the general analysis of the system. Therefore, the aircraft control process is divided into different stages in which the safety barriers are identified and each of them is modeled using a Bayesian Network.

3. **Conclusion:** The model developed gathers analytics and insights, as well as predictive capability, to answer how Airspace Separation Infringement are produced and which will be their frequency of occurrence. The main outputs of the network are a) the predicted probability of success for the ATM barriers; for example, the probability of interaction between aircraft, probability of potential conflict, probability of detection of the conflict, probability of resolution of the conflict, etc..; and b) the predicted probability distribution of the aircraft's vertical and horizontal separation at its CPAs. The global network allows for forward and backward analysis. Thus, with this calculation capacity, the network allows conclusions to be drawn about the impact that a modification in the airspace and traffic or operational conditions would have on the effectiveness of the barriers and on the final distance distributions between aircraft in the CPA, thus estimating the probability of SMI.

Dynamic sector characterisation model with the application of machine learning techniques

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1. **Introduction:** The complexity of an airspace volume is understood to be related to the workload it generates in the ATC segment when providing service. At present, different models have been proposed to measure complexity, without reaching a standard proposal. Different SESAR and Eurocontrol programs and projects are working on models to determine the complexity of the

airspace. Faced with this situation, FLUJOS II project, a collaboration between UPM, CRIDA and Enaire, has arisen with the aim of proposing a methodology that allows evaluating the complexity of airspace sectors based on the behaviour of the flows contained in them. The implementation of this model in the control service will make it possible to anticipate events and to better allocate resources. This model will therefore improve the organisation of the airspace in order to adapt it to air traffic flow conditions.

2. **Discussion:** In order to be able to characterise air traffic sectors, an estimation model is proposed to determine the impact of traffic flows on ATC service. This impact is defined as a function of flows traffic density, temporal distribution, vertical density, regulations and geographic complexity. Subsequently, the sector complexity is assessed on the basis of the behaviour of the flows with the greatest impact on the sector. The process has two components: First, it is analysed from an operational point of view which parameters allow to characterise a flow. Once identified, the impact variable is constructed from these parameters. This variable will have five categories in which to classify flows, according to its average value and variability. Once this point is reached, based on quantity of flows and their impact, the sector complexity variable is defined, with another five levels for its characterisation. The proposed methodology includes a continuous process of refinement and feedback, through the application of Machine Learning models. These models will review the relative importance of parameters in the learning process and in the impact and complexity variables definition process. In addition, Machine Learning algorithms will be applied to the review of the defined categories. This process will allow to establish a process of continuous learning from the data, so that the operational model and the experimental data adapt to each other. The final methodology will emerge from the convergence of this iterative process between the Machine Learning model and the operational model. Therefore, based on the expected demand for an operational period, the complexity of the ATC sectors can be assessed, looking for the possible configurations best suited to the projected traffic flows.
3. **Conclusion:** This line of research is the continuation of a long analysis of airspace complexity throughout different programmes and projects. Tangible results are expected with an applicable model in planning. The proposed model will support the organisation of airspace according to traffic conditions and improving the organisation of ATC service technical and human resources. In addition, thanks to the application of Machine Learning models in the classification process, the model is automatically renewed as air traffic evolves over time. This prevents the model from becoming obsolete and makes it very useful for the service provider.

Cross-border Free Route Airspace concept and its impact on flight efficiency improvement

Mrs. Aleksandra Pasich (Rzeszów University of Technology), *Andrzej Majka*

The implementation of Free Route Airspace (FRA) in European Airspace has significantly reduced flight distances. However, there are still elements in the conventional FRA that need to be optimized in order to allow a further improvement in flight efficiency and these are the predefined entry and exit points that are still obligatory to be inserted in a flight plan by the crews and to be flew over during the flight. The introduction of cross-border FRA, thus giving the flight crews freedom to plan crossing FIR's/UIR's borders over user defined entry/exit points, is another milestone towards the improvement of flight and Air Traffic Management (ATM) systems efficiency. The fundamental concept of the article is to examine the possibility of implementation and expansion of already existing cross-border FRAs and how much distance would be saved if it was possible to fly in a cross-border FRA, instead of a conventional FRA. Thus, two

possible scenarios on the extract of a chosen flight route, based on a real-world flight, operated by inter alia LOT Polish Airlines, are examined. Route distance extension was calculated using the Horizontal Flight Efficiency method. Subsequent calculations include potential flight time savings along with fuel waste, CO2 emission and operating costs. The validation of the results obtained through calculation was conducted on X-Plane 11 as a simulation of two examined scenarios, using a Boeing 737-800. The results of the calculations and simulations indicate that the implementation and expansion of cross-border FRA may have a positive impact on flight efficiency improvement due to the reduction of distance and consequently the flight time, fuel waste, CO2 emission and operating costs. It can also mitigate the problem of the European Airspace capacity gradually reaching its maximum level. Thus, there is still a lot of place for further optimization of air traffic flow in European Airspace.

A performance-oriented path planning algorithm for unmanned aerial vehicles based on bit-coded flight maneuvers

Mr. Egidio D'Amato (Università degli Studi di Napoli "Parthenope"), *Caterina Montefusco, Francesca Parrotta, Luciano Blasi, Immacolata Notaro*

This paper deals with a novel path planning algorithm, able to find optimal trajectories for Unmanned Aerial Vehicles (UAV) in presence of environmental constraints and compliant with aircraft performance. Constraints are defined in terms of obstacles, fixed way-points and selected starting and ending points. The proposed strategy is based on an original trajectory modelling, using a simplified flight mechanics model to evaluate aircraft performance, coupled with a Genetic Algorithm (GA) optimizer. The design variables of the optimization problem are used to describe the maneuvers needed to fly between the starting and the target point. Flight paths are divided into a finite number of pieces in which maneuvers are actuated. The optimal path is defined by a sequence of N maneuvers. Turning maneuvers are performed considering the maximum turn rate, in order to minimize the path length. The result is a piecewise trajectory made of segments and circular arcs, similar to Dubins paths and compliant with flight mechanics constraints. This formulation allows to easily handle the manoeuvres sequence with a fixed number of integer variables taking advantage of GA capability in handling discrete variables. Furthermore, the use of mixed-type variables provides to the optimization procedure a useful flexibility in the “decision making” modelling and operational scenarios definition as well. The use of an APM allows minimizing fuel/energy consumption instead of only path length. To prove the effectiveness of the proposed procedure, several applications to realistic urban and rural scenarios have been tested.

Air Traffic Management (ATM) & Airports (PART II)

Session Chair : Prof. Octavian Thor Pleter, University Politehnica of Bucharest, Romania

Regulatory Framework on the UAM Operational Concepts of the ASSURED-UAM Project

Mrs. Anna Maria Mazur (Lukasiewicz Research Network - Institute of Aviation), *Jens ten Thije, Joost Vreeken, Henk Hesselink, Bartosz Dziugieł, Anna Stańczyk, Teresa Idzikowska, Adam Liberacki, Agata Utracka, Piotr Ginter, Michele Giannuzzi, Sandra Melo, Adriana Witkowska-Konieczny*

ASSURED-UAM project aims at the development of a set of solutions to assure requirements resulted from integration with manned air traffic management with city mobility without compromising UAM acceptability, safety or sustainability. In this project UAM is considered as means of transport of people or goods enabling Door-to-Door (D2D) or near to D2D travel within or to densely populated urban areas

with manned and unmanned aircraft of different configurations. This concept introduces a new mobility layer to an existing network, promoting innovative aviation technologies such as small drones, electric aircraft and automated air traffic management, to contribute for a better and more sustainable urban transport system. The paper performs a literature review on the regulatory framework providing a clear view of the current regulations and standards already addressed by standard development organizations. The review also includes the insight on possible international regulations and standards for the future, considering operations in the specific and certified categories. The impact and trends of current and future regulations is presented. A synthesis on target level of safety is provided as well as a description on the impact of the regulations from different perspectives, including industry and the constant certification of urban aircraft, operational and air traffic management, cities and the governance of the urban airspace as well as technology. The developments identified in this paper show a clear trend towards UAM technical and operational developments as well as further potential of a successful incorporation in city mobility concepts. Regarding the effective integration of UAS in the urban space, the paper indicates the importance of the representatives of guideline development organizations, industry, agencies, and other important players involvement in the successful development of standards covering a wide range of issues.

Managing Airport Capacity and Demand: an Economic Approach

Dr. Alvaro Rodriguez-Sanz (Universidad Politécnica de Madrid (UPM)), *Luis Rubio Andrada*

This paper reviews major research trends and opportunities in airport demand and capacity management from an economic perspective. Airport capacity constraints lead to operational congestion and delays, which have become major threats to the aviation industry. They impose large costs on airlines and their passengers. Uncertainty in demand or unexpected events can cause a mismatch between capacity and demand, resulting in either capacity over-supply, with a decrease in efficiency, or airport congestion over an extended period. In general, there are two approaches to the congestion problem. The first one, called 'hard' management, is to expand airports (terminals, runways, aprons) so that this change in infrastructure provides a better match between supply and demand of capacity. This approach solves the capacity shortage directly. However, capacity adjustment can only be achieved over the long term, as the planning and construction of major airport infrastructure is notoriously lengthy. This time lag implies challenges for airport capacity planners and introduces a complex dynamic behavior of development and investment, which creates a demand for more flexible solutions. It also highlights the problem of risk aversion of airport operators, and, more generally, the problem of how expectations are formed regarding the likely investment return. The second approach, called 'soft' management, relates to strategic planning or tactical adjustments, and aims to control demand by improving the pricing and/or allocating mechanisms of airport capacity. It introduces measures to achieve higher efficiency or enhance planning within the given capacity limitation, as this strategy does not have an impact on the infrastructure itself. Therefore, these 'soft' measures include operational enhancements to improve the efficiency, reliability, and sustainability of airport operations, given the available infrastructure, and they can also include actions that aim to modify the temporal and/or spatial characteristics of demand through regulation or through incentives. Scheduling mechanisms can help to manage the expected air traffic based on demand forecasts. This paper outlines the different available interventions for demand and capacity management, from marginal capacity increases to strategic initiatives to adjust demand, as well as tactical measures in response to dynamic, real-time events like poor weather or schedule disruptions. We appraise the economic implications of each possibility, highlighting the factors that may support the underlying policy,

managerial and operational decisions. We obtain several insights regarding airport capacity and demand management. First, airport capacity is rather difficult to define due to its multi-faceted and dynamic nature, and it depends both on the available infrastructure and on operating procedures. Moreover, airport throughput is highly conditioned by the factors that shape capacity and delay and shows significant variability when these factors are modified. Hence, there is room for improving operational efficiency without infrastructure developments. Second, a marginal change in capacity at congested airports may have a great impact on demand distribution, airline competition, aircraft types, fares, operating revenues, route map, and other characteristics of a given airport. Behavior after capacity expansion is highly reliant on the slot allocation models. Additionally, overall social welfare is usually affected after changes in infrastructure in terms of increased connectivity, economic benefits, and negative externalities, including noise and local pollution. Third, on-time performance is clearly non-linear, and thus sensitive to variations in demand and capacity. Last, airport capacity and demand management involves a trade-off between mitigating congestion and maximizing capacity utilization, so decision-making tools are requ*ired to support and enhance policy and managerial choices.*

Acoustic impact of Capodichino airport by the use of the AEDT software

Prof. Massimo Viscardi (University of Naples), *Clementina Persico, Raffaele Migliaccio Giulia Attanasio, Giovanni Basile*

About the study of the acoustic impact of the Capodichino airport (Naples), a new acoustic simulation software was used to generate the study of noise propagation in the area near the airport and relative footprint. In the past, the INM (Integrated Noise Model) calculation code provided by the FAA (Federal Aviation Agency) has been represented the standard code for these simulation operations and widely used all over the international airports. Anyway, in the last three years, a new code has been implemented by the FAA, to overcome some of the limitation of the INM. This new tool, named Aviation Environmental Design Tool (AEDT) present a new management of the acoustic parameters (as, for instances the implementation of innovative sound absorption model such as the SAE-AIR-5534) and a different management of the acoustic maps definition (as, for instances, the use of dynamic grids) . It also allow to a contextual management of acoustic and air pollution (CO2) problems. AEDT also presents a catalog of aircraft updated and constantly updated, which INM did not have and for which equivalent aircraft should have been taken. In the framework of the present study, AEDT provisional results have been compared with data already available and based upon the use of the INM code. An in-depth study has been also dedicated to the comparison of numerical forecasted data and experimental one measured at specific target point through the use of the Capodichino Airport remote monitoring noise system. The study has highlighted some of the peculiarities of the new software consolidating the opportunity to use AEDT as future planning tool for Capodichino and another airport's scenario.

Protecting Aviation Safety Against Cybersecurity Threats

Mr. Peter Stastny (University Politehnica of Bucharest), *Adrian-Mihail Stoica*

In Air Traffic Management (ATM), Safety Management Systems (SMS) form the principal vehicle for implementing safety policies, practices and procedures in accordance with internationally agreed Standards. In a constantly changing operating environment, it is essential to maintain SMS effectiveness to maintain and enhance levels of ATM safety. Research at the University Politehnica of Bucharest (UPB) has analysed the major, fast-rising threats to ATM safety emerging in the cybersecurity field, and the related synergies between formal management systems in the fields of security and safety. Its ultimate

objective is to assess the feasibility of equipping SMS with protection against security risks, especially cybersecurity. It further explores the potential effects of cybersecurity threats to aviation safety and the available protection mechanisms. In considering the synergies between Security Management Systems and Safety Management Systems in ATM, the possibility of full integration of the two into a single protection system is explored. While, despite similarities, such a combination is not found to be an optimal arrangement, the examination nevertheless enables the derivation of the security measures required in order to enhance the effectiveness of SMS.

Reduction the turbulence impact on an aircraft in the flight planning process

Mr. Grzegorz Drupka (Politechnika Rzeszowska), *Tomasz Rogalski, Piotr Szczerba*

Predicting important natural phenomena such as the weather is absolutely quite important part of the process of route planning in aviation. Despite understanding of turbulence has been contributing to improve travelling comfort and increased safety of operations in airspace, reduction these phenomena methods still rely on avoiding areas where turbulences are predicted to occur. As a result, caused by adverse weather conditions limitations forces traffic flow reorganization. Since turbulence indicator reveals more accurate records of turbulence impact, more objective estimation based on an aircraft information can be reached - thereby causing less severe changes in air traffic. Turbulences defined as unexpected bumps are phenomena that characterizes different intensity expressed in peak modulus value in the relation to aircraft normal acceleration equated and scaled to 1g (in units where 1g - 9.81 m/s2). Moreover, as other severe weather conditions, turbulences threat a given, predicted by weather forecasts areas. Therefore, avoiding the entire area where turbulence has been predicting to occur with incomplete regard to its intensity causes unnecessary increasing in flight time, fuel consumption and delays in air traffic. Delay's accumulation causes enormous air traffic control officers (ATCO) workload and forces uneconomical aircraft's fleet management by airlines. Since equal turbulence intensity influencing quite unlike on different aircraft types, the paper presents solution that supports an aircraft operator (AO) in the task of turbulence impact estimation. Additionally, the solution makes it possible to seek and suggest path according to turbulence forecasts and aircraft performance resulting from construction to operational environment - including technical dimensions and parameters important for operation.

Influence of airspace avoidance due to political and safety issues on flight efficiency and environment

Mrs. Aleksandra Pasich (Rzeszów University of Technology), *Paweł Ostręga Andrzej Majka*

The incident involving Ryanair flight 4978 over Belarus airspace on 23rd May 2021 has led the European Union Safety Agency (EASA) to issue Safety Directive, calling all EASA member states to instruct aircraft operators that conducting operations in Belarus airspace is no longer allowed. As a result, all commercial aircraft operators based in EASA member states ceased flight operations over Belarus airspace. Putting that together with the necessity to avoid airspace over Eastern Ukraine, many airspace users have to perform deviations from their original, most optimal routes, which leads to a distance extension and consequently a serious increase of carbon dioxide emission or operational costs. The fundamental concept of the article is to examine the effects of the necessity to avoid certain airspaces by the operators due to safety reasons, using the latest incident over Belarus airspace as an example. Thus, the EUROCONTROL air traffic prediction reports over as well as the routes of flights over the considered region were analyzed, prior and after the issue of Safety Directive.

Based on the observations of air traffic flow, route distance extension was calculated using the Horizontal Flight Efficiency method. Subsequent calculations include potential increase in flight time, fuel waste carbon dioxide emission and operating costs. The results were extrapolated to a monthly and yearly amount, based on the air traffic prediction reports. The validation was conducted on X-Plane 11 as a simulation of a selected route, taking into account the following scenarios: original route, deviated route and possible alternative path. The air traffic prediction analysis as well as the results of the calculations and simulations indicate that the bypass of the airspaces, important to global economy, has a serious impact on the environment and operators' budget due to increased aircraft's fuel waste resulting in growth of carbon dioxide emissions as well as operating costs. It also leads to a deterioration in the European Airspace's capacity, causing the necessity for Air Traffic Management (ATM) units to reorganize the air traffic flow over the affected regions. Potential alternative solutions were proposed in order to mitigate the effects of the considered problem.

Non-destructive testing of aerospace components / Optimising Design for Inspection

Session Chair : Prof. Elena Jasiuniene, Kaunas University of Technology, Lithuania &
Dr. Helge Pfeiffer KU Leuven, Belgium

Structural Health Monitoring of Multi-layered CFRP Panel Using Ultrasonic Guided Waves

Mr. Mastan Raja Papanaboina (Prof. Kazimieras Barsauskas Ultrasound Research Institute), *Elena Jasiuniene, Vykintas Samaitis, Egidijus Zukauskas*

The manufacturing of aircraft components using laminated composite materials are significantly increased due to high-strength, lightweight, and reduction of additional components such as rivets and fasteners. The multi-layered composites are vulnerable to delamination defects due to impact damages. The key issues in aircraft wing box are delamination between composite layers due to impact damages. Structural health monitoring of aircraft components based on guided waves are highly sensitive, reduction in maintenance cost and increase safety. However, the inspection challenges are arising due to multi-mode guided waves, highly dispersive nature, anisotropic properties of materials and complex geometries. In this research, the semi-analytical finite element method was used to obtain the dispersion characteristics of the propagation of guided wave in the object under investigation and to select the optimal frequency range for inspection. The numerical simulation was performed on multi-layered carbon fiber reinforced polymer (CFRP) to examine the guided wave behaviour on delamination defects. The guided wave response to delamination on the CFRP panel was studied. The defect presence and location were estimated by measuring the time of flight (ToF) and time delay of the signal. The Short-Time Fourier Transform (STFT) and Continuous Wavelet Transform (CWT) was used to filter diffracted and overlapped modes which exhibited due to test panel boundaries. The implemented signal processing methods have shown great potential to filter guided wave signals when there is a presence of rivet holes in the test object. This research helped to expand the Transmitter-Receiver inspection configuration to a network-based inspection set-up for structural health monitoring using embedded sensors.

Finite Element Modeling and Analysis of Representative Wing Structure for Structural Health Monitoring Puposes

Mr. Ömer Necati Cora (Karadeniz Technical University), *Muhammed Latif Bekci*

Introduction: Structural health monitoring (SHM) is widely used in various engineering applications to detect and diagnose failures in real-time. The present study examined the behaviour of the representative wing structure in response to different loading conditions via finite element analysis (FEA) to understand the deformation characteristics of the wing structure and suggest locations for the sensors to be used for SHM purposes.

Methods: Representative wing structure consists of metal and composite components in general. SHM will conduct on top and bottom composite test panels on the structure, and this will be manufactured from 18 plies of CFRP. The finite element model of the wing structure was established with various solid element types, and about 560.000 elements were used in total. FEA was conducted on a PC with an Intel® Core™ i7-10700F processor and 64 GB RAM. The structure is loaded up to 2000 kN through rectangular bars along the width of the structure on its top. Each analysis lasted 22 minutes of CPU time approximately. Analysis results are used to determine the maximum vertical displacement and stress distribution on the structure, also the critical points for possible failure initiation on the composite test panels of interest.

Results and Discussion: The displacement of the rectangular loading blocks was obtained with respect to incremental loading values up to 2000 kN. This data will be compared with the actual test data to verify the accuracy of the model established. It was revealed that the top composite test panel fails at 2000 kN loading condition based on the maximum stress failure criterion. Nevertheless, the metallic truss structure was found to fail much earlier compared to composite panels at a load level of 300 kN, approximately.

Conclusion: To conclude, the representative structure fails due to the failure of load-carrying frames rather than composite skins. If the composite plate is required to be failed first, either the steel structure should be strengthened or some pre-cracks need to be introduced in composite plates.

Monitoring ice in fuel tanks and on aircraft fuselages by means of acoustic emission

Dr. Helge Pfeiffer (KU Leuven), *M. Stamm, J. Reynaert, D. Seveno, M. Sohail, P.J. Jordaens, Ö. Ceyhan, M. Wevers*

Due to condensation during aircraft operations or when filling tanks with kerosene, significant amounts of liquid and solid water (ice) accumulate in fuel tanks. This potentially leads to misreadings of fuel meters or, for certain aircraft types, ice can block the suction mouth of fuel feed tubes (from the tanks to the engines). Furthermore, water favors microbial corrosion inside tanks that even harm structural elements, resulting in large and costly repairs with long aircraft grounding times. There is up to now no generally accepted “non-invasive” method available to determine the moment when "water draining" has to be performed. Similarly, it is not yet possible to determine if, after draining, maintenance can ensure all water is drained and no ice blocks or water are still present inside the tank. Another issue regards ice accumulation on the outer surfaces of aircraft affecting e.g. aerodynamic drag. Early detection of those processes would therefore provide important information to take appropriate measures to improve safety and fuel efficiency.

A promising technology for ice detection makes use of acoustic signals generated and emitted during ice melting or freezing processes. Via acoustic emission in the ultrasonic frequency range, a multitude of events can be registered and used to characterize stress relaxation processes occurring during the transformations between liquid and solid water. The whole process can be analysed with respect to the energy and frequency distribution as well as to the total number of events measured. A proper mathematical treatment of the data set also allows to discriminate between real icing events and environmental noise that might be present at the same time. Research leading to these results has received funding from the "NDTonAIR" project (Training Network in Non-Destructive Testing and Structural Health Monitoring of Aircraft structures) under the action: H2020-MSCA-ITN-2016- GRANT 722134 as well as the "Fighting Icing" project (COOCK – VLAIO, Belgium). Part of the research is furthermore supported by the FUTPRINT50 project academy (No 875551) as well as the "SurfIce" project, a H2020-MSCA-ITN "Smart surface design for efficient ice protection and control" GRANT 956703.

Sigmoidal sensing devices for simplified data interpretation and enhanced robustness in Structural Health Monitoring of aircraft

Dr. Helge Pfeiffer (KU Leuven), *S. Sunetchiieva, L. Muyshondt, D. Seveno, M. Wevers*

Sensors to interrogating the structural integrity in an aircraft are frequently operating in a quasi-linear mode. Although quasi-linear-sensing is a prerequisite for versatile applications, tailored devices for applications where only one or two thresholds are of interest could provide more appropriate solutions. An interesting alternative is offered by sensors showing a sigmoidal response curve depending only on one outer parameter that is related to a certain damage threshold. They usually rely on phase transitions, crack phenomena or related physical principles and often show responses that range over many orders of magnitudes. This results in a certain independency of baseline variations which increases the probability of detection compared to many other technologies. There are a couple of highly non-linear sensing devices reported in the literature of which some are even in operation. Examples are the alarm wires in bleed air systems for aircraft providing information on overheat and crack propagation gauges used in fatigue testing. This presentation gives a systematic introduction into the field of non-linear sensors and discusses some recent applications in the aerospace sector. Besides the detection of corrosive liquids in aircraft (Boeing 737-500, Boeing 747-400), the detection of hydraulic liquids, moisture ingress in composite materials as well as detection of ice in the tanks of an aeroplane will be discussed.

Sensitivity analysis of non-destructive technique for determination of material properties in reinforced laminated composite plate

Mr. Andrejs Kovalovs (Riga Technical University), *Karlis Dzelzitis, Sandris Rucevskis, Andris Chate*

At the present time composite material, a major component on the construction in aviation and space field due to good properties of high strength and low weight. The knowledge of elastic properties of composite material is necessary for design of composite construction and they components. Determination of composite materials properties is much more complicated than of isotropic materials and need more time and efforts. Additionally, due to high costs of new materials, their experimental testing with conventional fracture methods suffers from high expenses too. Application of non-destructive evolution technique, based on vibration method is a rapid and inexpensive method to obtain data to identify of elastic properties. The problem associated with vibration testing is converting the measured modal frequencies to elastic constants. A standard method for solving this problem is the use of a numerical-experimental model and optimization techniques.

The numerical-experimental method proposed in the present investigation consists of the experimental set-up, numerical model, and material identification procedure. Firstly, vibration experiments are carried out to measure the resonance frequencies and corresponding mode shapes of composite plates. In next step construed experimental design depending on the number of measured parameters and experiments. Numerical calculations are carried out in reference point of plan to determine frequencies. Collected numerical data are used to determine simple functions using a response surface method. Finally, the identification of the material properties is performed by minimising the error functional, which describes the difference between the experimental and numerical parameters of the structural responses. The results obtained were verified by comparing the experimentally measured eigenfrequencies with the numerical ones obtained by finite element program ANSYS at the point of optima. The proposed numerical-experimental approach is used to identify the elastic properties of reinforced laminated composite plate. The investigated plate made of +450/-450 GFRP with thickness of 0.2 mm/layer. The thickness of plate varies in range of 0.8, 1.2 and 1.6 mm. These thicknesses were used for experimental study of sensitivity suggested method.

Damage Detection in Aircraft Structural Components Using Acoustic Technologies

Prof. Rhys Pullin (Cardiff School of Engineering), *M. Pearson, C. Featherston, M. Eaton, J. McCrory, F. Almudaihesh, J. Hill, B. Fisher, M. Naaman, S. Grigg*

Understanding how damage grows through the life of an aircraft certification fatigue test is of paramount importance for the aviation industry. Testing is performed on small components and full-scale structures. Larger tests are performed over long periods of time, where after a given number of cycles the structure is disassembled and assessed for damage through Non-Destructive Testing (NDT). If damage is detected, the part is repaired or replaced, and testing is allowed to continue. The identification of these failures allows engineers to specify maintenance procedures for in-service aircrafts. This process of full inspection is slow, costly and only identifies problems at inspection intervals, rather than when damage occurs. Structural Health Monitoring (SHM) aims to detect damage as it develops within a structure. In large scale testing strain gauges are used to detect unexpected changes in strain, often the product of damage. These provide significant information to engineers, however. they are limited in their ability to identify damage and costly to install. Alternative SHM approaches have been shown to effectively locate the presence and growth of damage, this information would enable engineers to better understand when and how damage is occurring. As part of an industrially funded project three acoustic based techniques are being investigated, Acoustic Emission (AE) monitoring, Acousto-Ultrasonics (AU) and Audible Acoustics (AA). The aim of this work is to investigate their applicability for real large scale aircraft structures. A large-scale demonstrator (Figure 1) has been manufactured and tested. The validity and applicability of the three techniques to detect disbond in a stiffener is presented.

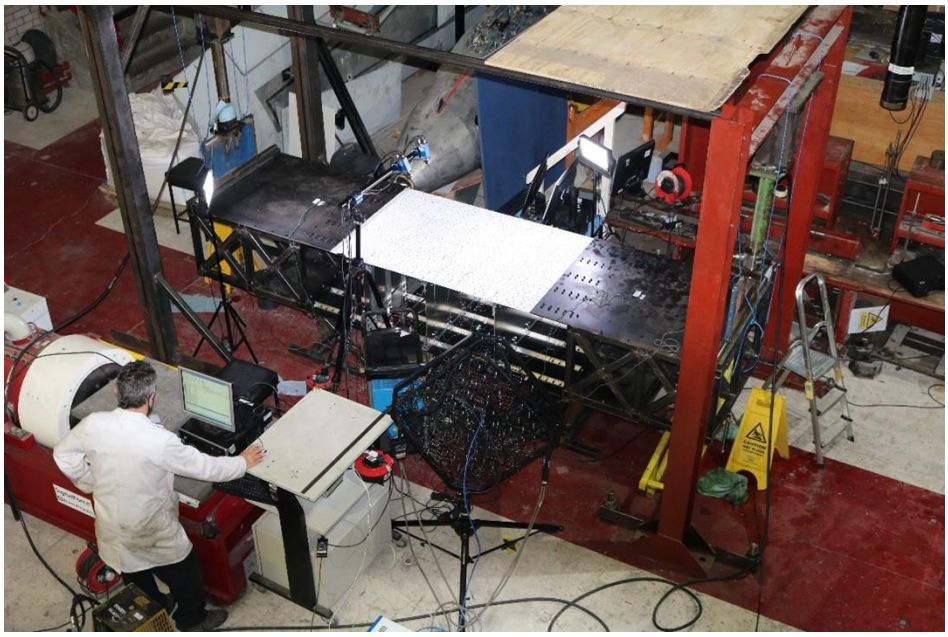

Figure 1: Large-scale demonstrator during

A Semi-supervised Deep Learning Method for Helicopter Anomaly Detection

Chenyu Liu, Prof. Konstantinos Gryllias (KU Leuven)

Data-driven condition monitoring technique has been widely employed by helicopter Maintenance, Repair, and Overhaul (MRO) providers. With a large number of sensors mounted in helicopters, maintenance engineers are trying to capture every nuance from the sensory data, pursuing early detection of the abnormal behaviors, thus enabling proactive MRO activities before failure. This necessitates the development of an intelligent detection method with high accuracy to identify the data outliers, which may foster potential systematic issues. Artificial Intelligence (AI) has been introduced into the condition monitoring operations due to its strong expertise in data analytics. By learning from the available data, Machine Learning (ML)-powered anomaly detection models are able to automatically recognize the irregular data from the normal pattern. Support Vector Data Description (SVDD) is one of the ML methods used for one-class classification problems. It encloses the data samples into a hyper-sphere as the feature space, and its optimization target is to minimize the sphere volume with margin violation penalties. The construction of the classic One-Class SVDD (OC-SVDD) model needs only the normal data, making it suitable for industrial anomaly detection tasks since most data are collected in normal operating conditions. Recently, SVDD is combined with deep neural networks to complement its end-to-end functionality, namely the Deep SVDD method. Instead of using engineering indicators as the inputs, Deep SVDD leverages the deep regime to automatically learn relevant features from the input signals without extra domain knowledge. The network optimization is synchronized with the sphere volume minimization in Deep SVDD, which also uses the normal data for model training. SVDD could also be applied in a semi-supervised way with the access of a few labelled abnormal objectives, namely the Negative sample SVDD (N-SVDD). With the extra negative training samples, the N-SVDD model tends to deliver a more robust detection boundary, leading to better detection performance than OC-SVDD. Similarly, Deep SVDD is also able to be upgraded to a semi-supervised method.

This paper aims to show the effectiveness of the Deep N-SVDD for helicopter anomaly detection. A Deep N-SVDD model is proposed with both normal data and artificial outliers for training. The model is applied to a helicopter vibration dataset with the raw vibration signals as the inputs. Comparative analysis is conducted between the classic OC-SVDD model, the Deep OC-SVDD model and the Deep N-SVDD model. Various neural network layers are also assembled to examine their feature extraction ability.

Next generation multifunctional and intelligent airframe & engine parts: manufacturing, maintenance, recycling: DOMMINIO, SUSTAINair, MORPHO joint session

Session Chair : Mr. Hugues Felix, CINEA, European Commission

DOMMINIO: Digital Method for Improved Manufacturing of Next-Generation Multifunctional Airframe Parts

Dr. Ricardo Losada Mateo (AIMEN)

DOMMINIO aims at developing an innovative data-driven methodology to design, manufacture, maintain and pre-certify multifunctional and intelligent airframe parts (composed of high-quality in-situ consolidated composite laminates and high-performance 3D-printed reinforcement elements) through a cost-effective, flexible and multi-stage manufacturing system based on the combination of robotized automated fiber placement (AFP) and fused filament fabrication (FFF) technologies, supported by advanced simulation tools, on-line process & quality monitoring, structural health monitoring (SHM) systems-enabled by embedded novel carbon nanotube (CNT)-based fibre sensors and data analytics.

Different innovative thermoplastic filaments will be employed to incorporate specific functionalities:

a) filaments reinforced with continuous CNT fibre as piezoresistive strain sensors in the laminate,
b) filaments embedded with magnetic nanoparticles to enable reversible joining, and

c) filaments reinforced with continuous carbon fiber to increase the structural integrity of the 3D-printed reinforcements. Flexible automation of AFP and FFF manufacturing processes will be enabled by the development of new laser-heating system and smart nozzle, the simulation of AFP plies consolidation and interlaminar delamination in FFF and the development of novel air-coupled ultrasound quality monitoring systems. Besides, advanced modelling will support the selection of right process window parameters and the optimal production planning strategy, ensuring the quality of the final component. In addition, physics- and data-driven models (Digital Twin) will provide real-time data-driven fault detection capabilities supporting the implementation of new methodologies for SHM&M of multifunctional airframe parts.

The DOMMINIO multi-stage manufacturing systems and digital pipeline will be tested and validated at lab-scale in two representative airframe parts (a multifunctional access door panel and a spoiler prototype), enabling the realization of the DOMMINIO solutions in laboratory environment, in order to assess novel MDO and MRO methodologies, their life analysis and virtual certification potential.

SUSTAINair: SUSTAINablility increase of lightweight, multifunctional and intelligent airframe and engine parts

Ligeia Paletti, Mihaela Rozman, Jürgen Roither, Gradinger Rudolf, Ruben Nahuis, Jan Haubrich, Miriam Löbbecke, Martin Schagerl, ***Prof. Christoph Kralovec (JKU)****, Chiara Bisagni, Antonio Raimondo, Stein Janssens, Marc Joulian, Jesper de Wit, Stephen M. Webb*

Horizon 2020 project SUSTAINair is researching and developing solutions to increase resource efficiency and aircraft performance while cutting down on waste and material costs throughout the aircraft life cycle, what is known as circular aviation. The central approach of SUSTAINair is to substantially increase the sustainability of the airframe value chain achieving a paradigm shift in aircraft manufacturing. As such

the project has been endorsed by the Future Sky flagship programme of EREA - Association of European Research Establishments in Aeronautics. SUSTAINair applies circular economy principles to the design, manufacturing, operations and end-of-life phases of aircraft. 11 European research organisations and industrial partners co-ordinated by the Austrian Institute of Technology AIT-LKR are working towards: Circular design of individual components and joining technologies for airframe construction (including morphing); Real-time structural health monitoring of materials and joints during operations; Improved maintenance and repair technologies to extend aircraft life time; Automated dismantling robotics for improved recovery of high quality recycling materials.

SLOWD project

Session Chair : Mr. Francesco Gambioli, Airbus, UK

Flexible Aircraft Wings with Fuel Slosh Effects

Ms. Wendi Liu (UK Research and Innovation, Science and Technology Facilities Council), *Stephen Longshaw, Alex Skillen, David R. Emerson*

Due to the use of highly flexible materials, aircraft wings can deform significantly during their operation due to atmospheric turbulence or a gust. Such deformation has the potential to induce significant sloshing of the fuel inside the wing. This phenomenon is of interest in the field of aircraft design since the dynamic loading of a sloshing fuel tank can have a significant impact on the structural dampening of the wing, potentially leading to an exploitable reduction in structural loads due to the energy of the slosh. The interaction between a flexible wing and the sloshing fuel tank is complex and challenging to numerically model due to its nonlinear, multiphysics and multiphase nature. In this study, we will outline a model capable of predicting this complex flow. Furthermore, we will investigate the impact of excitation amplitude on the geometry of the fuel-tank due to the sloshing dynamics. We have employed a highly scalable open-source multiphase fluid-structure interaction (FSI) framework, developed by the authors, to simulate the elastic sloshing aircraft wing and will present the results. The FSI framework uses a partitioned approach with an Aitken's implicit coupling methodology[74] to achieve a tight and stable coupling for multiphase FSI. The Multiscale Universal Interface (MUI) general code coupling library[75] is employed as the interface between fluid and structural domains. The computational fluid dynamics (CFD) package OpenFOAM[76] and the computational structure mechanics (CSM) solver FEniCS[77]are employed for the fluid and structural domains, respectively. The FSI simulation framework shows a good performance in HPC environments for simulating complex and challenging cases[78] [79]. In the present study, a simplified, beam-like aeroplane wing model is used to represent an elastic aircraft wing. The beam has a free-tip at one end and is fixed at the other. A fuel-tank with liquid fuel is embedded inside the beam. An external force, which linearly increases with time, is applied to the free tip of the beam for a fixed period of time, at which point the external force is removed to let the system oscillate freely with an excitation amplitude. Different excitation amplitudes will be achieved, and results shown, by varying the magnitude of external forces. Aircraft fuel tanks are typically compartmentalised. Different numbers of baffled regions within the tank will be simulated. Our results will be compared and analysed among different working conditions.

Experiments and scaling effects in the context of a SDOF vertical sloshing problem

Mr. Jon Martinez-Carrascal (Universidad Politécnica de Madrid), *Leo M. González-Gutiérrez*

The complex nature of the vertical sloshing problem in aircraft wings demands a simplified experimental SDOF testing. The work presents the non-dimensional formulation of the problem and studies the dependency of the relevant parameters with the fluid induced damping. A test campaign has been performed at the Model Basin Research Group Sloshing Laboratory of the UPM in Madrid, Spain. The main

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aim of this experimental campaign is to quantify the effect of the filling level, initial displacement and fluid density in terms of extra damping added by the fluid to the mechanical system. Furthermore, the influence of those three parameters is examined for different Froude scaled configurations that allow to perform a scale study and predict the sloshing loads in the real wing. The experimental investigation confirms that the the global liquid induced damping increases with the density of the liquid, the maximum damping is found for a 50% filling level and the extra damping increases with the initial displacement up until a saturation point after which the system no longer gives an additional damping for higher initial amplitudes. In the scale study, 1:4, 1:5 and 1:6 scales are tested and it is found that the scaling law holds within the first cycles where the sloshing phenomenon becomes more important.

Computing Aircraft Fuel Slosh Induced Dissipation via a Volume-of-Fluid Formulation

Dr. Leon C. Malan (Industrial CFD Research Group), *Arnaud G. Malan, Bevan W. S. Jones*

The computation of violent fuel slosh induced structural vibration dissipation is of importance to the aerospace community due its importance in design considerations like fatigue life predictions. As such, the EU H2020 SLOWD (SLOshing Wing Dynamics)[80] project aims to characterise and model the impact of fuel sloshing on the damping characteristics of a wing structure due to vertical excitation where the direction of excitation is normal to the initial liquid free-surface. This work presents results of the Elemental® volume-of-fluid (VOF) software in predicting this phenomenon.

The VOF scheme employs a specially formulated weakly compressible formulation for the gas. Turbulence is modelled with a Smagorinski-Lilly large eddy simulation (LES) formulation. Simulation results are compared to recent benchmark experiments involving violent 3D slosh.

Nonlinear sloshing integrated aeroelastic analyses of a research wing prototype

Prof. Franco Mastroddi (Sapienza University of Rome), *Francesco Saltari, Marco Pizzoli*

Modelling of dissipative behavior of vertically sloshing fuel may represent, for future flexible aircraft design, one of the point to stress for achieving structural mass reduction and aircraft-induced pollution reduction. This work aims at applying Reduced Order Models (ROMs) for sloshing to the case of Airbus Wing of Tomorrow (WoT), a research wing model prototype developed for testing technologies to be used for wings of future aircraft. Specifically, the introduction of sloshing ROMs able to describe a dissipating behavior arising when wing local vertical accelerations get higher is among the scope of the work. Vertical sloshing will be investigated making use of a low fidelity equivalent bouncing-ball model recently developed for replacing high fidelity models for vertical sloshing dynamics. Results will provide the effects of slosh dynamics on aeroelastic stability and response of wing structures also investigating extension of the aeroelastic stability margins (also involving the description of nonlinear limit-cycle oscillations) when violent sloshing phenomena, that cause energy dissipation, are taken into account.

Statistical analysis of sloshing-induced dissipative energy across a range of Froude numbers

Mr. Lucian Constantin (University of Bristol), *Joe J De Courcy, Branislav Titurus, Thomas C S Rendall, Jonathan E Cooper*

[80] Gambioli, F., Chamos, A., Jones, S., Guthrie, P., Webb, J., Levenhagen, J., Behruzi, P., Mastroddi, F., Malan, A. G., Longshaw, S., Skillen, A., Cooper, J. E., Gonz alez, L. & Marrone, S. (2020), Sloshing Wing Dynamics -Project Overview Sloshing Wing Dynamics–Project Overview, in 'Transport Research Arena 2020', April, Helsinki, Finland.

Fuel sloshing-induced damping is currently being extensively studied within the EU-funded SLOWD project as a means of passively reducing dynamic loads in aircraft wings. It is of interest to be able to determine which parameters have the greatest influence on the added damping from the sloshing motion. Simplified experiments that isolate the vertical component of the excitation motion have been considered involving both transient and periodic vertical excitation, with both of cases showing important sloshing-induced dissipative effects. Moreover, an uncertainty in the measured sloshing force is observed when multiple consecutive and identical oscillation cycles are considered, leading to variation in the experimentally identified energy dissipation. This current work considers a series of experiments conducted using vertical sinusoidal excitation applied to a rectangular tank containing a liquid. The liquid sloshes depending on the fill level and excitation conditions (frequency and amplitude), causing energy dissipation via several possible physical mechanisms. The sloshing dissipation is measured experimentally across a large number of excitation cycles and for each excitation amplitude, expressed in the form of Froude (Fr) numbers. Depending on the Fr number, distinct sloshing mechanisms dominate the dissipative effects and induce a particular variance across the identical cycles analysed. The sloshing-induced energy dissipation variation is quantified and correlated with different mechanisms depending on Fr number, helping thus to explain various non-stationary effects that are observed even in such well-controlled experimental conditions. Apart from improved insights into the inherent dispersion nature of the studied phenomena, this research will also establish experimental characteristics suitable for future model validation and calibration.

Prediction of energy dissipation in violent 3D sloshing flows by Smoothed Particle Hydrodynamics

Dr. Salvatore Marrone (CNR-INM, Institute of Marine Engineering), *Andrea Colagrossi, Danilo Durante, Julien Michel*

The present work is part of the SLOWD H2020 project which aims to investigate the use of fuel sloshing to reduce the design loads on aircraft wings. These are highly flexible structures, that can deform significantly under certain loading. Wings house the fuel tanks, and generally carry an amount of fuel comparable in weight to that of their structural components. In the present research the model is adopted to investigate the damping effect of fuel sloshing on the dynamics of flexible wing-like structures. This represents a quite challenging task for SPH and more in general, for CFD tools, being the fuel tank under study subjected to vertical accelerations as high as 10g. The resulting flow is extremely complex due to the highly turbulent flow, the violent impacts and intense fragmentation of the air-liquid interface. In previous work by the experiments in are reproduced in the two-dimensional numerical simulations comparing the flow evolution and the obtained forces and dissipated energy. In the present work three-dimensional simulations are considered and 3D effects on the energy dissipation mechanisms are investigated.

Smoothed particle hydrodynamics based reduced order model for sloshing analysis

Mr. Joe J. De Courcy (University of Bristol), *Lucian Constantin, Branislav Titurus, Thomas C. S. Rendall, Jonathan E. Cooper*

Fluid induced damping is being considered as a potential method for loads alleviation within civil aerospace structures. Quantification and a capability to model the additional fluid-induced dissipation provides a route for less conservative wing designs, producing an overall improvement in aircraft efficiency. The H2020 SLOWD (sloshing wing dynamics) project follows this objective, looking to provide

the necessary modelling capabilities to introduce sloshing physics and additional damping behaviour into the design cycle of civil aircraft. There is a requirement to formulate efficient numerical models that can capture the key dissipation characteristics in an adaptable framework. Within this work, a low-fidelity sloshing model based on a popular computational fluid dynamics method is used to achieve the above aim. Smoothed particle hydrodynamics (SPH) is the chosen method, which provides a Lagrangian description of fluid mechanics. This particle-based method, originally developed for use in astrophysics, has seen widespread adoption in fluid mechanics due to its inherent ability to capture free surfaces and robust conservation properties. In contrast to usual SPH work, the details of the formulation studied in this research aim to provide sufficient modelling capabilities with a relatively low number of fluid degrees of freedom, or particle numbers, such that efficient simulations are obtainable both in terms of computational cost and predictive capability. As sloshing problems generally consider the interaction between unsteady structural and fluid response, the low-order fluid model is cast in a fluid-structure-interaction framework such that the dissipation behaviour of the coupled system response can be analysed. The presented numerical model is validated against two well-defined experimental cases, considering purely vertical excitation of a fluid-filled rectangular tank. The coupled free-release and forced vertical motion cases are considered; analysis is focused on the capabilities to capture coarse and dominant features of the arising flow-regimes as well as fluid-induced dissipation metrics.

Space Technologies (Part I)

Session Chair : Dr. Athanasios Dafnis, RWTH Aachen, Germany

HERA Mission LIDAR Mechanical and Optical Design

Ms. Nicole Dias (Universidade de Lisboa), *Beltran Nadal, Paulo Gordo, Tiago Sousa, Pedro Marinho, Vasco Granadeiro, Rui Melicio, Duarte Valério, Belegante Livio, Patrick Michael, António Amorim*

The Asteroid Impact & Deflection Assessment (AIDA) is collaboration between the NASA DART mission and ESA Hera mission. The aim of these missions is to study the asteroid deflection through a kinetic collision. DART spacecraft will collide with Didymos-B, while ground stations monitor the orbit change. Hera spacecraft, composed by a main spacecraft and two small CubeSats, will study the post-impact scenario. HERA will monitor the asteroid through cameras, radar, satellite-to-satellite doppler tracking, LIDAR, seismometer, and gravimeter. The HERA LIDAR, designated by PALT (Planetary ALTimeter), is a ToF altimeter that provides time-tagged distances and velocity measurements. PALT will be used to support near asteroid navigation and provide scientific information to complement the Asteroid 3D topography. This paper addresses the PALT flight model preliminary design, namely: radiative budget; optical design; mechanical design; instrument thermal design (thermoelastic, radiative and conductive); and the relation between optical and thermoelastic models in term of optical performance and tolerances. During operation PALT will be subject to several thermal/radiative conditions, external temperatures vary typical between 150 ºC to -180 ºC. Near the asteroid, PALT will be illuminated by the sun up to 15 ºC, with an irradiance of 600 W/m2, on the other hand during travel PALT will be turned off and exposed to cold space. To survive this range of temperatures PALT is thermal shielded, PALT internal operational temperature range is -40 ºC to 60 ºC. PALT optics will be exposed to space and therefore need a careful opto-mechanical design to ensure performance for the wide thermal operation range. The opto-mechanical design is achieved by implementation of thermal shielding; implementation of isostatic mounts. The design iteration tails the following circular path: first optical and mechanical design with material selection, and determination of optical alignment tolerances; radiative models, thermoelastic and radiative simulations, and compliance check with optical tolerances; verification of optical performance degradation for the extreme operation scenarios. Optical design was done in ZEMAX, mechanical design was made in Solidworks, and thermal models were implemented in ANSYS (thermoelastic model) and ESATAN-TMS (conductive and radiative models). PALT, is positioned on the centre of the hot side (i.e. sun illuminated) of the HERA probe, so it cannot use radiators positioned in the cold face of the probe (i.e. side faces). The proposed thermal design (by using baffles, MLI and thermal washers) allow the implementation of the instrument in its position and an acceptable temperature range for its sensitive parts is assessed. Also, the telescope of the instrument has a 70 mm aperture primary mirror, isostatic mount for this mirror support is proposed.

Comparison of thermal protection systems for reusable microlaunchers

Mr. Stefano Piacquadio (RWTH Aachen), *Marco Kanngießer, Athanasios Dafnis*

In the last decades, growing efforts were dedicated to improve the performance of Thermal Protection Systems (TPS). Reusable launchers were demonstrated to effectively reduce launch costs. However, the re-entry flight phase necessarily brings to an increase of the take-off dry and wet mass. In alternative to the strategy of a re-entry burn, which requires additional propellant mass, Thermal Protection Systems (TPSs) can be employed to survive the thermal loads of a ballistic or lifting re-entry. Ablative TPS materials

commonly exhibit high heat absorption capabilities, but have the drawback of being expendable, thus requiring re-application on the outermost surface of a vehicle. Alongside with common ablative or passive TPS materials, so-called Integrated TPS (ITPS) were conceptualised in order to improve the mechanical stability of the TPS for a re-entry vehicle. These consist of load carrying sandwich structures which exploit the intrinsically low thermal conductivity of porous cellular structures. In this study, a numerical comparison of an ablative TPS and an ITPS is proposed. A solver based on a Finite Volume Method with grid contraction is used to simulate the behaviour of the ablative TPS, while a Finite Element Method is used to investigate the ITPS. A root finding algorithm is used in order to find the minimum TPS mass in the both cases. The comparison is based on the surface density obtained under the same temperature constraints. A consideration of the load carrying structure for the ablative TPS is also included, while the ITPS represents itself a self-sustaining load carrying structure. The percentage mass addition due to the presence of a TPS is thus evaluated for both cases and compared to the one of commercially available reusable launchers which employ other re-entry strategies. The reference vehicle and mission are the ones of a reusable microlauncher named MESO, which is being developed within the framework of the EU Horizon 2020 Recovery and Return To Base (RRTB) project.

CubeSat satellite patch antenna designed with 3D printable materials: a numerical analysis

Prof. Erika Pittella (Pegaso University), *Livio D'Alvia and Emanuele Piuzzi*

The aim of this work is to present a compact patch antenna system compatible with any CubeSat satellite structures designed using 3D printable materials. Nanosatellites are revolutionizing the space industry, enabling the access to the space with a significant reduction of costs for satellite industries and a shorter design development time with respect to large satellites. Moreover, using additive manufacturing it is possible to build customized system components, designing the inner part, also with complex geometry, without material wasting. Furthermore, 3D printing lets to go from production to consumption straight, having a great effect on the supply chain. Generally, CubeSats count on VHF/UHF communication systems with deployable monopole or dipole antennas for low bit-rate uplink and downlink. Instead, S-band is among the favourite choices for high bit rates, as the range 2400–2450 MHz is one of the international amateur satellite frequency ranges allocated by the International Telecommunication Union (ITU). An S-band printed patch antenna system is designed in this paper, considering the overall size (10×10 cm2) and weight constraints imposed by the CubeSat standard[81]. The antenna system is simulated with Microwave Studio (MWS) by Computer Simulation Technology (CST), using as substrate the polylactic acid, or polylactide (PLA), a thermoplastic polyester, a widely used plastic filament material in 3D printing. PLA is produced from renewable resources making it biodegradable and recyclable. Moreover, this material has dielectric properties similar to conventional material used to manufacture microwave components, with the great advantages deriving from 3D printing. For this preliminary study, a reconfigurable antenna system operating at 2450 MHz is considered. In particular, it consists of rectangular patches that, properly excited, allow to achieve different radiation pattern shapes. This characteristic makes this type of antenna useful for a wide range of different applications, satisfying requirements related to a mission with a single design[82]. First, considering the geometrical constraints, a rectangular patch geometry is simulated within the CAD considering PLA as substrate material. With such a substrate, the dimensions of a single patch

[81] E. Pittella et al., "Reconfigurable S-band patch antenna system for cubesat satellites," in IEEE Aerospace and Electronic Systems Magazine, vol. 31, no. 5, pp. 6-13, May 2016.

[82] E. Pittella et al, "Reconfigurable S-Band Patch Antenna Radiation Patterns for Satellite Missions," 2018 5th IEEE International Workshop on Metrology for AeroSpace (MetroAeroSpace), 2018, pp. 651-656.

have been computed first analytically, and then they have been optimized with MWS to achieve the best matching (S11 < -10 dB@ at 2450 MHz). Then, in a second phase, four identical patches are simulated, changing the phase of the feeding signals achieving different radiation patterns and different polarization of the antenna. As future development, using the PLA filament (Filoalfa©) for the substrate and conductive filaments[83] for the metallic part, the antenna system prototype will be manufactured and tested using a 3D printer, as for example the Raise3D Pro2 dual extruder printer[84].

Space Technologies (Part II)

Session Chair : Dr. Athanasios Dafnis, RWTH Aachen, Germany

PERIOD – PERASPERA In-Orbit Demonstration toward the transition into the in-space services, assembly and manufacturing paradigm

Mr. Stéphane Estable (Airbus Defence & Space), *Annelies Ampe, Apostolos Chamos, Gwenaelle Aridon, Daniel Silveira, Francisco Javier Colmenero Lechuga, Isabel Soto, Jeremi Gancet, Mark Shilton, Marko Jankovic, Torsten Vogel*

Space robotics technologies are maturing, bringing new capabilities for In-orbit Services, Manufacturing and Assembly (ISMA). These capabilities will generate on-orbit services improving the orbital infrastructure, creating in turn a very promising business opportunity in terms of market volume. The establishment of a European capacity is necessary for building this new space infrastructure and to capture a fair part of this market. The concrete objectives of the PERIOD project are focusing on the main levers to generate the capabilities, which are the further maturation of the space robotics technologies and the definition of an in-orbit demonstration to be implemented as soon as 2026. In the frame of the PERASPERA Strategic Research Cluster (SRC), key enabling products have been selected for technology maturation aiming at an increased technology readiness level (TRL). In support of the PERIOD activities, ESROCOS, ERGO and InFuse will be developed to TRL5 after an alignment of their perimeter to the demonstration objectives. The Standard Interconnects (SI), already at TRL5 at project start, will be tested in a benchmark for evaluating their performance. These SRC building blocks will be integrated in a breadboard at Airbus for supporting the system definition work. The PERIOD Consortium bringing together the competencies of Airbus Defence and Space, DFKI, EASN-TIS, GMV, ISISPACE, SENER Aerospacial and Space Application Services is proposing a very ambitious demonstration scenario and Factory concept. A satellite will be manufactured in an Orbital Factory to be designed in the study at SRR level and injected in LEO for operations. The manufacturing includes the fabrication of an antenna, the assembly of the satellite components and its reconfiguration and inspection in the Factory. Throughout the demonstration mission, the PERIOD facility will be upgraded to extend the level of capability validation from assembly and manufacturing of structures to attachment and refuelling experiments. Dissemination activities will maximize the impact of the project toward the Space Community. This demonstration covers the short and mid-to-long term ISMA business cases and will support the transition into the in-space services, assembly and manufacturing paradigm.

[83] https://www.multi3dllc.com/
[84] https://www.raise3d.com/pro2/

Fully Modular Robotic Arm Architecture Utilizing Novel Multifunctional Space Interface

Mr. Christopher Zeis (Institute of Structural Mechanics and Lightweight Design, RWTH Aachen University)*, K.-U. Schroeder, C. A. de Alba-Padilla, B. Grzesik, E. Stoll*

With increasing demand and research progress in the field of on-orbit-servicing (OOS) and on-orbit-assembly (OOA), robotic systems for space applications become more and more important. They are currently used for a variety of operations, such as docking assistance, support of extra-vehicular activities (EVA) and maintenance tasks. The study of robotic systems for OOS and OOA capabilities has been subject of many research activities. The current paradigm is the design of specialized robotic manipulators to meet the requirements for a specific mission profile. This research aims to develop a novel concept of a modular robotic manipulator for multi-purpose and multi-mission use that can be reconfigured for specific tasks. The overall approach for the developed robotic system is based on a modularized manipulator, where each module contains one rotational joint. All modules are identical in design. Each joint´s, rotation axis is tilted under an angle of 45 degrees to the adjacent links´ normal axis. Thereby the need for different types of joints is eliminated and the complexity of the system is reduced. Furthermore, this concept requires less stowage space compared to a traditional joint configuration. The modular approach offers several advantages. A manipulator can be reconfigured in orbit by adding or removing modules, resulting in modification of the degrees of freedom (DOF) as well as the operational range. The modular design allows for utilization of a variety of end effectors and tools. Another advantage is the implementation of redundancies in the system. In case of failure, one defect module may be removed from the configuration and the manipulator can continue operation with reduced DOF. Each module of the developed manipulator consists of one rotational actuator with adjacent tubular link structures on each side. Attached to each end of the module is a multifunctional interface, the iSSI (intelligent Space System Interface). It provides mechanical coupling as well as power and data transfer between the modules. Hence, the robotic manipulator is formed by serial connection of the number of modules in need via the iSSI interfaces. With each additional module the arm gains one DOF. The iSSI serves as interconnector between the modules and can act as an end effector as well. It also serves as an attachment point for other end effectors or tools and as mounting point between the robotic manipulator and a servicer satellite bus. This paper outlines the overall concept of modularization of a robotic arm. The development and mechanical design of a full-size on-ground demonstrator based on the iSSI-interface with four DOF is presented. Additionally, a smaller variant of the modular robotic system is presented, which can be stowed in a cubesat-sized environment. Due to its high number of DOF it can avoid obstacles and operate in spaces with limited accessibility. Hence, it is dedicated for tasks like inspection and delicate repairs. In the case of a modular robotic manipulator of this magnitude, additional design challenges are faced due to very limited integration space for mechanical and electrical components. Finally, a sample application scenario of the integrated full-size demonstrator with detachment and reattachment of modules via the iSSI interface is shown to prove the feasibility of the modular concept. An outlook to further research potential and future use cases for the modular robotic system is given.

Achieving Payload and AIT Flexibility by Separating Satellite Bus and Payload Unit

Thomas A. Schervan (RWTH Aachen University, Germany)*, Nima Jafarzadeh Aghdam, Christopher Zeis, Kai-Uwe Schröder, Daria Stepanova, Pouya Haschemi, Shahrokh Khodabakhshi*

The CubeSat standard drastically reduced space mission costs and makes satellites affordable and feasible for small business and universities. This results in a worldwide development of an unprecedented variety

of different payloads for both research and commercial purposes. In addition to that the past years show a shift of focus from one of a kind satellite, either prototype or small series designs with lot sizes below 50 units, like most global positioning systems GPS, Glonass and Gallileo, to large-scale productions with thousands identical satellites This type endeavors promoting large-scale production are driven by new space companies like SpaceX, Amazon an OneWeb with their mega constellations Starlink, Project Kuiper and OneWeb, manufacturing and launching thousands of small satellites in to Earth orbit in the last years. This development demands rethinking the established satellites designs. For a future economic design, a satellite system architecture must be developed and established which offers real series manufacturing readiness in combination with high system reliability and flexibility over the full path of the assembly, Integration and Test (AIT) process. This is one of the main goals within the SLOTD4.0 project, funded by the German Federal Ministry for Economic Affairs and Energy and administrated by the German Aerospace Center (DLR) Space Administration. This paper introduces and describes the developed SLOTD40 satellite architecture and design philosophy allowing to combine a distinct satellite bus with multiple different payloads integrated into a standardized 8U payload bay using a universal interface, providing a flexible mechanical, power and data connection. The focus of this paper lies on presenting the structural design considerations and AIT benefits of this payload unit, its mechanical analysis and test specifications. The payload unit is developed by the Institute of Structural Mechanics and Lightweight Design of the RWTH Aachen University in collaboration with the project partners from German Orbital Systems (GOS) and HOSTmi, responsible for developing the distinct satellite bus respectively providing insight into the needs of the payload market and the right choice of a representative reference payload.

Structural Design of a reusable microlauncher first stage

Mr. Marco Kanngießer (Institute of Structural Mechanics and Lightweight Design, RWTH Aachen), *Stefano Piacquadio, Panagiotis Trifa, Dimitrios Rellakis, Georgia Psoni, Marco Nebiolo, Stefano Ferroni, Athanasios Dafnis*

The rise of small satellites is changing the satellite industry. At the same time, micro-launch vehicles have significantly higher launch costs per kilogram than ride-sharing on large launch vehicles. Technological development and reusability are fundamental steps to reduce launch costs and thus improve access to space. The RRTB project, funded by the EU Horizon 2020 program (GA 870340), aims to develop a unique and novel solution to provide customized service for access to space for the micro satellite market. The first stage of a vertically launching rocket is designed to be reusable following a hybrid re-entry strategy. Here a combination of a parachute and a new type of horizontal landing technique using electrically driven fans provides a precisely controlled and safe landing. The vehicle's first stage is designed to achieve a minimum reuse of 10 times, which means that special attention must be paid to both the vehicle's primary structure and the required thermal protection systems (TPS). Both have to withstand the loads imparted on the vehicle during the mission as well as to provide accessibility for post-flight refurbishment and inspection. The lightweight potential of the load-bearing structure of the rocket is of particular importance in the context of a minimum launch mass. Due to the reusability and the novel landing strategy the structural design of the first stage presents a different approach compared to conventional launcher structures and introduces new unique design challenges and structural solutions. In terms of reusability, a fail-safe design philosophy for several important structural parts is pursed. In this paper the preliminary structural design process is described and the individual lightweight design concepts for the stiffening structure of the first stage are compared in order to assess the lightweight potential of reusable micro-launchers with additional landing systems.

Presentation of the MoonFibre Project: Recent Developments

Mr. Alexander Niecke (Institut für Textiltechnik RWTH Aachen University), *Stephan Kalapis, Tobias Meinert, Alexander Lüking, Thomas Gries, Kai-Uwe Schröder*

The in-situ process utilisation (ISRU) is a crucial process for establishing sustainable and low-cost buildings on the moon. Here, the local resources are used and processed into structures, decomposed into gas or water is extracted. The ideal ISRU-process does not need additional supplements to work. At RWTH Aachen, the MoonFibre group aims to build such an ISRU process. In this process the local regolith of the moon is transformed into fibres, while only energy from the sun is needed as supplement. These fibres can be used for all fibre-based purposes. This advantageous process makes it possible to produce on site on the Moon, avoiding costly transportation by sounding rockets. Since the main process is already working, the focus for future work is on miniaturizing the process and making it robust to the harsh conditions on the lunar surface. To ensure autonomous operation on the lunar surface, engineering challenges must be overcome. The MoonFibre project is presented here with its aims and goals. The roadmap of the project will be shown and achieved milestones further investigated. The future milestones will be discussed while recent developments are presented.

R&D Research in the Field of Aeronautics & Air Transport: ACACIA, ClimOP, GREAT, ALTERNATE Joint Session

Session Chair : Mr. Michael Finke, DLR, Germany

ACACIA: Developing improved understanding on aviation's climate impact

Dr. Sigrun Matthes (DLR Institute of Atmospheric Physics), *Klaus Gierens, ACACIA Team*

Non-CO2 emissions of aviation may impact climate as much as aviation's carbon dioxide (CO2) emissions do. However, the impact the non-CO2 effects, comprising e.g., ozone and methane induced from NOx emissions, together with contrails, or the indirect aerosol effects, is associated with much larger uncertainties. The research project ACACIA (ADVANCING THE SCIENCE FOR AVIATION AND CLIMATE) explores the climate impacts of non-CO2 effects which show a strong dependence on atmospheric conditions and synoptic situation; hence they depend on location and time of aviation emissions. While CO2 and non-CO2 effects in general introduce a warming effect for climate change, some indirect effects might result in a relatively large cooling. The EU Aeronautics project ACACIA has set out four dedicated aims for scientifically based and internationally harmonised policies and regulations for a more climate-friendly aviation system:

(1) ACACIA improves scientific understanding of those impacts that have the largest uncertainty, in particular, the indirect effect of aviation soot and aerosol on clouds.
(2) ACACIA identifies needs for international measurement campaigns to constrain our numerical models and theories with data and we will formulate several design options for such campaigns.
(3) ACACIA is putting all aviation effects on a common scale will allow providing an updated climate impact assessment. Uncertainties will be treated in a transparent way, such that trade-offs between different mitigation strategies can be evaluated explicitly.
(4) ACACIA provides the knowledge basis and strategic guidance for future implementation of mitigation options, giving robust recommendations for no-regret strategies for achieving reduced climate impact of aviation.

Particular attention in ACACIA is paid on those aviation climate impacts which have a large uncertainty, e.g. the indirect aerosol effect with its very large uncertainties. Additionally, ACACIA will reconsider the effects of gaseous aviation emissions, in particular non-linear processes of NOx, on atmospheric chemistry and the resulting climate effects. Key here is the provision of robust recommendations considering uncertainties of individual estimates. Particular attention in ACACIA is paid on those aviation climate impacts which have a large uncertainty, e.g. the indirect aerosol effect with its very large uncertainties. Additionally, ACACIA will reconsider the effects of gaseous aviation emissions, in particular non-linear processes of NOx, on atmospheric chemistry and the resulting climate effects. ACACIA explores to what extent strategic recommendations on operational concepts and design paths have the potential to reduce aviation climate impact by collecting information on uncertainty of key processes. Here, we are working on a concept for measuring and providing information on robustness of solutions; investigating and combining sources of uncertainty of involved processes and key parameters, e.g. by Monte Carlo method. Based on comprehensive assessments involving trade-offs and interdependencies identified, a variation of key parameters is used to estimate identified uncertainties, in order to work towards decision-making under uncertainty conditions. Such assessments allow formulating recommendations on mitigation strategies which satisfy robustness criteria as required for green trajectory planning. Strategies involve,

e.g. identification of those weather conditions which show a large and robust mitigation potentials, as well as a risk analysis in terms of aviation climate impacts. To this end, ACACIA brings together research across scales (from plume to global scale), from laboratory experiments to global models, and it proceeds from fundamental physics and chemistry to the provision of recommendations for policy, regulatory bodies, and other stakeholders in the aviation business. One element in this comprehensive approach is to design nNovel field experiments in order to close knowledge gaps and to allow proof of concepts for climate-optimal routing. ACACIA will cooperate with international partners, both research institutions and organisations. Additionally, ACACIA seeks for synergies with EU partner projects: ALTERNATE (Assessment on aLTERNative AviaTion fuEls development), ClimOp (Climate assessment of innovative mitigation strategies towards operational improvements in aviation), and GREAT (GREener Air Traffic operations). ACKNOWLEDGEMENTS: This project ACACIA receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 875036. Work for this contribution was supported by DLR project Eco2Fly (2018–2022). High performance supercomputing resources were used from the German DKRZ Deutsches Klimarechenzentrum Hamburg.

Non-CO2 Impacts of Aviation

Ms. Nadja Omanovic (ETHZ), *Colin Tully, David Neubauer, Ulrike Lohmann*

Aircraft emissions increased in the last 30 years, and are expected to rise even further in the coming decades. Yet, the formation of aircraft-induced clouds in high altitudes and their impact on Earth's climate is poorly understood. Especially the radiative forcing of aircraft-induced clouds is of high interest because of their potential warming impact on our climate, but no unambiguous answer can be given. They may have similar characteristics to their natural counterparts, i.e. natural cirrus clouds, which are known to exert a positive radiative forcing, i.e. a warming effect. Overall, the impact of aircraft emissions on cloud formation involves microphysical properties, such as the nucleation and growth modes in these clouds, and radiative properties, that warm or cool our climate. Here, we show through a series of sensitivity tests with a global aerosol-climate model using observed meteorology how soot emissions influence the competition of different ice nucleation processes and how this further impacts ice cloud properties. We find that including aircraft emissions in our simulations, in particular soot, causes a positive radiative forcing of 0.02 ± 0.34 Wm-2, highlighting the potential warming impact of non-CO2 aviation emissions on climate. Enabling soot to act as an ice nucleating particle increases heterogeneous nucleation, while reducing homogeneous nucleation. This confirms our knowledge of the competition between different ice nucleation modes in cirrus clouds. The impact of aviation is only weakly notable in slight changes of various cloud properties. Nevertheless, our findings agree well with the literature using latest observational and model data. Increasing our understanding of the climate impacts of aviation could lead to an additional mitigation strategy to constrain the increase in global temperature.

Occurrences of natural and contrail cirrus and their microphysical properties observed from in-situ measurements

Ms. Yun Li (Forschungszentrum Juelich GmbH), *Christoph Mahnke, Susanne Rohs, Andreas Petzold and Martina Krämer*

The aviation industry has been prospering before the severe strike by the Covid-19 pandemic. Global aviation is estimated to account for about 4.5% by 2018 of the net anthropogenic effective radiative forcing (~2.3 Wm-2, IPCC AR5), with the largest uncertainty in the contribution of contrails and contrail cirrus. One mitigation option of aviation's effects on climate is to reduce the cloudiness induced by

contrails and contrail cirrus through slightly changing flying coordinates. The occurrence of contrails and contrail cirrus depends largely on environmental conditions, such as relative humidity, air temperature, ambient pressure, etc. But without knowing the favorable atmospheric conditions of contrails and contrail cirrus formation, it is impossible to provide guidance for such a mitigation plan. In this context, we searched in the data set of the airborne ML-CIRRUS field campaign performed out of Oberpfaffenhofen, Germany, in 2014. This data set contains water vapor and cloud measurements from research flights dedicated to study contrails ad contrail cirrus in one of the busiest air traffic regions – the North Atlantic flight corridor. Using the Schmidt-Appleman criteria, that determines whether the environmental conditions favor the formation of contrails, together with statistical methods, we are able to, by far the best, identify the spatial occurrence of contrail cirrus and separate them from natural cirrus based on their microphysical properties. We find that contrail cirrus clouds appear most likely in the pressure range of 215-245 hPa at the cruising altitude and in sightly subsaturated to supersaturated regions instead of merely supersaturations as believed hitherto. Also, we confirm that contrail cirrus tends to contain more ice particles than natural cirrus, but that natural cirrus has a higher ice water content and larger mean ice crystal sizes. In conclusion, the differences in the microphysical properties of contrail cirrus and natural cirrus enable us to find patterns in the occurrence of contrails and contrail cirrus and avoiding the most probable environment conditions to form them will help to realize the mitigation of aviation's climate impact. [Note: This work is carried out under the frame of EU H2020 Research and Innovation Action "Advancing the Science for Aviation and Climate (ACACIA)", Grant Agreement No. 875036.]

ClimOP Project – Climate assessment of innovative mitigation strategies towards operational improvements in aviation

Mr. Patrick Peter (DLR), *Sigrun Matthes, Volker Grewe and ClimOP Team*

Air Transport has for a long time been linked to environmental issues like pollution, noise and climate change. The share of aviation amongst all anthropogenic emissions is about 3-5%. Considering the projected growth of air traffic for the next decades, aviation's share of the total anthropogenic climate impact is expected to increase further. While CO2 emissions are the main focus in public discussions, non-CO2 emissions of aviation may have a similar impact on the climate as aviation's carbon dioxide, e.g. contrail cirrus, nitrogen oxides or aviation induced cloudiness. These non-CO2 effects are highly variable in their occurrence, with a strong spatially and temporally variation, while acting on short- and long-term atmospheric time horizons. Reducing these non-CO2 effects can be exploited to significantly reduce the overall climate impact of aviation by avoiding regions with high climate sensitivity. The ClimOP project, funded by the Horizon2020 programme, investigates which operational improvements do have a positive impact on climate, taking non-CO2 effects into account. Subsequently, the project will analyses and will propose harmonized mitigation strategies that foster the implementation of these operational improvements. Some of these operational improvements include optimization of flight network operations, climate-optimized flight planning or upgrades to the airport infrastructure. The final goal of ClimOP is to provide recommendations to steer the decision and policymaking in the European Union (EU) Aviation sector. To reach this goal, ClimOP employs a six-step methodology that focuses on stakeholders' needs by using an iterative validation process. To this end, the ClimOp consortium builds on its knowledge and expertise covering the whole spectrum from aviation operations research as well as atmospheric science and consulting to airline and airport operations. The research work presented here focusing on further developments of methods used for identifying climate optimized flight trajectories. We investigate what physical processes are responsible for the climate impact of contrails, their spatial and temporal

variation and explore how can such information be efficiently made available for operational climate mitigation options and trajectory optimizations. In order to study the physical processes resulting in the climate impact of contrails we use the global Earth System model system called Modular Earth Submodel System (MESSy) and the Earth-system model EMAC, which contains various sub-models. This model is employed to calculate the atmospheric impact of standardized air traffic emissions at predefined latitudes, longitudes, altitudes and times. In this framework, numerical simulation on Lagrangian trajectory transportation are performed. The presentation will give an overview of the current status and achievements of the ClimOP project and in addition conceptual developments within the modular Earth system model EMAC will be highlighted. ACKNOWLEDGEMENTS: This project has received funding from European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N° 875503.

The analysis of NOx-ozone effects from optimised air-traffic using algorithmic climate change functions

Mr. Pratik Rao (Delft University of Technology), *Feijia Yin, Volker Grewe, Hiroshi Yamashita, Patrick Jöckel*

The aviation industry is an essential contributor to total anthropogenic climate change, and the ever-growing demand for air transport requires serious attention. While efforts have been made to curb CO2 emissions, non-CO2 effects that are even more significant according to recent research have not been given enough attention. The EU Horizon 2020 project ClimOp steps in to follow a more holistic approach to tackling the climate impact of aviation using novel operational measures. One such measure is climate-optimised flight planning, where small deviations can be made in aircraft trajectories to minimise their overall climate impact. In order to achieve this, algorithmic Climate Change Functions (aCCFs) are used to estimate the climate impact of local non-CO2 effects such as Nitrogen oxide (NOx) emissions (via Ozone formation and Methane depletion), aviation water vapour, and contrails by using meteorological inputs directly. By plugging these functions directly into an aircraft trajectory optimisation module, climate sensitive regions are detected and avoided leading to climate optimised trajectories. While a preliminary verification conducted specifically for NOx-ozone aCCFs showed positive signs, this research entails a more detailed verification procedure, which provides a deeper insight into its capability in predicting the impact of aviation NOx emissions on atmospheric changes in ozone. Air traffic simulation is performed concerning a subset of one-day European flights on the specifically chosen days characterised by high variability of NOx-ozone aCCFs. The air traffic on these days is optimised for cost and climate. A subsequent chemistry simulation captures the NOx effects from these re-routing procedures, and the climate impact of both scenarios can thereby be directly compared. It is expected that the results will confirm the effectiveness of NOx-ozone aCCFs in producing climate-friendly trajectories.

Remotely Piloted Aircraft Systems: SESAR Joint session of INVIRCAT, URClearED, CORUS-XUAM, PJ13 & SAFELAND projects

Session Chair : Ms. Nil Agacdiken, SESAR Joint Undertaking

INVIRCAT – A concept of operations to efficiently integrate IFR RPAS into the TMA

Mr. Florian Löhr (DLR)

INVIRCAT is a European project co-funded by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme (GA No. 893375), which is dedicated to developing means for a safe and efficient integration of RPAS (Remotely Piloted Aircraft Systems) into the existing Air Traffic Control (ATC) procedures and infrastructures within Terminal Manoeuvring Areas (TMA) under Instrument Flight Rules (IFR). The 30 months project (01.07.2020 – 31.12.2022) has produced an initial concept of operations for remotely piloted aircraft systems in the TMA of airports, which will be assessed and validated through a set of human-in-the-loop simulations. INVIRCAT focusses on the influence of RPAS specific challenges, such as latency and failure of the voice and command and control links, on human factor aspects of air traffic controllers and remote pilots and investigates possible mitigations, such as the use of automatic take-off and landing systems and predetermined contingency procedures. Thereby, INVIRCAT considers different RPAS types, from MALE/HALE configurations to retrofitted airliners used for cargo operations and an operational environment in which multiple RPAS at a time share the airspace of the TMA with manned aircraft.

URClearED – A well clear concept for integration of certified RPAS in airspace classes D-G

Mr. Gianluca Corraro (Centro Italiano Ricerche Aerospaziali)

Nowadays the full integration of Remotely Piloted Aircraft Systems (RPAS) into civil airspace is subject to various regulations issued by aviation authorities, primarily to increase safety. In this framework, the Detect and Avoid (DAA) technology represents a key enabler for RPAS integration into controlled and uncontrolled airspaces. A DAA system supports the remote pilot (RP) in the resolution of potential conflicts by means of a Remain Well Clear (RWC) function that operates on the long mid-term, and a Collision Avoidance function that operates in the short term as a last resort in case of loss of well clear. In this scenario, the URClearED project, co-funded by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme, aims to support and complement other SESAR European initiatives related to the development of a DAA system, by performing relevant steps to define the requirements and capabilities for the RWC function to be integrated in RPAS flying under instrument flight rules into airspace classes D-G.

URClearED considers the challenges of operations in airspace classes D-G characterized by small and medium-sized aircraft, equipped or unequipped (i.e. without any transponder on-board), covering a wide range of aircraft performance, flying under visual or instrument flight rules with or without air traffic services availability. An overview of the URClearED project and its current state will be presented, highlighting the process that has allowed to identify the functionalities and the architecture of the RWC proposed solution and that of related DAA functions needed for its exploitation, such as the RP human machine interface.

CORUS-XUAM: tackling the airspace integration challenges of Urban Air Mobility

Mr. Giancarlo Ferrara (EUROCONTROL), Mr. Andrew Hately (EUROCONTROL), Mr. Giovanni Riccardi (ENAV)

Over the last century, the development of the aviation industry has fundamentally changed the way we live, work, and travel, and aviation has not stopped innovating during this time. In the last few years, new types of aircraft have started to be developed, including Unmanned Aircraft Systems (UAS or drones) and Urban Air Mobility (UAM) aircraft. With the development of these new aircraft types, aviation is once again taking a significant step forward. UAM refers to an ecosystem that enables on-demand, highly automated, passenger or cargo-carrying air transport services, with particular reference to the urban and sub-urban environments, where aviation is often highly regulated today. The UAM industry's vision involves new vehicle designs, new system technologies, the development of new airspace management constructs, new operational procedures and shared services to enable an innovative type of transport network. The CORUS-XUAM research project will demonstrate how U-space services and solutions could support integrated UAM flight operations, allowing air taxis, drones and other airspace users (unmanned and manned) to operate safely, securely, sustainably and efficiently in a controlled and fully integrated airspace, without undue impact on operations currently managed by air traffic management (ATM). The project is being undertaken by the consortium that delivered the SESAR JU-funded CORUS U-space Concept of Operations (ConOps) in 2019, extended by the addition of UAM expertise.

CORUS-XUAM activities started with updating of the U-space ConOps, addressing the integration of UAM and drone operations into the airspace, as well as identifying new U-space-phase U3 and U4 services. The project's activities will continue with the preparation and execution of six challenging Very Large Scale Demonstration (VLD) campaigns in Belgium, France, Germany/UK, Italy, Spain, and Sweden. These VLD activities will be at the core of the CORUS-XUAM project. They will demonstrate integrated UAM, drone and manned aircraft operations, through advanced forms of interaction using digital data exchange, supported by integrated and advanced U-space services in urban, sub-urban, and inter-city scenarios, as well as in and near ATM-controlled airspaces and airports. The VLDs will focus on different types of mission, such as passenger transport, logistics, delivery, emergency response and surveillance, using different U-space deployment architectures and state-of-the-art technologies. They will consider coordination between ATC and U-space, including interaction with air-traffic controllers and pilots. The VLDs will combine flights by air taxis with other traffic and operations in the control zones (CTR) of major airports. Vertiport procedures, separation, and data services will be also demonstrated. The main results of CORUS-XUAM will be used to further consolidate the ConOps at the end of the project. The project will also involve extensive consultation and communication initiatives involving authorities, U-space stakeholders and end-users. Innovative ATM/U-space services and the development of smart, automated, interoperable, and sustainable traffic management solutions will be key enablers for achieving the high level of integration needed to make urban air mobility a reality. These challenging objectives can only be achieved through an evolutionary development process ensuring the definition and timely deployment of appropriate, advanced and interoperable ATM/U-space infrastructure, technology, and traffic management capabilities, providing advanced services that fit with expected types of operation and levels of demand. The CORUS-XUAM project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 101017682.

The ERICA project: another step toward the integration of RPAS into the civil airspace

Mr. Ermanno Girardelli (Leonardo S.p.A.)

In the frame of the SESAR programme, the ERICA project aims to define the operational and technical capabilities that will allow remote piloted aircraft systems (RPAS) to operate in controlled airspace safely, during nominal and emergency conditions. In particular, ERICA aims at providing the basis for defining, developing, and validating the key operational and technological enablers that are necessary to assure the proper insertion of RPAS into non-segregated airspace. The objective is being pursued in three parallel steps, starting from the development and validation of a detect and avoid (DAA) system for safer operations by preventing collisions. The project activities cover two timeframes, with the first accommodating the initial RPAS demand in the short/medium term, establishing harmonised procedures across low/medium density and low/medium complexity European airspace. The second timeframe addresses the full integration of civil and military RPAS, in the longer term, enabling their deployment in a cooperative environment in full integration with the manned aviation. Coordinated by Leonardo, the consortium involves 20 beneficiaries from 12 countries across Europe. By enabling the integration of RPAS into controlled airspace, the project will pave the way for the development of recognised European RPAS operations in non-segregated airspace, enabling civil and military RPAS, in particular fixed wing platforms, to operate mixed with manned traffic under the Single European Sky. These activities also contribute to regulatory and standardisation processes, in order to assure interoperability with air traffic management (ATM) systems within and outside Europe. The smooth integration of RPAS in controlled airspace will also help foster new market perspectives and ultimately new services to the community. The project has received funding from the SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme under grant agreement No 874474.

SAFELAND: managing in-flight incapacitation in single pilot operations

Dr. Stefano Bonelli (DeepBlue)

A major challenge for the implementation of single pilot operations (SPO) in commercial aviation is how to deal with the potential risk of in-flight pilot incapacitation. The SAFELAND project aims at providing a conceptual approach to support flight and landing of a SPO aircraft in case the single pilot on-board becomes incapacitated during the flight, including a specific focus on the ATM side. The concept considers the interaction of a ground-based pilot operating through a remote cockpit position with onboard automation and air traffic controllers to manage the flight, specifically detailing the envisaged operating methods allowing the transition from single piloted aircraft to Remotely Piloted Aircraft (RPA). A description of the foreseen operational processes and procedures is provided, detailing required technical characteristics, tasks distribution and function allocation between the involved actors.

Innovative applications of drones: Drones4Safety, Labyrinth, 5D-AeroSafe & RAPID joint session

Session Chair : Dr. Damiano Taurino, DeepBlue, Italy

EU project Labyrinth (Unmanned Traffic Management 4D Path Planning Technologies for Drone Safety and Security in Transport EU project Labyrinth

Mrs. Garbiñe González (innCome)

The main objective of the EU project Labyrinth (Unmanned Traffic Management 4D Path Planning Technologies for Drone Safety and Security in Transport) is to create and validate new swarm drone applications to enhance safety, security and efficiency in the civil system transport, through the research and development of drone swarming 4D path-planning algorithms -for implementation in Ground Control Stations- and new U-space services supporting drone swarms auto-guidance. The project aims to eliminate the need for drone pilots in controlled environments to fly swarms of up to 10 drones through a new autopiloted technology and to validate drone swarm pilot services in different transport related scenarios: seaport, road traffic transport surveillance operations, airport scenario and emergency assistance operations in urban areas. This will achieve progress in accelerating the European Union's regulatory adaptation and public acceptance of drone services. The objectives of the project include the aim to develop technologies to create an autonomous aerial traffic control system that will involve the research on: i) 4D path planning algorithms; ii) U-SPACE system, iii) 5G communications for real-time transmission of data among the drones and the control station and iv) developing cybersecurity technologies for both communications and cloud platform in order to assure the whole solution integrity and protection against external attacks. These objectives constitute the backbone of the project and are organized around four main tasks:

- Multidrone path planning and path control
- 5G communications
- Cybersecurity
- U-Space and UTM/Ground Control Station

From the analysis of the type of missions, different end users may require from an UAV fleet the individual operation or the operation in coordinated formations. In the project it is assumed that it can operate with Fixed Wing or Multirotor UAVs with different specifications. From this analysis a set of basic missions that can be executed individually or in formation has been defined. This basic set of missions is used by the system to plan the UAV paths. Different basic path planning strategies have been defined according to the mission and the UAV type and are under development (level imposed, free flying tubes and coverage path planning) with different and increasing level of coordination at path planning. The basic path planning technology to be used is Fast Marching 2 (FM2) and it will let to provide 4D paths for the UAVs. For the path control aspects an automatic flying level imposition is being developed to order the UAV traffic and limit the potential conflict in a way that it can be easily managed/deconflicted or in case of free flying tubes to eliminate a wide part of the potential in-flying conflicts. The main communication technology of the UAVs has been decided to be based on 5G solutions. It implies not only that the access radio technology will be based on cellular communications (5G where available) but also that the system will make good use of 5G achievements in the network layer architecture, integrating solutions (like the NFV, Network Function Virtualization or SDN, Software Defined Networks), that will allow a fast deployment of

value-added services in the drones together with a better control of the network management and applications traffic (including navigation data, video streaming, voice data, etc.). The UAVs are expected to include additional network interfaces other than the cellular ones like WiFi interfaces to facilitate potential device to device communications, to eventually enable wireless access points for end users or to extend the cellular network when it is unavailable, or its capacity is insufficient. Other interfaces like satellite ones have also been considered and in general the communication architecture will be able to manage this multi-access feature. Finally, the task of implementing the UTM system has recently started. While the Labyrinth initial goals are mainly concerned with the trajectory planning service, at UTM we will try to build a U-space system as close as possible to one providing the services for U3 Z volumes in the ConOps categorization. This implies many other services, some of which cannot be implemented yet; some of them would deserve a project per se, others require information that is not yet available. Therefore, we will try to implement some key services, setting up the building bricks of a system that will evolve as the U-space standards are defined and the required services become available.

Partners: Technological/industrial: EXPACE, TID; Scientific: DLR, INTA, AIT, UC3M; End users: ADSPMLO, DGT, SAMUR; Consulting partners: PONS, INN and Implementation enabler partners: ECTL, DIN EXPACE, TID, DLR, INTA, AIT, UC3M, ADSPMLO, DGT, SAMUR, PONS, INN, ECTL, DIN.

Towards Validation of Drone Embedded "Sense and Detect" Hazard Perception

Mr. James Riordan (University of the West of Scotland)

Early warning systems are essential for disaster prevention, especially concerning transport system infrastructure where it is known that statistically 1 in 10 bridges are classified as high risk of collapse due to undetected structural deterioration. The EU-funded RAPID project will combine and extend drone technology to deliver an automated and scalable maintenance-inspection service for bridges, ship hull surveys and more. Specifically, the service will combine self-sailing unmanned surface vehicles with autonomous unmanned aerial systems (drones). The aim is to reduce the time and cost of structural condition monitoring of maritime transport infrastructure and thus remove people and workers from dangerous situations. While drones are seen as the most promising candidate solution, their current modes of operation are hyper localised, requiring manual close-quarter piloting, observation, and hazard detection. The full potential socio-economic benefits of drones will only be realised when they are capable of autonomous operations beyond visual line of sight (BVLOS), unlocking the scale and reach to deliver high-value services on demand. However, fully-autonomous and/or BVLOS UAV operations may only be achieved when drones are able to comply with the requirements to sense, detect, and avoid other aircraft, and ground and air collision risks. Current aviation platforms support flight planning by aggregating known factors such as air exclusion zones and ADS-B airspace tracking data with 3D annotated maps. However, the capability to detect unpredictable and uncooperative small objects with fast-changing and unscheduled trajectories in complex urban industrial environments remains an unmet prerequisite. Since drone and future urban air mobility vehicles operations will largely be performed at low altitudes and in unsegregated airspace, this non-stationary requirement is extended to 'detect and avoid' other drones, and in cluttered and densely populated built environment situations. To enable its maintenance-inspection ambition, the RAPID project is focused on developing the safety assurance frameworks to enable rigorous validation testing and future certification of drone risk management systems, including autonomous and BVLOS sense, detect, and avoid systems. Leveraging theatre level Digital Twinning, strategic and tactical hazard mitigation software is being developed to predict the accuracy and confidence of air-air collision risk detection such that vulnerability discovery, explainability, and safety

intelligence become integral parts of pre-flight planning and approval. RAPID will improve strategic and tactical air and ground hazard detection through software acceleration, continuous delivery and automation of machine learning pipelines, and scenario digital twinning to achieve a high-accuracy real-time generalised model of drone cognitive sensing. The project aligns with the ISO/IEC 25000 family of standards for software product certification, EASA Artificial Intelligence roadmap 2020-2025, and the UK Aerospace Technology Strategy by advancing and validating autonomous systems for efficient and safe air transport and services in urban and sub-regional airspace. It will develop risk assessment as a service to improve the Specific Operational Risk Assessment required for BVLOS flight approval from national flight authorities. The ground service will provide a validation framework oriented towards compliance and certification of perception and decision-making AI, which will be validated in the relevant real-world use case of maintenance inspection of transport infrastructure in the Port of Hamburg in 2023.

Inspection Drones for Ensuring Safety in Transport Infrastructures

Mr. Emad Samuel Malki Ebeid (SDU)

H2020 Drones4Safety project aims at building a cooperative, autonomous, self-recharging, and continuously operating drone system for autonomous, accurate and frequent inspections of transport infrastructures. The project uses satellite and open maps and develops and improves artificial intelligence (AI) algorithms to optimize the inspection results. In addition, it utilizes the energized powerline infrastructures to recharge the drones autonomously. This system will be made available to railway and bridge operators to remotely monitor the status of their infrastructures and notifying them if a fault is detected. The speech will give an overview of the project and explore the latest drone system design and developments in it with an emphasis on the core Hardware/Software architecture, sensor selections for cable detections, and algorithms for disturbance rejection.

Applications offered by 5D-AeroSafe project for airports and waterways safety

Ms. Anna Nikodym-Bilska (Air Force Institute of Technology), *Philippe Chrobocinski, Effie Makri*

H2020 5D-AeroSafe project aims at developing a solution for the safe and efficient integration of UAS – Unmanned Aerial Systems in airport and waterway daily operations.

The project is focused on the solution which will be able to conduct Flight Inspections, i.e. inspections and calibrations on CNS (Communication, Navigation and Surveillance) systems and landing visual aids, safeguard airport restricted areas and also inspect runways and taxiways (and water runways) to detect Foreign Object debris or any other threat to aircraft movement on the ground (and water surface).

The speech will give an overview of the project and explore the concept which will allow the smooth operation and integration of UAS in Aerodrome ATM (Air Traffic Management) systems via the co-operation with UTM (Unmanned Aircraft System Traffic Management) Systems, enhancing mutual situation awareness.

Hybrid Electric Flight: PART I - Distributed propulsion

Session Chair : Prof. Teresa Donateo, University of Salento, Italy & Prof. Andreas Strohmayer, University of Stuttgart, Germany

Wing structural model for electric distributed propulsion GA/Regional aircraft

Raquel ALONSO-CASTILLA, ***Mr. Florent LUTZ (ISAE-SUPAERO),*** *Emmanuel BENARD, Joël JEZEGOU, Juan Pablo RUSCIO*

In the context of reducing the environmental footprint of tomorrow's aviation, Distributed Electric Propulsion (DEP) has become an increasingly interesting concept. With the strong coupling between disciplines that this technology brings forth, multiple benefits are expected on the overall aircraft design. These interests have been observed not only in the aerodynamic properties of the aircraft but also in structural design. However, current statistical models used in preliminary wing sizing were shown to have real difficulties capturing the benefits coming from these new design trends. This paper details a semi-analytical methodology compliant with the performance-based certification criteria presented by European Union Aviation Safety Agency (EASA) to predict the structural mass breakdown of a wing. This makes the method applicable to any aircraft regulated by the EASA CS-23. Results have been validated with a conventional double-engine aircraft, the Beechcraft 76 and an innovative concept using DEP, the X-57 Maxwell. Next, parametric studies are led to investigate different aircraft design choices. Finally, the integration of this methodology in an aircraft sizing analysis and optimization software program developed by ONERA and ISAE-SUPAERO called FAST-OAD-GA is briefly discussed.

Structural and aerodynamic analysis of wing distributed electric propulsion for potential wing replacement of conventional aircraft

Dr. Pavel Hospodar (Czech technical university in Prague), *Jan Klesa, Dan Demovic, Nikola Zizkovsky*

In this paper, an aerodynamic and structural computation framework is performed to develop a more efficient aircraft configuration by taking into account a wing with a distributed electric propulsion (DEP) system and its use in different flight missions. For that reason, a model of a regional airplane is used as a case study. The considered model is a nine-seat twin-engined light aircraft with cruise speed of 400 km/h at an altitude of 3000 m. The presented work is divided into three main parts. First is the aerodynamic design of the new wing with DEP system. There are computations included of different wing aspect ratios for two sets of airfoils and wingtip-mounted propeller optimization procedures are applied to minimize aerodynamic drag. These calculations take into account the drag of the existing parts of the aircraft such as fuselage, tail surfaces, and nacelles. A modified lifting line theory supplemented by blade element momentum theory is used for the investigation of propeller-wing aerodynamic interaction. This procedure is validated with CFD results and experimental measurements. The second part deals with weight estimation for considered wings. Flight envelope composite for gust and maneuver envelope is used to determine aerodynamic loads and velocities for structural design under CS-23 regulation. After that a geometry of spars, ribs and skin are estimated with buckling effect of full aluminium material consideration. Additional weights such as electric engines, controllers, batteries, power source of DEP system are calculated. The third and final part of the work is focused on flight performance and cost effectiveness analysis of calculated geometries. Different range and fuel consumption for the relevant wing is investigated to determine optimal results.

Energy consumption and environmental impact of urban air mobility

Prof. Teresa Donateo (University of Salento), *Luca Surdo, Antonio Ficarella*

Urban Air Mobility (UAM) is a recent concept proposed for solving the urban mobility problem, such as urban traffic pollution, congestion and noises. The goal of this investigation is to develop a backward model for an electric aerial taxi in order to estimate the electric consumption and the indirect emissions of carbon dioxide along a specified mission. The model takes as input the time histories of speed and altitude and calculates the forces acting on the rotorcraft in order to evaluate the power at the rotor shaft during the mission with a quasi-static approach. The shaft power is used as input for the electric drive where the motor is modeled with an efficiency map and a transfer function while the battery is modeled with an equivalent circuit model that includes aging effects. The emissions of CO2 are compared with that of a hybrid electric taxi performing the same mission with the same payload. The plug-in Toyota Prius is used as reference for the hybrid electric taxi and modelled through the software ADVISOR. After validating the model with literature data, a suitable route for the road taxi is developed assuming the same starting point and destination of the air taxi. The road route is assumed to performed in different kind of traffic conditions. The direct and indirect emissions of the Toyota Prius are then calculated and compared with that of the aerial vehicle.

Aeroelastic assessment of distributed electric propulsion wings

Dr. Vittorio Memmolo (University of Naples "Federico II"), *Aniello Daniele Marano and Fabrizio Nicolosi, and Leandro Maio and Francesco Marulo*

During recent years, aircraft manufacturers focused on environmentally friendly and aerodynamically efficient aircraft concepts that could allow a radical reduction of emissions. The use of hybrid-electric powertrain is one of the most effective ways to design near-zero emission aircraft. These aircraft are highly performing and sophisticated so the design process must be extremely accurate. Among the various innovative aspects, the use of distributed engines to improve aerodynamic performances poses new challenges from structural perspective. Despite the static relief, generally introduced thanks to the load alleviation induced by outboard mass of the engines, the dynamic response of the wing gives rise to concern. It is indeed expected that outboard mass and especially tip mounted propeller may require a complicated design due to reduced flutter performances. This results in a higher stiffness requirements and conse-quent increased mass. Both the weight penalty, needed to prevent dynamic instability, and the wing aeroelastic tailoring, crucial to minimize such an additional weight, are of utmost importance and should be addressed long before the certification stage, whose flight tests may reveal undesirable dynamic response and claim for a new wing design increasing manufacturing cost of the aircraft. In view of setting up a preliminary approach to estimate the static and dynamic effects of such a non-conventional wing architecture, the present paper shows a comprehensive structural analysis of a wing opportunely designed according to certification specification and equipped with a variable position powertrain. A number of different engines are then moved along the wingspan to estimate how it affects the dynamic response using a simplified beam-stick finite element model solved by Nastran. The results show that the engine position strongly affects the flutter velocity with a particular band bell curve over the wingspan with the maximum in between 60-70% wingspan. In addition, it is worth noting how the tip propeller may cause a reduction of flutter velocity respect to the conventional configuration with the turbine mounted in between 30-40% wing-span.

Evaluation of the prospects of distributed electric and hybrid propulsion systems utilization on commuter aircraft

***Mr. A. Dunaevsky (TsAGI, Russia, Zhukovsky**), E. Bobyr, A. Redkin, D. Kurochkin, Y. Michylov, Y. Chernavskich, A. Korobov*

An assessment was made of the possibility of radically improving the flight performance of 19-seat MVL aircraft through the use of technologies of the 2030s in the field of aerodynamics, weight perfection and the use of various types of power plants, including hybrid ones. Preliminary requirements for commuter aircraft have been established, included fuel efficiency – 25 - 30 g/(pass × km).

Such a significant advance in transport capabilities and improvement of fuel efficiency is impossible without a significant increase in the aerodynamic, weight efficiency of the airframe and propeller, also increasing the efficiency of the engines. As the initial layout of the promising commuter aircraft for 19 passenger seats, the layout of the L-410 UVP-E20 aircraft with two turboprop engines on a high-positioned wing was adopted. Forecasts of the characteristics of electric units of hybrid power plants were evaluated by specialists of MAI and CIAM. The final quantitative estimates on the possible improvement of the corresponding indicators due to the introduction of advanced technologies that were used for calculations in this work are shown in the presentation.

A number of options for a promising commuter aircraft with different types of power plants are considered and their characteristics are evaluated:

- aircraft with serial hybrid propulsion systems (HPS);
- aircraft with booster engines;
- aircraft with additional retractable distributed electric propulsion systems (DEPS);
- aircraft with turbo electric propulsion systems (DPS).

Calculations performed for 5 technical concepts that differ in the type of power plant used (classic theater, serial hybrid, parallel hybrid, additional retractable DEPS, turboelectric DPS) showed that the technical concept with an additional retractable DEPS, whose screws blow the wing on takeoff and landing, and are removed in cruising flight mode, is the closest to satisfying these specified requirements

Design of near-zero emission aircraft based on refined aerodynamic model and structural analysis

***Dr. Vittorio Memmolo (University of Naples "Federico II"),** Francesco Orefice, Fabrizio Nicolosi and Fabrizio Ricci*

During recent years, aircraft manufacturers focused their attention on environ-mentally friendly and aerodynamically efficient aircraft concepts that could allow a radical reduction of emissions. The use of hybrid-electric powertrain is one of the most effective ways to design near-zero emission aircraft. These aircraft are highly performing and sophisticated so the design process must be extremely accurate and should make use of multidisciplinary design optimization. It is indeed crucial to establish both aerodynamic and structural models to simulate the aircraft performance and design required according to top level aircraft requirements. Despite the largely discussed literature about preliminary design of such an unconventional aircraft, there is still a lack of reliable weight estima-tion approaches, simulation-based mission analysis and optimization tools. In order to step towards higher technological readiness levels, the purpose of this paper is to describe and apply a design platform for conventional, turboelectric, hybrid-electric and full-electric aircraft, integrating aero-propulsive interactions, accurate power system

modelling and medium-fidelity structural weight estimation. In particular, the comprehensive structural analysis of the aircraft wing opportunely designed according to certification specification and equipped with different powertrain architectures shows that it is worth looking into structural dynamics from preliminary design to estimate aircraft weight properly. Meanwhile, the mission analysis reveals performance benefits by implementing distributed engines all over the wingspan.

Hybrid Electric Flight: PART II - Hybrid electric powertrains

Session Chair : Prof. Teresa Donateo, University of Salento, Italy & Prof. Andreas Strohmayer, University of Stuttgart, Germany

Optimal sizing of hybrid electric propulsion system for eVTOL

Mr. Taher Marzougui (Capgemini Engineering), *Kolja Neuhaus*

Electric propulsion unmanned aerial vehicles (UAVs) attract much attention in aviation industry, with electric vertical take-off and landing (eVTOL) aircraft tending to gain ground. The current development of hybrid eVTOL aircraft intended for urban air mobility is facing many technical challenges. Among these challenges rises the optimal sizing of its hybrid power system (HPS). The latter requires an energy management strategy (EMS). In this paper, the adopted management strategy is based on filtering techniques using frequency-separation. The EMS ensures the optimal distribution of the load power requirement between the different sources while considering their limits. In addition, the optimal sizing allows to strengthen the complementarity between sources and to indirectly reduce their mass. In this work, the studied HPS consists of a fuel cell associated with an energy storage system (ESS), composed of lithium polymer batteries (Li-Po) and supercapacitors. The onboard sources are connected in parallel on the power bus through three DC-DC converters. The results of this study are presented and discussed to highlight the relevance of the proposed approach.

Comprehensive studies of the characteristics of a hybrid propulsion system

Mr. Shirokov A. (Moscow Aviation institute), *Ivanov N., Zhuravlev S., Kholobtsev D., Zdorova M., Kharkina O., Zhuravleva E.*

The paper defines the technical requirements for electric machines, primary energy sources (batteries) and semiconductor converters. The required power of hybrid propulsion system is determined based on the flight modes and conditions according to the technical specification. Various combinations of energy sources for the serial and parallel schemes of a hybrid propulsion system are considered. For each variant, the main parameters of each element included in the system and the total mass of the system and fuel consumption are determined. A program for optimizing synchronous generators with permanent magnet excitation has been developed. The program determines the maximum specific parameters of electric machines for different power and rotation speeds. To calculate the electrical part of the scheme, a database with electric energy sources from various manufacturers has been created. The battery was selected using a developed program. It determines the most energy-efficient battery option by considering combinations of serial and parallel cells from different manufacturers. The analysis of the existing samples-analogs of converters, the characteristics of which are presented at the suppliers, is carried out.

First Principle Model of an Electric ECS Pack

Dr. Peter Eschenbacher (German Aerospace Center (DLR)), *Dirk Zimmer, Niels Weber*

Electric environmental conditioning systems for aircrafts are discussed but not really used to a full extent. Simulation models of planned systems developed at the DLR have shown a lot of problems: high electric power demand, complicated architecture, difficult control strategies and difficult sizing. In order to explore what performance figures are physically possible, a first principle model has been developed on the basis of thermodynamic considerations. Like a Carnot thermal engine, which tells what efficiency is reachable, the first principle model of an ECS can serve as a reference system which tells the minimum amount of electric power needed to fulfill the thermal requirements.

An optimized strategy for the Power Management Unit on a More Electric Aircraft

Immacolata Notaro, Luciano Blasi, ***Mr. Egidio D'Amato (Università degli Studi di Napoli "Parthenope"),*** *Massimiliano Mattei*

In this paper, an optimal control based Power Management Unit (PMU) has been designed, robust to faults (i.e. generators, DC/DC converters, switches etc.), in order to be integrated in future electrical systems for a More Electric Aircraft [1]–[3]. Our PMU optimizes power distribution by solving a Mixed Integer Quadratic Programming problem [4] at each time step. The limited number of variables allows to solve the problem almost in real time, making the approach deployable on real systems. With more details, the system finds the optimal configuration in terms of links between buses and cells, the reference power for each DC/DC converter (cell), considering constraints on bus power balance and underpowering low priority loads in case of unavailable power from generators. The paper gives a rigorous mathematical problem formulation with simulations used to validate the proposed method. The More Electric Aircraft (MEA) and the more futuristic All Electric Aircraft (AEA) are two key concepts introduced to reduce emissions and the onboard weight. This concept starts from a study carried out by NASA where is shown that using more electrical technology on a 200 passenger aircraft could lead to a 10% reduction in the aircraft's empty weight, a 13% reduction in engine thrust and a reduction of 9% of fuel combustion [5]. For these reasons, one of the objectives of the aeronautical industry is the gradual replacement of hydraulic, mechanical and pneumatic systems with electric systems. The concept of MEA and AEA obviously leads to greater loads on the electrical system and this forces a re-design of the on-board electrical system. Currently, a typical electrical system consists of a combination of a DC bus at 28 volts and an AC bus at 115 volts (400 Hz). The 115/200 V generation and distribution with 400Hz AC is the most common electrical power source for civil and military transport aircraft. The 28 VDC is used to feed the onboard equipment by means of transformers TRU (Transformer Rectifier Unit). The emergency is guaranteed by 28V batteries, linked to AC loads through inverters. In the latest generation aircraft, the power increase impose the adoption of powerful generators, and the emerging standard adopts high voltage DC bus with variable speed generators connected to rectifiers to produce current. Surely, by using high voltages for distribution, the advantages of weight reduction, cable cross-sections and losses are obtained, resulting in an increase in transmissible power. However, the voltage increase is limited by the Paschen law, and in particular depends by the insulation materials and the pressure of the power electrical distribution system. The MIL-STD 704 F defines the standard for the new high voltage DC bus, fixing the nominal voltage to 270V, for safety. Fixing the same insulation material and conductor distance, the total power can be doubled by using two high voltage lines +/- 270V or 540V if used in differential mode.

Certification Gap Analysis for Distributed Electric Propulsion Airplane in EASA CS-23 category

Mr. Joël Jézégou (ISAE-SUPAERO)

Development of appropriate certification requirements and safety standards is on the roadmap towards the entry into service of novel low- to zero-emission aircraft. To address limitations of the traditional approach for certification and of the associated means of compliance, a performance-based regulatory framework that considers innovative products is in place in Europe with CS-23 Amendment 5 and special condition for Electric/Hybrid Propulsion System. Furthermore, detailed airworthiness standards are existing or under development. In this context, this paper presents a certification gap analysis that aims at evaluating the relevancy of existing regulatory material for Distributed Electric Propulsion normal category airplane with a focus on Flight and Cockpit Interface requirements, and at developing some proposals to clear the certification path of this configuration.

Layout and Testing of Serial Hybrid Electric Powertrain for Light Twin Demonstrator Platform with Jet Fuel and Hydrogen Fuel Cell Application

Mr. Jonas Lay (University of Stuttgart), *Andreas Bender, Andreas Strohmayer*

The Project “RS hybrid 1.0” funded by the LuFo Program of the German BMWi is being executed in order to develop and investigate a serial hybrid electric powertrain to be used in a light twin aircraft, that could be exclusively operated on two electric motors. The powertrain includes a generator system, that provides the energy to the powertrain and the low voltage demand of the aircraft. All necessary components are developed including the electric propulsion units, the hybrid generator system, battery modules, and DC-Link and associated subsystems.

Everything is assembled in an iron bird testbed to be able to run the powertrain in an isolated fashion and screen for potential issues and measure operational data. Furthermore, a comprehensive control logic for the overall system and safety management of the powertrain is being developed and tested.

Results show operational data from the test campaign. A comparative study for global efficiencies is conducted and backed by real world data. This data is also fed into a benchmark comparison of the demonstrator platform using the new technology versus a conventional aircraft of similar layout and flight performance. The studies show the implications of using regular jet fuel and hydrogen as energy source on typical flight missions. Also, a system analysis focuses strongly on the safety concerns and feasibility aspects of this and other prospective aeronautical applications.

Aircraft Testing

Session Chair : Prof. Ivo Jebacek, Brno University of Technology, Czech Republic

A motorized and remotely controlled Horizontal Tailplane for efficient WT testing

Matthias Berger, Stephan Adden, Jendrik Seiler, ***Dr. Nicola Paletta (IBK Innovation GmbH & Co. KG),*** *Luca Flamini, Roberto Pasta, Luciano Flamini, Cesare Servadio*

The H2020-Cleansky 2 project EULOSAM II supports the development and assessment of an innovative natural laminar aircraft wing by integrating innovative aerodynamic control surfaces and high lift technologies. The project focuses on the modification and completion of a WT-model to enable robust and efficient testing. In order to ensure efficient testing a key element of EULOSAM II was to develop and validate a solution to improve the WT test productivity, which was achieved by designing, manufacturing and testing a remotely controlled, actuated HTP which significantly reduces the time needed in the WT for model-configuration changes. The model under review is a business jet half-model, test will be performed in the ONERA F1 Wind Tunnel, at high Reynolds numbers in low speed conditions. This paper presents the outcome of the whole development process of the actuated solution. This development included the mechanical design as well as the control-solution to be applied in the WT. Pre-Tests have been performed in order to show that the implemented solution is working well and robust inside the model. The documentation will include the details on the design as well as an explanation on why specific solutions were down-selected and found to be most effective ones. During the final development phase, to investigate the functionality and robustness of the system, ground tests have been conducted with the assembled model on test benches to save WT time and to enable faster troubleshooting. Actuating WT models are seen as key to increase WT test efficiency, therefore this is in particular interesting for WT-test which have high hourly test-costs. Lessons learned for future applications therefore will be given to discuss if solutions found so far can be extrapolated to other, comparable applications.

Static Structural Behaviour of Composite Beam for Carrying Electric Propulsion Systems

Mrs. Milica P. Milic (Faculty of Mechanical Engineering of the University of Belgrade), Ivana D. Atanasovska, Dejan B. Momcilovic

Design of unconventional unmanned aircraft is based on innovative structural solutions for improving performance of structure and reducing weight. New materials are necessary to fulfill such demanding structural design which influence on static aircraft performances. Composite materials are mostly used for these purposes. In the early phases of the structural modeling, design can be analyzed and improved by FEM analysis. In this paper the static structural behaviour of the composite beams which carry the electric propulsion systems for an unconventional unmanned aircraft is studying. The overall equivalent bending and torsional deformations of a thin-walled composite beam are analyzed and presented. The simplified beam model is demonstrated by the variation of laminates layup, for the same load condition, which is defined as: pressure caused by aerodynamic flow of the beam surface, concentrated mass at the places of electric propulsion systems and equivalent wing bending moment. The comparative analysis performed for two types of laminates layup is described in detail.

Vibration testing and modal analysis of the e-Genius-Mod

E. Eymann, ***Mr. K. Keller (ISD, Universität Stuttgart),*** *D. P. Bergmann, J. Denzel, A. Strohmayer, T. Ricken*

The focus of this talk is the investigation of the vibration test of an unmanned aircraft performed by a student-team at the University of Stuttgart. Object of the study is the e-Genius-Mod, a modular research and technology test platform developed at the Institute of Aircraft Design (IFB). The aeroelastic digital twin of the e-Genius-Mod will be presented, a project in the Finite Element application course of the Institute of Mechanics, Structural Analysis and Dynamics of Aerospace Structures (ISD). An Abaqus FEA model was built and modal analysis is performed. As reference, experimental data from ground vibration testing via laser Doppler vibrometer performed by Polytec GmbH were used to validate the simulation results. The model is improved iteratively concerning geometry, interfaces and materials. The challenge is to be able to predict the behaviour of the e-Genius-Mod variants with various propulsion systems and to estimate - in the best case - critical flight conditions as flutter phenomena in general or even whirl flutter for further developed more economic regional aircrafts with small electric distributed propellers or turbines in the future. In a first step the basic configuration of the e-Genius-Mod will be shown.

Gappy pod methodology applied to select the worst design limit load conditions for the wing of a civil tilt-rotor

Mr. D. Cinquegrana (CIRA Scpa), *D. Quagliarella, M. Belardo, G. Diodati, L. Di Palma*

Aircraft structural stress analysis is a very time-consuming step when the number of loads conditions to analyze is huge, namely in the order of tens of thousands or even more. Indeed, when the Load Department issues the Design Limit Loads (DLL) Book, many stress analyses under the heaviest load conditions must be produced to substantiate the design and the static tests and, consequently, obtain the Permit to Flight from the authority. The selection of the heaviest design limit load conditions is usually performed with the aid of shear, bending and torsion (SFBM) diagrams cross-plotted in specific sections of the structure. A significant amount of engineering judgment is needed to carry out this step. In this work, an alternative and more automated approach to select the heaviest load conditions is proposed. It is based on a well-established methodology within the computational fluid dynamics domain, namely the Gappy - Proper Orthogonal Decomposition (G-POD). The work presented herein has been developed within the T-WING project funded by H2020 Clean Sky 2 JU, in the framework of NGCTR-TD Integrated Aircraft Demonstrator. In particular, the methodology has been set up - in its central pillars - to aid the stress engineers in selecting the worst Design Limit Load Conditions for the wing structure. This new approach differs from the traditional approach based on SFBM cross plots and consists of building a number of “surrogate models” of the wing structure. The buildup of the surrogate models needs limited knowledge coming from FE calculation. In particular, it is based on the knowledge of a limited set of DLL SFBM and, in addition, on the knowledge of the structural state (strains, stresses, internal forces, derived from the homogeneous limited set of DLLs) in a-priori selected locations of the wing, namely the most critical locations. Once the model is built - and adequately trained - it will be used to predict, for the whole DLL book, with a certain degree of reliability, in the same a-priori selected locations, the strain/stresses/internal forces that exceed a predefined threshold, and the correspondent selected DLL conditions that from this prediction come out to be the worst. In this preliminary work, the main pillars on which the methodology is based are reported, particularly on the loads clustering step, on the errors management, and on the potentiality of the surrogate models of being adaptive, with an advantage in terms of reliability of the prediction.

Investigation of the impact of a particle foam insulation on frost buildup on the aircraft structure

Dr. Victor Norrefeldt (Fraunhofer-Institut für Bauphysik IBP), *Gerhard Riedl*

The aircraft insulation separates the thermally comfortable cabin interior environment from the extremely cold outside condition. However, the fabrication and installation of the insulation in the aircraft is a labor intensive task, especially due to the need to be adjusted and wrapped on every frame. Tailored, rigid particle foam parts could be a solution to speed up installation process. The presented study investigates the feasibility of such a concept from a hygrothermal point of view. Due to the temperature difference between the cold air trapped between aircraft skin and insulation on one side and the warm cabin air on the other side, a buoyancy induced pressure difference forms. This effect drives the warmer air through leakages in the insulation system towards the cold skin. Here, moisture contained in the air condenses on the cold surfaces, increasing the risk for uncontrolled dripping ("rain in the plane") when it melts. Therefore, the study investigates different means to seal the flexible frame bay insulation mats against the rigid particle foam frame insulation. Tests are hosted in the Fraunhofer Lining and Insulation Test Environment.

Development of an innovative noise generation system for turboprop aircraft fuselage testing

Dr. Mattia Dal Borgo (KU Leuven), *Mariano Alvarez Blanco, Sjoerd van Ophem, Hervé Denayer, Pasquale dell'Aversana, Tiziano Polito, Luigi Staibano, Raffaele Bianco, Bart Peeters, Bert Pluymers, Wim Desmet*

High cabin noise levels inside propeller driven aircraft are motivating the development of noise attenuation solutions for improving the passengers' comfort. The aim of the CSJU CONCERTO research project (GA886836) is to develop cabin noise testing equipment that will be used to evaluate the interior noise of regional aircraft and to aid the development of noise reduction techniques. A cost-effective approach is the use of a near-field array of loudspeakers to synthesize a pressure field on the fuselage surface similar to the loads generated by both the turbulent boundary layer and the propeller blade passages. This paper presents the development of an innovative noise generation system that uses a feedback control loop to realise the desired sound pressure levels at each third-octave band along fuselage sections using such loudspeaker setup. The innovative noise generation system consists of three modular frames that hold evenly distributed loudspeakers at a given distance around the fuselage circumference. The frames can be adjusted to accommodate fuselages of differing diameters. The sound pressure level is measured by a number of microphones scattered on the fuselage surface. These microphone signals are used to drive the loudspeakers through multi-input multi-output (MIMO) feedback control strategies with the purpose of minimising the error between the target pressure field and the measured one. The number and location of the microphones used in the control loop are selected using a pre-test optimisation analysis, which aims to reduce the time and cost of the test set-up (from days to hours). A small-scale noise generation demonstrator has been built to develop and demonstrate the MIMO control approach. A frequency domain MIMO feedback controller is used to replicate the random pressure field generated by the turbulent boundary layer excitation. The multi-harmonics of the propeller induced excitation are then added to the time histories of the broadband noise using a time waveform replication technique. The driving signal distribution and the control channel selection are both investigated. The results are presented in terms of accuracy of the reproduction of the pressure field.

JETSCREEN project

Session Chair : Dr. Bastian Rauch, DLR, Germany

JETSCREEN project: Achievements towards fueling the future of aviation

Dr. Bastian Rauch (DLR), *M. Fortunado, S. Blakey, M. Sicard, G. Howe, J.B. May-Carle, M. Rullaud, P. Le Clercq*

In December 2020, the EU Green Deal announced the need to reduce transport emissions by 90% by 2050 (compared to 1990 levels). This requires the production and deployment of sustainable aviation fuels, which offer one effective way to mitigate both CO2 and non-CO2 impacts on the climate as well as improving airport local air quality. During the JETSCREEN project 31 fuels were used in a matrix of 34 experiments to study in detail the fuel impact on a wide set of fundamental and performance properties. With this broad dataset, JETSCREEN has developed or improved upon a rich set of modelling tools capable of predicting these properties from fuel composition information alone. The developed tools can be used to support the design of fuel-optimized aircraft and jet engines as well as for the rapid screening and assessment of new candidate fuels. In JETSCREEN as in other programs it was shown that fuels without aromatics can reduce nonvolatile particle emissions by up to 80%. If the fuel specification were changed to permit such fuels, this would have an immediate impact on improving air quality at airports and significantly reduce aviation's non-CO2 climate impact. While the feasibility of using zero aromatic fuels can be justified from a combustion emissions perspective, a deeper understanding of the consequence of removing aromatic and sulfur from the fuel on all aircraft systems, components and materials has to be obtained to ensure aviation's high safety standards are preserved. In JETSCREEN zero or reduced aromatic/sulfur fuels were systematically studied in a wide range of experiments. Results were used to improve the understanding of the impact of such fuels on existing aircraft and to enable the design of future SAF-optimized aircrafts.

The impact of fuel chemical composition on the products of incomplete combustion in an APU gas turbine engine

Dr. Simon Christie (Manchester Metropolitan University)

The characterisation of aviation combustion emissions is a key issue in better understanding their downstream impacts on local air quality, atmospheric chemistry and radiative balance. We report the emission properties from a number of aviation fuels, tested in a small gas turbine engine (auxiliary power unit), within the frame of the JETSCREEN project, and referenced to emissions from a typical Jet A-1 fuel. The candidate test fuels represent a broad range of possible chemical compositions, including extreme fuels, hydrotreated fuels, and biofuels. Details of the standard ICAO engine emission species (CO, UHC, NOx, SN) as well as condensable polycyclic aromatic hydrocarbons (PAH) and black carbon (BC) particulate matter characterised in terms of mass, number and size will be discussed. The data show a pronounced reduction in the emission of PAHs and BC that scale with the proxy metric of fuel hydrogen content, and which asymptotes towards a non-zero reduction limit. Within this dataset, synthetic fuels such as ATJ and HEFA offer the greatest reductions. The data imply a partial relation between the total mass emissions of BC and PAH may exist ($R2 \approx 0.7$). The PAH species in the emissions and the PAH species in each parent fuel are qualitatively and quantitatively ($R2 < 0.4$) dissimilar, indicating the genesis of PAHs is predominantly within the combustion process. In contrast, the PAH species in the emissions from the different parent fuels are qualitatively and quantitatively ($R2 > 0.8$) similar, which may suggest a common

PAH formation mechanism. Hydrotreatment of Jet A-1 is shown to notably reduce the concentration of mono-aromatics (16.8% to 7.1% v/v) and PAHs (7010 mg/kg to 540 mg/kg) in the parent fuel, which delivers a corresponding decrease in the emission of BC (≈ 40% mass reduction) and PAH (≈15% mass reduction). The scatter in the BC data away from a model predictive trend line will be discussed in terms of fuel correction methodologies and uncertainties within the new non-volatile Particulate Matter (nvPM) mass and number standards that will govern both new and in-production engines from 2023 onwards.

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Development of a JETSCREEN model for the prediction of Seal Swell in Sustainable Aviation Fuels

Dr. Simon Blakey (The University of Birmingham), *Ehsan Alborzi, Christopher Parks, Spiros Siouris*

The interaction of candidate Sustainable Aviation Fuels (SAF) with elastomeric seals in the supply infrastructure and engine and airframe fuel systems must be demonstrated as part of the D4054 process for the approval of new fuel compositions for use in aviation. In particular, the interaction is required to result in seal swell as a result of penetration of particular components of the fuel into the polymer matrix of the seal to maintain sealing in the fuel systems. A low order model is developed to predict swelling of elastomers resulting from interaction with the components of candidate aviation fuels. Previous models have focused on the aromatic, di-aromatic and cyclo-alkane content of fuels in isolation, this deliverable presents a model combining these interactions into an overall model. The use of Hansen Solubility Parameters (HSP) to model the interaction of the elastomer with the fuel has been reassessed, and earlier literature, which considered the HSP of the fuel in isolation, has been combined with the HSP of the elastomer material to calculate the Relative Energy Distance (RED). A correlation between the RED of the fuel / elastomer combination and the normalised swell (as measured by an increase in sealing force) from the experimental deliverable. The overall bonding energies between specific aromatic components and a polymer have been studied using Quantum Chemistry Density functional Theory (DFT) techniques as demonstration of a route to expand the HSP database for aviation fuel specific components. The model proposes limitations to the blending ratios for these representative components to recreate the swell of Nitrile elastomers observed for a minimum of 8% aromatics for conventional fuels, and provide a tool to predict conventional fuel and SAF fuel blending limits on a fuel by fuel basis. The correlation is validated against available experimental results and has been used to extrapolate to new fuel blends. These extrapolated fuel / elastomer interactions provide a good tool to direct future validating experimental efforts into elastomeric interaction with fuels.

Development of a JETSCREEN model for the prediction of Thermal Stability in Sustainable Aviation Fuels

Dr. Simon Blakey (The University of Birmingham), *Ehsan Alborzi, Christopher Parks, Spiros Siouris*

Poor thermal stability performance will reduce periods between required engine maintenance, increase the operating cost of the engine hardware, and inhibit engine designers to consider higher temperature operation of the fuel system, that could otherwise increase the operating efficiency and lower specific fuel consumption. The thermal stability of fuels is a function of its chemical composition. However, unlike many of the other performance properties of fuel which are determined by the bulk chemistry of the fuel, the thermal stability is influenced to a greater extent by minor, trace chemistries present in the fuel. Examples of these species are the heteroatomic, trace metals, and sulphur species which are often

present in the fuel at ppm or ppb level. The presence of these species comes mostly into the fuel from the crude oil refining processes, and their concentrations reduce with increased hydroprocessing. It is unusual for these species to be present in SAFs, as they are either entirely synthetically produced, or are severely hydroprocessed, all of which improve the thermal stability performance of the fuel. For the experimental assessment of the transition between autoxidation and surface deposition, JFTOT breakpoint (laminar flow) and HiReTS (Turbulent flow) tests were conducted on the JETSCREEN fuels. The impact of hydroprocessing on the thermal stability performance of the fuels (Group A fuels) was marked, with increasing hydrotreatment resulting in lower levels of deposit formation. The comparison of the impact of Sulphur concentration (Group D fuels) was more complex, but the importance of even trace concentrations of Sulphur in the levels of deposit formation was clearly identified. The ranking of the fuels by these two methods was not the same, however this level of disagreement between tests is common as their test conditions are in different flow regimes. The deposition test results were further analysed by post test deposit measurement techniques which measured the thickness of deposits at particular locations along the test piece using microscopy and this additional dataset was used to validate a low order deposition model developed in JETSCREEN. The low order model used a 1-D momentum and heat transfer approach along with the Colburn analogy to estimate a local mass transfer coefficient in the system. In all cases, the produced model underpredicts the deposit rate formed and is highly sensitive to changes in the Nusselt number correlation used. The model offers some significant improvement on the state-of-the-art low order deposition modelling. This is due to the additional precursor formation steps offered by a more accurate representation of the sulphur chemistry and the inclusion of flow characteristics in the deposit formation step. Although the absolute values from the model do not match the experimental work, the trend as the fuel composition changes is well captured.

Kinetic modeling of jet fuel combustion, from fuel characterization to pollutants formation

Matteo Pelucchi, Patrick Osswald, Alessio Frassoldati, Simon Christie, ***Mr. Marco Mehl (Politecnico di Milano)***

The partial displacement of fossil-based jet fuels with sustainable drop-in alternatives has been considered as a viable solution for reducing greenhouse gas (GHG) emissions from the aviation sector. While the correlation between the origin of the fuel (e.g. fossil vs renewable) and GHG formation is intuitive, an unintended but beneficial secondary effect of the introduction of sustainable fuels is the one on the emissions of micro-pollutants. As an example, recent studies highlighted how the use of non-traditional fuels in existing combustion devices can affect the amount and composition of soot produced as well as the formation of harmful byproducts such as polyaromatic hydrocarbons. A deeper insight into the compositional effects of sustainable jet fuels on NOx, PAH and soot performed by means of experiments, surrogate fuel formulation and the development of predictive detailed kinetic models will allow to better exploit this opportunity. In this work, several jet fuels from the JETSCREEN palette are analyzed by means of chemical kinetics. Starting from their detailed compositional analysis, adequate surrogates are formulated. Simulated fuel properties such as ignition delay times and burning velocities as well as speciation from controlled combustion experiments are compared to experimental data to assess the ability of the model in reproducing chemistry related behaviors. The fuel models were finally used to simulate the formation of pollutants at conditions relevant to aero-engine combustors, with the intent of comparing the potential for harmful emissions and clarify how compositional variations resulting from the introduction of sustainable aviation fuels (SAF) could contribute to cleaner combustion strategies and a sustainable aviation sector.

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Using machine learning to predict the quantity of a fuel sorbed into a polymer

Créton Benoit, Klopffer Marie-Hélène, Baroni Axelle, Veyrat Benjamin, Alves Fortunato Maira, ***Mr. Mickael Matrat (IFP Energies Nouvelles)***

In December 2020, the EU Green Deal announced the need to reduce transport emissions by 90% by 2050 (compared to 1990 levels). This requires the production and deployment of sustainable aviation fuels, which offer one effective way to mitigate both CO2 and non-CO2 impacts on the climate as well as improving airport local air quality. The European project JETSCREEN aims at developing a screening and optimization platform to evaluate alternative fuels. In the frame of this project, experimental and theoretical methods were developed and used to predict physical, chemical and thermophysical properties for seven fuels candidates. One task of this project stands in the use of data mining-based approaches to derive models to predict sorption values – the quantity of a penetrant sorbed into a polymer matrix – for fuels. Over last decades, our group has devoted efforts in the domain of Chemoinformatics and the development so-called Quantitative Structure Property Relationship (QSPR) that relates fluid properties to values considering fluid descriptors. For instance, we have demonstrated that it is possible to correlate the amount of fuel ingress into a polymer with the fluid structure [Villanueva et al., 2015]. A database including sorption values for a series of hydrocarbons in NBR (nitrile butadiene rubber) has been created based on measurements previously performed in our laboratory. Genetic programming was applied on the database, and resulting models stand in combinations of mathematical operators, counts of relevant chemical functions, and time when appropriate. Two approaches have been followed [Creton et al., 2021]. First, models return for each considered fluid the plateau value, i.e. the maximum mass percentage gain. In the second approach, models return sorption values (mass percentage gain) as a function of time. The resulting models were applied to the seven fuel candidates to determine their sorption value in NBR. Comparisons performed with available experimental data demonstrate the approach interest and limitations.

Aircraft Design

Session Chair : Prof. Emmanuel Benard, ISAE-SUPAERO, France

Fully automated piping in an Airbus A320 landing gear bay using graph-based design languages

Mr. Moritz Neumaier (Institute of Aircraft Design, University of Stuttgart), *Stefan Kranemann, Bernd Kazmeier, Stephan Rudolph*

Designing hydraulic pipes in industrial applications is a challenging task. To overcome these difficulties a new approach of a fully instrumented, automated and simulation-enabled engineering software platform capable to automate the manual model-based systems engineering (MBSE) design process for pipes manufactured by rotary draw bending was developed and implemented. The capabilities of the new developed software are demonstrated on the pipe installation in an Airbus A320 landing gear bay. The paper is based in large parts on the outcome of the CLEANSKY2 research project PHAROS. During the life cycle of an airplane aircraft systems and pipe work are impacted by several design evolutions. From the initial design of an aircraft up to the cumulative incremental design during its service life the pipe routing, for example, has to be designed, modified and adapted several times in an aircraft life to meet the latest aviation and manufacturing technologies or due to improvements or design corrections. One major cost driver besides manufacturing and in service costs are design efforts for creating new pipes and routings in an earlier stage as well as design costs that will accumulate during the in service life of an aircraft. With increasing age of an aircraft program and complexity of systems the design cost increase in the same manner to modify or introduce pipes in the existing aircraft. The reasons are that the majority of aircraft systems are routed in the same areas, segregation and clearances are at their limits, access and installation sequences needs to be considered from the beginning and modification of one system must not lead to a cascading change of other surrounding systems. Pipe design for an aircraft has to cope with all these challenges. And it is, despite of the today's state of the art design tools, an iterative and manual approach. Today the pipe design is not automated. The tube has to be manually routed through the installation area while considering all clearances, manufacturing and installation requirements. Thus, pipe design is complex, time consuming and inefficient. For future aircraft design trades for optimization of the overall system must consider different architectures and locations of equipment and pipe routings. Also different trade criteria as minimum length and weight are of interest. The proposed automation is achieved with an integrated design optimization and design compiler approach. The design compiler represents a compiler for graph-based design languages. These graph-based languages are inspired by natural, human languages, in which the vocabulary and rules form a grammar. The term "design language" means that every sentence built with the available vocabulary and allowed by the grammar is a valid expression of a design. The term "graph-based" means that each node in a graph is used to represent a requirement, a product function, a solution principle, a component or an assembly, or any other arbitrary engineering concept one may encounter in or along the product life-cycle. The design compiler finally translates the design language into a executable program which generates the 3D CAD-model of a collision-free pipe network in an arbitrary complex installation space such as a landing gear bay of an A320 aircraft. To generate the pipe work a set of input data is given by a user. This set consists of the installation space geometry, a set of usable bending machines with their features like the bending radius and the minimum straight length between two bends, a connection list, an assignment of the pipes to the bending machines and weightings for the optimization criteria (e.g. length of the pipe, weight, number of bends) to influence the evaluation of the generated pipes and thereby the final solution. In an initial step of the

automatic pipe generation a route through the installation space is found. Subsequently the installation space is simplified and if desired a respective minimal distance to each obstacle which a pipe should satisfy is added. Afterwards for each pipe an initial solution is estimated and each pipe is optimized by a simulated annealing algorithm. This optimization can be done in parallel to reduce the computation time. For the optimization an evaluation function is proposed which also considers that the pipes must not undergo a given minimal distance between each other. Finally, the pipes are automatically reviewed to ensure that all given requirements are met. This automatic workflow can be the basis for a future product life cycle management and a more efficient collaboration in the design team. The dense installation space of a landing gear bay of an Airbus A320 with dozens of pipes to route is successfully mastered by the proposed algorithm. The paper summarizes key aspects of the research findings of the 2-year H2020 CS2-project PHAROS running from 10/2019-9/2021, see https://cordis.europa.eu/project/id/865044 for details. The PHAROS consortium members are AIRBUS Operations GmbH (Germany), NOESIS (Belgium), University of Stuttgart (Germany) and IILS mbH (Trochtelfingen, Germany).

Creation of Innovative Concepts in Aerospace based on the Morphological Approach

Mr. Vladislav T. Todorov (Technical University of Berlin), *Dimitrij Rakov, Andreas Bardenhagen*

The development of innovative aircraft configurations can be an important contribution to achieving the emission reduction goals set for the aviation industry. However, current common aircraft conceptual design processes allow the consideration of a limited number of initial configurations thus leaving possibly more efficient solutions out of scope. A significantly wider range of aircraft configurations can be taken into account by applying the morphological analysis. After a brief presentation of its historical background and actual applications in other domains, this article focuses on the use of this method and its benefits in aerospace. The summary and comparison of several applications in the field of aircraft design show that these still require a higher level of formalisation and robustness. For this purpose, we identify the main steps required to integrate morphological analysis into the aircraft conceptual design phase based on the Advanced Morphological Approach. These are the definition of the morphological matrix along with the evaluation criteria, the obtaining of option evaluations, filtering the impossible solutions and exploration of the solution space.

Parametric Studies on Tank Integration for Hydrogen Jet Engines

Mr. Jon Huete (Cranfield University), *Pericles Pilidis*

Hydrogen is generally seen as a sustainable fuel and a complete solution given the absence of carbon, aromatics, particle emissions and sulphur; there is very high potential for low NOx, and contrails can be eliminated by careful rerouting. Hydrogen aviation and aircraft concepts have been widely studied. A challenge that always arises is storing a low energy density fuel and maintain aircraft usefulness. Tank integration difficulties has led to concepts that offer a compromise between passenger payload and range, with lower that current airliner values for both parameters. Long-range hydrogen-powered airliners are accidentally placed in the long term, relying on disruptive aircraft concepts that are more prone to allocate large hydrogen tanks. From volumetric considerations, it would be desirable to have small and close to shape tanks along with large fuselage inscribed tanks. From gravimetric considerations, lightest tanks would be preferred. Geometric characteristics of tanks do have a strong impact on aircraft performance. This presentation is based on recent research undertaken to explore the design space of hydrogen tanks. Central to the tank design decision is the consequential weight of the tanks and the venting requirements at the airport and during cruise. The presentation reveals the effect of tank size and geometry in pressure

variation and in gravimetric efficiency for different tank architectures. It explains the wide range of gravimetric efficiencies found in the literature of previous research. A novel method for optimising tank design based on dormancy time, or time for the tanks to reach to maximum allowable pressure is presented. Finally, several recommendations for tank design depending on aircraft application is given.

Spectral project - application of FAST-OAD code to the conceptual design of hydrogen fueled commercial aircraft

Mr. Mayur Oak (ISAE-SUPAERO), *Alice Fabre, Martin Delavenne, Eric Nguyen Van, Emmanuel Benard, Sébastien Defoort, Karan Kini-Karkala, Thomas Fournier, Zoé Bouchard-Ahmedou, Johan Dionot*

In just over a century since its birth, aviation industry has progressed from learning to fly to having more than 100,000 commercial flights occurring around the world each and every day. But with the increase in the air traffic we are also exceedingly impacting the environment. This has called for more research in the area of using alternative fuels which will reduce the greenhouse gas emissions and which can provide similar or better performance. Hydrogen comes as a natural choice of fuel considering it can reduce the NOx and CO2 emissions and it also has almost 3 times more mass energy density as compared to kerosene, but it presents a specific challenge in terms of volume management. This work presents a preliminary design methodology of a mid-range single aisle commercial aircraft using Hydrogen as fuel. Since cylindrical shape has proven to be an optimized shape for storing Hydrogen fuel and because of the high volume requirement, storage within the fuselage was the selected integration strategy. The iterative design process was achieved by using overall aircraft design approach through FAST-OAD open source software, jointly developed by ISAE-SUPAERO and ONERA. This work is based on a modified version of FAST-OAD with implementation of models specifically developed for liquid hydrogen storage, systems, and engine and it was co-supervised by ONERA and ISAE-SUPAERO. This procedure allow to take into account a first approximation of structural and insulation weight of liquid Hydrogen tank, the CG impact of liquid Hydrogen tank location and the additional fuselage length required to accommodate the tank. An additional parametric study has also been carried out to understand the effect of several design parameters on overall design. Through a lengthened fuselage, a realistic payload range performance can be obtained. Therefore it is suggested that without radical change of the geometry, a mid-range single aisle commercial aircraft using Hydrogen as fuel is a realistic proposal, as initially assessed in the 1970s for larger aircraft and longer missions. Finally, an environmental study has been conducted to evaluate the direct emissions of this aircraft in operation. The only emissions that result from the combustion of hydrogen are nitrogen oxides (NOx) and water vapor (H2O), all evaluated using the Boeing Fuel Flow Method (BFFM2). As a result of this study significant reduction in NOx and CO2 emissions as compared to existing design are envisaged, thus showing the promising potential of Hydrogen fueled aircraft.

Conceptual design of a fixed wing hybrid UAV UUV platform

Mr. Charalampos Papadopoulos (Laboratory of Fluid Mechanics and Turbomachinery Aristotle University of Thessaloniki), *Stathis Vlachos, Kyros Yakinthos*

In this work, the conceptual design methodology of a hybrid Unmanned Aerial Vehicle (UAV) – Unmanned Underwater Vehicle (UUV) platform is presented. As the mission complexity and the need for interoperability between different platforms increases, hybrid platforms are becoming an essential solution. Hybrid UAV-UUVs can operate seamlessly and repeatedly in both aerial and underwater environments, something that various animal species already do in an optimized way. The design methodology presented in this work starts with the review of the limited available prototypes, creating

initial design trends and continues with analytical calculations. These calculations are based on aircraft design textbooks, but they are modified to take into account the innovative characteristics of the hybrid platform, such as the phase of transition between the water and the air. A Blended Wing Body (BWB) layout configuration is selected because of the numerous aerodynamic advantages that it can offer. The analytical calculations are then validated with the use of high fidelity CFD calculations. The results from the conceptual design indicate that the proposed methodology for the hybrid UAV-UUV configurations provides a good design accuracy. Finally, the outcome of this methodology is the answer to the operational gap for missions that include both underwater and aerial environments.

Flight Testing of Wing Tip Propellers - Review of the Flight Test Results

Mr. D. P. Bergmann (University of Stuttgart, Institute of Aircraft Design), *J. Denzel, O. Pfeifle, S. Notter, W. Fichter, A. Strohmayer*

The use of electric motors enables new possibilities for propulsion arrangements and aircraft configurations. Driven by the goal of creating greener aviation for the future, electric and hybrid electric propulsion systems are an important technology. The use of wing tip propulsion can support this goal and is enabled by advanced electric motors with high efficiency ratios combined with a compact and light-weight design. For the unmanned modular test platform e-Genius-Mod that is operated by the Institute of Aircraft Design at the University of Stuttgart, a wing tip propeller system was developed and tested in a relevant environment. The flight tests focus on the effects expected from literature and wind tunnel tests. A measurement system was developed for the flight tests to measure thrust, angle of attack, airspeed, etc. to investigate the effect of wing tip propellers on the induced drag and the aircraft/aerodynamic performance. The contribution will give a brief overview of the flight test results with wing tip propellers in the project ELFLEAN (electric wing tip propulsion system for the development of energy-efficient and noise reduced airplanes).

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Regional jet retrofitting through multidisciplinary aircraft design

Mr. Massimo Mandorino (Università degli studi di Napoli Federico II), *Pierluigi Della Vecchia, Fabrizio Nicolosi, Giovanni Cerino*

Multidisciplinary collaborative aircraft design is applied to a 90 passengers regional jet aircraft highlighting the impact on costs and performance. Two retrofitting packages have been considered: the re-engining of conventional power-plant platform with advanced geared turbofan and the on-board-system modernization, considering different level of electrification. Starting from a reference existing aircraft, the impacts of retrofitting process have been carefully evaluated on capital costs and revenues at industrial level through a developed methodology. At aircraft level, masses, performance, noise, and emissions have been computed with dedicated competences increasing the estimation reliability. Overall process is implemented in the framework of the AGILE 4.0 research project in a collaborative remote multidisciplinary approach. Results show that such retrofitting activities are expensive and must be evaluated since the design stage with a bottom-up approach requiring competences coming from designer experience to correctly define the process work-breakdown-structure and its implications.

Advanced Manufacturing Technology for Aeronautics (PART I)

Session Chair : Prof. Yi Qin & Dr. Jie Zhao, University of Strathclyde, UK

Design of composite aircraft flight control surfaces supported by virtual allowables approach: prediction of hybrid-laminate mechanical behaviour in manufacturing variability contest

Eng. Filomena Starace (Magnaghi Aeronautica (a MA Group Company)), *S. D. Orlando, V. Giacalone, V. Avigliano*

The design and certification of composite structures is based on the building block approach (BBA), following a bottom-up procedure. Starting from the bottom level of Rouchon's pyramid of test, thousands of coupons need to be produced to determine design allowables and capture manufacturing, geometrical and microstructure variability values. The numerical approach provides desirable data to be confirmed by a reduced testing campaign, especially for the preliminary design process stages and material selection. In this paper a carbon fibers reinforced epoxide resin used for aerospace application has been analyzed, in form of both fabric and unidirectional tape to validate the numerical model considering Salver manufacturing process variability data. Hybrid laminates composed of unidirectional plies and woven fabric layers have been tested to pursue a tailored approach based on design guidelines and stress requirements for aircraft flight control surfaces. Benchmarking the experimental-numerical test results allows to assess the statistical reliability of the proposed method.

Development of innovative technologies for manufacturing of certified narrow body aircraft composite flap

D. Alberotanza, ***Miss Francesca Pinto (MAGroup SALVER),*** *S. Polo, G. Zaccaria, D. Capoccello, S. Nobili*

Fiber-reinforced polymer composites perfectly meet the basic requirements of aircraft construction, i.e. lightness, strength and stiffness. New technologies have been designed and developed to increase Salver's competitiveness in the use of composite materials by ensuring a continuous manufacturing process, a streamlined and balanced flow of activities, synchronized as much as possible with customer and market demand reducing material scraps and non-value-added activities. The TO BE manufacturing process intervenes by re-engineering the most critical steps of the composite detail part lay-up and curing. Resin excess, tool mark-offs, out of tolerance dimensions are only some of the non-conformities generated during the AS IS process. Innovative technologies for manufacturing of certified narrow body aircraft composite flaps have been designed and developed in order to achieve the best quality of the product and the next years program ramp-up. Detailed tooling analysis and several simulations, included process flow and bottlenecks detection, have been performed in order to design a TO BE process with high level of automation and reliable devices for human safety and production repeatability, that fully meets the customer's expectations. The TO BE process represents a drastic, rapid and everlasting improvement project capable of eliminating any kind of waste both in terms of material and time, while maintaining a high level of product quality.

Numerical and experimental investigation into laser-metal-deposition based additive manufacturing with difficult-to-machine materials

Mr. Yankang Tian (The University of Strathclyde), *Quanren Zeng, Yi Qin*

The difficult-to-machine materials like Inconel 718 and Gamma Titanium Aluminide Alloy are widely used for aerospace/aeronautics components due to their superior properties at elevated temperatures. However, it remains a challenge to manufacture components with these materials and maintaining the material properties, especially when complex shapes are to be achieved. Additive manufacturing with laser metal deposition (LMD) could well address the challenge mentioned here by providing high degree of freedom for design and manufacture. The development of LMD for fabricating engineering components is still ongoing, and the focus is particularly placed on the quality control. While the effort still largely relies on experimental trials, lack of effective and efficient modelling tools have hampered the progress in process design and optimisation. The strategy implemented in the University of Strathclyde is to develop comprehensive understandings of the interactions of the material and process parameters during LMD and their relations to the quality of the parts formed. This has been enabled by establishing an integrated numerical model taking into account in-process powder dynamics, heat transfer, liquid/solid interface, part geometric formation via solidification and resulting mechanical properties of the material. The simulated formation of the deposited geometry was further compared to those obtained from the experiment. The latter also facilitated the conditioning of the numerical model as well as underpinned the process optimisation in which both experiment and numerical modelling were combined. The effort described above has resulted in an integrated numerical tool and technical details for guiding LMD process design and parameter setting for quality control in LMD for aerospace and aeronautics applications.

Compressive properties of additively manufactured PETG composites reinforced with different fibres

Ms. Sara Valvez (University of Beira Interior), *Abílio P. Silva, P.N.B. Reis*

According to the technical committee of the American Society for Testing and Materials, additive manufacturing (AM) is described as the processes of material joining for manufacturing of three-dimensional (3D) part. In this context, fused filament fabrication (FFF), also known as fused deposition modeling (FDM), is a 3D printing process based on thermoplastic polymers that uses a continuous filament to produce complex three-dimensional parts. In terms of materials, Poly(ethylene terephthalate)-Glycol (PETG) is one of the most used materials in 3D printing technology due to the chemical alkali resistance, transparency, gloss, low haze, good printability, among other benefits. Furthermore, with the correct print settings it is possible to obtain excellent layer adhesion and very low shrinkage properties. At the same time, it is extremely strong, which allows to print objects that can sustain high temperature, food-safe applications, and exceptional impact performance. All these advantages make this material suitable for both food and medical industry. In the last case, for example, its rigid structure allows it to survive harsh sterilization processes, making it a perfect material to be used in medical implants, as well as pharmaceutical packaging and medical devices. However, when adding carbon fibre reduces the risk of warpage even further, makes the material more resistant and resilient making it an excellent choice for automotive and other industrial applications. However, the addition of carbon fibre extends its field of application to the automotive sector, and others (such as prosthetics or adaptable parts of wheelchairs.), because the material becomes more resistant and resilient, in addition to further decreasing the risk of warping. On the other hand, when reinforced with aramid fibres, the applications can be extended to

sectors where high resistance to friction and impact are expected. Therefore, this work aims to study the compressive properties of PETG and PETG reinforced with carbon and aramid fibres, because most studies available in the open literature focus essentially on the tensile mode. However, the compressive properties are also very important to the design criteria because various types of failure modes can occur. For this purpose, the samples were printed using a Creatbot F430 printer, with a brass nozzle of 0.4 mm diameter, and the printing parameters were optimized for each material. Five specimens for each variant were tested according to ASTM D695. The benefits obtained with PETG reinforced by different fibres revealed that, from the point of view of compression properties, these composites can be used in various applications, from secondary structures in the aerospace and automotive sectors to small applications in orthotics and prostheses.

PADICTON – Part distortion prediction, design for minimized distortion, additive manufactured polymer aerospace parts

Miss Vasiliki Loukodimou (TWI Ltd)

To unlock the full value additive manufacturing (AM) has to offer, simulation tools are needed in order to predict and mitigate part warpage, as well as realise the impact of design decisions on the manufacturing process before the part is printed. The PADICTON project target is to develop validated, rapid distortion prediction models for AM of polymeric and composite parts and integrate these directly into design optimisation tools (topology and/or shape optimisation) in order to produce novel part designs that are a best compromise between low weight and manufacturability. This reliable method for accurately predicting and preventing distortion will enable the decrease of design and development costs through reduction of scrapped components and expensive design alterations during prototype-based development cycles. It will also result in a lower level of risk in designing integrated and complex shaped AM components. The development of the distortion prediction models will be accompanied by an extensive material characterisation campaign. The latter will be undertaken for the assessment of the influence of the printing process and thermal history on the quality of 3D printed parts and to experimentally verify and validate the developments at different scale and complexity levels. The AM techniques considered are the Fused Filament Fabrication and Selective Laser Sintering.

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Prediction of thermo-mechanic effects through numerical simulation of induction heating of thermoplastic composites

Mr. Albert J. de Wit (NLR - Royal Netherlands Aerospace Centre), *N. van Hoorn, R. Nahuis, W.J. Vankan*

Induction welding of thermoplastic carbon fibre reinforced plastics (CFRP) is one of several fusion bonding techniques that exploits the melt and freeze properties of the thermoplastic matrices. When heated sufficiently, the matrix material in both adherends liquefies and jointly solidifies after cooling down, regaining the original mechanical properties. Induction welding has the advantage that no contact between induction coil and workpiece is required to generate the heat. Several heating mechanisms take place in the induction heating of thermoplastic CFRP. The extent in which each mechanism contributes to the heating process, depends on the material that is heated and the process parameters that are applied. In this work we focus on modelling and simulation of the induction heating process of unidirectional (UD) CFRP material. In particular the influence of material properties and stacking sequence on the generation

and distribution of heat inside the composite laminate is investigated. A numerical simulation model is created using finite element (FE) software to simulate the electromagnetic heating process and predict the thermo-mechanic effects inside the material. The required electro-thermal properties of the CFRP material are not readily available. In particular, a measurement technique to determine the electrical conductivity properties is presented. The experimentally obtained properties are applied in the numerical model and the simulation results are discussed.

Principle and strategy of 'Design for Recycling' for energy harvesters

Mr. Song Yang (The University of Strathclyde, Glasgow), *Kate Trompeta, Yi Qin*

The concept of 'Design for Recycling' (DFR) has become more popular in material and product developments, in order to take into account environmental implications of design choices. The effort made by the authors recently was to review the common 'Design for Recycling' principles, strategies and techniques, with specific focus on the development of energy harvesters. The two main topics covered were design considerations for material recyclability and design for disassembly. As significant effort has focused on vehicles and electronic products, in terms of "Design for Recycling", our work investigated four types of energy harvesters (EH), named thermoelectric, photovoltaic, hybrid solar/TE and piezoelectric EHs. We addressed market trend, design considerations, development works and their applications. Based on a review of general principles and strategies that are used to-date for 'Design for Recycling' for general mechanical/mechatronic/energy products, physical and chemical approaches for material separation and recovery as well as disassembly methodologies and techniques that could help to reduce the product development cost and time, we assessed and analyzed characteristics of energy harvester designs and specific considerations for manufacturing of these products. These were followed by developing general checklists for the material selection/uses and design for disassembly for the development of suitable energy harvesters. These checklists address capabilities of the methods, techniques and procedures for design, manufacturing and remanufacturing of thermoelectric/photovoltaic/piezoelectric energy harvesters, including considering material toxicity in product manufacturing, uses and disposals as well as for achieving ease of disassembly for better recyclability and reusability.

Advanced Manufacturing Technology for Aeronautics (PART II)

Session Chair : Prof. Yi Qin & Dr. Jie Zhao, University of Strathclyde, UK

Innovative tooling and end-effectors for multifunctional thermoplastic fuselage components welding

Dr. Sadik Omairey (Brunel Composites Centre, Brunel University London), *Sofia Sampethai, Luka Hans, Chris Worrall, Stuart Lewis, Daniele Negro, Tariq Sattar, Eduardo Ferrera, Elena Blanco, John Wighton, Leo Muijs, Sebastiaan L. Veldman, Marco Doldersum, Rik Tonnaer, Nithin Jayasree, Mihalis Kazilas*

In this study, the development of innovative tooling and end-effectors system for welding multifunctional thermoplastic fuselage components is presented. The increasing demand for more new and cleaner aircraft requires utilising novel materials and technologies. Advanced thermoplastic composites provide an excellent material option thanks to their weldability, low density, low overall production cost, improved fracture toughness and recyclability. However, to fully appreciate their potentials in terms of weight, cost and production rate, new manufacturing approach and techniques are needed. Hence, this project aims developing three end-effects solutions to demonstrate the feasibility of assembling a 180°

full scale multifunctional integrated thermoplastic lower fuselage shell, including cabin and cargo floor structure, see Figure 1. This demonstrator has a length of around 8m and a varying radius between 2m and 2.5m. The developed first end-effector is attached to an automated adaptive assembly tool and used to place and weld up to 8 meters length stringers to the fuselage skin. The second end-effector is supported by a robotic system hanging downwards from a gantry to pick-and-place injection moulded thermoplastic frame clips. In contrast, the third end-effector conducts various short welds at hard-to-reach locations while being attached to a robot arm. Finally, this automated assembly process is combined in a digital twin to provide a complete description of the product.

Fabrication of micro-components through Micro-FAST

Dr. Jie Zhao (Advanced Forming Research Centre, Dept. of DMEM, The University of Strathclyde), *Yi Qin, Yi Yang, Kunlan Huang*

Micro-FAST is a process which scales down a conventional FAST process for the forming of micro/miniature components, especially with difficult-to-cut and difficult-to-form materials, which provides an efficient alternative to the micro-manufacturing technology. The process combines powder sintering with micro-forming to enable shaping components under coupled multi-field actions to achieve high-density, near-net-shape components with high efficiency. The main techniques developed for overcoming the barriers for the applications of FAST at the miniature/micro-scales include: (i). directly pressing/forming loose powders in the die without using binders; (ii). combining heating and shaping to enable complex shapes/features; and (iii). dedicatedly controlling fusion bonding and material's plastic flow to enable high-quality forming. Forming from the powder without using a binder significantly shortens the process cycle, which also leads to high-purity of the parts formed. Combining forming and sintering has led to high-density components produced as well as achievement of complex-shaped components. Large current density enables very high heating rates, and involving a small volume of the material in forming a miniature component results in a high cooling rate, leading to a much shorter forming/sintering cycle which enables consolidation of the micro/nanocomposite into the bulk-sized component while also preserving their micro-nanostructures. In this talk, a review of the forming technology will be presented, to be accompanied with showing formed sample components and introducing machines and tools used. Outlooks and remarks on the future development will then be given.

ELADINE: sensor monitoring and numerical model approach for composite material wing box shape distorsions prediction

Mr. Andrea Torre Poza (AIMEN), *A M Rodrígues-Pinto, T Grandal-González, N González-Castro, L Carral, R Travieso-Puente, E Rodríguez-Senín, C Banu, A Paval and M Bocioaga*

The composite manufacturing process is still presenting many challenges associated with the process parameters control. There are many different manufacturing processes with endless possibilities of material combinations (resin, fibre and orientations), which still presents difficulties on ensuring a good final quality, especially the final geometry of the part, which is crucial for the aero-structures requirements. This requires the design and development of powerful computational models able to identify process induced deformations, optimized the manufacturing for each new component and eventually reduce the production of faulty parts. The main outcome of ELADINE project is to provide a method for shape distortions phenomena prediction on composite integral structures using an experimental-numerical approach. Different manufacturing parameters have been monitored using Fiber Bragg Grating (FBG) sensors and DC-dielectric (DC) sensors and the resulting part geometry has been

examined by means of coordinate analysis. Two different manufacturing methods were studied: LRI (Liquid Resin Infusion) and pre-impregnated fabric (pre-preg) and several scenarios were considered for the calibration a Finite Element Method (FEM) based simulation tool. The resulting model will be used for evaluation of a sub-scale demonstrator and, in the end, a full 7-meter composite wing.

Digital Image Correlation enhanced three point bending material test system

Mr. Xingguo Zhou (Centre for Precision Manufacturing, Dept. of DMEM, The University of Strathclyde), *Bo Chen*

Three-point bending test is used to determine the modulus of elasticity in bending of engineering materials, including metallic materials and non-metallic materials such as steel, aluminium al alloys and composites, which find wide application in the aviation industry. Based on displacement field and strain field in three-point bending test, which are measured by digital image correlation (DIC), a novel set of procedures to determine elastic-plastic material properties of the beam specimen is established. The set of procedures converts the load-displacement curves into stress-strain curves without specifying plastic hardening models. The proposed method is particularly useful when the material hardening law is unknown, or too complicated to fit into any existing parameterized models, while being still able to enjoy the benefit of three-point bending test, such as easy specimen preparation. The proposed method in the investigated case shows at least equally accurate results compared with the method using the Ramberg-Osgood model for aluminium alloy.

Process and energy efficiency in aeronautic production through smart industry implementation

Dr. Miguel Ángel Castillo (VP Technology Development Aernnova)

This contribution includes Aernnova approach on Smart Industry for energy and manufacturing processes efficiency. This approach develops and integrates, throughout the value chain of parts and production units, from the design to the supply and manufacturing process in the production plant, a tool to improve the efficiency:

- seeking an improvement in the sustainability of the processes,
- aiming to reduce the use of material and energy resources,
- reducing the environmental impact in terms of waste and emissions.

The new monitoring tool is developed to enable observation of the environmental impacts of the processes and / or operations, depending on the different variables defined for their control. This monitoring tool will make possible to measure the evolution of sustainability on a continuous basis of the modeled manufacturing process. This tool enables:

- to implement a plan for the continuous improvement of the energy performance of the pilot plan, through an energy management system module
- to make a more efficient and sustainable consumption of the raw materials necessary for the manufacture of the components.
- to identify the most efficient productive equipment.

There is a need to study the manufacturing processes and operations. This is carried out to identify the parameters that regulate the manufacturing processes functionalities and the generation of environmental impacts. From the collection of data on the parameters defined by the studies described

before, and their analysis, those parameters that have a direct influence on environmental impacts will be identified. Then, the relationships between key productive parameters and environmental impacts are concluded.

Optimization of the induction welding process through the integration of a thermal camera

Mr. Giuseppe Buccoliero (CETMA), *Michele Arganese, Alessandro Marseglia*

Continuous induction welding process (CIW) for carbon-fibre-reinforced thermoplastics (CFRT) meets the market needs of process technologies with minor capital investment and high flexibility. An important limit for the exploitation of IW process to the aerospace sector is related to possible defects onset due to material local heating, especially when components with complex shapes are welded . In these cases not-positive feedbacks from NDI inspections and changes in the surface roughness of the adherends can take places. One of the objectives of DEWTECOMP project is the development of a fully automated induction welding system to achieve innovative and efficient way of structural bond of reinforcement parts to structural frames. In the project this was realized by combining the induction welding system with a jointed-arm robot so that complex and curved parts can be joined with a high degree of automation. In particular the quality control system was upgraded through the implementation of a new control system, based on the use of a thermal camera on the welding head instead of a pyrometer, which is the most used system to monitor the surface temperature of the component to be welded. In fact through the pyrometer it is possible to measure only the temperature of a spot on the composite surface, and in the case of the induction welding process it matches the point at the maximum temperature. An incorrect position of the pyrometer affects the measurement of the maximum temperature, causing possible surface overheating. With the infrared camera and field measurements it is possible to monitor the temperature over a relatively large area. The development of this new Induction Welding equipment allowed the production of defects-free joined components, in an automated way and exploitable for components with complex shape, thus allowing an interesting exploitation of the induction welding technique in the aerospace sector.

Development a high precision hybrid machining processes for superhydrophobic on epoxy painting materials adhering to an aluminum alloy

Mr. Wenlong Chang (Centre for Precision Manufacturing, DMEM, The University of Strathclyde), *Yankang Tian, Yi Qin*

The painting materials and their thickness coated on the airframe of an aircraft would affect the overall weight of the aircraft as well as effectiveness of the protection of the airframe. Epoxy is one of the most popularly used painting materials widely used in the aviation industry for the airframes, and capable of providing a high resistance to chemicals, has less color fading and lower attendance to oxidation. It does not break down easily and adheres onto Aluminum alloys well. At the same time, avoiding icing on the epoxy paintings at different flight altitudes and/or in high latitude countries is essential. In this study, a high precision machining processes has been developed to build a series of micro-structure patterns on the Epoxy painting surfaces. These micro-structures with superhydrophobic characteristics lead to an improvement of the anti-ice and anti-fog capability and render self-cleaning and water-adhesion reduction functionalities. The high precision machining processes are including micro milling to machine 3D freeform surface, Inkjet machining to print Epoxy materials on the freeform surface, and laser machining process to machine micro structures. The results showed that the superhydrophobic surface

could delay the time of freezing by 28%, comparing to those with normal epoxy painting surfaces without artificially created micro-structures.

Advanced Manufacturing Technology for Aeronautics (PART III)

Session Chair : Prof. Yi Qin & Dr. Jie Zhao, University of Strathclyde, UK

Design methods and manufacturing techniques applicable for constructing dynamically scaled airplane models

Mr. Jaroslaw Milczarczyk (Military University of Technology), *Aleksander Olejnik, Robert Rogólski, Michał Szcześniak*

The article describes design methods and preparation technology intended for manufacturing scaled airplane models applicable in experimental flight testing. Reduced model with resized geometric dimensions should be constructed in such way to keep similarity its structural properties in relation to properties of the real aircraft. Having kept the similarity of weight, stiffness and aerodynamic load distribution and maintaining properly scaled values of thrust-to-weight and wing loading ratios we can prepare scaled model showing in flight features identical to the real airplane. A series of measuring and technological activities have to be undertaken to develop full CAD model mapping geometry of the aircraft and including all crucial structural elements of the airframe. The process chain includes measuring, design and technological activities. The development of the geometry model includes: scanning outer geometry of the real airframe, development of the surface geometry model in the CAD environment and then introducing inner geometry items which together with outer skin face make the assembled solid model of the aircraft. For the needs of constructing scaled model the full-size CAD model has to be reduced. The structure of that resized model do not have to be the same as the real one. Materials and structural element can be quite different but after assembling them the similarity in relation static or dynamic structural effects should be proved. The manufacturing phase is the preparation of molds for laminating surface elements, milling of solid elements, assembly of structural components, surface finishing of the model-body surface. The finished part of model was subjected to a load test in a special test stand to check its deformability under specific load. In the same way the numerical static analysis of the full-size FEM model was conducted. The distribution of static displacement results obtained in both cases were compared. The other way of checking structural properties of the scaled model is comparable analysis of free vibrations. Normal modes obtained after testing the full-size FEM model and its scaled counterpart should be the same. The eigenfrequencies are the same only in case if weights and stiffness values are scaled in the same proportions. The procedure and results were elaborated on the example of the scaled model of Tu-154M aircraft developed in Faculty of Mechatronics, Armament and Aerospace of the Military University of Technology (FMA MUT Warsaw, PL). Constructing and testing dynamically scaled model is one of many tasks solved in the framework of complex research project, of which the general purpose is to elaborate a series of numerical and experimental analyses useful in analyzing the circumstances of the Smolensk disaster.

Particle foam molded cores in a one-shot resin infusion process for high-rate production of wing moveables

Mr. Karim Shehata (University of Applied Sciences Upper Austria - School of Engineering), *Franz M. Sendner, Gernot Schneiderbauer, Markus Wolfahrt, Jonathan Glinz, Karl H. Semlitsch, Roland M. Hinterhölzl*

For the single-aisle segment a recover to pre-COVID level is expected between 2023 to 2025. Therefore, a manufacturing method like the vacuum infusion, which represents an interesting possibility with a short production cycle, while maintaining the mechanically efficient lightweight sandwich construction, has to be enabled. The vacuum infusion process, in particular the Membrane Assisted Resin Infusion (MARI), can significantly reduce production time. This process requires the use of an alternative core system compared to the honeycomb cores usually used in high performance composite parts. While maintaining the advantages of the mechanically and weight efficient sandwich construction, foam cores made of polymers represent a very interesting alternative. For example, the particle foam polymethacrylimide (PMI) is already used in some aerospace applications. Due to the fact that the particle foam can be foamed in mold, even though a molding tool is needed, the process is not only faster but also cheaper regarding high production rates. The foam cores are foamed in blocks and then mechanically brought to their final contour. This project aims to develop a methodology for the design and implementation of PMI foam cores in sandwich structures. To compensate for the high PMI foam density, which is limited to 75 kg/m³ other than the usually used honeycomb core (Nomex) with 48 kg/m³, a weight optimized core structure has to be found. Two different simulation approaches are being pursued to obtain a lightweight foam structure. The first utilizes different subcomponents with optimized grid structures, to replace sections of the spoiler foam core. To evaluate the behavior of the grid structures three-point bending simulations were performed and will be validated against experimental tests. If a three-dimensional lattice or cave structure made of PMI foam enclose within a vacuum infusion carbon fiber reinforced polymer (CFRP) it must be ensured that the resin cannot penetrate either through the intercellular pore spaces or through the adhesive layer during production. The curing reaction of the resin is exothermic. Resin accumulations in foam cells lead to self-reinforcing, overshooting exothermic reactions, which leads to local hotspots. Post-foaming temperature of the foam is thereby exceeded. Smoke due to exothermic resin reaction can leak through damaged foam and result in bagging damage that leads to the contamination of the working environment. The aim here is to further investigate the impermeability of PMI foam cores in sandwich structures during the infusion process. In order to be able to analyze a complex three-dimensional cell structure of the closed-cell foam and its impermeability, X-ray computed tomography (XCT) is used as an imaging technique. Subsequently, XCT scans of vacuum infused PMI foam specimens were performed on two different systems for overview and detail investigations at smaller cutout regions of each specimen. For the second approach, regions with different foam core densities are defined, depending on local mechanical loads and stresses. In a subsequent step, the two previous approaches might be combined to maximize the weight reduction. Another focus was set on the low-velocity impact behavior of sandwich panels made of carbon fiber reinforced polymer (CFRP) facings and PMI foams with three different densities. Damage characterization were done by non-destructive techniques (e.g. ultrasonic, lock-in thermography) and by micrographs of the impacted damaged area. For performance comparison of the foam core sandwich structures to typically used Nomex honeycomb cores compression after impact (CAI) tests were carried out.

Friction stir welding trade-off studies on a tilt rotor nacelle primary structure

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Friction Stir Welding (FSW) is a relatively recent technology that was invented in 1991 at The Welding Institute (TWI) of Cambridge. It represents a significant revolution in the panorama of the joining techniques. As a matter of fact, FSW is a solid-state joining technique which does not include a molten state during the welding process. The employment of FSW to join airframe structures can have a huge impact on the weight saving opportunity, with a reduction of raw material blocks lead time and a considerably lower environmental impact associated both with the weight saving and with the manufacturing process. However, material's mechanical properties, in the area affected by the welding process, are strictly dependent on the process parameters that if not properly set up, flaws and defects can occur in the seam weld, thus resulting in a significant loss in the material's mechanical properties.

The present work is developed within the H2020 Clean Sky 2 project T-WING, in the framework of NGCTR-TD Integrated Aircraft Demonstrator. In particular, one of the objectives of the project T-WING is the development of the Nacelle Primary Structure (NPS) until TRL6. The NPS is the structural interface between the wing and the engine propeller and transmission. A study was conducted to investigate the trade-off between the NPS baseline solution (mechanical parts all manufactured from one-piece raw material blocks) and an innovative solution which foresees some parts manufactured by using also FSW. A selection of the parts more prone to FSW application was made as first step, with the concurrence of the manufacturing partner. As a second step, the figures of merit to compare the two solutions were defined, such as cost, raw material blocks lead time, environmental impact, mechanical behaviour, and airworthiness considerations. Detailed cost analysis and Finite elements (FE) calculation aided the trade-off. FE analyses encompassed both the static and the dynamic behaviour of the two NPS configurations, showing negligible differences in the stress contours, the modal shapes and frequency. Finally some scalability considerations are drawn, especially for which regards the cost advantage when the NPS is scaled up to a tiltrotor having a MTOW equal to 17 tons.

Simulating the Induction Welding Process of thermoplastic composite materials for aircraft structures

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The induction welding technology implemented on advanced thermoplastic composites for aircraft structures is expected to reduce the environmental impact of aviation by reducing the emission during production process, as well as by reducing energy consumption[85]. The induction welding process combines the melting of the joining materials due to the generation of eddy currents into the composite plates which are in contact; they arecaused by a coil generating an alternating electromagnetic field and

[85] NHYTE: New HYbrid ThErmoplastic Composite Aerostructures Manufactured by Out of Autoclave Continuous. Eur. Union's Horiz. 2020 Res. Innov. Program. under grant Agreem. No 723309 2017.

the pressure enforcement by a consolidation roller[86] [87] [88] [89] [90]. When electric currents are induced into composite materials, three mechanisms occur simultaneously leading to heating: i) heating by Joule losses along the fibers; ii) heating by contact resistance at junctions between fibers and iii) heating by dielectric hysteresis at fiber junctions, where fibers act as a capacitor when are separated by a layer of thermoplastic resin[91]. In this work two different numerical approaches for simulating the induction welding process of a hybrid thermoplastic material have been performed. The results are experimentally validated. The experimental configuration might be seen in Figure 1

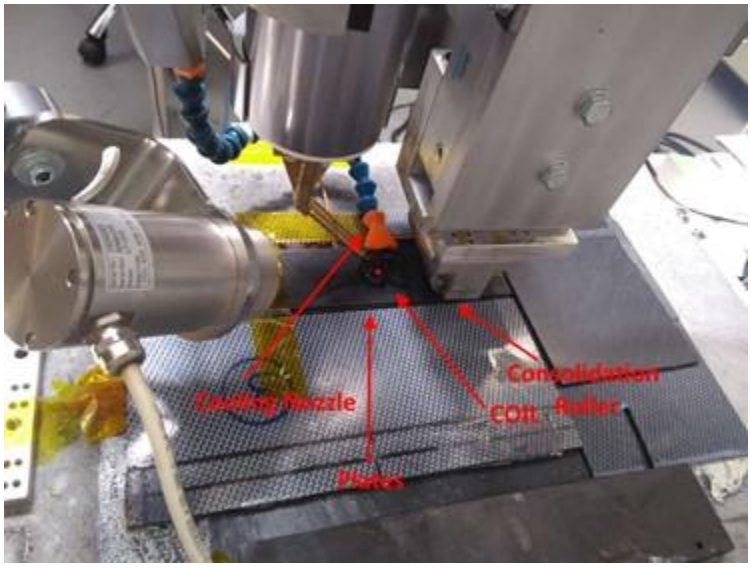

Figure 2: Figure 1: Experimental configuration of the induction welding process

The first approach is based on a numerical model which combines electromagnetism, heat transfer and solid mechanics in the same numerical environment in MSC Marc software. In parallel, a computationally efficient approach which combines the results for the steady-state electromagnetism in specific intervals in Ansys EM suite as well as the heat transfer and solid mechanics in Ansys Workbench has been performed. The reults of both numerical approaches correlate very well with the experimental results.

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Evaluation of nitrogen permeability properties of thermoplastic composite materials for the production of next generation aircraft pressure vessels

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from the Clean Sky 2 Joint Undertaking (JU) under GA No. 865291. The aim of the TRINITI project is the development, production, validation and verification of high-pressure vessels for aircrafts with thermoplastic based multi-material composites by automated and OoA fabrication processes. First the methods which were used for permeability measurement are presented, then results for different material layups are presented and finally consequences for the design of high pressure vessels for nitrogen storage are derived

Vessel's materials were selected considering that one of the main project requirements is the nitrogen permeability of the tank wall. In general, permeability properties of the most used polymeric materials are available in literature because they are homogeneous materials. Instead, these values are not available for composite materials since the performance of the structure is a function of several factors, such as the manufacturing process parameters, the layup etc.. Taking into account that for the assessment of the permeability properties the percentage and the distribution of voids are fundamental, it has been designed and built an experimental equipment for the measurement of the permeability value of structures fabricated by automated fiber placement technology. The equipment consists of a sealed chamber in which one face is the sample to be investigated (a composite material specimen) . FEM analyses have been carried out to verify and validate the functionality of the tool. The tool being made of aluminium, the only way out for the pressurized nitrogen is through the composite material specimen, so this system allows to measure the pressure decay in a certain time frame. With these data and using the Darcy's law, the permeability value can be calculated. With regard to the selection of the most suitable thermoplastic composite material, based on a literature review, the PEEK/C composite was identified, both from mechanical and physical points of view. Several specimens have been produced by automated fiber placement technology to assess the permeability value according to two main configurations. The first option deals with usage of a thin layer of 500 µm of unreinforced PEEK material (inner liner) to create a barrier to the nitrogen passage. Such vessel configuration allows to significantly reduce the permeability.,. To have a comparison of these data, tests of the PEEK panels without a fiber reinforcement were carried out and the results are similar to those of the composite material. This approach allowed to validate the experimental tool and to confirm that the results obtained with PEEK/C composite material are promising, for the aim of the project.. The second option has dealt with the development of a vessel structure using only reinforced thermoplastic composite material without an inner liner. The results of the permeability tests confirmed the possibility to avoid the usage of the inner liner. The permeability values have been of the same order of magnitude of the best results obtained with the inner liner (PEEK/C with unreinforced PEEK liner of 500 µm or unreinforced PEEK alone). Based on that, the ambitious goal to produce a pressure vessel without liner seems to be a realistic opportunity to reduce the chain of manufacturing processes needed for the tank fabrication, which means a reduction of weight (no liner) and also a reduction of recurring and non-recurring costs, since only structural material can be used.

STRATOFLY project

Session Chair : Dr. Nicole Viola, Politecnico di Torino, Italy

Main achievements of the H2020 STRATOFLY PROJECT

Dr. Nicole Viola (Politecnico di Torino), *Roberta Fusaro*

The worldwide incentive to reconsider commercial high-speed transport urges Europe to quantitatively assess the potential of civil high-speed aviation with respect to technical, environmental and economic viability in combination with human factors, social acceptance, implementation and operational aspects.

As investigated in previous studies, with special reference to those carried out in the European framework, some innovative high-speed aircraft configurations have now the potential to assure an economically viable high-speed aircraft fleet. They make use of unexploited flight routes in the stratosphere, offering a solution to the presently congested flight paths while ensuring a minimum environmental impact in terms of emitted noise and greenhouse gasses, particularly during stratospheric cruise. Only a dedicated multi-disciplinary integrated aircraft design approach can realize this, by considering airframe architectures embedding the propulsion systems as well as meticulously integrating crucial subsystems. In this context, starting from an in-depth investigation of the current status of the activities, the STRATOFLY project has been funded by the European Commission, under the framework of Horizon 2020 plan, with the aim of assessing the potential of this type of high-speed transport vehicle to reach TRL6 by 2035, with respect to key technological, societal and economical aspects. Main issues are related to aero-thermal and structural integrity, low-emission combined propulsion cycles, subsystems design and integration, including smart energy management, environmental aspects affecting climate change, noise emissions, social acceptance accounting for safety and human factors, and economic viability.

This paper aims at summarizing the main challenges and results achieved by the H2020 STRATOFLY project, highlighting the steps forward with respect to the past European Projects.

Large eddy simulation of the STRATOFLY small scale flight experiment

Dr. Christian Ibron (Swedish Defense Research Agency (FOI)), *Niklas Zettervall, Kevin Nordin-Bates, Christer Fureby*

Time resolved, reacting, three-dimensional (3D) numerical simulations of high-speed reactive flow are performed on the STRATOFLY Small Scale Flight Experiment (SSFE) hydrogen propelled scramjet scale-model. The simulated flight conditions correspond to a flight altitude of 28 km and a speed of Mach 7.8. The simulations are performed using a code developed within the OpenFOAM C++ framework using the Large Eddy Simulation (LES) approach combined with comprehensive chemical kinetics and the Partially Stirred Reactor (PaSR) model for dealing with the turbulence-chemistry interactions. The chemical reaction mechanism employed is based on the Z22 hydrogen-air reaction mechanism supplemented with a 20 step reaction mechanism for nitrous oxides. Simulated wall heat-flux of both the intake and the upstream part of the combustor show good agreement with experimental measurements performed at DLR Göttingen. The computed gas composition in the combustor is compared to spatially resolved spectroscopic data at several line-of-sight measurement locations at various depths in the scramjet. Qualitative agreement is observed in the spatial distributions of major species along the length of the combustor. Formation of moderate to low levels of nitrous oxides are generated in close vicinity to the

reaction zones, particularly in the late stage injection zone of the combustor where shock induced ignition is present.

Computational Evaluations of Emissions Indexes Released by the STRATOFLY Air-Breathing Combined Propulsive System

Dr. Guido Saccone (Italian Aerospace Research Centre - CIRA), *Ali Can Ispir, Bayindir Saracoglu, Luigi Cutrone, Marco Marini*

Emissions Indexes of Nitrogen Oxide (EINO) and water vapour released by Air Turbo Rocket (ATR) and Dual Mode Ramjet (DMR) engines of the STRATOFLY air-breathing, hypersonic scramjet vehicle, propelled by hydrogen/air were evaluated. ATR engine operation was assessed for several cruise conditions in both subsonic and supersonic flight regimes in Ecosimpro software which is an object-oriented thermodynamic design and simulation platform. ATR combustor inlet flow conditions play an important role for the computation of species mass fractions and these conditions are highly dependent on turbomachinery performance and engine flight regime. A propulsive operational database was created by varying mass flow rates of fuel and flight conditions such as cruise speed and altitude to investigate possible engine operations. The all-inlet conditions in this map are provided to the Cantera-Python 0D chemistry solver implementing a special designed and formulated 0D kinetic-thermodynamic methodology successfully used to model and simulate the electric spark ignition required to activate the combustion process of the reacting mixture in the ATR combustion chambers. While the coupled aero-thermodynamic/aero-propulsive 0D/1D code i.e., SPREAD, designed and developed by the Italian Aerospace Research Centre (CIRA) was used for DMR calculations. SPREAD is a 1D engineering tool able to provide a real-time simplified design and analysis of several engine/airframe configurations and the identification of the most promising one/s, in terms of vehicle performances, ignition delay times, Emission Indexes, with respect to user-defined constraints and requirements. The novel multi-step, kinetic scheme for hydrogen/air high pressure combustion, developed by the Swedish Defence Research Agency (FOI) including a detailed NOx generation reactions sub-mechanism was implemented and employed for EINO calculations in both ATRs and DMRs. Results indicated low emissions of NO according to the optimized design of the ATR and DMR combustion chambers. Analogously, the released amount of water vapour is in good agreement with the required combustion efficiency and the expected propulsive performance.

Aerodynamic Characterization of the Hypersonic Civil Aircraft STRATOFLY-MR3

Mr. Pietro Roncioni (CIRA - Italian Aerospace Research Centre), *Marco Marini, Oscar Gori, Roberta Fusaro, Nicole Viola*

The H2020 STRATOFLY Project is a highly-multidisciplinary project and is the last one of a series of projects co-funded by the European Commission in the last fifteen years, combining technological and operative issues for hypersonic civil aircrafts and aiming to study the feasibility of high-speed passenger stratospheric flight. Technological, environmental, operational and economic factors, that allow the global sustainability of new air space's exploitation, are considered, drastically reducing transfer time (i.e. antipodal flights in less than two to four hours), emissions and noise, and guaranteeing the required safety levels. The main project objectives are to refine the design and the concept of operations of the LAPCAT-II MR2.4 vehicle, and to reach the ambitious goal of TRL=6 by 2035 for the concept, considering that the crucial technologies of STRATOFLY MR3 vehicle may represent a step forward to reach the goal of future reusable space transportation systems.

In this framework, a detailed aerodynamic characterization of the hypersonic cruiser configuration was conducted targeting the generation of an aerodynamic database covering all the flight conditions in terms of speed regimes (from Mach 0.3 to Mach 8), angle of attack, control surfaces deflections and far field conditions. The STRATOFLY MR3 presents a highly integrated structure which is characterized by a complex waverider configuration with dorsal mounted propulsive subsystem; therefore, even at conceptual design stage, the aerodynamic characterization of the configuration, achieved by means of engineering tools coupled with low-fidelity CFD simulations, aims at precisely describing both the external vehicle layout and the contribution of the internal vehicle propulsive flowpath. Moreover, the understanding of the contribution of the flight control surfaces and consequently their correct sizing is crucial to properly assess the trim-ability and the fly-ability of the vehicle concept. A build-up approach is adopted in order to obtain the aerodynamic contributions of all control surfaces, thrust pitching moment thrust to be added to the clean configuration. The results of this activity will be shown in terms of global aerodynamic coefficients, control surfaces effects, stability derivatives and trim analysis. In addition, a comparison of the results coming from the engineering methods and CFD will be included. Eventually, the paper will highlight the crucial role of the developed aerodynamic database as a unique and reliable base for mission analysis and trajectory simulation.

The Climate Impact of Hypersonic Transport

Mr. Johannes Pletzer (DLR), *Didier Hauglustaine, Patrick Joeckel, Volker Grewe*

The climate impact of aircraft emissions is a hot topic that has been studied for decades. A recent study estimates the current contribution of aircraft activity to human made climate change to 3.5 % (Lee et al, 2021). This estimate is based on conventional aircraft fleets that are powered with kerosene and fly at altitudes from 10-12 km. Supersonic aircraft could affect the climate up to 3-14 times (depending on altitude) as much as conventional aircraft (Grewe et al, 2010). Compared to supersonic aircraft, hypersonic aircraft with hydrogen propulsion are seen as a potentially more climate friendly alternative. These high-speed aircraft, flying at middle and upper stratospheric altitudes (25-50 km), emit mostly water vapour besides nitrogen oxides and unburned hydrogen. Water vapour, however, is a potent green house gas. Nevertheless, literature suggests that photolysis and chemical reaction of water vapour with O(1D) efficiently remove the emitted water vapour at high altitudes. Thus, potentially keeping the climate impact of hypersonic aircraft at a minimum. This presentation will show the impact of hypersonic emissions on atmospheric composition and the resulting climate impact. Results are based on a comparison of two hypersonic aircraft with two high-level models (EMAC, LMDz-INCA) and a response model (AirClim).

Integrated subsystems design for the STRATOFLY MR3 vehicle

Dr. Roberta Fusaro (Politecnico di Torino), *Davide Ferretto, Luca De Giorgi, Nicole Viola*

The H2020 STRATOFLY project aims at suggesting a realizable path from the theoretical investigations and lab tests towards an operational high-speed transportation. To assure a reliable convergence towards this goal, the project concept approaches the topic from two different but complementary design spaces: the operational design versus high-speed aircraft & technology design. As eluded in previous EC funded projects, some innovative high-speed aircraft configurations have now the potential to assure an economically viable high-speed aircraft fleet. They make use of unexploited flight routes in the stratosphere, offering a solution to the presently congested flight paths while ensuring a minimum environmental impact in terms of emitted noise and green-house gasses, particularly during stratospheric

cruise. Only a dedicated multi-disciplinary integrated design approach could realize this, by considering airframe architectures embedding the propulsion systems as well as meticulously integrating crucial subsystems. It was shown that this design philosophy assures a specific fuel consumption being proportional to the flight speed, offering a flat optimum with additional flexibility in the design space.

In details, the present work aims at describing the complex and highly integrated subsystems design which characterizes STRATOFLY MR3. Targeting a 300 passengers flight along long-haul routes with maximum cruise speed of Mach 8 using liquid hydrogen, the propulsion and propellant subsystems design become crucial to understand the concept feasibility. From the propulsion standpoint, STRATOFLY MR3 is equipped with 6 Air Turbo Rocket and a Dual Mode Ramjet, integrated in an internal duct completely embedded on the top of the vehicle. In order to feed these engines, in all modes of operation, the vehicle can host up to 180 t of hydrogen stored cryogenically in dedicated bubble structures spread all along the vehicle. The design of the propellant subsystem, including the optimization of the depletion strategy is essential to limit the CoG shift throughout the mission, thus reducing the deflections requested to the Flight Control Surfaces. To ensure flight stability and control, the STRATOFLY MR3 has been designed to host a fully movable canard, a double pair of ailerons, two rudders in a split V-shape tail and a pair of body-flaps mounted on top of the nozzle. Moreover, the presence of liquid hydrogen is a key element for the thermal and energy management subsystem, a multifunctional subsystem intended to manage both the thermal and energetic issues, carrying out the functionalities of three main subsystems such as the Thermal Protection and Control, Environmental Control and Life Support and Electrical Power Generation subsystem. The present work aims at providing an overview of the results achieved in the design of the on-board subsystems of STRATOFLY MR3, highlighting the high level of complexity and integration.

Recent advances on developing civil supersonic aircrafts

Session Chair : Dr. Andrey Kazhan, Dr. Evgeny Andreev & Dr. Boris Nesterenko, TsAGI, Russia

Bionic structure and new capabilities to provide safety and high level of comfort for the new generation of supersonic passenger aircrafts

Dr. Alexander Shanygin (TsAGI, Russia, Zhukovsky)

Configurations of currently designing perspective supersonic passenger aircrafts (SPA) have a number of specific features as compared to the ones of subsonic passenger aircrafts. These features lead to sufficient increase of complexity of their airframes. At those requirements of safety and comfort give additional constraints of SPA structure, connected with more complex flight regimes. Up-to-date requirements on noise and sonic boom make the task of searching rational structure layout for SPA even more difficult and form new constraints on the structure. Experience of development of the new generation of structures for subsonic passenger aircrafts shows that development of airframes based on bionic principles, formulated in TsAGI, as a result of international and domestic projects, give new opportunities not only in weight saving, but also in additional increase of safety and comfort for passengers. This is reached due to interaction of the main parts of bionic structure (stiff grid of unidirectional composite ribs and system of protective elements). In the present work results of numerical investigations for searching of rational bionic structure of a hypothetic SPA, having low supersonic speed with almost no heating, are presented. It is shown, that in frame of bionic layout due to selection of rational grid structure and using positive synergy effect of grid-protection interaction, higher level of safety and comfort in cabin including decreased level of thermal/noise insulation, increased size of windows and lower shake in turbulence can be provided without weight penalty. The report is prepared in the implementation of the program for the creation and development of the World-Class Research Center “Supersonic” for 2020-2050 funded by the Ministry of Science and Higher Education of the Russian Federation (Grant agreement of December, 8, 2020 № 075-11-2020-023).

Effect of nozzle geometry on acoustic characteristics of isolated and installed turbulent jets

Kopiev V.F., Zaytsev M. Yu., ***Dr. Belyaev Ivan V. (TsAGI),*** *Faranosov G.A., Bychkov O.P., N.N. Ostrikov*

Noise reduction of turbulent jets is a formidable problem, which recently received new attention due to the significant (and even dominant) contribution of turbulent jets to the community noise of future supersonic civil aircraft. The present paper reports on the results of an experimental study on the shielding effect of dual-stream coaxial jets with round, chevron, and corrugated nozzles. For shielding, both a rectangular plane screen and a small-scale tail model of aircraft with the engine-over-the-wing layout were considered. It is shown that chevron/corrugated nozzles reduce jet noise in the low-frequency region but typically have high-frequency penalty; on the other hand, the shielding is effective in this high-frequency range. Therefore, when both these technologies (nozzle modification and shielding) are used simultaneously, they can prove supplementary to each other and result in jet noise reduction with respect to the isolated round jet in the entire frequency range.

The study comprises two parts: (i) investigation of the effect of chevron and corrugated nozzles on dual-stream coaxial jet noise, and (ii) investigation of the shielding effect on the noise of jets from different nozzle configurations. The tests on the effect of chevron and corrugated nozzles on isolated jet noise allowed two low-noise configurations to be selected: 1) the chevron nozzle with 14 chevrons at the

secondary (bypass) nozzle and with the round primary nozzle, 2) the corrugated nozzle with 12 corrugations at the secondary (bypass) nozzle and with the round primary nozzle. As a reference case, the round nozzle without chevrons or corrugations is considered. The diameters of the low-noise and reference nozzles were the same and equal to 85 mm; the jet was unheated. The pressure ratios were πn=1.8 (V = 301 m/s) and πn=1.655 (V = 280 m/s) for the primary and secondary nozzles, respectively. The study of jet noise shielding by the rectangular screen showed that the shielding effect for the round (reference) nozzle at the angle of 30° to the jet axis (where the jet noise directivity has the maximum) is rather weak and does not exceed 0.8 dB for all the considered relative positions of the nozzle and the screen. For the microphone in the geometric shadow region (90°), the effect of shielding manifests itself in noise reduction for the mid- to high-frequency range (frequencies higher than 700 1400 Hz, the value increases when the screen is closer to the nozzle) up to 3.5 dB, whereas for lower frequency the noise increases by up to 3.2 dB. The latter effect seems to be due to the intensification of diffracted waves produced by strong pulsations in the jet mixing region in the vicinity of the sharp edge of the screen. It is shown that the shielding by the screen is larger for the corrugated nozzle than for the chevron nozzle: 5.5 dB and 3.4 dB, respectively, at angle 90°. The noise is reduced for all measured frequencies (from 200 Hz to 25 kHz) and angles (30° - 100°), unlike the case for isolated jets when the chevron and corrugated nozzles tend to reduce noise for low frequencies and increase it for higher frequencies. Thus, it is experimentally demonstrated, that the efficient noise reduction is due to the synergy between the different methods: the nozzle modifications are efficient for low frequencies but have the high-frequency penalty, whereas the shielding does not suppress the low-frequency noise but is very effective at higher frequencies. It is also demonstrated that chevron and corrugated primary nozzles do not affect the shielding. Experiments of noise shielding by the tail part of aircraft showed that the shielding effect for the round (reference) nozzle is rather weak as well. The corrugated and chevron nozzles lead to significant shielding effect for all angles and frequencies considered, so that the noise reduction reaches 2.6 – 4.1 dB and 2 – 2.7 dB for the corrugated and chevron nozzles, respectively. The paper is prepared in the implementation of the program for the creation and development of the World-Class Research Center “Supersonic” for 2020-2050 funded by the Ministry of Science and Higher Education of the Russian Federation (Grant agreement of December, 8, 2020 № 075-11-2020-023).

Supersonic Platform Specifications for SENECA Project

Dr. Atif Riaz (Cranfield University), *Craig Lawson, Christos Mourouzidis, Vassilios Pachidis*

This paper presents the development of platform specifications for supersonic aircraft in an EU research project named SENECA “(LTO) noiSe and EmissioNs of supErsoniC Aircraft”. The project will contribute to the potential next generation of supersonic civil aircraft through ICAO level discussions and the European perspective on the necessary regulations for supersonic transport aircraft. The aim of the project is to develop deepened understanding and detailed modelling for the emissions, landing and take-off noise, and global environmental impact of supersonic civil aircraft. In order to meet the aim of SENECA project, Cranfield University developed platform specifications for supersonic business jets and airliners, which are suitable for assessing environmental impact. Two platform specifications are proposed for supersonic business jets comprising of 8-20 passengers with cruising Mach numbers of 1.4 and 1.6. In addition, two further platform specifications are developed for supersonic airliners comprising of 100 passengers and cruising Mach numbers of 1.8 and 2.2. The missions under consideration for these platforms will be supersonic over water and subsonic over land. After specifying the top-level aircraft requirements (TLARs), the airframe and propulsion teams at Cranfield University generated platform specifications (by sending

thrust requirements and receiving engine performance decks respectively in iterations) which include geometrical data, performance characteristics, and mission profiles. The results provided in this paper will be employed in SENECA project to develop novel methods for assessing emissions, LTO noise, and global environmental impact.

Goals, tasks and technic concept of Russian flight civil supersonic jet technology demonstrator

Mr. Andrey V. Kazhan (Central Aerohydrodynamic Institute (TsAGI)), *Igor G. Bashkirov, Vyacheslav G. Kazhan, Evgeny V. Karpov, Andrey A. Poukhov, Sergey L. Chernyshev, Alexander N. Shanygin, Andrey V. Shenkin*

The fundamental difference of new generation civil supersonic jets (SSJ) from existing supersonic airplanes is a requirement of providing minimal environmental impact. The task of ensuring efficient flight at supersonic speed with minimal influence on ecology demands development and implementation of a wide range of new technologies and technical solutions in aerodynamic layout, powerplant, construction, flight control system etc. Existing by now in Russia scientific and technical groundwork on SSJ requires proof of effectiveness, feasibility and integration ability for a complex of technologies and technical solutions in real operating conditions on a flight civil supersonic jet technology demonstrator. Creation and flight tests of such a demonstrator will increase technologies readiness level, decrease technical risks of new generation SSJ's development and provide a basis for formulating future SSJ ecology norms. This work presents goals and tasks for Russian flight civil supersonic jet technology demonstrator and considers some key technologies for new generation SSJ.

Development of computer code and calculation of the propagation of sonic boom to the ground in a real atmosphere

Mr. Vladlen S. Gorbovskoy (Central Aerohydrodynamic Institute named after prof. N.E. Zhukovsky (TsAGI)), *Andrey V. Kazhan, Sergey S. Vasin, Alexey O. Korunov*

The estimation of the characteristics of sonic boom is the one of the general tasks in supersonic aircraft design. In the absence of aircraft with principles of sonic boom reduction, the numerical calculation is the single way of sonic boom investigation in the far field and the tool of predicting the level of sonic boom loudness on the ground of supersonic aircraft under development. Due to the fact that the overpressure signature from aircraft flying at supersonic speed overcomes huge distance up to tens or hundreds kilometers to the ground, the real characteristics of atmosphere (temperature, humidity, wind profiles) have a great effect on the transformation of sonic boom wave (signal duration and intensity, pressure rise time, loudness). One of the ways to predict the sonic boom attenuation in propagation to the ground is the solution of augmented Burgers equation. In this article the numerical calculation technics for sonic boom propagation in real atmosphere is presented. The computer code called "vBoom" is developed and the comparison with the results of the propagation cases in 3rd AIAA Sonic Boom Prediction Workshop is performed.

Design solutions synthesis at advanced supersonic passenger aircraft preliminary aerodynamic design under parametric epistemic uncertainty conditions

I.G. Bashkirov, A.A. Dvoinikov, ***Mr. G.S. Veresnikov (V.A. Trapeznikov Institute of Control Sciences of RAS)***

The problem of parametric synthesis of design solutions at advanced supersonic jet (SSJ) preliminary aerodynamic design under conditions of epistemic uncertainty is considered. To solve this problem, optimization models with objective functions and constraints that depend on input and optimizable

nondeterministic parameters, the information on which is formed on the basis of expert evaluations, have been developed. The nondeterministic representation of such parameters is formed on the basis of Baoding Liu (Tsinghua University, China) uncertainty theory[92], providing low computational complexity for a wide range of objective functions and constraints at the SSJ preliminary aerodynamic design stage. Using the developed nondeterministic optimization models, typical problems of SSJ parameter synthesis under conditions of epistemic uncertainty are formulated and solved.

[92] Liu, B. Some research problems in uncertainty theory / B. Liu — Journal of Uncertain Systems, Vol.3, No.1, 2009. — 3-10 p. (pp.3-10).

MORE&LESS Academy

Session Chair : Dr. Nicole Viola, Politecnico di Torino, Italy

LTO noise prediction methodology for SST aircraft conceptual design

Mr. Grazia Piccirillo (Politecnico di Torino), *Nicole Viola, Roberta Fusaro, Luigi Federico*

To gain a better understanding of the impact of noise requirements on the design of a new generation of Supersonic Transport (SST) aircraft and identify new promising low-noise design, the introduction of noise emission estimation at conceptual design level is needed. Hereby, the current study addresses the development of a methodology to account for Landing and Take-O (LTO) noise requirements as constraint in the early stages of the SST aircraft design process, supporting a design-to-noise approach (Figure 1). To accomplish this goal, a noise prediction methodology aiming at predicting noise levels during LTO cycles has been developed. The methodology includes a supersonic aircraft noise model in which overall air-craft noise is predicted as an assembly of major noise sources (Figure 2), each modelled with an individual semi-empirical noise source model based on the equations reported in \ Aircraft Noise Prediction Program {Theoretical Manual" published by NASA. Following the aeroa-coustics modelling applied in Aircraft Noise Prediction Program (ANOPP), the major LTO noise sources of an SST aircraft have been selected and in addition the noise attenuation due to the propagation in the atmosphere has been considered in accordance with SAE ARP 866 B. The integration of the noise model with the simulation of a take-o and landing flight trajectory leads to the prediction of the aircraft noise level. The accuracy of the method in predicting the overall aircraft noise level has been estimated through a dedicated validation with experimental data provided by the Aircraft Noise and Performance (ANP) database for flyover trajectories at different altitude and thrust rating. Considering that the goal of the methodology is to predict noise levels for future supersonic aircraft, the only available super-sonic aircraft of the ANP, i.e. the Concorde, has been selected as case study. The overall methodology has been applied to predict noise level at the three certification measuring points (sideline, yover and approach) de ned by ICAO. The results have been reported for each noise source contribution and overall aircraft noise. The outcome of this research activity demonstrates that the application of the developed methodology can be useful to verify the compliance with noise requirements since the early stages of aircraft design and can provide useful guidelines for the design of future low-noise SST together with operational procedures able to mitigate the LTO noise.

Mission analysis activities for the conceptual design of high-speed transportation systems

Mr. Oscar Gori (Politecnico di Torino)

The development of environmentally sustainable solutions for civil aviation has become one of the main goals of the aerospace community. At the same time, an increasing interest for high-speed aircraft has been experienced. Several research activities have been carried out to explore the possibility to fly at Mach greater than one, while at the same time reducing the environmental impact of such technologies. Given the expected high-level performance and complexity of high-speed vehicle design, it is fundamental to enhance the conceptual design stage, supporting the different design steps with mission analyses activities. This could provide the capability to immediately estimate the most impacting vehicle characteristics which directly affect the entire mission, to avoid any undesired erroneous estimations of fuel consumption and range.

This presentation focuses on the preliminary mission analysis activities carried out in the field of the H2020 STRATFOLY project, for a Mach 8 waverider vehicle designed to cover antipodal routes. However, before dealing with the mission analysis task, the static stability and trim analysis is presented, on the basis of the vehicle detailed aerodynamic model. This is a crucial task for the design of a civil passenger aircraft, which is expected to fly stable, controllable and trimmed during the entire mission. For that reason, the contribution of the deflected control surfaces is needed to guarantee stability at each Mach number. The first outcome of the analysis is a set of trim maps, which are then used to create the complete set of trimmed conditions at each Mach number. The exploitation of the trimmed aerodynamic database while computing mission trajectories is essential for a reliable estimation of the vehicle performance during the different mission phases. The results are also compared to the untrimmed conditions, to highlight which is the impact of the trim requirements on the overall performance of the vehicle. Since these limitations directly affect the feasibility of the mission, a set of shorter routes is also considered to provide possible alternatives. As a consequence, different mission profiles and trajectories are considered and studied. The mission simulations are performed using the ASTOS 9.17 software. As a next step, a Mach 5 version of the first vehicle is considered, taking advantages from the outcomes of the STRATOFLY project. Mission analysis activities are also presented: the Payload-Range study is performed to understand which could be the maximum range achievable considering the reference vehicle cruising at Mach 5. The external shape and dimensions of the vehicle remain unchanged, while payload and fuel mass varies for each simulation. The trimmed aerodynamic database developed for the STRATOFLY vehicle is also used for this analysis. However, one main limitation should be highlighted: the vehicle considered is optimized for cruising at Mach 8 and not Mach 5. For that reason, the possible scaling of the vehicle and a re-design of the propulsion plant is currently under investigation with the aim of optimizing the vehicle to cruise at Mach 5. Moreover, both for the Mach 8 and Mach 5 case, some improvements for the propulsive database are expected. Mission simulations will be performed as soon as this data will be available, to evaluate the updated vehicle performance and to verify the compliance with the mission requirements.

AeroTermO: Implementation of Genetic Algorithms for Supersonic Airfoil Optimization

Mr. Andrea Michelotti (Politecnico di Torino), *Andrea Cavini, Riccardo Giacopino, Francesco Misino, Lorenzo Piottoli*

Our work verted on the application of optimization algorithms to supersonic wings as they are a key component of a suborbital vehicle; the objective has always been to get the maximum efficiency at a given lift coefficient. The surrogate model implements the shock-expansion theory, and the optimization problem is constrained with respect to three design variables since Bézier curves are used for the parameterization of the Diamond-Shaped and the 40-elements Double Circular Arc airfoil geometries. Using a Genetic Algorithm, these were optimized for three different Mach numbers (2.5, 3 and 3.5) and two different lift coefficients (0 and 0.5). After this initial process, a thickness-constrained optimization has been run, to evaluate the obtainability of a given lift coefficient for the entire Mach number range and to understand how this parameter influences the optimized airfoil shape performance in terms of efficiency and angle-of-attack range of use. In conclusion, as thickness reduces from 0.1 to 0.08 the efficiency has a 25% improvement, and the angle of attack range becomes wider. An off-design evaluation allowed for a comparison of the optimized geometries in terms of versatility: since their performance has been calculated for Mach number values other than the one used in the optimization process and over a wide range of possible angles of attack, the efficiency and the lift coefficient distributions were obtained.

The results of all these optimization processes have been evaluated considering both the performance and the geometries of the optimized airfoils, as well as the reliability of the shock-expansion theory simulations, especially in borderline scenarios such as detached shockwaves. In parallel, high fidelity 3D models were validated to ensure higher quality in the results. In the end, the surrogated model has been validated: a broader angle of attack range can be explained considering that in CFD simulations the results are still plausible even in a detached shockwave scenario. Future works will include the optimization of asymmetrical geometries, further mesh refinement, tridimensional case studies, morphing and thermal fluxes in real gas hypothesis.

GreenHawk3: mach 3 biofuel supersonic business jet

Mr. Samuele Graziani (Politecnico di Torino), *Gabriele Luzzani, Martina Membola, Mattia Mulè*

In line with the 2050 European Green Deal, supersonic aviation is currently at the center of a renewed wave of interest, with particular attention devoted to sustainability and economics goals. The purpose of this research is to provide a conceptual design of a Mach 3 business jet propelled by biofuel. This allows to have lower emission compared to conventional propellants, exploiting today's already existing green resources. A key objective of this project is indeed to make the aircraft fly by 2030. After a state of the art analysis, a quantitative evaluation of the aircraft main systems and subsystems was developed achieving a detailed CAD model. Specific attention has been given to minimize sonic boom problem. A mission-profile-based simulation strategy for the GreenHawk3 was implemented in order to validate the study.

Design of supersonic and hybrid engine based advanced rocket (SHAR)

Mr. Naresh Relangi (Sapienza University of Rome), *Caio Henrique Franco Levi Domingos, Amalia Fossella, Phaneendra Peri, Júlia Meira Leite Henriques*

The cost and payload carrying capacity are still challenging aspects in conventional launching vehicles. The need for carrying oxidizer increases the launch vehicle mass and reduces the payload mass which results in low overall efficiency. A promising approach is necessary to overcome these challenges, especially using available oxygen in the atmosphere during the flight, which rises payload/ structural capacity and overall performance of the launcher. By considering the above-mentioned criticalities, team HySIA-2021 is going to propose a Rocket Based Combustion Cycle with reusable concept to access the Lower Earth Orbit. Even though the idea of using RBCC is known for decades, the scarcity of available detailed models pushes the researchers to work on it. The proposed rocket SHAR- Supersonic and Hybrid engine based Advanced Rocket consists of 3 stages. A solid booster, scramjet engine and hybrid rocket will be used to inject the satellites into orbit. The launch vehicle is designed to insert a payload mass of 100 kg at an altitude of 200 km. During the first stage, solid booster will be used to accelerate the rocket up to supersonic speeds and the combination Hydroxyl-terminated polybutadiene (HTPB) (12%) + Ammonium perchlorate (AP) (68%) + Aluminum (Al) (20%) has been chosen as a propellant due to its accessibility, non-toxicity and large number of previous missions. The solid rocket motor will burn up to 25 km to achieve supersonic speeds, i.e., Mach 5.9- 6.1 and the first stage ΔV1= 2075.1 m/s. Then, the 2nd stage will be driven by a trans-atmospheric flight, propelled by scramjet. Among the critical components of the scramjet engine, the combustor poses critical issues. To achieve greater fuel-air mixing and flame stabilization, axisymmetric combustor based on aft wall cavity has been introduced which is a new and innovative concept. Gas generator will be used to inject hydrocarbon fuel to have the supersonic combustion. The flight shall be accelerated up to 35 km in a Mach range of 6-10, since the fuel consists of hydrocarbons (due to which we have Mach number limitation). The ΔV for the second stage is 1326.4 m/s. The payload along with the

hybrid rocket will be accommodated in the upper portion of the air breathing plane. At the end of the cruise, 3rd stage will separate from the flight. The 3rd stage will start from 45km altitude after finishing the 2nd stage coasting period. Then the 2nd stage, i.e., the flight with a scramjet engine will return to the surface of earth. And it will be reused for future launches. Payload insertion during the final stage will be driven by a hybrid rocket motor which is an interesting aspect. Hybrid propulsion allows throatability, multiple ignitions, higher specific impulse than solid rocket motors and the propellants are environmental friends. The fuel is paraffin, due to the high regression rate of the wax in comparison with classical polymers, which increases the thrust and reduces the diameter of the stage. The oxidizer chosen is nitrous oxide (N2O) in order to take advantage of the self-pressurized properties of this fluid, which avoid the need of a pressurization system and also can be used for the ignition by means of a catalytic pack. From 45 km circular orbit to reach 200 km circular orbit, Homan transfer shall be performed. The upper stage ΔV is 4382.4 m/s. The overall ΔV helps to achieve the target orbit of 200 km which requires an orbital velocity 7754 m/s. With the proposed mission, it's possible to address the criticalities which are existed in convention launching systems and to access LEO with high overall efficiency, low cost. So, the goal of the proposal is to design whole launcher, perform numerical simulations on scramjet, solid booster and experiments on hybrid engine, gas generator. After complete investigation, it's possible to define the SHAR with optimised parameters with scramjet and hybrid engine in corresponding stages to deliver the satellites.

EPIC SRC projects joint session: iFACT, NEMESIS, GIESEPP, EDDA

Session Chair : Dr. Franz Georg Hey, Airbus, Germany

iodine Fed Advanced Cusp Field Thruster - iFACT

Dr. Franz Georg Hey (Airbus, Toulouse), *Stephen Gabriel, Peter Klar, Max Vaupel, Gerrit Kottke, Clio Drimala, Maxim Ploncard, Jochen Schilm, Fabrizio Scortecci, Giuseppe Sisinni*

Since several years, the industrialisation of the satellite market has accelerated. In particular, the market for telecom satellites has changed significantly, because of several new players and numerous plans for satellite constellations. In addition, also the market for Earth observation satellites is in motion, due to the fact that the new market actors are not only focusing on telecommunication services, but also target earth observation missions. In parallel to this development, electric propulsion, with its high mass efficiency, became an enabler to improve the cost efficiency of satellites, especially with respect to launch costs, because it allows the launch of more satellites per launch vehicle instead of one. So far, the savings have been potentially eaten up by the additional costs of the electric propulsion system, which are mainly influenced by the complexity of the required electronics (PPU) and the high cost of the xenon propellant. In the scope of the European framework programme for research and technological development Horizon 2020, the iodine Fed Advanced Cusp Field Thruster programme investigates ways to enable:

- Iodine as disruptive propellant for electric thruster,
- Maturation of the Advanced Cusp Field Thruster (ACFT) as disruptive thruster principle, in three different power classes,
- Calcium aluminate (C12A7) as disruptive, low-work function emitter material for cathodes,
- Significant reduction and simplification of the PPU required

The programme strongly focuses on iodine as alternative propellant for electric thruster. Iodine as propellant can lead to a significant simplification of the propellant feeding subsystem architecture, which enables a significant cost reduction. It will further allow decreasing the mass of the feeding subsystem because of its high storage density. In order to enable iodine as propellant several challenges have to be mastered such as its corrosive nature, potential feeding line clogging, or cathode compatibility. The programme aims to identify and solve each single challenge to increase the technology readiness towards a higher level. We will present an overview of the iFACT programme, its current status including preliminary results and the key milestones of the programme.

Key design and operation factors for high performance of C12A7: e-based cathodes

Mr. Angel Post (Advanced Therma Devices - ATD)

The Novel Electride Material for Enhanced electrical PropulSIon (NEMESIS) project was selected for Horizon 2020 Programme funding under Call: H2020-SPACE-2018-2020. NEMESIS addresses the R&D of electride-based new cathode technology compatible with all kinds of electric propulsion (EP) systems requiring emission of electrons for ionization of the propellant gas and/or ion beam neutralization. The different cathode conceptions, which make use of the material C12A7:e- electride as the source of electrons, are designed and tested in the laboratory. In addition to Argon and Xenon, the potential efficiency of other alternative propellants to optimize the performance of cathode prototypes is investigated. NEMESIS project activities results are allowing to figure out some of the key factors that

determine the best performance of C12A7: e- electride based cathodes. Key design factors and operation of cathodes based on the physical properties of the electride material, as well as on its interaction with alternative gas propellants will be discussed. Some of the C12A7: e- relevant characterization parameters being analysed are the work function and thermionic emission, the emissivity, the thermal expansion coefficient, as well as its thermal and electrical conductivities, amongst others.

Performance comparison of LaB6 and C12A7: e-ceramics for space EP cathodes

Mr. Angel Post (Advanced Therma Devices - ATD)

NEMESIS project was selected for H2020 funding. The NEMESIS project is a transversal project strategically aiming at developing electride-based cathode technology which is compatible with all kinds of electric propulsion (EP) systems requiring neutralization addressing the full span of required electron currents from 50 mA to 5 A. Its target is to develop high perfomance neutralizers for the different needs of the European space EP industry based on disruptive cathode technologies enabled by novel thermionic materials. Also it is intended to demonstrate and validate Electric Propulsion (EP) device's performance improvements expected by using novel C12A7:e- electride material as electron emitter, instead of traditional thermionic emitters like LaB6 or BaO. In this work, we will be presenting the results of the different comparison tests performed on LaB6 and on C12A7:e- as thermionic emitters in EP applications. Test comparisons have been carried out addressing pure material characterization parameters like work function under different methods (UPS, XPS, …). Also performance comparisons of C12A7:e- and LaB6 working under the same cathode design will be discussed when operating both under vacuum and under ionized gasses.

GIESEPP – Gridded Ion Engine Standardized Electric Propulsion Platforms: Going Green in Space

Linda Kimeisa, ***Mr. Cyril Dietz (ArianeGroup GmbH)***

In recent years a substantial paradigm change has occurred when it comes to space propulsion. From a high thrust quick access imperative, the focus has continuously shifted to an approach that considers low mass and high efficiency. Therefore, electric in-orbit space propulsion is undoubtedly first choice. And among the different technological options there is one which is unbeatable with regard to efficiency in the overall range: Gridded Ion Engines. This is where GIESEPP comes in. Aligning Europe´s primary competences in gridded ion engines this EU-co-funded initiative has set-up a modular solution for the most diverse applications from low-earth orbit, to geostationary up to deep space mission. Enabling all those the advantage of using noble gases like xenon and krypton as green propellant while ensuring the highest efficiency in their use which leads to a maximum weight and volume reduction. This in particular is what enables integrators to minimize their platforms and thus to both dramatically reduce the launch costs and conceive extreme deep space missions. The following introduces into the technology, iterates the programmatic and technological status of the development and closes with an outlook on the way forward.

Direct-Drive Architecture for Solar Electric Propulsion

Mr. Gilles Bouhours (Thales Alenia Space)

The space industry is undergoing a major breakthrough today. The evolution of the space business enables new opportunities to adopt innovative technologies and architectures that can help in facing the increasing demands on compactness, cost reduction, performance, and flexibility. One of the numerous keys to overcome this demand is electric propulsion at high voltage. Preliminary European study HV-EPSA

demonstrated that there is no show stopper to increase power bus voltage to several hundred volts. This capability allows to supply a Hall Effect Thruster (HET) directly by the solar array without any voltage conversion. European Direct Drive Architecture (EDDA) study is in progress to verify performances of the closed loop between HET and solar array. Less conversion provides a better end to end efficiency, less dissipation, less power converter mass as long as drawbacks of high voltage are mastered (arcing due to Paschen's law inside the spacecraft, or due to conductive plasma outside, mainly around solar array because of the high voltage). The main principles of Direct-Drive (DD) Architecture are presented through this article, as well as the applications and advantages this new technology could provide to the space industry and the everyday life of European citizens.

Systems / Prognostics / Safety (PART I)

Session Chair : Prof. Matteo Dalla Vedova, Politecnico di Torino, Italy

Model-based prognosis for spalling identification in a flight EMA with differential ball-screws

Ing. Federico Salvi (Università di Pisa - Dipartimento di Ingegneria Civile ed Industriale), *Gianpietro Di Rito, Nicola Borgarelli*

The paper deals with the development of a model-based prognostic algorithm aiming to identify spalling damages in the ball-screw mechanism of a fault-tolerant Electro-Mechanical Actuator (EMA) for primary flight controls designed and manufactured by Umbra Group - Italy.The basic idea is to definethe procedure and the time scheduling of a Maintenance Built-In Test (MBIT), in which, while the EMAis driven at constant speed, the accelerations in different points in the mechanical transmission are measured. The signals are then analysed via Fast-Fourier-Transform, by identifying structural resonant peaks related to possible damages. The monitoring algorithm is designed to provide an estimation of the EMARemaining Useful Life (RUL), by executing a MBIT composed of two tests, at low and high speed respectively. The prognostic algorithm is developed in two steps. In the first one, the prognostic database in terms of FFT peak as function of damage characteristics is created by using an experimentally-validated EMA model, including mechanical transmissionnonlinearities, digital controllers, and sensors' noise. In the second step, the algorithm is verified, by injectingdifferentlevels of damages in the EMA model, together with random variations on non-deterministic model parameters (friction, sensors' noise). The accuracy and the limitations of the prognostic algorithm are finally characterised and discussed, with a particular attention to the appropriate definition of the MBIT time scheduling.

Model validation for a transient ECS failure case in a business jet mock-up

Mr. Andreas Lindner (Fraunhofer IBP), *Marie Pschirer, Victor Norrefeldt*

One of the goals of the CleanSky2 Airframe project is the maturation of model-based certification methods, replacing cost intensive and sometimes even impossible tests with simulations. One such impossible test scenario is the hazard assessment in case of an ECS failure in a business jet, leading to a continuous decrease of cabin temperature.by conduction to the exterior environment and thus to a potentially hazardous condition for passengers and crew. Such failures have been tested on the Business Jet Cabin Demonstrator in the Fraunhofer Flight Test Facility. With the test data, a model based on the zonal approach is validated. Zonal modelling subdivides the indoor environment into typically 100-1000 zones, thus providing a local resolution of airflow and temperature distribution while still being numerically fast enough to simulate transient profiles. The zonal model is coupled with a human thermophysiological model in order to predict the human reaction to cold environments. As the study focusses hazard conditions, subject testing is not considered possible while modelling allows for a judgement on the risk level.

Dressman 3.2 - A novel method to determine the equivalent temperature for comfort assessment in the aircraft

Michael Visser, Sumee Park, Sebastian Stratbücker, ***Mr. Victor Norrefeldt (Fraunhofer IBP)***

One of the goals of the CleanSky2 Regional project is the advancement of the human centered cabin. For this aim, the Dressman 3.2 system objectively assesses thermal comfort by measuring air temperature,

air velocity, solar and long-wave radiation and contact temperature on the different body segments. The measured quantities are transferred to a local and global human heat balance model allowing the attribution of a predicted local and overall comfort levels. With the Dessman system, the local determination and root causes of discomfort become measurable. The system is widely used in the automotive sector and shall now contribute to the thermal comfort assessment in the cabin.

Real Estate Advisory Drone (READ): system for autonomous indoor space appraisals, based on Computer Vision and Visual Inertial Odometry techniques

Prof. Alessandro Barazzetti (Science Adventure Sagl), *Federico Cecconi, Elena Brunato, Tiziano Leidi, Andrea Quattrini, Alessandro Mascheroni, Ambra Vandone*

READ aims at developing a revolutionary system capable of autonomously performing appraisals of indoor spaces. The production of appraisals is one of the main activities in the real estate market. It is necessary to have information on the value of a real estate unit.the use of the READ system makes it possible to replace the inspection carried out by a real estate appraiser with a UAS, with a reduction in costs and environmental impact. The challenge is to replace the human being with a UAS capable of autonomously navigating indoors, mapping the contents of the house, measuring its surface to detect construction fraud.

UAV-based high resolution image processing for hydro-geomorphological high-risk area monitoring

Mr. Marco La Salandra (Department of Earth and Geo-Environmental Science - University of Bari), *Giorgia Miniello, Stefano NIcotri, Alessandro Italiano, Giacinto Donvito, Giorgio Maggi, Pierfrancesco Dellino, Domenico Capolongo*

High-resolution images processing for land surface monitoring is fundamental to analyze the impact of different geomorphological processes on Earth surface for different climate change scenarios. In this context, photogrammetry is one of the most reliable techniques to generate high-resolution topographic data, being key to territorial mapping and change detection analysis of landforms in hydro-geomorphological high-risk areas. Thanks to the development of new image processing techniques (e.g. Structure from Motion - SfM) and of Unmanned Aerial Vehicles (UAVs) that allow on-demand acquisition of high-resolution aerial images, it is possible to survey remote areas of the Earth surface, monitoring active phenomena through multi-temporal surveys. An important issue arises when the main goal is to conduct analyses over extended areas (such as fluvial systems) in short times, since the need to capture large datasets to develop detailed topographic models may limit the photogrammetric process, due to the high demand for high-performance hardware. In order to investigate the best set up of computing resources for these very peculiar tasks, a study of the performance of a Free and Open-Source Software (FOSS) photogrammetric workflow using different cluster configurations was performed exploiting the computing power of the ReCaS-Bari data center. The study areas are located along two reaches of the Basento river (in Basilicata region of southeastern Italy) with hydro-geomorphological high-risk. Two datasets made of 1139 and 2190 UAV high-resolution images (1.09 cm/pixel) were processed to generate the orthophotomosaic, the dense point cloud and Digital Elevation Model (DEM) of the detected areas in the shortest time lapse. Leveraging the high-computing resources available at clusters and a specific set up of the photogrammetric workflow steps, an important reduction of several hours in the processing time was recorded, especially compared to classic photogrammetric process on a single workstation with commercial software. In the case of this study, the resulting output is key to recognize the level of flooding

hazard and to timely plan the emergency management activities after a catastrophic event, with significant time and cost savings.

Enabling In-Flight Connectivity with the new Generation of Electronically Steered Antennas

Mr. Manuel J Gonzalez (TTi), *Ana Ruiz, Alberto Pellon, Jose Luis Flores, Palma Garcia, Keith Howland, Nigel Silverthorn, Jaime Perez-De-Diego*

In-flight communication (IFC) services offered to passengers and crew are of great importance to the air transport sector. The improvement of the satellite capacity with High Throughput Satellites (HTS) in GEO and the advent in MEO and LEO constellations will support the forecast growth of IFC market. Antenna equipment for satellite communication will face multiple scenarios from G2G (Gate-to-Gate) to multi-operation under GEO-MEO-LEO systems. Under these conditions, antennas with the ability of tracking multiple satellites and leading superior performance and reliability will play a key role. Electronically steered antennas (ESA) have emerged as a viable solution to response to these demands. The EU-funded LESAF project proposes an ESA solution of reduced size and great efficiency for the next generation of in-flight connectivity services. This will be managed through the requirements definition, system analysis, technology assessment, prototyping and validation of ESAs. The project has successfully passed the first milestone corresponding to requirements consolidation, baseline architecture definition and candidate technologies trade-offs. Multi-beam Electronically Steered Antennas, separated apertures for both transmission and reception, flexible modular approach coupled with planar multilayer integration and advanced beamformer are the basis for the proposed concept. Following project phase will be focused on the design and validation of an antenna demonstrator aimed to prove the superior added value of ESAs technological solution for the aviation industry needs.

Fault-tolerant control via four-leg converter of a full-electric propulsion system for lightweight fixed-wing UAVs

Prof. Gianpietro Di Rito (Università di Pisa - Dipartimento di Ingegneria Civile ed Industriale), *Aleksander Suti, Roberto Galatolo*

The work deals with the development and the performance characterization of a novel control strategy for the detection, isolation and accommodation of coil faults in a three-phase Permanent Magnet Synchronous Motor (PMSM), used to drive the propeller of a modern lightweight fixed-wing UAV. The health-monitoring algorithms on motor currents (used to detect the coil fault and to activate the control reconfiguration) are based on a slope method, associated to the evaluation of the current phasor trajectory in the Clarke plane. Actually, when an open-circuit fault occurs in PMSM driven by a standard three-leg converter, the typical circular trajectory of the current phasor in the Clarke plane collapses into a linear track and relevant torque ripples are generated. On the other hand, if the PMSM is driven by a four-leg converter, a control reconfiguration can be applied: the fourth leg of the power bridge is in stand-by when the system operates without faults, but it is enabled to regulate the current flowing at the central point of the Y connection of the 3-phase PMSM. The performances of the fault-tolerant algorithms are assessed by simulating severe flight manoeuvres with a high-fidelity nonlinear model of the propulsion system. The results demonstrate that the health-monitoring algorithms and the fault-tolerant control strategies permit to obtain extremely small detection and isolation latencies, and that negligible performance degradation in terms of UAV thrust.

Systems / Prognostics / Safety (PART II)

Session Chair : Prof. Matteo Dalla Vedova, Politecnico di Torino, Italy

Vibration based SHM analysis for an unmanned rotor vehicle

Prof. Massimo Viscardi (University of Naples), *Gianluca Isernia*

Due to their non-destructive nature and their ability to supply extremely useful information on the real time condition of the elected component, SHM methods are largely employed in the aeronautical industry. They are specifically used for maintenance purposes, for increasing structural safety and for preventing losses both human and economic-wise. SHM methods used in the aeronautical industry can be either online or ground based. The difference between the two is that in the latter the aircraft needs to be grounded, resulting in a higher downtime and thus a longer maintenance process. The online SHM, on the other hand, consists in monitoring elected systems or components during flight and then comparing their acquired parameters with the baseline reference values. Through this comparison, the damage to the said system or component can be diagnosed. SHM methods used in the aeronautical industry can be either online or ground based. The difference between the two is that in the latter the aircraft needs to be grounded, resulting in a higher downtime and thus a longer maintenance process. The online SHM, on the other hand, consists in monitoring elected systems or components during flight and then comparing their acquired parameters with the baseline reference values. Through this comparison, the damage to the said system or component can be diagnosed. While the online method is largely used for fixed-wing aircraft, it is not convenient to use it as far as helicopters are concerned, indeed "online SHM of helicopter rotors, using a model-based approach, can be complicated due to the difficulties in accurately predicting rotor system behavior. For example, helicopter vibration is very difficult to predict accurately even when using sophisticated aerodynamic and dynamic models, as found in a study comparing various analysis predictions with flight test data". Both the online and the ground-based methods, like many other SHM methods, are mainly based on vibrational analysis, vibrations being a very versatile diagnostic tool. In general, vibration based SHM methods rely on the idea that relevant changes in vibration parameters sytem from structural damage, but the correct way to evaluate these changes and the relative correlation to specific faults represent a very challenging item. Within the present paper, the implementation study of an SHM system for a Robinson R22 helicopter has been assessed in the LUC .ME. research framework, mainly related to the conversion of the rotor vehicle form manned to unmanned version. The results of in-flight vibrational data, specific computational algorithms study and preliminary implementation of the system will be herein presented and discussed

Simulation of runway irregularities in a landing gear test rig

Dr. Andrea De Martin (Politecnico di Torino), *Giovanni Jacazio, Massimo Sorli*

A research project (E-LISA) under way within the Clean Sky 2 framework has the objective of developing an innovative iron bird dedicated to executing tests on the landing gear of a small aircraft transport equipped with electro-mechanical landing gear and electrical brake. The E-LISA iron bird consists of a multi-functional intelligent test facility integrating hardware and software allowing to perform all the tests and analyses perceived as fundamental to demonstrate the maturity of an electro-mechanical landing gear, hence paving the way for its implementation in a small passenger aircraft and will include PHM functionalities for the electrical brake system. The E-LISA iron bird will be able to reproduce fully comprehensive test scenarios and conditions, including:

- Loads on the landing gear actuator and aircraft velocity during the entire landing phase, as well as taxi and take-off
- Aircraft inertia and weight
- Lift and drag forces acting on the aircraft during landing, taxing and take-off
- Real contact between landing gear wheel and runway

With specific reference to the last topic, an important condition to be explored is the effect of runway irregularities on the landing gear while the aircraft is moving on the runway at different speeds. The runway is reproduced in the iron bird by a rotating cylinder with large diameter whose tip velocity is equal to that of the aircraft, and the contact force between simulated runway and landing gear wheel is generated by a hydraulic force control system, with the contact force continuously modulated as a function of aircraft conditions (weight, speed, attitude, etc.). The effect of runway irregularities is reproduced by superimposing fluctuations of the controlled force, which are a function of the irregularities and of the aircraft operating conditions, to the progressively varying contact force resulting from the variation of aircraft speed and attitude during landing. A dedicated algorithm computes the instantaneous force command, and a highly responsive force control system generates the required contact force. This paper presents the innovative solution which is being implemented in the E-LISA iron bird for enabling the execution of tests on a landing gear reproducing the effects of any type of runway irregularities, and the results of simulations showing the system effectiveness.

The thermal control system of NASA's Curiosity rover: a case study

Mr. Gaetano Quattrocchi (Politecnico di Torino), *Andrea Pittari, Matteo D.L. Dalla Vedova, Paolo Maggiore*

In any space mission, maintaining subsystems temperature within the allowed limits is a dicult challenge. Parts exposed to the Sun need to be cooled because temperatures rise extremely high, while parts not directly exposed to the Sun need to be heated, because temperatures can drop dramatically. The vacuum does not conduct heat, so the only way to transfer energy is through electromagnetic radiation, generated by the thermal motion of particles in matter. Operating on a planet surface allow convective dissipation and, to a lesser extent, conductive heat dissipation. Furthermore, Mars' thin atmosphere mitigates the strong temperature gradients that would occur in a vacuum. Nevertheless, external parts of the rover are exposed to temperature ranging between 123oC - +40oC. In this paper, the thermal control system of NASA's Curiosity rover will be presented, analyzing the challenges of maintaining suitable operating conditions in Martian environment and the solutions adopted to allow safe operations.

Analytical Design of Conventional and Electrical Aircraft Environmental Control Systems

Dr. Raghu Chaitanya Munjulury (Linköping University), *Hemanth Devadurgam, Soorya Rajagopal, Petter Krus*

Environmental control system holds vital importance as it is responsible for passenger’s ventilation and comfort. This paper presents an analytical design of environmental control systems and represents the estimated design in three-dimensional. Knowledge-based engineering application serves as the base for designing and methodology for the environmental control systems. Flexibility in the model enables the user to control the size and positioning of the system and also sub-systems associated with it. The number of passengers serves as the driving input and three-dimensional model gives the exact representation with respect to the volume occupied and dependencies on the number of passengers. It also provides a faster

method to alter the system to user needs with respect to the number of air supply pipes, number of ducts and pipe length. Knowledge-based engineering gives the freedom to visualize various options in the conceptual design process.

Digital twins for prognostics of electro-hydraulic actuators: novel simplified fluid dynamic models for aerospace valves

Dr. Pier Carlo Berri (Politecnico di Torino), *Matteo D.L. Dalla Vedova, Simone Santaera*

In the design and development phases of electro-hydraulic actuators (EHAs) used for aircraft flight controls, it is often necessary to carry out accurate and high-fidelity fluid dynamics simulations to evaluate the system behaviour within its entire operating range and, if necessary, investigate its most critical issues. These high-fidelity simulations (nowadays achievable with different techniques and commercial software) generally become pretty expensive from a computational perspective. Therefore, especially in the preliminary design phases or implementing system health monitoring algorithms (in real-time), the need to adopt simplified models emerges definitely (albeit capable of guaranteeing the appropriate level of detail and accuracy). These simplified models are also essential for developing effective and reliable model-based prognostic strategies capable of performing early health assessments of EHA valves. This work proposes a new lumped-parameters simplified numerical model, which, despite having a very compact formulation and reduced computational costs, simulates the internal fluid dynamics of the valve, overcoming some critical issues typical of other models available in the literature. It evaluates valve performance as a function of spool position and environmental conditions (e.g. supply pressure), better-assessing flow rate feedback, internal leakages, and other operating conditions (e.g. spool fine adjustment, pressure supply variable, overpressure, or water hammer). The performance of this numerical model is evaluated comparing with other simplified models published in the literature. Moreover, it is validated with a high-fidelity digital twin that simulates the behavior of the valve, taking into account the geometry of the spool, the properties of the hydraulic fluid, and the local internal fluid dynamics (laminar or turbulent regime, cavitation, etc.)

A novel model-based metaheuristic method for prognostics of aerospace electromechanical actuators equipped with PMSM

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), *Pier Carlo Berri, Omayma Aksadi*

The prior knowledge of incipient failures of primary flight command electromechanical actuators (EMAs) with prognostic algorithms can be very beneficial. Indeed, early and proper detection and interpretation of the deterioration pattern can warn for replacing the servomechanism before the actual manifestation of the abnormal behaviour. Furthermore, such algorithms often exploit a model-based approach established on the direct comparison between the actual (High Fidelity) and the monitor (Low Fidelity) systems to identify fault parameters through optimization processes. The monitor model allows the acquisition of accurate and precise results with a contained computational effort. The authors developed a new simplified monitor model capable of faithfully reproducing the dynamic response of a typical aerospace EMA equipped with a Permanent Magnet Sinusoidal Motor (PMSM). This digital twin senses mechanical and electrical faults: friction, backlash, coil short circuit, static rotor eccentricity, and proportional gain. Fault detection and identification task are performed by comparing the output signal of the reference system (real or simulated) with the one obtained from the monitor model. After that, the Genetic Algorithm is chosen as the optimization algorithm to match the two signals by iteratively changing the fault parameters to detect the global minimum of a quadratic error function. Once a suitable fit is

obtained, the corresponding parameters are assumed to be acceptable. The reference models analysed in this work have been previously developed, implemented in Matlab-Simulink, and validated experimentally by researchers of the ASTRA group of the DIMEAS of Politecnico di Torino.

New active monitoring techniques for asymmetry control of flap actuation systems

Prof. Matteo D.L. Dalla Vedova (DIMEAS - Politecnico di Torino), *Josè M. Cejudo Ruiz*

This work aims to propose innovative active monitoring techniques aiming to reduce the trailing-edge high-lift devices asymmetry. Different system failures may cause the control surfaces asymmetry, such as the drive shaft torsion bar breaking and the control surface actuators wear and tear. The innovative asymmetry active monitoring techniques developed by authors both detect and identify the high-lift device (flap) position asymmetry. Once the failure side is known, the active techniques command the wingtip brakes to stop the failure surface. On the other hand, the operative surface is commanded to reach the failure surface braking position to minimize the flap asymmetry. Hence, the vehicle roll dynamic response will be more stable while the aircraft manoeuvrability after failure will be increased. The control logic inside each model is position-based. These asymmetry active monitoring techniques have been widely tested in different external conditions, using either wear-free or wear-out actuators and considering every failure side scenario. The behaviours of the proposed active models are evaluated in terms of time response and stability margin under certain operating conditions, depending on the asymmetry control algorithm. A general comparison of the proposed active monitoring techniques is performed for each operating condition, in which the most performing models are chosen in each case.

Small Air Transport (SAT) Technologies (PART I)

Session Chair : Dr. Vittorio Di Vito, CIRA, Italy

Cost Optimized Avionics System - Navigation Solution for Small Aircraft Transportation Segment

Mr. Tomas Vaispacher (Honeywell), *Zdenek Kana, Milos Sotak, Pavol Malinak, Radek Baranek, Matej Kucera*

Per EASA statistics, the main cause of general aviation fatal accidents is a loss of control during flight, controlled flight into terrain (CFIT) followed by the low altitude operation (LALT). Significant reasons that are relevant and can be addressed by one system, are the collision with obstacle during take-off and landing (CTOL) and the mid-air collision (MAC). The key prerequisite for any hazard prevention function is to be aware of the hazard, i.e., be able to detect it. Rapidly increasing amount of low-level airspace users (primarily drones) increases risk of mid-air collision involving GA aircraft both due to higher traffic density and small size of these vehicles which makes their visual detection very difficult. Thus, it implies that system being capable to provide complete protection against traffic, terrain and obstacles at an affordable price would be highly beneficial for SAT. The first part of the paper describes the concept of a such surveillance system that integrates multiple systems, namely ADS-B, Terrain & Obstacles database and radar. Significant attention must be provided to radar system selection, based on performance parameters and at the same time comply with SWAP-C (Size, Weight, And Power Consumption Related to Cost) requirements. Therefore, second part of this paper will focus of radars from the SAT suitability point of view. Performance requirements are derived from the hazard prevention use cases and physical parameters of the radar must comply with installation on Small Air Transport Aircraft. The trade-off analyzes of performance, frequency bands and antenna size are described in the paper. There is no COTS radar available that will fulfil all, above discussed, requirements. Besides the technology development challenges, available frequency bands are for radar very limiting commodity. This paper would like to highlight the need for available spectrum for airborne radars that is actually under strong pressure of telecommunication lobby with progressive 5G technology development plans. Included are also proposals for legislation activities that could clarify the frequency availability for radars.

Acknowledgement: This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under the European Union's Horizon 2020 research and innovation programme under Grant agreement for Members No.: 945535.

Enabling SAT single pilot operations: Tactical Separation System design advancements in the COAST Project

Dr. Vittorio Di Vito (CIRA), *Giulia Torrano, Giovanni Cerasuolo, Michele Ferrucci*

Small Air Transport (SAT) is emerging as the most suitable transportation means in order to allow efficient travel, in particular for commuters, on a regional range based on the use of small airports. In this framework, the project COAST (Cost Optimized Avionic SysTem), funded by the Clean Sky JU and started in the year 2016, aims to deliver key technology enablers for the affordable cockpit and avionics, including dedicated technology for Tactical Separation decision support to the pilot. This paper first reports the

description of the COAST proposed Tactical Separation System (TSS) and, then, outlines the design advancements of the system up to the current project status, focusing on the preparation and execution of dedicated flight demonstration. TSS is an ADS-B-based self-separation system aimed to extend traffic situational awareness and to provide the pilot with suggested manoeuvres to maintain the required separation minima. It is aimed to constitute an enabling technology for implementation of the separation responsibility delegation to the flight segment (self-separation) in the future SESAR environment, in this way supporting the implementation of single pilot operations for Small Aircraft. The TSS receives consolidated traffic picture (position and velocity of all tracks) from the ADS-B receiver and its own position and velocity from the GNSS receiver. Additional surveillance information, if available, can be also sent in input to the TSS, such as TCAS status, if available. Based on this overall information in input, the TSS performs its main assigned functions, i.e. Conflict Detection and Conflict Resolution. In the paper, a description is reported of the overall TSS architecture and of its concept of operations, while also providing some indication about each functionality implemented in the system (Coarse Filtering, Conflict Detection, Severity Assignment, Conflict Resolution, TSS Logic) and about the dedicated HMI. Then, the preparation and execution of dedicated flight demonstration campaign is reported, discussing the achievements reached up to date and possible future improvements.

This paper follows the previous one, already presented in the EASN conference 2020, with the aim of describing the current status and achieved advancements in the activities addressing the design of the Tactical Separation System in the COAST project.

Design Advancements for an Integrated Mission Management System for Small Air Transport vehicles in the COAST project

Dr. Vittorio Di Vito (CIRA), *Piotr Grzybowski, Tomasz Rogalski, Piotr Maslowski*

Small Air Transport (SAT) is emerging as suitable transportation means in order to allow efficient travel over a regional range, in particular for commuters, based on the use of small airports and fixed wing aircraft with 5 to 19 seats, belonging to the EASA CS-23 category. In this framework, Clean Sky 2 Joint Undertaking, in the European Union's Horizon 2020 research and innovation programme, funded the project COAST (Cost Optimized Avionics SysTem), which started in 2016 with the aim of delivering key technology enablers for the affordable cockpit and avionics, while also enabling single pilot operations for aircraft in the SAT domain. In the project, some relevant flight management technologies to support single pilot operations are considered, namely the ones of tactical traffic separation and enhanced situational awareness, meteorological enhanced awareness, and pilot's incapacitation emergency management. These technologies have been subject to a dedicated design and implementation process, based on individual approach where each of them has been considered as independent and dedicated single pilot operations enabling technology. In order to properly integrate and enhance such technologies, in the COAST project a unique Integrated Mission Management System (IMMS) is therefore designed. It constitutes a further technological advancement to support more effective and safe management of situations of pilot's incapacitation during the flight, under single pilot operations, and a relevant step forward towards more autonomous aircraft. The IMMS is of relevant importance, both from the single pilot support perspective and from the aircraft autonomy perspective, because it represents a system able to automatically optimize the aircraft path by taking into account trajectory optimization needs that include at the same time consideration of traffic and weather, as well as best destination selection in case of pilot incapacitation.

This paper outlines the main concepts implemented by the baseline individual technologies (Flight Reconfiguration System, Tactical Separation System, and Advanced Weather Awareness) representing the basic building blocks of the IMMS and, after that, describes the high-level requirements allocated to the IMMS, its main expected functionalities and its preliminary high-level architecture. Finally, the IMMS design and implementation process is indicated in the paper.

Latest developments in AWAS: the Advanced Weather Awareness System in the COAST Project

Ms. Myriam Montesarchio (CIRA), *Alessandra Lucia Zollo, Michele Ferrucci, Edoardo Bucchignani*

In the framework of the COAST (Cost Optimized Avionics SysTem) project funded by Clean Sky 2 Joint Undertaking in the European Union's Horizon 2020 Research and Innovation Programme, several key technologies are under development, aimed to enable single pilot operations of Small Air Transport (SAT) vehicles. One of these technologies is AWAS (Advanced Weather Awareness System), which aims to provide on board of the aircraft updated weather information regarding areas affected by weather hazards, in order to increase the weather awareness of the pilot. The system is composed by two main applications. The first one is AWAS on-ground, devoted to send on board data regarding weather hazards observed and forecast along the flight route. Several textual files are generated, including information concerning the polygons enclosing dangerous areas; specifically, in order to reduce the data amount to transfer, only vertices and severity level of the polygons are reported in the text files, considering a limited geographical area centered on the aircraft position. The meteorological information is extracted from MATISSE (Meteorological AviaTIon Supporting System), a prototype software developed by the Meteorology Laboratory of CIRA, which manages data (both observations and forecasts) coming from different sources. The second main application of the system is AWAS on-board, aimed to send on-ground input information concerning aircraft position and current time and to elaborate the data provided by AWAS on-ground, allowing the visualization on-board. This last one is carried out by means of a dedicated Human Machine Interface (HMI) over a Portable Electronic Device (PED) into the cockpit. AWAS on-ground and AWAS on-board segments are connected each other via a low-cost satellite communication system. This work will describe the main functionalities and components of the system under development, highlighting the advancements achieved with respect to the papers already presented at the EASN conferences held in 2017 and 2020. The tests carried out to verify the AWAS proper functioning will be described and, more generally, the work performed to allow the system integration on-board of the aircraft, also in view of the first flight test campaign planned in the COAST project.

Experimental verification of the emergency destination definition in Flight Reconfiguration System in the COAST project

Mr. Piotr Grzybowski (Politechnika Rzeszowska im.Ignacego Łukasiewicza), *Tomasz Rogalski, Maciej Filipowicz*

Pursue on Single-Pilot-Operations within the CS-23 commuter aircraft class (which are part of Small Air Transportation) is stimulated by multiple projects all over the world. One of the key challenges is to have the possibility of performing a safe return to the emergency destination in case of the pilot's incapacitation. Within the project COAST (Cost Optimized Avionics SysTem) multiple technologies are developed which are enablers for this kind of operations. One of such is Flight Reconfiguration System (FRS) which is intended as a higher-level decision-making device that constantly analyzes possible emergency destinations dependent on the current aircraft state, performs multi-criteria decision-making to pick the best possible destination, and on activation of emergency button guides autopilot to such a

destination. This paper shows methods behind the testing of such a complex system including Hardware-In-The-Loop tests conducted within a dedicated laboratory stand, and some methods used during actual flight tests. The methodology shown is followed by the results of the tests as well as the comparison between simulation and flight tests. For those who seek technical knowledge on implementation problems, a separate part of the paper is prepared. It is dedicated to putting some insight on selected problems of implementation and integration are shown, as well as methods used to overcome them.

Cost-Optimized Avionics System - Surveillance Solution with Radar for Small Aircraft Transportation Segment

Mr. Petr Kanovsky (Honeywell), *Marketa Palenska, Milan Sopata, Lubos Korenciak, Eva Josth Adamova*

Per EASA statistics, the main cause of general aviation fatal accidents is a loss of control during flight, controlled flight into terrain (CFIT) followed by the low altitude operation (LALT). Significant reasons that are relevant and can be addressed by one system, are the collision with obstacle during take-off and landing (CTOL) and the mid-air collision (MAC). The key prerequisite for any hazard prevention function is to be aware of the hazard, i.e., be able to detect it. Rapidly increasing amount of low-level airspace users (primarily drones) increases risk of mid-air collision involving GA aircraft both due to higher traffic density and small size of these vehicles which makes their visual detection very difficult. Thus, it implies that system being capable to provide complete protection against traffic, terrain and obstacles at an affordable price would be highly beneficial for SAT. The first part of the paper describes the concept of a such surveillance system that integrates multiple systems, namely ADS-B, Terrain & Obstacles database and radar. Significant attention must be provided to radar system selection, based on performance parameters and at the same time comply with SWAP-C (Size, Weight, And Power Consumption Related to Cost) requirements. Therefore, second part of this paper will focus of radars from the SAT suitability point of view. Performance requirements are derived from the hazard prevention use cases and physical parameters of the radar must comply with installation on Small Air Transport Aircraft. The trade-off analyzes of performance, frequency bands and antenna size are described in the paper. There is no COTS radar available that will fulfil all, above discussed, requirements. Besides the technology development challenges, available frequency bands are for radar very limiting commodity. This paper would like to highlight the need for available spectrum for airborne radars that is actually under strong pressure of telecommunication lobby with progressive 5G technology development plans. Included are also proposals for legislation activities that could clarify the frequency availability for radars.

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Small Air Transport (SAT) Technologies (PART II)

Session Chair : Dr. Vittorio Di Vito, CIRA, Italy

Derivation of top-level aircraft requirements for small aircraft transport by modelling demand in Europe

Mr. Florian Will (DLR), *Nico Flüthmann*

Advancements in aircraft technologies and in the process of aircraft electrification allow for the design of new small aircraft transport (SAT) configurations with a significant impact on sustainability, travel time and operating cost. Additionally, the European Flight Path 2050 creates a European-wide political landscape to enable developments in that field to thrive. All this together provides an environment that promises to open new business opportunities in the form of new and revived mobility services. However, the described ecosystem raises the question of what demand exists for SAT and what top-level aircraft requirements (TLAR) need to be achieved to realize customer-centric SAT. Data of the existing traffic patterns in Europe is analyzed to create a demand model, derive the TLAR and ultimately lay the foundation for a successful European SAT transport system. Initially traffic pattern data is collected with a resolution on county and airport level, thereby ensuring a high accuracy of larger and smaller travel distances. Subsequently, to the data collection, the income distribution in European countries is analyzed and in combination with a willingness to pay function the actual existing SAT demand is determined. The demand optimized TLAR were then derived by varying the demand models input parameters to maximize the demand. The above-described approach allows to extract the potential annual demand in Europe for a certain set of requirements, it also details how a single parameter effects the demand. Hence, it provides sensitivities to illuminate design focal points. Furthermore, the high resolution of the data highlights which connections will be most promising to introduce an additional form of mobility to. In consideration of all the described factors the paper defines the TLAR, thereby enabling the design of new SAT configurations.

Ground and flight tests of the composite engine nacelle developed in the SAT-AM (Clean Sky 2) project

Paweł Guła, Dawid Ulma, Jacek Dudziak, ***Mr. Arkadiusz Gawlik (Sieć Badawcza Łukasiewicz – Instytut Lotnictwa)***

The main objective of the SAT-AM project is to develop technologies for manufacturing lighter and cheaper airframes while their reliability is maintained or increased. Demonstrators study prove feasibility, synergy and benefits of the selected technologies in comparison to traditionally produced assemblies. Expected technologies should offer high level of flexibility allowing efficient modernisation of airframes production.

CFD wind tunnel assessment on the case-study of the MOTHIF blown flap

Mr. Paolo D'Alesio (Piaggio Aerospace), *G. Travostino, P. Planquart, G. Glabeke*

The interest in small air transportation is increasing since this type of aircraft can be operated on smaller airports, allowing to easily connect remote areas not served by other means of transportation and consequently improving, in this way, the global connectivity. One of the key factors to guarantee aircraft operability from small airports is the reduction of the take-off distance. Consequently, maximum lift coefficient needs to be increased without penalizing neither the drag nor the aircraft weight with the use

of complex flapped configuration. Inside the AIR ITD (Airframe Integrated Technology Demonstrator), within the EU (European Union) CleanSky 2 research project, a blown flap configuration has been developed to allow STOL (Short Take-Off and Landing) capabilities of a future affordable and green hybrid/electric small commuter, up to 19 seats, belonging to EASA CS 23 (European Union Aviation Safety Agency Certification Specification) regulatory base. The developed blown flap has been tested in a wind tunnel facility through the collaboration between Piaggio Aerospace and the MOTHIF consortium, composed by VKI (von Karman Institute) and SONACA. The blowing system has been thought to obtain a considerable lift increase when working, but without penalizing the performance in case of blowing system failure: consequently, the blown flow is acting mainly on the main airfoil, activating a supercirculation because of an aspiration effect on the boundary layer. This design choice has been done to maintain very low the pitching moment unavoidable increase, thus reducing the trim drag effect when mounted on the aircraft and allowing acceptable aircraft take off performance also in case of blowing failure. A 1.5m x 1,35m wing/flap model has been designed, built and then tested in the VKI large subsonic L1-A wind tunnel. The resulting experimental data have been compared with the bi-dimensional preliminary results obtained during the system design phase, thus experimenting also different flap angles and blown flow speed. To reduce three dimensional effects in the wind tunnel, due to the wing model dimensions and structural supports, and to better predict blockage effect on lift coefficient, CFD (Computational Fluid Dynamic) has been extensively used to develop a proper endplate dimensioning and positioning, thus obtaining a proper test chamber configuration. Finally, CFD has been extensively used to reproduce some wind tunnel test results, so assessing both Wind tunnel and design simulations accuracy. This work presents the comparison between experimental data and CFD simulations to demonstrate the usefulness of simulation to reduce the risk for misleading results in experimental activities. Through the proper use of CFD, bigger scale wind tunnel models can be used also in a smaller wind test chamber. This possibility may unlock the chance to test breakthrough technology, like a blown system, which for its inner characteristics (blowing piping) cannot be miniaturized as much, and furthermore reducing experimental costs. Good correlation between CFD wind tunnel test simulations and wind tunnel results themselves are crucial to better predict the aerodynamic effect on full scale aircraft, reducing experimental cost, uncertainties and risk of failure in the experimental campaign.

Flight Control

Session Chair : Prof. Tomasz Rogalski, Rzeszow University of Technology, Poland

Automatic approach with the usage of runway light systems

Prof. Tomasz Rogalski (Rzeszow University of Technology), *Dariusz Nowak*

The paper discusses an aircraft automatic control in both longitudinal and lateral channels during automatic approach using a PAPI light and other runway light systems as a source of data on aircraft relative position to a desired trajectory of the final approach. A flight control system presented in the paper is composed of two curtail components. The first of them is a Vision System containing image processing algorithms determining the number of PAPI lights in red appearing to a pilot during final approach and flare phases of landing and calculating aircraft lateral deviation by interpreting image of runway approach lights. They were implemented into an embedded system and tested under laboratory conditions according to the Hardware-In-the-Loop method. An output of the Vision System was used as an input to the second component of the control system - Automatic Landing System. Its major element are control algorithms based on the fuzzy logic expert system. They were created to imitate pilot actions during landing with aircraft. Both systems were connected with one another for cooperation and to control an aircraft model in a simulation environment. Selected results of tests presenting control efficiency and precision are shown in the final section of the paper.

Comparison of selected algorithms for estimating the angle of attack of a transport airplane - flight simulations

Piotr Szwed, Dr. Paweł Rzucidło (Rzeszow University of Technology), *Tomasz Rogalski*

In modern transport aircraft designs using integrated on-board systems and fly-by-wire systems, the impact of angle of attack data has increased significantly. Discrepancies in the signals from the angle of attack sensors may generate incorrect warnings and prevent the proper functioning of several systems at the same time. A stationary simulator of transport aircraft have been used to compare selected algorithms for estimation of the angle of attack. The analyzed estimation algorithms assume the use of data available from the following on-board systems: ADC (Air Data Computer), IRS (Inertial reference System) and GPS (Global Positioning System). In this way, many problems related to different types of construction, and the installation of additional sensors and structural changes can be reduced. The scope of the flight simulations includes normal take-off and landing procedures as well as the range of critical angles of attack during stall maneuvers in different flaps and gear configurations. The results of the flight simulations have allowed to determine the accuracy of the estimation algorithms in comparison to the data obtained directly from the angle of attack sensor (with the accuracy to the simulation process). The use of angle of attack estimation could provide additional redundancy for the abnormal functioning of the angle of attack sensor or its mechanical damage for the operation of the integrated on-board systems. Algorithms could increase the safety level of take-off and landing phases, especially in gust conditions where the airplane may encounter a sudden change in the angle of attack.

Take-off phase control algorithm for general aviation light aircraft

Mr. Łukasz Wałek (Rzeszow University of Technology), *Tomasz Rogalski*

The article describes a method of automatic control of a small general aviation aircraft during take-off phase. The paper splits the take-off into several separate stages (i.e., from an acceleration, up to the climbing phase after lift-off) and assigns them dedicated control algorithms. The first stage of the take-off phase is a slow rolling. At this stage, aerodynamics forces acting the airplane are negligible. The aircraft movement can be described by geometrical dependencies only. The steering using the front wheel only is sufficient to maintain a desired direction of the rolling. The second stage is a fast rolling until a rotation speed is reached. During this stage the aerodynamics forces acting the plane allow the control surfaces to be used to control the motion in both longitudinal and direction / lateral channels. The third stage begins from the rotation and continues until lift-off. At this stage plane lifts the front wheel and moves only on main landing gear. The last stage is the climbing, during which the pitch angle should be maintained at the desired magnitude and bank angle at zero degrees to assure proper vertical trajectory and levelled flight respectively. The article also investigates methods of acquisition and processing information about aircraft position at the runway, both from external sources (radio navigation and GNSS systems), as well as aircraft's dedicated equipment (vision system and inertial measurement units). Authors uses the MP-02 Czajka light aircraft model and describes plane's equipment (e.g. weight on wheels measurement system). Thesis are based on simulations in the Matlab / Simulink (control system) connected to X-Plane (plane and environment simulation), recorded real flight data was also used.

Unmanned helicopter flight control actuator specification through mission profile analysis

Mr. Jérémy Roussel (ICA Institut Clément ADER), *Marc Budinger, Laurent Ruet*

Helicopter dronization is expanding, as for example with the VSR700 project, and leads to the design and the integration of electromechanical actuators (EMA) into the primary flight control system (PFCS). The PFCS is in charge of controlling the helicopter flight over its 4 axis (roll, pitch, yaw, vertical). It controls blade pitch through dedicated mechanical kinematics and actuators. The hydraulic technology has been conventionally used in actuators for more than 60 years. On the other hand, the introduction of the MA technology requires reconsideration of design practices right at development start. Indeed, the establishment and synthesis of the specification come to deal with - new design drivers (high performance points and wear) and - new inherent technological imperfections (friction and inertia with reduction ratio). To address these topics, this paper draws a list of the main EMA design drivers to focus on along with a brief description of the main EMA components and architectures. Then, it suggests indicators that are evaluated over a complete mission profile in time coming from measures on a given applicative helicopter flight. These indicators are elaborated to provide an image of the new design drivers responsible for rapid and gradual degradations of actuator components. Also, they give an idea of the importance taken by the new imperfections into the global performance. Comparing with a standard aircraft mission profile, these indicators easily emphasize the specificity of the helicopter application use case. Furthermore, the analysis of mission profile reveals that speed, acceleration & load fit statistical distributions which bring an important piece of information to final consideration on extremum values. Finally, since the pitting and rolling fatigue phenomena are both dominant degradation preoccupation of the actuator designer, we suggest a helpful representation displaying fatigue and rolling distribution over displacement.

From sensors to onboard systems

Session Chair : Dr. Cezary Szczepanski, Warsaw Institute of Aviation, Poland

The TecALSens Project: New solutions for load sensors in aeronautics

Dr. Valerio Carli (tecsis GmbH)

Europe and the entire world are facing new challenges concerning sustainability and growth. Transportation plays a key role in today's globalisation and air traffic contributes to global mobility and economic benefits but also to the impact on environment and air quality: Also, in this sector environmental issues are becoming more and more important. Europe has been seriously considering this challenge and has defined a clear and aggressive road map for facing these problems. ACARE (Advisory Council for Aeronautical Research in Europe) has defined up to 2050 clear targets for reducing the amount of pollutant from air traffic: Reduction of CO2 emissions by 75% per passenger kilometre, reduction of NOx emissions by 90%; reduction of perceived noise by 65%. The Clean Sky 2 Programme has been set-up for achieving these ambitious objectives and at the same time maintaining Europe's industrial leadership in this strategical asset of European economy and technological sector. In Clean Sky 2 within the Systems ITD (Integrated Technology Demonstrator) more-electric and all-electric A/C configuration is one of the revolutionary approaches to A/C design and a key enabler for achieving the environmental goals set by the European agenda. Major contribution to this new aircraft architecture is given by partial or full replacement of current hydraulic and pneumatic systems with electric drives: primary and secondary flight controls, landing gear, braking system and engine are the targeted systems that can mostly benefit from this new approach. Load sensors play a key role for enabling a robust control of these devices, assessing their correct functionality and ensuring safe performances. In this paper the TecALSens project, developed within the Systems ITD of the Clean Sky 2 programme, is presented. The objective of the project is to develop a novel load sensor for aeronautic application based on thin-film sensing technology. So far thin-film as sensing element has not been used in commercial aeronautic products: The outcome of this project tries to close this gap by providing a new class of load sensors complying with demanding aeronautic requirements. Project's activities foresee the complete development of this device. Initial work has focused on the analysis and comparison of most suitable sensing principles for aeronautics (thin-film, strain gauges, LVDT, piezoelectric elements, etc.). Especially, thin-film sensor technology has been compared to strain gauge sensor technology as benchmark. Further, several valuable applications for more an all – electric aircraft architecture, like Electro-mechanical actuators (EMA), Weight on Wheel (WoW) measurement, landing gear load monitoring, have been analysed considering load measurement applicability and potential benefits. After selection of the most suitable application, electronics and all mechanical parts have been designed. A compact and pure analogue electronics is responsible for sensor output, while mechanical design has been conceived and realised considering sensing properties, protection of electronics and sensing element and integration issues. Electronics and mechanical components have been manufactured and their properties have ben experimentally validated considering DO160G standards. Integration of the load sensor in the selected application, namely the landing gear of an helicopter, has been carefully considered and load sensor performances have been experimentally validated. Final sensor's configuration enables load measurement in two independent and perpendicular directions and the fulfilment of all requirements. Current project activities show very promising results: TecALSens provides a new approach to the design and manufacturing of load sensors for aeronautic applications: Especially, this new class of load sensors overcomes some of the drawbacks of strain gauge-

based solutions. The final objective of the project is to deliver a load sensor complying with TRL 5. Electronics and several solutions are flexible and can be used as modules for other applications. Load sensors plays a key function for future's aircraft systems: TecALSens outcome widens the possibilities offered by force sensing in aeronautics and strongly supports the evolution of aircraft design toward a more environmentally friendly approach.

Flight test verification of automatic stabilisation system using aircraft trimming surfaces

Mr. Albert Zajdel (Łukasiewicz Research Network - Institute of Aviation), *Mariusz Krawczyk, Cezary Szczepański*

Previous research on the cost-effective and less electrical energy consuming automatic stabilisation system for an aircraft resulted in constructing a laboratory model of the system. Such features are beneficial in initiatives like Future Sky, electric aircraft and aircraft stabilisation system retrofit. The system was developed using Model-Based Design, tuned and tested in Model, Pilot and Hardware in the Loop Simulations. The paper presents the next stage of system testing results – verification in flight on the PZL-130 Orlik aircraft. The implementation of this system does not modify the pilot's primary manual controls. The electrical trim system is used for automatic stabilisation or manual trimming, depending on the chosen operation mode. The flight tests were planned according to civil aviation authority and aviation law requirements. Results from series of flights were analysed and presented. Tuning of the stabilisation system gains and other parameters was conducted in flight. A unique application was developed to allow the operator inside the aircraft to change stabilisation system parameters during the flight on a touchscreen tablet. Logged aircraft parameters were compared with previous Hardware in the Loop real-time simulated flights. The outcome of the stabilisation system flight test campaign was a verification of its performance on a real aircraft. In addition, pilot feedback about aircraft handling qualities was gathered. Comparison of real and simulated data allowed identification of aircraft model deficiencies and implementation of improvements.

Onboard computer controlling the flight stabilisation system with the use of trimmers

Mr. Maciej Filipowicz (Łukasiewicz Research Network - Institute of Aviation), *Cezary Szczepański*

The paper presents the design and performance of the flight stabilisation system onboard computer developed in Łukasiewicz – Institute of Aviation. The presented unit is an electronic block developed to perform automatic flight stabilisation of an aeroplane using trimmers. It can be characterised as a specialised, low-cost, low power consumption, the highly integrated electronic device responsible for sensors signals acquisition, control algorithm execution and control surfaces (trimers) actuation.

Onboard computer was developed based on requirements of launch platform PZL-130 Orlik aircraft. Computational unit software was prepared for porting automatically generated code from the Simulink model containing system state machine and control model previously tested in simulations including Model, Pilot and Hardware in the Loop. Design for specified platform required specific cockpit controls and onboard sensors, but it can be easily adapted for other platforms.

Hardware was prepared and tested to meet DO-160G environmental and electrical conditions and restricted test for electromagnetic compatibility. After Hardware in the Loop laboratory tests, onboard computer flight tests were performed on PZL-130 Orlik aircraft. Flight tests results bring conclusions and other improvement ideas.

Optimal flight trajectory synthesis for an anti-collision maneouvre performed within environment of moving obstacles

Mr. Jerzy Graffstein (Łukasiewicz Research Network – Institute of Aviation)

For solving the airplane to obstacle collision avoidance problem two methods are necessary: one, for detecting a collision threat, and the other one, for synthesizing a safe manoeuvre avoiding threating obstacles. In the article a method for detecting a threat of collision to obstacle was presented for the case of many obstacles moving within the neighbourhood of the airplane. Methods for optimal anti collision trajectory synthesis and for proving the workability of such a result were proposed too. A solution of an optimisation problem, obtained by the Swarm of Particles Optimization (PSO) was used for trajectory synthesis. A form of quality index was proposed for this task and the analyses of its behaviour for several values of weighting factors were presented. Results of simulations of flight along an optimal, anti collision manoeuvre trajectory proved that such a manoeuvre is workable.

Impact of sensors excellence on the accuracy of tactical guided missiles

Mr. Krystian Borodacz (Łukasiewicz Research Network – Institute of Aviation), *Cezary Szczepański*

Tactical missiles are required to be highly effective, allowing the mission to be accomplished with as few missiles as possible. For this purpose, rockets are equipped with guidance, navigation and control systems to compensate for the effects of certain disturbances. Analogous systems can also be used in sounding rockets to ensure that the impact point is within the boundaries of a safe area. With their properties, inertial navigation systems are particularly predisposed to such applications, providing continuous localization even in case of outage or failure of other navigational means. However, the influence of measurement system errors results in a position determination error that increases with time and represents the lower limit of attainable accuracy. As the accuracy of sensors increases, their price also increases very rapidly. Thus, it is necessary to optimize the selection of sensors to achieve a balanced cost to accuracy ratio so that the proposed solution is economically justified and cost-effective. The paper will present the results of the analysis of the influence of the parameters of the sensors used on the achievable delivery accuracy. It will indicate the ranges within which it is rational to use sensors of the assumed accuracy. The analysis is based on sensor parameters given in the documentation of selected actual inertial measurement units. The theoretical analysis is complemented with the simulations of missile flight for the assumed flight profiles, which allowed taking into account the sensor error characteristics dependent on the instantaneous motion parameters.

The impact of sensor errors on flight stability

Mr. Michał Welcer (Łukasiewicz Research Network – Institute of Aviation), Mariusz *Krawczyk, Cezary Szczepański*

Sensors play a significant role in flight control systems. The accuracy of the measurements of state variables affects the quality and effectiveness of flight stabilization. When designing closed-loop systems, it is desirable to use sensors of the highest class and reliability, the signals of which will be as error-free as possible. False indications lead to malfunction of the stabilization system, the operation of which does not meet the requirements set for it. There are many types of errors such as bias, white noise, hysteresis or bias drift, which affect the measurement signals from the sensors. One of the significant problems is assessing what maximum level of sensor errors stabilization system will still operate as required. In this paper, the impact of different sensor errors on flight stabilization was presented. The research was carried

out on the example of the automatic flight stabilization system using aircraft trimming surfaces in a longitudinal control channel in a Hardware in the Loop simulations. The model simulates various types of sensor errors during the flight, while the stabilization system is implemented in hardware interfaced with a real-time computer. The results of the simulations are presented and analyzed. After their comparison, it was indicated which sensor errors affects the flight stability the most and how the effectiveness of the stabilization system changes as error increases. Presented results show changes in flight parameters due to added sensor errors.

MAHEPA project (PART I)

Session Chair : Dr. Fabrizio Gaspari, PIPISTREL, Slovenia

Flying hybrid with the MAHEPA project: challenges, achievements and future scenarios

Mr. Fabrizio Gaspari (Pipistrel Vertical Solutions d.o.o.)

MAHEPA (Modular Approach to Hybrid Electric Propulsion Architecture) is a European project funded under the Horizon 2020 programme with the aim of designing, manufacturing and flying two advanced variants of low emissions serial hybrid-electric powertrains integrated in two different aircraft: the Pipistrel Panthera and the Hy4. Namely, the former was hybridized with a conventional internal combustion engine while the latter with an optimized hydrogen-based fuel cell system, thus enabling zero-emission flights. By performing parallel analyses, such as scalability studies, 19 and 70 passenger's hybrid aircraft designs, short to medium haul operations demand estimations, future aviation ground infrastructures assessment etc., MAHEPA helped fostering the needed gaps to finally fly greener and more efficient, making the European Green Deal's objectives one step closer to reality. In this presentation, MAHEPA's main achievements, together with future challenges and scenarios, will be presented.

Hybrid-electric power-train modelling for airplane performance analysis and sizing

Mr. Lorenzo Trainelli (Politecnico di Milano), *Alberto Rolando, Carlo E. D. Riboldi, Francesco Salucci, Yasir M. Khan*

The present paper describes a framework for the parametric modelling of the components of hybrid-electric (HE) power-trains, aimed at conceptual design and performance analysis of innovative aircraft. This methodology has been developed in the EU-funded H2020 MAHEPA project, which includes a substantial effort in predicting the scalability of the currently-developed hybrid-electric propulsion technologies towards regional aviation applications. The MAHEPA project features the full development and flight testing of two serial HE power-trains which adopt a power generation system (PGS) to complement the battery pack: the first uses a thermal engine coupled with an electric generator as a PGS and the second employs a hydrogen-fed fuel-cell system. Both types of power-trains have been modelled and validated with respect to experimental data. The paper provides an overview of the full modelling framework conceived for airplanes of arbitrary size and mission specifications. Particularly, commuters and large regional propeller-driven aircraft are of interest as they may represent a substantial asset in the near term for enhancing European citizens' mobility while insuring environmental sustainability. We address the modelling of the crucial components of the propulsive system: the battery pack, the fuel cell system and the hydrogen tank, for both the cases of gaseous and liquid storage. These elements are integrated within a preliminary sizing methodology conceived for conceptual design of HE aircraft based on performance and operational requirements, including a detailed sizing mission simulation. Examples of application to both retrofit and clean-sheet design solutions are illustrated.

Conceptual studies of hybrid-electric passenger airplanes

Mr. Lorenzo Trainelli (Politecnico di Milano), *Francesco Salucci, Yasir M. Khan, Carlo E. D. Riboldi, Alberto Rolando*

The present paper illustrates the work performed within the EU-funded H2020 MAHEPA project in studying the scalability of hybrid-electric (HE) propulsion technologies for regional aviation applications. The MAHEPA project addresses serial multiple HE power-train architectures in which the battery pack is

complemented by a power generation system (PGS). Two PGS variants are investigated: the first uses a thermal engine coupled with an electric generator and the second employs a hydrogen-fed fuel-cell system. The latter is further considered in two versions: the first employing gaseous hydrogen storage (GH2) on board and the second liquid storage (LH2). The implications of these alternatives play a crucial role in the design of the aircraft. We discuss the preliminary sizing of two classes of passenger airplanes, ranging from CS-23 commuters to CS-25 large regional liners, making use of an aircraft design methodology specifically developed for HE solutions. This includes the detailed modelling of the battery pack, the fuel cell system and the hydrogen tank, for both the GH2 and LH2 cases, which imply a high-pressure vessel and a cryogenic tank, respectively. For both certification categories, a preliminary validation with respect to existing production aircraft and existing pure-electric and HE experimental models confirms the reliability of the HYPERION preliminary tool. This has been applied to the conceptual study of 19-passenger and 70-passenger clean-sheet design solutions based on specified mission requirements. In the present discussion, "concentrated" propulsion (i.e. twin wing-mounted thrust-generating units) was considered, leaving more advanced configuration options for further discussion. A parametric analysis was carried out to assess the impact of expected technology maturation in the time horizon ranging from 2025 to 2050, showing promising opportunities for enhanced mobility and transportation network sustainability.

Impact of Distributed Propulsion on the Design of a Hybrid Electric Aircraft

Dr. Fabrizio Oliviero (Delft University of Technology)

The study presents a novel methodology for the conceptual design of a Hybrid Aircraft featuring Propulsive devices distributed along the wingspan of the wing. Distributed Propulsions is a solution that can theoretically augment high lift capabilities so that the resulting needed wing loading can be lowered; in addition, electric propulsion can potentially enable the introduction of such solutions with a relatively low penalty in terms of increased structural weight because of the relative lightness and compactness of electric motors. The proposed sizing procedure consists of several intermediate steps: first, the thrust, lift and drag decomposition are modified to take the effect of aerodynamic interaction into account, leading to a set of modified flight performance constraining equations. Subsequently, a hybrid powertrain model, containing information and operating characteristics extrapolated by the components used in the Mahepa project, allows to determine a series of component-power oriented power loading diagrams; in addition, the energy requirements can be calculated on the basis of a certain mission profile and energy/power management assumptions. Finally, class I weight estimation are used to determine the Maximum Take Off Weight of the aircraft through an iterative procedure. A second sizing procedure, that relies on the use of a lifting-line model where propellers are represented by actuator disks. Two study cases are considered: a CS25 regional aircraft and a CS23 commuter. Preliminary results suggest a slight reduction of the payload-range energy efficiency.

Optimal power management and mission profile for a Hybrid Aircraft

Dr. Fabrizio Oliviero (Delft University of Technology)*, Thibault Clar, Kilian Swannet*

The paper focusses on a methodology developed to determine both mission parameters and power management for a generic Hybrid aircraft in such a way its energy consumption and/or flight time can be minimised.

In fact the system dynamics of a Hybrid aircraft has generally one or more degree of freedom, when compared to a conventional one, related to the number of energy (or power) sources present on board with the consequences that classic solutions of mission analysis (e.g. climb rate that minimise the burn fuel) can be no longer valid. The approach adopted in this study is to couple mission perfomance analysis to optimal control methods so that the core mathematical problem is reduced to an optimiziation problem that aims at finding optimal values for certain control variables in such a way an arbitrary objective function can be minimized in presence of a certain set of constraints deriving from limitations of both flight envelope and propulsion operating conditions. To fully characterize the problem, the optimal contol algorithms are coupled to a simulator developed in house to model the operating characterisitic of a generic Hybrid powertrain. The simulator, based on Objected Oriented Paradigm, consists of modules that are used to describe the operation conditions (in terms of efficiency map and delivered Power/Energy) of each powertrain component. Subsequently, those modules can be assembled together to model either a Serial or a Parallel architecture, with several possible power sources: batteries, Combustion Engine, Fuel Cell. Two optimal control approaches (Single Phase and Multi-Phase) have been tested on a Hybrid Electric study case considering different objective functions, namely minimum energy, minimum fuel (when a Combustion Engine is considered) and minimum time. Prelimiary results show an agreement of both the Single-Phase and Multi-Phase approaches. In addition, both the power management and the mission profile differ greatly at varying the considered objective function.

Electrical machines: design principles and main aspects

Mr. Richard Bernauer (Compact Dynamics GmbH)

High power-density electric machines are becoming increasingly important in aviation. In hybrid applications, efficiency and the possibility of a redundant drive system play an important role. Battery technology is continuously improving and therefore more and more battery powered propulsion systems are used in aviation. Starting from the system structure, the influence of the various components on the design of the electrical drive is discussed. Particular attention must be paid to the choice of power electronics and the use of a gearbox. Overall efficiency and low weight play an important role. Design strategies to realize high power densities are presented. At the same time, a high level of safety and reliability must be ensured. Furthermore, NVH issues are also considered, which are especially important for air taxi. Last but not least, it is important to install a quality management system already in the development phase. This presentation will describe the development approach of the electrical machine and the parameters which have to be considered.

MAHEPA project (PART II)

Session Chair : Dr. Fabrizio Gaspari, PIPISTREL, Slovenia

Development, Testing and Integration of a new Power Management Control and Delivery Module for a Hybrid Electric Aircraft

Ms. Pia Hoenicke (Institute for Energy Conversion and Storage, Ulm University), *Adel Muhandes, Moritz Staudacher, Debjani Ghosh, Sumantra Bhattacharya, Tobias Graf, Fatih Tuerk, Christiane Bauer, Josef Kallo, Caroline Willich*

Hybrid technologies using fuel cells and batteries are a promising technology for vehicles and aircrafts to reduce CO2 emissions. To connect the fuel cell and battery to one or more motors, an electric circuit for

power transmission is needed. In this project a new power transmission module, called power management control and delivery (PMCD) module, was developed which is easier to control than a DC/DC converter and more flexible than a direct hybrid. This new module also has redundant power paths to assure high aircraft safety criteria and enables battery charging during flight from the fuel cell and by recuperation. A simulation of the PMCD module was evaluated to confirm the concept and a hardware PMCD was built using commercially available components. The main development aspects for the hardware set-up were weight, size and safety. In addition to the hardware parts, the PMCD consists of a control unit which manages mode transitions and safety measures. The functionality of the PMCD module was examined in extensive tests on a test-bench and to confirm airborne qualification, the PMCD was integrated into the aircraft HY4 and ground testing was performed followed by a flight campaign in 2020. This contribution will give an overview over the developed architecture, the control of the PMCD and the obtained test results.

Exhaust Emission Measurements Applicable to the Hybrid Panthera: Emission Mapping for the EU project MAHEPA

Ms. Grace Neubauer (Institute for Energy Conversion and Storage- Ulm University), *Daniel Frank Christiane Bauer, Caroline Willich, Josef Kallo*

Within the light sport aircraft (LSA) sector, developing new technologies which require limited sacrifices for performance, while decreasing aircraft emissions, has been an important research and development topic. There are many low or unleaded fuels already on the market and used to power light sport aircrafts, nevertheless it is still necessary to continually research even cleaner fuels, for instance, by increasing the amount of biofuel content like bioethanol in this sector. Within the scope of the MAHEPA project, emission maps for a Rotax 915 iS3 engine were obtained through experimental measurements on an engine test bed. Because the Rotax 915 engine already is certified for lead free fuels, this engine choice allows for full analysis of alternative fuel usage in a commercially available engine for LSA applications. For obtaining these maps, the engine was run at several measurement points (4500, 5000, 5500, 5800 rotations per minute [RPM]) within the usable power range with varying throttle (85, 102, 119, 135 kPa manifold air pressure [MAP] to 100% open throttle) all the way up to maximum power. All of the same setpoints were obtained for four different fuels: AvGas 100LL, Super 98 E5, Super 95 E10, and a mixture of Super 95 E10 with additional bioethanol ("Super 95 E20"). Additionally, a simulation of the engine using GT-POWER with the different fuels has been performed and the results qualitatively correspond well with the experimental data. The results indicate that utilizing bioethanol could be beneficial for decreasing emissions of LSA engines, as well as displaying the effect of the utilization of hybrid electric aircrafts. Nevertheless, other aspects like the effect of high ethanol content on aircraft safety at increasing altitudes need to be taken into account and more research and development needs to be done.

Safe, redundant and efficient Hydrogen Fuel Cell System powertrain for electric aircraft applications

Prof. Dr.-Ing. Josef Kallo (H2FLY GmbH, DLR - German Aerospace Center, Ulm University), Steffen Flade

Hydrogen Electric energy conversion with fuel cells is an innovative way to build new emission free, low noise propulsion systems for aircraft applications. During the EU Project MAHEPA a highly redundant hydrogen fuel cell system architecture was elaborated. By using standard components from automotive hydrogen applications and combining that base technology with highly customised aviation focused balance of plant parts a new redundant and highly functional propulsion system was build and tested

during the project. Highlights are the innovative solutions and testing for coupling the fuel cell systems with a highly redundant electric power distribution network and redundant highly integrated hydrogen storage systems. An extended test phase on the ground and in-flight showed the upscaling capabilities of this technology for up to a 40-seater emission free aircraft application.

How to fly hybrid-electric: MAHEPA flight test experience

Mr. Alberto Favier (Pipistrel Vertical Solutions d.o.o.)

Within MAHEPA project, two advanced variants of low emission serial hybrid-electric powertrains were designed, developed and flight tested on two different 4-seater aircrafts. Namely, the Pipistrel Panthera was hybridized with a conventional internal combustion engine while the Hy4 aircraft was hybridized with a hydrogen fed fuel cell system. MAHEPA consortium joint forces enabled to successfully complete complex flight test campaigns, where the advantages of hybrid-electric flying, but also the challenges related to novel technologies, were showcased. Flying hybrid is possible, now. From dedicated Human Machine Interface through optimized mission management and dedicated safety measures, this presentation will focus on the main results and challenges of the flight test campaigns conducted on the MAHEPA Panthera aircraft.

Ground infrastructure investments for operation of hybrid-electric aircraft

Ms. Maršenka Marksel (University of Maribor), *Anita Brdnik Prapotnik, Rok Kamnik, Stanislav Božičnik*

The introduction of hybrid-electric aircraft will require an adaptation of airport ground infrastructure, as the existing airport ground infrastructure is not suitable for the operation of hybrid aircraft, i.e. either non-existent, insufficient or unsuitable. Hybrid electric aircraft, discussed in two feasibility studies in this article, are either a combination of internal combustion engine (ICE) and battery (ICE -hybrid) or fuel cell hydrogen and battery (fuel cell hybrid). As part of the MAHEPA project, two study cases have been developed to estimate the technical requirements for the relatively novel ground infrastructure at airports. The first study relates to the multiple charging of ICE -hybrid aircraft, while the second study relates to the refuelling of fuel cell-hydrogen hybrid aircraft. Since the charging technology for hybrid electric vehicles is already available in the automotive industry and is transferable to the aviation industry, the initial investment is expected to be less than the investment for fuel cell hybrid aircraft. The article examines in detail various technical aspects of the necessary adaptation of airport infrastructure to enable smooth operation of ICE hybrid and fuel cell hybrid aircraft.

Strategy for hybrid-electric short-haul air transportation

Ms. Maršenka Marksel (University of Maribor), *Stanislav Božičnik, Rok Kamnik, Anita Brdnik Prapotnik*

Various ways and scenarios have already been outlined by Destination 2050, Waypoint 2050 and IATA Aircraft Technology Roadmap on how to minimize the environmental impact of aviation in the coming years, including measures such as the introduction of new technologies. As the new technologies, such as ICE hybrid-electric and fuel cell-hydrogen propulsion, are more likely to be deployed in smaller rather than larger aircraft in the short term, a broader vision is also needed, not only on how to design and develop a new aircraft, but more importantly where is the market for its day-to-day operations. The short-range hybrid electric aviation strategy therefore presents a vision for the potential use of small hybrid electric aircraft in short range aviation in the near, medium and long term. In this context, the most appropriate technical characteristics of aircraft for passenger transport (size, range, number of passengers on board, etc.), the identification of ground infrastructure requirements and investments will form the basis for

defining the most optimal potential transport services suitable for hybrid-electric aircraft (e.g.: Feeder/Hub and Spoke services, on-demand and scheduled services, inter-regional/cross-border services, small aircraft transport services, tourist and sightseeing flights) and identifying the potential market segments (passenger, business or leisure). Identifying the potential size of the future market will allow a more accurate assessment of the overall environmental impact resulting from the introduction of clean propulsion technologies in a wider air transport system.

AIRPOXY project

Session Chair : Dr. Nerea Markaide, CIDETEC, Spain

AIRPOXY: Thermoformable, repairable and bondable smart epoxy based composites for aero structures

Ms. Nerea Markaide (CIDETEC)

With strong growth rates of 13% in the aeronautical sector and forecasts that demand could be doubled by 2032, carbon composites (CC) are in the spotlight. CC production requires a quick ramp-up that needs to be based on robust materials & processes, and a solid manufacturing supply chain, where higher production rates and cost reductions are essential. The objective of AIRPOXY is to reduce production and maintenance, repair & operating (MRO) costs of CC parts in aeronautics, by introducing a new family of enhanced thermoset composites that preserve all the advantages of conventional thermosets, while showing new unprecedented features such as Re-processability, Repairability and Recyclability. This new generation of 3R composites are obtained by using dynamic hardeners which create reversible crosslinks in the cured epoxy resin. Once the 3R composite has been produced, the dynamic chemical bonds of the cured resin can be reshuffled under determined external stimulus, such as temperature or the exposure to a specific chemical agent. For these reasons the 3R composites are easily re-processable, repairable and recyclable. The first phase of the project, practically completed, is related to the upgrade of various 3R technologies from TRL3 to TRL4. Thus, several aero grade 3R epoxy resins have been formulated and characterized to be used in the thermoforming process. Several enduring prepregs and laminates have been produced to investigate 2 thermoforming processing strategies: Continuous Compression Moulding (CCM) and Discontinuous Compression Moulding (DCM). On the other hand, conventional RTM and SQRTM processes have been adapted for the use of 3R epoxy resins in the production of 3R laminates for additional 3R bonding and repair studies. In parallel, two 3R adhesive films for adhesive bonding and welding have been formulated, manufactured and characterized, and joining parameters have been defined. Regarding SHM and repair technologies, the NDE technologies have been applied on various specimen geometries to detect the defects induced by mechanical tests. In some cases, NDE methods have been applied online to simulate the in-service scenario. The knockdown effect assessment between the conventional and the 3R composites has been evaluated. Supporting tools such as simulation and life cycle assessment/ life cycle costing/ human health risk assessment (LCA/LCC/HHRA) are being applied from the early stages of design. The second phase of the project, in progress, is related to the validation of the 3R materials and processes in an industrial environment to their upgrade from TRL4 to TR5. To do this, two representative parts of a FAN COWL and a LEADING EDGE are being designed, produced and tested.

Design of high performance 3R vitrimers and 3R adhesives for Aerospace industry: Development, Applications and Future trends

Ms. Alaitz Ruiz de Luzuriaga (CIDETEC), *Nerea Markaide, Asier M. Salaberria, Diego Calderón, Stefan Weidmann, Vincent Gayraud*

Polymer composite materials are widely used in Aerospace industry in applications such as leading edge, fan cowl, interiors, nacelles etc. The high demand of these materials in Aerospace industry comes from properties such as strength and durability compared to weight. The development and implementation of light-weight, composite materials will allow the next generation of high-performance, economical aircraft

designs to materialize. Usage of such materials will reduce fuel consumption, improve efficiency and reduce direct operating costs of aircrafts. However, the difficulties of composite materials for reprocessing, repairing or recycling, which are inherent to their thermoset nature, are limiting their fast growth in many applications. In an approach to solve such limitations, in AIRPOXY project a novel aero grade "dynamic" epoxy resins have been developed. In AIRPOXY project, fiber reinforced polymer composites (FRPCs) made of dynamic resin and adhesives have been developed: 3R Vitrimers and 3R adhesives (3R: repairable, reshapable and recyclable). The obtention of these 3R materials has been done by the introduction of reversible aromatic disulfide bonds in the crosslink points of epoxy resin. It was demonstrated that this epoxy network presents vitrimer like behavior[93]. In this presentation, we will establish a conceptual framework to obtain aero grade epoxy vitrimers via a simple and scalable method that can be effectively implemented in currently used composite manufacturing methods and address current challenges in recycling thermoset polymers. During AIRPOXY project, 3R epoxy resin with similar mechanical and thermal properties of standard aero grade resin was formulated and characterized. In this presentation the comparison between both resins will be done and the 3R advantages will be demonstrated. In addition, the advantages of having a disassembleable and reparable 3R epoxy adhesive will be also highlighted and demonstrated. The qualification and certification of these novel 3R materials will permit to open new manufacturing methods for Aerospace industry towards more green Aerospace industry.

Bonding strategies for dynamic 3R-resin in functionalized composites surfaces made by the SQRTM process

Mr. Alain Leroy (Coexpair SA), *Stefan Weidmann, Alaitz Ruiz de Luzuriaga, Thibault DE Lumley, Juan Pedro Berro Ramirez, Priya Dasan Keeryadath*

During the past 10 years, the SQRTM process (Same Quality Resin Transfer Moulding process introduced by Radius Engineering Inc. and Coexpair s.a.) has demonstrated to be an efficient composites parts manufacturing process for the aeronautic industry. SQRTM is an out of autoclave or closed mould process that combines the advantages of both Autoclave Prepreg Moulding and Resin Transfer Moulding (RTM) processes. The pressure inside the mould is applied by a small quantity of qualified prepreg resin that is injected around the edges of the part to control the pressure until the gel of the prepreg material. The unique combination of cavity and injection pressure allows producing parts with very low level of porosities. The heating profile and pressure range of the SQRTM injection/curing cycles are typically within the current autoclave process specifications of OEMs and allows to produce faster large numbers of high quality and high complexity almost net shape composites parts. SQRTM is particularly suited for the integration of various elements into single assembly and has great impact on the overall cost of a finished structure. Composite materials made by SQRTM not only offer material weight savings but offer the opportunity to combine multiple components into single moulded structure, significantly reducing the part count and the numbers of secondary operations. The increasing demand of composites parts requires the development of innovative processes, tooling, reinforcements, and resin systems to cope with fabrication challenges.

[93] (a) Ruiz de Luzuriaga, A., et al., Epoxy resin with exchangeable disulfide crosslinks to obtain reprocessable, repairable and recyclable fiber-reinforced thermoset composites. Materials Horizons, 2016. 3(3): p. 241-247. (b) Ruiz de Luzuriaga, A., et al., Correction: Epoxy resin with exchangeable disulfide crosslinks to obtain reprocessable, repairable and recyclable fiber-reinforced thermoset composites. Materials Horizons, 2020. 7(9): p. 2460-2461.

The AIRPOXY project opens the possibility to develop breakthrough technologies based on a novel 3R (repairable, re-shapable, recyclable) thermoset resin. 3R resin presents reversible dynamic bonds that enable a series of smart properties creating a new generation of composites and adhesives resin systems. Combining 3R AIRPOXY resin systems and SQRTM process offer the possibilities to functionalize the composites parts further in preparing them totally or locally for future secondary operation such as bonding and welding. In this work bonding strategies for dynamic 3R-resin in functionalized composites surfaces made by the SQRTM process have been investigated. Several CFR panels were manufactured by SQRTM while incorporating locally 3R resin film patches that serve for induction welding or induction bonding experiments. In these regions, the creation of covalently or dynamically bondable structures will help in removing the need of surface preparation for gluing process or for the placement of abundant rivets and fasteners. A demonstrator representing an existing aircraft composite part (Leading Edge) has been manufactured and will be presented to complete the introduction of the potential of this unique process and 3R resin combination.

Manufacturing, thermoforming and mechanical characterization of 3R-composites

Mr. Stefan Weidmann (Institut für Verbundwerkstoffe GmbH), *Alaitz Ruiz de Luzuriaga, Andreas Kraemer, Juan Pedro Berro Ramirez, Vincent Gayraud, Peter Mitschang*

High production rates and short cycle times are becoming increasingly important - not only in the automotive industry but also in the aerospace industry. New materials and processes are requested to achieve an efficient production of high-performance components made of carbon fiber reinforced polymer composites (CFRPC). The presentation will report recent research results on the manufacturing and processing of a new family of improved composites using an epoxy-based vitrimer matrix polymer (3R composites). At temperatures above the glass transition temperature (Tg), they are thermoformable, weldable and repairable due to dynamic chemical bonds. At room temperature, vitrimers are fully cross-linked like thermosets and show similar properties regarding high stiffness, chemical resistance and low creep tendency[94] [95] [96] [97] [98]. The presentation will cover the manufacturing processes for 3R vitrimer composites developed in the Airpoxy project including:

- Manufacturing of 3R parts by infusion of dry preforms with 3R-resin using the RTM process.
- Continuous manufacturing of flat laminates and thermoforming of omega profiles using the continuous compression molding process.
- Thermoforming of 3R components in the discontinuous compression molding process.

To optimize the thermoforming processes, numerical simulations were performed in order to identify negative effects during thermoforming in advance and to fine-tune the processes and materials, resulting

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[98] *A. Ruiz de Luzuriaga, R. Martin, N. Markaide, A. Rekondo, G. Cabañero, J. Ro-dríguez und I. Odriozola, „ Epoxy resin with exchangeable disulfide crosslinks to obtain reprocessable, repairable and recyclable fiber-reinforced thermoset composites"Materials Horizons Vol. 3, pp. 241-247, 2016.*

in almost defect free parts. The presentation also includes mechanical properties such as tensile strength, interlaminar shear strength and others in comparison to established RTM6 composites. In summary, it can be concluded, that thermoforming of fully crosslinked 3R composites is possible but challenging, due to the high matrix viscosities. The mechanical properties are close to those of the RTM6 reference material, but requires further developments in order to be suitable for aerospace applications.

Evaluation of repair efficiency on 3R polymers & composites using mechanical and NDE tests

Mr. Georgios Foteinidis (University of Ioannina), *Maria Kosarli, Kyriaki Tsirka, Alkiviadis S. Paipetis*

Fibre-reinforced polymers have a vast development during the last years in the aeronautic field due to their low weight to strength ratio. A challenge on the thermoset epoxy polymers and composites is their repair. Several self-healing approaches have been developed, such as the micro-capsules that contain the healing agent, vascular networks, intrinsic polymers, etc. In this work, a novel Re-processable, Repairable and Recyclable (3R) thermoset resin is presented. The 3R properties are due to the reversible crosslinking in the cured thermoset resin. This resin can offer a reduction in costs and the time of the repair. A comparison between various 3R production processes was established by mechanical and Non-Destructive Evaluation (NDE) techniques, including Impedance Spectroscopy (IS), Electrical Resistance Change Method (ERCM), IR-thermography, phased array ultrasonic and Acoustic Emission (AE). These techniques were applied before and after the damage or simultaneously with the mechanical test. The repair efficiency was also estimated and correlated with each production method.

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Numerical Analysis & Virtual Testing of aircraft structures

Session Chair : Prof. Konstantinos Tserpes, University of Patras, Greece

Numerical parametric study of the laser-shock paint stripping on aerospace aluminum substrates

Kosmas Papadopoulos, ***Prof. Konstantinos Tserpes (University of Patras)***

In recent years, laser-induced shock waves have been used for various engineering applications such as the enhancement of fatigue strength of metallic materials, the evaluation of adhesion strength and the selective stripping of external coatings. This study focuses on the development of an explicit 3D FE model in LS-DYNA, to simulate the laser selective stripping on aircraft aluminum/epoxy substrates. After the model validation against experimental back face velocities, a parametric study has been performed with the main objective to explain some physical mechanisms that take place, during the laser shock initiation and propagation, in terms of stress evolution and stripping shape and size. To simulate aluminum's behavior, the Johnson-Cook plasticity model and the Gruneisen Equation of State (Gruneisen-EOS) have been applied. Stripping has been simulated through the cohesive zone modeling (CZM). The parameters considered in the study are the aluminum thickness, the epoxy paint thickness, the laser spot diameter, the fracture toughness of the aluminum/epoxy interface and the maximum applied pressure. In every case, a circular or hollow stripping pattern has been predicted, which agrees with experimental findings. Results have shown that increasing the aluminum thickness, a transition from the annular to uniform stripping pattern takes place. On the contrary, with increasing the epoxy thickness, a transition from a solid circular to an annular stripping pattern takes place. The laser spot's diameter significantly affects the stripping initiation, propagation and the final stripping pattern. For values larger than 4 mm, an incomplete stripping pattern is predicted. The mode-I critical energy release rate affects the first stages of stripping evolution, while the mode-II critical energy release rate does not affect stripping evolution. Finally, with increasing the maximum applied pressure, a transition from the annular to the solid stripping pattern takes place. As a conclusion, the model is capable to efficiently simulate the laser shock stripping process and as next step of the current work is a proper characterization of the fracture toughness properties of the interface and a further experimental verification and validation of the model.

Towards simulation of disassembly of bonded composite parts using the laser shock technique

Panagiotis Kormpos, ***Prof. Konstantinos Tserpes (University of Patras)***

In this work, a model for simulating the laser shock-based disassembly of composite components is developed using the LS-DYNA explicit code. The lase shock technique has been used in the past for the non-destructive testing of adhesive bonds, but with appropriate adjustments it is possible to create a localized tensile stress that is high enough for adhesive failure to occur, making it suitable for use in the disassembly of bonded parts. In this first attempt, we focus on the development of a multiple loading instances simulation process, aiming to completely debond two carbon fiber reinforced plastic (CFRP) plates. The process of laser shock for disassembly requires an increased number of loading instances in order to cover the full bonded area. That, in addition to the short time duration in which the phenomena are evolved, poses a serious challenge for the numerical simulations, and thus a reliable procedure must be defined in terms of functionality and computational cost. Indeed, an iterative method, where the deformed model is used as input in subsequent simulations is tested, optimized and compared with a more traditional single model simulation.

Numerical structural analysis of composite nose landing gear for UAV

Mrs. Milica P. Milic (Faculty of Mechanical Engineering of the University of Belgrade)

The main purpose of this study is to determine the optimum mass to strength ratio for the composite nose landing gear of a UAV. The analysis in first phase is achieved by using numerical methods, based on the finite element analysis of the nose landing gear. Nose landing gear is exposed to static and dynamic load. Both load cases should be taken into account during the design. The load cases calculation was done by the analytical method and modeled using ANSYS finite element software. Geometry of the nose landing gear is discretized using the layered shell elements. The result of this study will show if is the types of laminate configurations adequate for this geometry and load cases.

Virtual test approach of titanium/composite repair in service, installed on certified narrow body aircraft composite structure flap

Mr. Vittorio Giacalone (Salver spa, MA Group)*, V. Avigliano, L. Pascali, S. D. Orlando, F. Starace*

Virtual test methods can contribute to reducing the great effort for physical tests in the development of composite structure and in particular on the In-service Repair. The present work describes an approach for virtual testing of titanium/composite repair based on the Building Block Approach and the Finite Elements Method. Building on a multitude of physical tests on composite panels and joints, adequate sub-models are developed, validated and the results show that the method used for the substantiation of the generic repairs (GREOs) compared with test results is conservative. This thesis intends to provide a hierarchical virtual testing approach, which enables the prediction of the failure behavior and the strength of composite In-service repairs by means of validated FEM simulation. In particular the objective of this work will be to investigate the damage mechanisms in composite bonded skin/stringer constructions with metallic (titanium) bolted repair under uniaxial (in-plane/out-of-plane) loading conditions as typically experienced by aircraft flap skin panels.

Analysis of the application of fuselage skin reinforcements with beam element representations in flexible full aircraft models for ditching simulations

Ms. C. Leon Muñoz (German Aerospace Center (DLR), Institute of Structures and Design), *B. Langrand, D. Kohlgrüber*

Novel aircraft models for overwater operations must be compliant to aircraft certification requirements for the case of a planned emergency water landing, commonly known as ditching. To investigate the structural behaviour of the airframe exposed to high hydrodynamic loads during the impact and the resulting kinematics of the aircraft in the subsequent landing phase, mainly physical experimental methods or similarity considerations with already certified aircraft are common practice. Beside the fact that experimental campaigns are cost-intensive, the methods are constraint in terms of repeatability, parametric variations and in the local analysis of structural deformations. Nowadays, adequate hi-fidelity numerical representations can be used to complement experimental campaigns and to predict the ditching behaviour of the aircraft even in the pre-design phase by implementing multi-disciplinary design process chains. However, an affordable and realistic representation of the aircraft structural behaviour as well as the interaction between the fluid and the aircraft are challenges. The German Aerospace Center (DLR) and the French Aerospace Research Center (ONERA) have been contributing for years to develop and investigate suitable computational representations for ditching simulations. A coupled approach is applied in which the structural model, e.g. the aircraft, is discretized with a classical Finite Element (FE)

method while due to large deformations the fluid is modelled using the Smoothed Particle Hydrodynamics (SPH) or the Arbitrary Lagrangian-Eulerian (ALE) method. The interaction between fluid and structure (FSI) is computed using a node-to-surface penalty contact definition or using an embedded interface[99]. To reduce the computational effort, the simulation can include multi-model coupling to define separate convenient time steps for each sub-model. Initial investigations regarding full aircraft ditching simulations with mainly rigid aircraft models are presented in[100] [101]. In an analysis study using beam-stiffened flexible aircraft panels for ditching simulations, the feasibility of the beam element reinforcements modelling technique compared to more detailed extruded reinforcement representations using shell elements was shown[102]. The resulting behaviour during ditching of both models were comparable. By implementing coarser structural meshes and considering adequate fluid particle densities the computational effort could be reduced by a factor of 15, indicating the capability to integrate these considerations in more complex architectures, like in the full aircraft application. The presented work analyses the contribution of the application of simple beam finite element representations in skin-reinforced airframe structures and in flexible aircraft models for ditching simulations. In addition, this investigation includes comparisons with different formulations (i.e. ALE or SPH) considering performance and time aspects.

Automatic tool-based pre-processing of generic structural models for water impact simulations in the aircraft pre-design

Ms. C. Leon Muñoz (German Aerospace Center (DLR), Institute of Structures and Design), *M. Petsch, D. Kohlgrüber, M. Pedelaborde-Augas*

Among several emergency landing requirements for new aircraft models, aircraft manufacturers must investigate the structural capability of the airframe to sufficiently withstand loadings caused under impact conditions, e.g. during an emergency water landing. Since modifications in the late aircraft design phase are difficult to implement and very cost-intensive, the integration of adequate tools to predict and analyse the structural behaviour in early design phases is desirable. For this purpose, multidisciplinary aircraft design process chains and common data transfer formats are introduced to generate, analyse and optimize aircraft models, which can be virtually tested using hi-fidelity numerical representations like the Finite Element (FE) method. At the Institute of Structures and Design of the German Aerospace Center (DLR) a python-based framework with packages for the modelling, analyse, and sizing of aircraft structures, called PANDORA (Parametric Numerical Design and Optimization Routines for Aircraft) has been developed over the last years. The geometrical, structural and physical description of the aircraft is

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based on the Common Parametric Aircraft Configuration Schema (CPACS)[103] [104]. The aircraft data is processed internally in various packages according to the intended functionality using standard python packages and open-source toolkits like Open Cascade (OCC) and the Visualization toolkit (VTK), as shown in Figure 1 (left). The modular architecture of the framework provides versatility to incorporate new interfaces and to extend existing packages[105]. In the scope of the integration of new processes and features to extend the framework capabilities to explicit and crash applications (e.g.[106], a previously independent process to generate aircraft structures for water impact simulations (formerly AC-Ditch[107]) was adapted and integrated, too. By using the CPACS data format, generic full-aircraft models can be evaluated applying suitable computational representations for water impact simulations[108], as presented in Figure 1 (right). For the simulation of water impact, the aircraft is discretized with a classical FE method and the fluid in different methods such as a hybrid fashion using the FE as well as the Smoothed Particle Hydrodynamics (SPH) method. The structural and fluid models are coupled using a penalty contact definition. Apart from the model generation the framework includes the possibility to launch the simulation directly from its graphical user interface and to visualize results, as depicted in Figure 2. Additionally, the conversion package of PANDORA allows for the generation of equivalent models suitable for different explicit FE codes. The presented work demonstrates the new integrated capabilities of the framework for the automatic pre-processing of structural models with different discretization approaches for water impact simulations using different explicit solvers. These are analysed in terms of flexibility, performance and handling using specific benchmarks.

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Novel approaches on aeronautical composite materials

Session Chair : Prof. George Lampeas, University of Patras, Greece

Development of a novel hybrid thermoplastic material and holistic assessment of its application potential

Dr. Ch. V. Katsiropoulos (University of Patras-Laboratory of Technology and Strength of Materials), *Sp. G. Pantelakis, M. Barile and L. Lecce*

During the last decades the mostly used composite material type for aviation applications is carbon-epoxy thermosets. The use of these materials is related to long curing cycles and thus relatively reduced volume production, as well as emerging environmental issues correlated to their waste handling. These shortcomings and the related rigorous environmental policies imposition have attracted the attention of the aviation industry in evaluating thermoplastic composites as a promising alternative [e.g. 1]. In terms of material properties, it is well known that the most significant opportunity of thermoplastic resins is related to their processing capabilities. Thermoplastics can be processed by single stage fabrication technologies and assembling of components can be performed by welding without the need to use adhesives or fasteners. Furthermore, thermoplastic composites recycling is much simpler than recycling of thermosetting composites, since thermoplastic resins are recyclable and can be re-melted by heating. Currently, one of the vital barriers for the extended range adoption of thermoplastic composites for producing primary aircraft structures [e.g. 2-3] lies to the limitations of the existing production processes which make the manufacturing of such structures not affordable. Regardless whether working with thermosets or thermoplastics, cost and environmental impact for manufacturing an aeronautic component are today of vital interest, in addition to the permanent necessity for keeping the weight as low as possible whilst maintaining sufficient quality. Therefore, it needs to be underlined that by introducing a novel material, the assessment of cost and environmental footprint aspects is mandatory. For this reason, Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) models are used prior manufacturing as tools for the selection of the most appropriate process [4-5]. These analyses are performed in addition to the need of meeting the non-negotiable requirement of satisfactory quality. In the present work the development of a novel hybrid thermoplastic prepreg material enabling the fabrication of next generation recyclable composite aerostructures produced by affordable automated technologies, is presented. The new hybrid material is produced using an automated equipment designed and developed for this reason. A preliminary assessment of the application of the new material is made by involving Differential Scanning Calorimeter (DSC) tests to obtain material properties related to its processability as well as Inter Laminar Shear Strength (ILSS) tests related to its mechanical strength. To assess the potential of the new material for producing aircraft structural parts a typical aeronautical flat skin panel has been identified and produced using an Autoclave based process. To enable a more holistic comparison of the suitability of the materials used for the panel production a newly developed holistic Index developed in [6] is implemented. The aspects considered for the material comparison have been quality, environmental footprint and cost. In this frame, among other Life Cycle Assessment (LCA) and Cost Analysis were carried out. The results of the study pointed out that the hybrid thermoplastic material developed represents a viable manufacturing option from industrial point of view, and ist implementation for the structural component manufacturing leads to a clear cost and environmental advantage.

Influence of polymer indicator coating thickness on damage tolerance and residual strength of composite material

Mr. Kudryavtsev Oleg (Sout Ural State University), *Leshkov Egor, Olivenko Nikita, Ignatova Anastasia, Bezmelnitsyn Alexandr*

Timely maintenance and health monitoring throughout the entire life cycle allows to ensure the safe operation of aerospace structures made of polymer composite materials. Therefore, important tasks are to detect barely visible impact damages and assess their influence on the residual strength of composite elements. One of the ways to recognize defects is to apply indicator coatings on composite. This work discusses the use of an indicator coating based on hollow glass microspheres to identify the impact site and associated damage. The influence of the coating thickness on the mechanical behaviour of GFRP specimens subjected to low-velocity impact and flexure-after-impact tests was evaluated. It was found that the coating with the thickness of 1 mm made it possible not only to clearly indicate the impacted place but also to significantly reduce the damaged area. Residual flexural strength of the GFRP specimens with the 1 mm coating increased by 27% in comparison with the uncoated ones.

Influence of preloading cyclic bending on the residual strength and stiffness of a composite material

Mr. Zhikharev Mikhail V. (South Ural State University)

As part of the study, specimens of GFRP, having the shape of a beam of equal strength, were made for testing for cyclic alternating bending. The tests were carried out on an LDS V780 shaker using the appropriate equipment. The tests were conducted at two frequencies of 5 and 20 Hz and three different amplitudes of 3 mm, 5 mm and 7 mm. For each frequency and amplitude, a different number of loading cycles was investigated: 100, 500, 1000, 2500, 5000, 7500, 10000, 15000. After testing for alternating bending, the residual strength and stiffness tests at three-point bending were carried out. The tendency to decrease the residual strength and stiffness becomes more clearly, the larger the preload amplitude and reaches 41% at an amplitude of 7 mm. This is due to the fact that at high amplitudes, there is an intensive accumulation of scattered microdamages in the outer layers of the composite. At amplitudes of 3 and 5 mm, the loading frequency had practically no effect on the accumulation of scattered microdamages in the samples, and the dependences of the residual bending strength and stiffness on the number of cycles did not practically differ. At an amplitude of 7 mm, the differences are already pronounced and significantly exceed the experimental scatter. It was assumed that the process of accumulation of scattered microdamages in the composite under cyclic loading is influenced by the phenomenon of self-heating.

Ballistic impact response of reinforced honeycomb sandwich panels

Mr. Saiaf Bin Rayhan (Northwestern Polytechnical University), *Mahtab Uddin Chowdhury*

Honeycomb sandwich panels are widely adopted in various industries including aerospace, marine, automobile, and, infrastructure due to their excellent flexural rigidity and bending strength in contrast to their low weight. They are also known for their attractive energy absorbing capability and resistance to ballistic impacts. Reinforcement of the honeycomb panels is an efficient way to improve the impact energy dissipation. However, improvement of ballistic limit resistance due to reinforcement has not yet been studied before. Therefore, the current research investigates the improvement of damage, ballistic velocity limit, and specific energy absorption (SEA) of reinforced honeycomb structure due to high-velocity impact.

A numerical approach is adopted with commercial finite element code Ansys Explicit to study the phenomena. In total, five different reinforcement type is examined. The plate of the honeycomb panel is assumed as Al-7075-T6, while the honeycomb core is made of Al-5083-H116 alloy. For both the alloy variants, the Johnson-Cook material model is utilized. For the impactor, a cylindrical-shaped structural steel bullet is designed. It is found that, for the current investigation, reinforcement does not help much to improve the ballistic velocity limit of the panels.

Determination and Validation of Low Velocity Impact Behavior of GLARE for Different Energy Levels and Specimen Thicknesses

Mr. Eren Calis ( ), *Mustafa Yurdakul*

In the competitive environment in aerospace industry, maximum performance with minimum weight is the most fundamental goal of the design process. In this sense, new materials and production methods are constantly worked and developed by the companies and institutions. One of these materials are Fiber Metal Laminates, i.e. FML, which are basically hybrid composite materials composed of very thin metallic sheets and proper glass, carbon like fiber/epoxy layers. ARALL, CARALL and GLARE are the well-known Fiber Metal Laminates which are composed of metal layers and aramid, carbon, and glass, respectively. Inherently, FML materials aggregate the characteristics of the constituent materials so that they have very high mechanical and fatigue properties. For this reason, they have wide area of usage in aircrafts such as wing lower skin, fuselage skin etc. Since the skins of an aircraft is a potential zone of impact during ground maneuvers and maintenance, it is needed to investigate impact properties of these materials. In this study, by considering wing lower skin as a potential zone of application, GLARE is investigated for impact resistance since it is known that fatigue and strength properties of GLARE is superior. First, an analysis model is created for simulations. Then, low velocity impact test matrix is designed, and tests are conducted with different levels of energy and different specimen thicknesses. Test results are used to both validate analysis tool and create a statistical model. After that, validated analysis tool and statistical model are compared with each other inside and outside of the test matrix. Finally, analysis tool and statistical model will be used for determination of low velocity impact behavior of a GLARE aircraft skin for future design processes.

Effect of Temperature on Low Velocity Impact Behavior of GLARE Material

Burhan Cetinkaya, ***Prof. Ibrahim Ozkol (İstanbul Teknik Üniversitesi)***

In today's competitive aerospace environment, it is very important to design and produce aircrafts with high performance and lightweights and in this context, to find new production processes and new production materials. One of this material is GLAss-REinforced aluminum laminate, i.e. GLARE, which are basically hybrid composite materials composed of very thin aluminum sheets and proper structural glass i.e. S2 layers. Due to its high impact resistance and fatigue properties, GLARE is used in different parts of the aircraft such as the wing & fuselage skin and cargo floor. When producing GLAREs to be used for different purposes, first of all, the metal layer must be abraded mechanically or chemically (etching with chromic acid or phosphoric acid) in order for the fiber/epoxy layer to adhere better. After the metal and fiber/epoxy layers are laid, the autoclave curing process is applied. In aviation applications, types of impacts encountered in aircraft structures can be divided into three titles; low-speed impact, high-speed impact and explosion. Since GLARE consists of both metal and composite layers; damage types such as plastic deformation, matrix cracking, delamination in composite layers, buckling in metal layers and separation between different layers are observed as a result of impact effect. Since the skins of an aircraft

is a potential zone of impact during ground maneuvers and maintenance, it is needed to investigate impact properties of these materials. In this study, by considering wing lower skin as a potential zone of low-velocity impact application. As a preliminary study, within the scope of this research, GLARE 4A material was designed as a flat plate and 16 pieces of 5x5 mm2 defects were placed on certain layers and 3 thermocouples were placed to monitor the temperatures in different parts of the panel during curing. The purpose of placing these defects is to show that damage or cracks that may occur in the inner layers of the GLARE lower skin panel of the aircraft wing can be seen by non-destructive testing. So far in this study, GLARE panel has been designed and the best curing cycle has been determined for the GLARE panel. Afterwards, the defects placed inside the panel were examined by ultrasonic nondestructive testing method. As future studies within the scope of this research, low-speed impact will be applied to samples prepared according to ASTM standards at different temperatures (-55 and +90 Celsius Degrees), at different energy levels and different thicknesses. Difference from the literature, for GLARE materials, the effect of the temperature of the GLARE material on low-speed impact, which has never been studied before, will be investigated.

European Policy Actions in the Field of Aviation & Space

Session Chair :

The Learn & Fly Project: Increasing Students Interest in STEM Through Aeronautics

Ms. M. Guedes (Instituto Politécnico de Setúbal), *N. Nunes, R. Cláudio, M. Piteira, A. Dias, K. Śliwa-Martinez, G. Santamarina*

Learn&Fly is an Erasmus+ project encompassing educational, corporate and industrial partners from Poland, Portugal and Spain. These countries have in common a significant ratio of underachievers in math and science, and a thriving aeronautic industry. The project proposes to intersect those features, showing students the importance and application of STEM subjects in aeronautics. Concepts in physics, mathematics and science are explained by engaging students in the construction of a glider aircraft aimed to compete in a flight contest. Students must envisage, design, draw and calculate the aircraft, simulate its flight, make necessary adjustments to initial design, and build it. The project attracted a total of 121 students, aged between 17 and 21 years old; girls corresponded to 19.5% of participants. During one academic year students work on the glider was accompanied -chronologically and in contents- by lectures in physics, materials, drawing and technologies. Comprehensive information about professions in aeronautics and education paths to embrace them was also provided, aiming to support career decisions. A questionnaire was used to quantify students' perception on project usefulness. Results show that students considered the project to be "effective" in improving their STEM skills and in raising career awareness, and "very effective" in improving soft skills. This outcome is expected to result from the stimulating STEM learning environment, that was student-centred and problem-based, and provided access to contents, materials and activities not usually available to high school students from the partaking countries.

Policy actions within the aerospace projects developments. Particular case: RoRCraft fuselage manufacturing for RACER Demonstrator

Ms. Daniela Mocenco (INCAS)

The European strategies and programs developed at European level applied in the aerospace sector have led to the optimization of investments, developing the infrastructure and increasing the cooperation. This also had an impact on the national programs and strategies of each European country. Many actors of the aerospace value chain- – researchers, industry and public authorities have been involved. Although, as many high-level representatives of the European and aeronautics environment states, is still needed significant efforts and investments from the entire value chain to develop the necessary technology breakthroughs. RoRCraft fuselage manufacturing for RACER Demonstrator it is a project developed by Romanian Consortium (Roc) within Clean Sky 2 program, under Airbus Helicopters coordination. The main activities included in the RoRCraft project refer to the conception, design, production, testing and permit to fly support for the fuselage of the Racer Demonstrator. Simultaneously with the activities of RACER, RoC initiated two other projects in order to support the additional activities necessary for the project, mainly for manufacturing preparation test (composites parts) also some additional activities for permit to fly testing process. This project have been financed within national funding mechanism as a results of the cooperation and the policy actions applied in the aviation field. This year, 2021, RoC marked the completion of the fuselage manufacturing within an event organized in Bucharest, in a hybrid form, which included both the presence of partners who contributed to the realization of RACER, stakeholders and

representatives of the contracting authority from the European Commission and Romanian Government Organizations (Ministry & Contracting Authorities). The participation of an important number of guests is the result of the policies applied within aerospace field at European and national level. The aim of this paper is to describe the policies applied and their impact in developing this project.

Acceptance, Safety and Sustainability Recommendations for Efficient Deployment of UAM - Outline of H2020 CSA Project

Dr. Bartosz Dziugiel (Lukasiewicz Research Network - Instytut Lotnictwa), *Vittorio Di Vito, Sandra Melo, Jens ten Thije, Michele Giannuzzi, Gabriella Duca, Raffaella Russo, Adriana Witkowska-Konieczny, Henk Hesselink*

In recent years, rapidly developing technologies have made the concept of vertical take-off and landing air transportation, also known as Urban Air Mobility (UAM), over populated areas, very real and nearly ready for implementation. The vision of a third dimension added to hitherto nearly flat urban/metropolitan transport system gained the potential to become a mobility revolution for both logistics operators and, in the near future, for passengers as well. In spite of the expected emergence of this new form of transport and respective benefits for the efficiency of the mobility system at urban and suburban scale, UAM implementation also involves unprecedented and numerous challenges for cities and for all local public and private stakeholders. The local governing bodies are expected to provide policy, regulations and guidance for the implementation of UAM and to assure its integration with the ground mobility systems as well as with other urban functionalities in harmony with all stakeholders. Taking into account both potential benefits and associated challenges related to UAM implementation, ASSURED-UAM (Acceptance, Safety and SUstainability Recommendations for Efficient Deployment of UAM) project aims to support that effort, by providing a multidisciplinary study on operational and policy frameworks for the process of the introduction of unmanned modes of UAM. Specifically, the project covers:

- A knowledge base covering the technology progress, regulatory review and integration of UAM into existing and operational urban transport systems.
- A concept of operation and definition of up to 10 of the most promising and credible UAM use cases.
- Foresight of UAM deployment covering detailed scenarios for the development of UAM and divided into three main areas: operational constraints, Life Cycle Cost (evaluating the real cost of system deployment and operation, including the cost for the natural environment), as well as financing and public acceptance aspects.
- Standards and recommendations for UAM components, products and processes, covering integration, environmental objectives and city planning aspects.
- Three individual and independent cities' project development support as well as technical assistance.

The ASSURED-UAM project aims, with the knowledge produced along its duration plus the integration with the wider UAM community, cooperation, and synergy with other UAM projects, industry and user groups, to contribute to the deployment of UAM integration in cities, in an effective and sustainable framework that results from the co-creation with the public and private stakeholders.

InnEO'Space PhD: Preparing Young Researchers for a successful career on Earth Observation applications

Prof. Josiane Mothe (IRIT-CNRS, UT2J, Université de Toulouse), *Aurélie Baker, Valentina Castello, Valentina Ciaccio, Fabio Del Frate, Mihai Ivanovici, Anne Lehuerou Kerisel, Josiane Mothe, Daniela Necșoi, Aude Nzeh Ndong, Maude Perier-Camby, Marco Recchioni, Mihaela Voinea*

InnEO'Space PhD project is preparing young researchers for a successful career by developing modernized and transferable PhD courses and learning resources based on innovation skills and employers' needs as well as in-depth knowledge of high stakes and approaches of Earth Observation in many application domains.

The mains objectives of Inn'EO Space PhD are to:

- Enhance and develop researchers' innovation-oriented mind-sets and skills through Earth Observation
- Raise awareness about employment opportunities in academia and industry among researchers and scientists.
- Tackle future skills mismatches
- Create new synergies between PhD students and researchers and potential employers.

ENABLEH2 project

Session Chair : Dr. Vishal Sethi, Cranfield University, UK

Enabling Cryogenic Hydrogen-based CO2-free Air Transport (ENABLEH2)

Dr. Bobby Sethi (Cranfield University)

Liquid Hydrogen (LH2) has the potential to completely decarbonise civil aviation. At the moment this is a minority view within the industry, mainly due to the anticipated higher costs. But considering heightened environmental awareness emissions taxation scenarios, and the sheer necessity of transformation, the cost of transition will be relatively modest for such a fundamental, long-term solution. Flightpath 2050 targets very ambitious emissions reductions, relative to year 2000. It will be extremely challenging to meet these targets with carbon-based fuels, despite large research efforts on disruptive airframe and propulsion technologies, even when coupled with improved asset and lifecycle management procedures. Even if we were able to meet these targets, this would not be sufficient for a fully sustainable future for civil aviation, particularly considering the rate at which other sectors are decarbonising. ENABLEH2 is providing thought leadership through revitalising enthusiasm in LH2 research for civil aviation by maturing key technologies to achieve zero mission-level CO2 and ultra-low NOx emissions, with long term safety and sustainability. The key technologies being researched and matured are H2 micromix combustion and fuel system heat management. As part of the overall technology evaluation, a suite of models is being developed to evaluate LH2-fuelled aircraft with respect to energy efficiency, emissions, life cycle CO2 and costs, for potential fuel price and emissions taxation scenarios. The benefits and economic viability of LH2 will be quantified relative to best-case scenario projections for Jet A-1, Biofuels and LNG. ENABLEH2 is also generating best-practice safety guidelines for LH2 at aircraft, airport and operational level and will also deliver comprehensive roadmaps for the introduction of LH2. This introductory presentation for the ENABLEH2 session will provide overviews of the strategic importance and expected impacts of the ENABLEH2 project, the overall work scope and partners, and the role of a dedicated industry advisory board. A brief introduction of the presentations for the session will also be provided namely:

1. Development of fuel and heat management systems for liquid hydrogen powered aircraft
2. Advances in numerical and experimental research of hydrogen micromix low emissions combustion systems
3. Modelling studies of the hazards posed by liquid hydrogen use in civil aviation Evaluating and roadmapping hydrogen propulsion in the ENABLEH2 project
4. Understanding infrastructure and operational challenges generated by alternative energy aircraft
5. Enabling Cryogenic Hydrogen-Based CO2-free air transport: Technology Evaluation and Road Map to Accelerate Entry into Service

Heat Management Opportunities in Hydrogen Fuelled Gas Turbine Engines

Mr. Carlos Xisto (Chalmers University of Technology), *Isak Jonsson, Tomas Grönsted*

In 2019 aviation was responsible for emitting 918 million tonnes of CO2, accounting for approximately 2% of global emissions. Albeit the drastic drop during COVID19, analysts expect aviation to pick up again at a pace of 4-5% a year, threatening to triple today's emissions by 2050 and reaching a far larger share of global CO2 due to ongoing decarbonization of other sectors. The current pace of 1-2% in efficiency improvement per year helps to curb some of the effect, but a more aggressive strategy targeting a phased

decarbonization of the aviation sector is necessary for the next 30 years if we are to meet the threshold of 1.5 C set by the Paris agreement. The presentation covers several aspects related with the heat-management system of liquid hydrogen (LH2) fueled aircraft. LH2 is stored at cryogenic temperatures (-253C), requiring the usage of heat exchangers to increase its effective heating value on the way to the combustion chamber. The heat exchangers can be placed in the vicinity of the engine to reject the heat generated by the gas turbine core to the fuel. Ideally, they are strategically located to use heat management to maximize the engine efficiency and ensuring sufficient component durability. Moreover, the combination of liquid hydrogen's high specific heat with cryogenic storage temperatures results in a formidable cooling capacity that can be explored by more compact heat exchanger solutions (e.g. using existing turbomachinery surfaces). The presentation provides an outlook on the opportunities given by different heat exchanger solutions and the challenges associated with engine integration. The evaluation is supported by experimental and high fidelity CFD results obtained at two strategic heat recovery locations within the core path: the compressor interconnecting duct; and turbine rear structure and core nozzle.

Advances in numerical and experimental research of hydrogen micromix low emissions combustion systems

Mr. Xiaoxiao Sun (Cranfield University), *Romain Le Dortz, Pierre Gauthier, Bobby Sethi*

Flightpath 2050 very ambitiously targets 75% CO2 and 90% NOx emissions reductions, relative to year 2000. It will be extremely challenging to meet these targets with hydrocarbon fuels, despite large research efforts on disruptive airframe and propulsion technologies, even when coupled with improved asset and lifecycle management procedures. Hydrogen micromix combustion has the potential to complete decarbonize aviation with ultra-low NOx production. This presentation describes the recent research on applying this technology to an aero engine combustor within the scope of EU H2020 ENABLEH2 project. A small-scale micromix injector numerical experimental campaign has been established. The impact of a number of design parameters on the flame-flame interaction and NOx production has been investigated numerically, with a particular focus on the momentum flux ratio and jet penetration. The potential risk of micromix combustion instabilities has been analysed. With the guidance of numerical simulations, the design of a lab-scale hydrogen micromix combustion rig has been developed to collect measurement data on temperature, flame visualization, flame dynamics and emissions. Latest progress of this experiment campaign will be presented, with regards to rig layout, measurement conducted, and preliminary results obtained, as well as challenges encountered for this hydrogen combustion rig. Additionally, the sizing methodology of a hydrogen micromix combustor for Y2050 UHBR aero engines has been developed. Based on the calculated combustor size, an injector array representing a segment of the full annular combustor has been designed, along with a high pressure high temperature rig to test such injector array, The design incorporates injector fuel staging strategy and the relevant temperature and emissions measurement. Numerical simulations were performed to analyse the combustor temperature distribution and heat transfer with rig walls.

Modelling studies of the hazards posed by liquid hydrogen use in civil aviation

Dr. Paul Holborn (LSBU), *James Ingram*

The use of liquid hydrogen (LH2) as a fuel can potentially enable civil aviation to deliver zero CO2 and NOx emissions and offer a long-term sustainable solution. The usage of LH2 as an aviation fuel will require the development of new types of aircraft and cryogenic fuel tank design, as well as the need for large-scale

LH2 aircraft refuelling operation and storage facilities at airports. A key challenge that will need to be met in order to allow such a transition is that of safety. Hydrogen has unique properties and behaves very differently to conventional aircraft fuel. However, only a limited amount of information is currently available examining the behaviour and the extent of flammable gas clouds, pool fires and explosions resulting from LH2 spills, particularly in the context of the aircraft and airport safety. As part of the ENABLEH2 project, modelling studies have been carried out to examine liquid hydrogen release and dispersion behaviour for different LH2 aircraft and airport infrastructure leak/spill accident scenarios. The FLACS CFD model has been used to simulate the potential hazard effects following an accidental LH2 leak, including the extent of the flammable LH2 clouds formed, magnitude of explosion overpressures and pool fire radiation hazards. A comparison has also been made between the relative hazard consequences of using LH2 with conventional Jet A/A1 fuel. The results indicate that in the event of accidental fuel leak/spill LH2 has some safety advantages over Jet A/A-1 but will also introduce additional hazards not found with Jet A/A-1 that will need to be carefully managed and mitigated against.

Understanding infrastructure and operational challenges generated by alternative energy aircraft

Dr. Alejandro Block (ATI)

The use of liquid hydrogen (LH2) as a fuel can potentially enable civil aviation to deliver zero CO2 and NOx emissions and offer a long-term sustainable solution. The usage of LH2 as an aviation fuel will require the development of new types of aircraft and cryogenic fuel tank design, as well as the need for large-scale LH2 aircraft refuelling operation and storage facilities at airports. A key challenge that will need to be met in order to allow such a transition is that of safety. Hydrogen has unique properties and behaves very differently to conventional aircraft fuel. However, only a limited amount of information is currently available examining the behaviour and the extent of flammable gas clouds, pool fires and explosions resulting from LH2 spills, particularly in the context of the aircraft and airport safety. As part of the ENABLEH2 project, modelling studies have been carried out to examine liquid hydrogen release and dispersion behaviour for different LH2 aircraft and airport infrastructure leak/spill accident scenarios. The FLACS CFD model has been used to simulate the potential hazard effects following an accidental LH2 leak, including the extent of the flammable LH2 clouds formed, magnitude of explosion overpressures and pool fire radiation hazards. A comparison has also been made between the relative hazard consequences of using LH2 with conventional Jet A/A1 fuel. The results indicate that in the event of accidental fuel leak/spill LH2 has some safety advantages over Jet A/A-1 but will also introduce additional hazards not found with Jet A/A-1 that will need to be carefully managed and mitigated against.

Enabling Cryogenic Hydrogen-Based CO2-free air transport: Technology Evaluation and Road Map to Accelerate Entry into Service

Dr. Devaiah Nalianda (Cranfield University), *Andrew Rolt, Vishal Sethi, Ian Williamson and Anders Lundbladh*

Strategic Research & Innovation Agenda (SRIA) goals have been set up for the European aviation industry to ensure future environmental sustainability, while meeting society's needs for fast efficient transportation. As a part of these goals, Clean Sky 2 proposes to introduce a number of concept aircraft and rotorcraft to replace reference technology counterparts at different time scales (2015/2020/2035/2050). In this context, "Fast" rotorcraft are set to play a key role as an enabling technology, in contributing to and achieving ambitious environmental objectives and future targets. In order to ensure the realisation of these objectives of the European aviation industry, it is also necessary

to assess and evaluate the environmental and socio-economic impact of these new technologies in that time scale. This paper will therefore describe such assessments for Fast rotorcraft concepts, which are currently being undertaken as part of the CS2 project DEPART2050 (Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050). Based on the requirements of the Technology Evaluator, the project is currently undertaking performance assessments of simulated advanced tilt-rotor and compound rotorcraft configurations. The assessments are being undertaken at the airport and Air Traffic System (ATS) levels and include quantification of potential environmental (emissions and noise) and mobility (connectivity and productivity) improvements that may be accrued through replacement of reference technology over the designated time scales. The focus of the presentation will be to firstly introduce the technical activities being undertaken within project DEPART2050. It will further provide an overview of the modelling methodologies being followed within the project to simulate reference and fast rotorcraft concepts. Hence, this will include a description of the physics-based models and the modelling framework employed to assess performance, environmental and mobility improvements. The presentation will finally include an illustrative case study, wherein utilising the defined methodology and framework, mission results for a generic fast rotorcraft concept, obtained for realistic four-dimensional operational scenarios will be discussed in comparison with a reference state-of-the-art technology. Assessments of perceived improvements in performance, emissions, mobility and cost benefits, arising from the introduction of the configuration within the future fast rotorcraft fleets will be presented. Strategic Research & Innovation Agenda (SRIA) goals have been set up for the European aviation industry to ensure future environmental sustainability, while meeting society's needs for fast efficient transportation. As a part of these goals, Clean Sky 2 proposes to introduce a number of concept aircraft and rotorcraft to replace reference technology counterparts at different time scales (2015/2020/2035/2050). In this context, "Fast" rotorcraft are set to play a key role as an enabling technology, in contributing to and achieving ambitious environmental objectives and future targets. In order to ensure the realisation of these objectives of the European aviation industry, it is also necessary to assess and evaluate the environmental and socio-economic impact of these new technologies in that time scale. This paper will therefore describe such assessments for Fast rotorcraft concepts, which are currently being undertaken as part of the CS2 project DEPART2050 (Design Evaluation and Performance Assessment of Rotorcraft Technology by 2050). Based on the requirements of the Technology Evaluator, the project is currently undertaking performance assessments of simulated advanced tilt-rotor and compound rotorcraft configurations. The assessments are being undertaken at the airport and Air Traffic System (ATS) levels and include quantification of potential environmental (emissions and noise) and mobility (connectivity and productivity) improvements that may be accrued through replacement of reference technology over the designated time scales. The focus of the presentation will be to firstly introduce the technical activities being undertaken within project DEPART2050. It will further provide an overview of the modelling methodologies being followed within the project to simulate reference and fast rotorcraft concepts. Hence, this will include a description of the physics-based models and the modelling framework employed to assess performance, environmental and mobility improvements. The presentation will finally include an illustrative case study, wherein utilising the defined methodology and framework, mission results for a generic fast rotorcraft concept, obtained for realistic four-dimensional operational scenarios will be discussed in comparison with a reference state-of-the-art technology. Assessments of perceived improvements in performance, emissions, mobility and cost benefits, arising from the introduction of the configuration within the future fast rotorcraft fleets will be presented.

Propulsion (PART I)

Session Chair : Prof. Michael Weigand, Vienna University of Technology, Austria

Health Monitoring, Fault Diagnostics and Failure Prediction for Fuel Cells in Aviation

Dr. Kathrin Ebner (Bauhaus Luftfahrt), *Lily Koops*

A safe and reliable operation of fuel cells is key for the successful application of these energy conversion devices in aviation. Moreover, long operational lifetimes aid their economic viability. In that context, in situ health monitoring and diagnostics can contribute significantly to avoiding irrecoverable damage and further enable a greater understanding of the aging behavior under aeronautic conditions ultimately promoting design optimization. In this work, expected load profiles of different fuel cell application scenarios in aviation (e.g. employed as auxiliary power unit or as a main power source) are considered and provide the basis for assessing the relevance of specific failure modes. Thereupon, state-of-the-art diagnostic methods are reviewed and matched to the respective application's requirements according to their suitability and potential. Finally, opportunities of exploiting the gathered data by means of promising control strategies and prognostic approaches aiming to increase the devices' performance and service life are discussed.

Initial Assessment of a Fuel Cell – Gas Turbine Hybrid Propulsion Concept

Dr. Arne Seitz (Bauhaus Luftfahrt e.V.), *Markus Nickl, Florian Troeltsch, Kathrin Ebner*

Driven by the drastic need for decarbonisation in aviation, hydrogen as a zero in-flight CO2 emissions fuel has recently come to a great revival in aeronautical research and development. Beyond the well-known and demonstrated option of hydrogen combustion in classic gas turbine engines, significant technological progress in electrochemical conversion systems adds to the dynamic development of hydrogen-based visions for future air transport. However, the application of fuel cells in the scheme of propulsion and power for transport category aircraft holds great challenges, and, classic gas turbine engines still feature significant advantages in power-specific weight over future fuel cell systems. At the same time, further efficiency improvements and significant NOx emission reduction will be required for future aero engines. The injection of water in the compression section or the combustion chamber of a gas turbine engine is well-known for its enhancement of cycle specific work and efficiency as well as the potential for signification cuts in NOx emissions. In this paper, a synergistic concept for a fuel cell – gas turbine hybrid aircraft propulsion system (cf. attached supportive material) will be introduced and initially assessed. The concept utilises the product water of the fuel cell in order to improve the performance and emission characteristics of the gas turbine engine. The fuel cell product water in the present concept is first condensed, then separated, pressurised and re-evaporated before being injected in the gas turbine engine. This treatment process allows for minimum work effort for the water pressurisation – due to the incompressibility of the liquid water – while the energy required for its re-evaporation may be drawn from the gas turbine exhaust heat. The electric power produced by the fuel cell is available as a convenient source for on-board electric customers including aircraft subsystems and possibly decentralised or distributed propulsors.

After a brief literature survey on water / steam injection effects in gas turbine engines and emerging key technologies for potential future airborne fuel cell systems, the proposed fuel cell – gas turbine hybrid energy and propulsion system will be explained in detail. Pre-conceptual assessment estimates focusing

on the fuel cell product water treatment process and the associated gas turbine thermodynamic cycle implications will be presented. Concept-specific challenges and limitations will be highlighted and discussed. The discussion will include system integration effects such as fuel cell heat management and power utilisation options at aircraft level. An initial parametric study on overall vehicular efficiency and cruise NOx impact will be presented. The results will contribute to a better understanding of the principal potentials associated with advanced fuel cell - gas turbine hybrid propulsion systems. The study will help identifying concept-specific technical limits as well as key target requirements for future airborne fuel cell systems.

Revamping of a high-pressure centrifugal compressor stage - a numerical case study

Dr. Valeriu Dragan (INCD Turbomotoare Comoti), *Oana Dumitrescu, Ioana Bucur, Bogdan Gherman, Mr.* ***Lica Flore (National Research & Development Institute for Gas Turbines - COMOTI)***

The current paper addresses the problem of increasing the mass flow rate through an existing high-pressure stage, without distorting any of the size characteristics of the machine. Steady state simulations are used to test proof the new design and compare with the baseline, complemented by a thermodynamic analysis of the two stages. Turbulence was modelled using the SST k-omega formulation. It was found that the flow rate could be increased without any efficiency penalty. Of particular interest is the vanned diffuser design, which was modified substantially and allowed for improved flow management in terms of axialization and diffusion. The experimental phase will need to be completed in order to confirm the data presented herein.

Study of cavitation phenomena in a directional spool valve by means of Chaos Theory

Mr. Vincenzo Niola (University of Naples Federico II), *Mario Spirto, Giuseppe Quaremba, Chiara Cosenza, Sergio Savino*

For several years, researchers have been studying the cavitation phenomenon on different types of systems, such as valves, pumps, turbines, etc. This paper deals with the study of cavitation using Chaos Theory, highlighting how this phenomenon leads to greater instability in flow rate of a directional spool valve. For this purpose, a test bench has been set up to study the behaviour of a directional spool valve, powered by an external gear pump. Various tests have been carried out on this system acquiring accelerometric signals and analysing them using the Chaos Theory, both when the phenomenon of cavitation is present and when it is absent. Analysing the spectrum of Kω it was possible to observe how the study system always presents a stable behaviour in a given frequency range despite the presence of imploding bubbles. The maps of Translation Variables, plotted for different values of ω suitably chosen, showed how, consequently to the increase in the flow rate and pressure values and therefore to the birth and consolidation of the cavitation phenomenon, the degree of chaoticness of the system always increases. The same result is highlighted by the Quadratic Mean of the Displacement, whose value and oscillatory component increase, due to the increase in the flow rate and pressure values, as well as the implosion of bubbles due to cavitation.

Analysis of working fluids applicable for high-temperature loop heat pipe applications

Mr. Pavlo Gakal (National Aerospace University "KhAI"), *Donatas Mishkinis, Artis Leilands, Igors Usakovs, Roman Orlov, Yevhen Rogoviy*

A new generation of turbojet engines with ultra-high bypass ratio (UHBR) will surpass existing engines in technical, operational and environmental performances. At the same time, the UHBR engine components and systems will operate in a harsher environment due to the increased compression ratio and gas temperature in front of the turbine. For example, an air bleed system will require a separate cooling system to remove the heat from the sensitive elements of the valves and ensure their long-term operability and reliability. Nowadays, the best candidate for thermal management of sensitive bleed system valves is loop heat pipe (LHP), a passive two-phase heat transfer system in which the working fluid movement happens due to the effect of capillary forces. LHPs have superior thermal conductivity, extremely small temperature gradients along the loop, and do not require any additional energy supply from the outside operate. LHPs are widely used in space and being actively introduced to terrestrial applications such as thermal management of high-power density chips, computers, electric and hybrid vehicles, etc. However, an operating range of the state-of-the-art LHPs based on water, ammonia, ethanol, pentane, and other traditional working fluids is limited. The maximum temperature of the hot source does not exceed 100°C, while the heat sink temperature is usually below 50°C. An objective of this study was to perform an extensive analysis of available working fluids and to select those one(s) that will be able to comply with the specific requirements of the UHBR engine air bleed system for heat dissipation (hot source temperature up to 200°C; heat sink temperature about 100°C), ensure efficient LHP operation and meet the aeronautical standards. A multi-step approach was applied to analyse more than 700 working fluids and select four potential candidates, taking into account (1) working fluids compliance with various EU regulations regarding environmental and work protection; (2) working fluids freezing, boiling and critical points for the operating temperature range; (3) working fluids specific properties that influence the LHP heat transfer characteristics. Selected candidate fluids (toluene, acetone, methanol, 1,2-dichlorobenzene) were subjected to accelerated lifetime tests to check their chemical compatibility with AISI 316 stainless steel to be used as the LHP wick and envelope material. Also, specific characteristics of the working fluids such as capillary pressure and permeability were determined experimentally to predict the LHP performances that strongly depend on the interaction between the working fluid and the wick. Based on the results received, the toluene was selected as the primary working fluid for application in the innovative LHP-based thermal management solution for the UHBR engine air bleed system. The research leading to these results has been performed within the “Aircraft Engine Valves Thermal Management with Advanced Loop Heat Pipe (EVAL)” project. This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union’s Horizon 2020 research and innovation programme under grant agreement No 886615.

Piston Engine Modelling for Hydrogen Fueled Composite Cycle Engines

Mr. Markus Nickl (Bauhaus Luftfahrt e.V.), *Florian Winter, Volker Gümmer*

In order to achieve aviation’s ambitious emission reduction targets specified by ACARE [1] radically changes in propulsion system concepts will be necessary. One promising candidate, representing a Composite Cycle Engine (CCE) which introduces piston engines to the high-pressure section of conventional turbo machines (figure 1), was initially discussed by Kaiser et al. in 2015 [2]. Further investigations consistently predict an efficiency improvement potential of 10 to 15 % beyond evolutionary

development of turbo machineries [3, 4] for this propulsion system concept. To fulfill the goal of carbon dioxide emission neutrality in 2050 and beyond, plenty propulsion system concepts are currently under investigations, mainly focusing on batteries and hydrogen as energy source. Especially for long range aircraft applications, hydrogen might by favorable due to its outstanding specific gravimetric energy density. Therefore, the CCE concept should be evaluated for hydrogen combustion. In a first step, the applied time resolved 0D piston engine performance simulation model of the CCE is adapted for hydrogen combustion. In example, heat transfer and combustion characteristic differ significantly between kerosene and hydrogen combustion and require specific modeling approaches. The current publication will illustrate the piston engine performance simulation model and the modifications needed to account for hydrogen combustion. Furthermore, results of validation case calculations as well as initial sensitivity studies of the hydrogen fueled piston engines model will be presented and discussed in the CCE context. For example, sizing effects and the influence of combustion timing on piston engine performance will be evaluated.

Propulsion (PART II)

Session Chair : Prof. Michael Weigand, Vienna University of Technology, Austria

Specific Aspects in Numerical Simulation of Complex Processes in Gas Turbine Engine Bearing Chamber

Mr. Taras Mykhailenko (National Aerospace University "Kharkiv Aviation Institute"), *Oleksii Lysytsia, Illia Petukhov, Artem Kovalov*

The growing thermodynamic parameters of modern gas turbine engines as well as reduction of their overall size make special demands to the bearing chambers designing process. The heavier thermally stressed state of the engine, higher rotational speeds, temperatures, pressures and velocities of airflow moving through the gas path make challenges directed to both bearing chamber and lubrication oil protection against the temperature impact. Some challenges have to be solved on the way to minimization of power consumptions for lubricating of the friction zones as well as minimization of air supply to pressurize and protect the bearing chambers from the hot gases. In this regard, only a deep understanding of the thermal and hydraulic processes in the bearing chamber within the entire range of operating conditions can bring to the solution. The complex interrelation of thermal and hydraulic processes in the bearing chamber makes it necessary to use modelling methods based on the multiphase flow mechanics and Computational Fluid Dynamics (CFD). This approach principally allows to take into account the influence of all factors in the mathematical model. However, the uncertainties associated with the describing of the oil film behavior, specifying the parameters of the droplets flow and the conditions of interfacial interaction in the wall region complicate the application of existing mathematical models. The correct choice of the mathematical model structure and boundary conditions, the modelling methods, and the mesh parameters that take into account the computational resources remain relevant. This paper presents the study of approaches to CFD modelling of multiphase oil-air flow in the bearing chamber. It was analyzed the VOF and Eulerian multiphase models, Steady and Transient solvers, "Realisible k-e" and "k- ω SST" turbulence models etc. The results are presented for individual phases and mixture. To model the oil film formation on the chamber walls, Eulerian Wall Film Model implemented in ANSYS Fluent was also considered. CFD-results were compared with experimental data presented in the references. Based on the obtained results, the study presents practical recommendations for reliable

processes modeling in the bearing chamber. The research leading to these results has been performed in the frame of the "Advanced Modelling Methodology for Bearing Chamber in Hot Environment (AMBEC)" project. This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 785493.

Full electric and Hybrid powertrain: the AI challenge and the real environmental choice

Dr. Eng. Sergio Durante (D4S Durante Space Tech), *Veronika Statauskiene, Luca Morfino*

In the past months, a lot of electric power units have been developed and shown to the technical community by big OEM and also small start ups; with some disappointment it is to notice that in most of cases they are linked to very conservative technical approaches, missing the possibility to think to specific and innovative solutions offered by the different requirements for an electric power unit in comparison to conventional powertrains. The main objective of this article is to analyse the real environmental impact of a full electric unit with respect to a conventional IC or Hybrid solution and the key of the development of an innovative (but not exotic) integrated power drive module aimed to comply with the increasingly stringent legislation and rules requirements. At the same time the performances achievable using conventional approaches for electric power trains will be analyses in a scientific approach, based on a 30 years experience in the aerospace and transport world.

Ventilation Analysis of Simplified Engine Nacelle for Pusher Configuration Aircraft

Dr. Łukasz Kiszkowiak (Military University of Technology, Faculty of Mechatronics and Aerospace), *Aleksander Olejnik, Adam Dziubiński*

In recent years a development of new, more reliable tools for multiphysics calculations allowed the designers to address more problems at the very beginning or at early stages of the design process. Such a multiphysics problem is a cooling of the pusher configuration piston engine with air. The authors have tested a set of solutions to increase the efficiency of the cooling system of this type of engine. Unfortunately, all the positive effects of the fact, that the aircraft engine appears in the wake of the propeller during taxiing and waiting for take-off, are non-existent in this type of configuration. An engine overheating is here a problem, because an airflow has to be pulled through the nacelle to cool down the engine block and radiators of cylinder heads. That design demands to analyze a shape of the nacelle, to properly use the main propeller pressure jump on the one hand, and rather adequate and complicated flow inside the nacelle to be modeled on the other. The aircraft CAD geometry has been simplified to allow for simple changes of nacelle cover shape and easily introducing new inlets and outlets. Also the cases with different parts (baffles, parts of the cover) have been tested. The Computational Fluid Dynamics method used here, allows to account for both natural and forced convection mechanism. The presented method helps to introduce and test modifications on the prototype nacelle cover, to be compared with all the other cases and analyze in depth the flow inside. Additionally, it helps to get rid of a problematic (also because of the heat) instrumentation used in wind tunnel tests for the flow visualization. At last but not least, presented method decreases the time to obtain efficient solution, because the complicated, multiphysics processes (flow and heat transfer) could be analyzed at the early stage of design. The research described in this paper is an example of professional and innovative approach to the subject matter.

Development of a combined Artificial Neural Network & Principal COmponent Analysis technique for Engine Health Monitoring

Mrs. De Giorgi Maria Grazia (University of Salento), *Strafella Luciano, Menga Nicola, Ficarella Antoni*

High reliability is a crucial point for an aircraft engine. To ensure a high level of safety during operative life complex machine learning techniques are widely used today for Engine Health Monitoring (EHM) purposes. To monitor the health state of an engine by means of machine learning technique a certain amount of information is necessary, obtained by means of sensors installed in the various sections of the powertrain. However, an excessive amount of data to be processed necessarily leads to an increase in analysis times and computer efforts required, compromising the quality of the system. In order to make an EHM system more efficient, a data reduction technique can be very useful in order to reduce the amount of total information contained in the used dataset without losing the main ones. In this paper, Principal Component Analysis (PCA) technique is used together with an Artificial Neural Network (ANN) in order to obtain a reliable EHM system capable of predicting the Remaining Useful Life (RUL) of an aircraft engine obtaining advantages from the point of view of safety and operating costs. The dataset used was generated using the Gas turbine Simulation Program (GSP) software with which different degradation conditions relating to different engine components were simulated. Subsequently, PCA technique was used in order to reduce the amount of data to be used to train the artificial neural network to detect the presence of performance degradation in one or more of the constituent components of the engine by comparing the values obtained from the sensors in real time with those that should be detected in a healthy engine. In addition to an increase in flight safety, a well-made health monitoring system is also an advantage in terms of costs, avoiding unnecessary maintenance operations and carrying them out only when really necessary.

Development of plasma assisted actuators for re-ignition of aeroengine under high altitude conditions

Mrs. De Giorgi Maria Grazia (University of Salento), *Mehdi Ghazanfar, Bonuso Sara*

The development of secondary ignition systems under relatively low temperature and pressure conditions is of great importance to the safety and use of lean-burn aeroengine combustors. In recent years, numerous research organizations are working on the advancement of low NOx combustors and aeronautical engines in order to fulfil the regulations of international organizations. In this context, various passive control technologies are commonly used to improve the flame stabilization by modifying the injector geometry or flame holders in a permanent way. Besides this, active control technologies have ability to control the flow and combustion parameters in consonance with real-time operating conditions without altering the combustor design. Non-thermal plasma (NTP) is the well-established technology that actively controls the combustion characteristics of coaxial burners and axisymmetric air jets. It not only enhancing the efficiency of combustors, increasing flame stabilization, improving low temperature oxidation, extending the limits of lean blow out, at the same time it also reducing the significant amount of exhaust emissions i-e nitrogen oxides (NOx). Among all NTPs dielectric barrier discharge (DBD) plasma actuators gained great attraction for aeronautical applications because of lower power consumption, easy to handle, no any movement of mechanical parts, light weight, cheap to build, implement and maintain high frequency response permitting real time operating conditions. Nanosecond pulsed discharge has been drawn much attention due to its efficient aptitude of producing excited states and free radicals by dissociation, ionization and electron impacted excitation reactions by subjecting high reduced electric

field EN which kinetically improves the combustion process. The present work investigates the experimental characterization of flow dynamics and combustion characteristics in rectangular burner. A disk and needle type plasma actuator was developed and driven by high voltage nanosecond pulsed generator by subjecting various plasma actuation conditions. All experiments were performed at a laboratory ambient temperature of about 298K and pressure of 1bar. The acquisition system was completely covered with faraday cage in order to avoid interference of electromagnetic fields produced during the discharge process. Experimental tests were performed at different applied voltages and repetition frequencies. The comparative behavior of electrical feeding with flame was performed to recognize the economical and reliable conditions of plasma discharge. Thermal power delivered to the fluid and power dissipation rates were also estimated. Two different measurement techniques were adopted. First technique concerned with the visualization of the smoke flow by using high resolution camera (Memrecam GX-3), which allowed to qualitatively analysing the evolution of the flow in the presence of plasma actuation. The second technique is the Laser Doppler Velocimetry (LDV), which allows the measurement of flow velocities and turbulent kinetic energy in the rectangular cross-sectional burner. Moreover, the flame ignition characteristics were analysed in the low temperature condition by considering different plasma actuation parameters. At this aim a numerical study will be also performed using ChemKin in order to well understand the suitability of these plasma based actuators to be used as secondary systems for re-ignition of aeroengines at high altitude.

Model-based dynamic performance simulation of a microturbine

Mr. Mario Leonardo Erario (University of Salento), *Maria Grazia De Giorgi, Radoslaw Przysowa*

Microturbines such as Jetcat P140 RXi-B and Jetpol GTM140 can be used not only in models and education but also to propel aerial targets or other high-speed drones. However, their wider adoption by the defense, general aviation, and energy sectors is limited by their relatively low efficiency and durability. Validated simulation models are required to monitor their performance, improve their lifetime, and design engine control systems. This project aims to develop a model of a micro gas turbine for engine performance predictions and prognostics. To build a reliable zero-dimensional model, the available compressor and turbine maps must be scaled to meet the performance of the engine achieved during bench and flight tests. The model will be validated with flight data and then used to generate performance data to train a machine learning model. Component maps were scaled to available test bench data with the least squares method. First, a GSP steady-state model was developed and compared with experimental operating points. Selected flight data were then used as input for a GSP transient model. EGT and fuel flow were chosen as the two key parameters to validate the GSP model, comparing the values calculated in the simulations with the correspondent experimental ones. Finally, neural network techniques were implemented to find a correlation between the input flight data and the key parameters. The observed difference between the model and flight data was lower than 3% for both EGT and fuel flow. Modeling microturbines is challenging because microturbines have larger production errors than full-scale engines and use sensors with high uncertainty; furthermore, gas turbine simulation tools such as GSP have been designed mainly for larger gas turbines. However, the engine model created here is accurate and can be successfully used to simulate flight missions of microturbines of 140 N class predicting their performance.

Trade-off studies between NOx and CO2 to evaluate the future development strategies for aircraft engine

Ms. Feijia Yin (Delft University of Technology), *Arvind Gangoli Rao, Volker Grewe*

The fuel efficiency of civil aviation has improved significantly by more than 70%, hence reducing aviation's CO2 emissions. Among the 70% fuel reduction, more than half has been achieved due to engine technology development, e.g., advanced engine cycles and technologies. To reduce fuel consumption, engine designer and manufacturers are striving to increase operating pressure and turbine inlet temperature; however, this increase causes adverse effects on NOx emissions for a given combustion technique. Especially at higher operating temperature and pressure, this trade-off between fuel consumption and NOx emission is highly nonlinear. This study tends to quantify the aviation's climate impact from CO2 and NOx emissions by considering the nonlinear variations of CO2 and NOx caused by the nature of engine cycles. The analysis starts with engine modelling combined with emission calculations to understand the trade-off between CO2 and NOx emissions when varying the design variables, like overall pressure ratio and turbine inlet temperature. A typical turbofan engine with a high bypass ratio is considered. We then apply the exchange rate of CO2 and NOx emissions to the baseline emission inventory, the well-known AERO2K dataset. The state-of-the-art climate assessment tool, AirClim, is used to calculate the changes of climate impact concerning the exchange rate of CO2 and NOx emissions. Accordingly, we quantify the development trend of aviation's climate impact from CO2 and NOx concerning the intrinsic feature of an engine cycle. This research can provide us with insights into the engine development strategy that could be adapted to optimize the engine not only to reduce fuel consumption but also for climate impact reduction.

AI and future scenarios in aviation

Session Chair : Mr. Simone Pozzi, DeepBlue, Italy

Integrated approaches of Machine Learning and engine data to evaluate spare parts request for aircraft engines

Dr. Antonio Caricato (University of Salento), *Antonio Ficarella, Luca Mainetti, Roberto Vergallo*

Aircraft uptime is getting increasingly important as the transport solutions become more complex and the transport industry seeks new ways of being competitive. To reach this objective, traditional Fleet Management systems are gradually extended with new features to improve reliability and then provide better maintenance planning. Main goal of this work is the development an integrated approach of iterative algorithms based on Artificial Intelligence to define removal plan and its maintenance work, optimizing engine availability at the customer and maintenance costs, as well as obtaining a procurement plan of integrated parts with planning of interventions and implementation of a maintenance strategy. In order to reach this goal, Machine Learning has been applied on a workshop dataset and engine data with the aim to optimize warehouse spare parts number, costs and lead-time. Workshop dataset consists of the repair history of a specific engine type, from several years and several fleets, and contains information like repair claim, engine working time, forensic evidences and general information about processed spare parts. Engine data consists of sensors data and mission information for each aircraft and fleet. A multi-label classification approach has been used in order to build and train, for each spare part, a Machine Learning model that predicts the part repair state as a multiclass classifier does. Mainly, each classifier is requested to predict the repair state (classified as “Efficient”, “Repaired” or “Replaced”) of the corresponding part, starting from two variables: the repairing claim and the engine working time, and engine data. Then, global results have been evaluated using the Confusion Matrix, from which Accuracy, Precision, Recall and F1-Score metrics are retrieved, in order to analyse the cost of incorrect prediction. These metrics are calculated for each spare part related model on test sets and, then, a final single performance value is obtained by averaging results. In this way, three Machine Learning models (Naïve Bayes, Logistic Regression and Random Forest classifiers) are applied and results are compared. Naïve Bayes and Logistic Regression, that are fully probabilistic methods, have best global performances with an accuracy value of almost 80%, making the models being correct most of the times.

A Hybrid Approach of Machine Learning and Expert Knowledge for Projection of Aircraft Operability

Mr. Sagar Shenoy MANIKAR (ISAE SUPAERO), *Joël JEZEGOU, Pierre DE SAQUI SANNES, Philippe ASSEMAN, Emmanuel BENARD*

Operational performance of aircraft is one of the key drivers for flight punctuality and airline profitability. Operational performance of aircraft is characterized by some Key Performance Indicators (KPIs) like Operational reliability, Maintenance unavailability, and Direct Maintenance Cost. The ability of an aircraft to meet these operational requirements is termed as 'Operability'. Hence, it is imperative to address and project aircraft operability from the early stages of its development. Along with technical performance, operability forms one of the key trade-off criteria during aircraft architecting. This paper develops a hybrid approach of using knowledge-based and data-driven techniques to aid the projection of operational

performance of aircraft. Machine learning techniques are utilized to benefit from the huge amount of in-service data available from the flying Airbus fleet all over the world. This helps in identifying the key technical issues and what are the different ways in which they have been resolved in practice by airlines. Understanding these insights from artificial intelligence allows one to project the impact of technical issues and their associated maintenance on future aircraft operations. It was observed that in-service data had to be complemented with expert knowledge for making a holistic projection. Parameters regarding the operational context and the airline network are taken into account during the analysis. The impact of technical issues are then mapped over different operational states of an aircraft like flying, turn-around, etc. which are defined in the form of a state machine in order to see the deviation from the nominal behaviour. This allows one to observe the influence of change in inputs on the operability KPIs. This methodology is demonstrated on a use-case of system failure.

GRETEL: sustainable aircraft technologies for green Turboprop configuration

Session Chair : Mr. Andreas Kötter, ALTRAN, Germany

GRETEL lifts up: sustainable solutions for rapid integration of new technologies

Ms. Dorothea Pohlmann (Altran Deutschland S. A. S. & Co. KG), *Andreas Kötter*

The overall objectives for the GRETEL project have been (amongst others) the increase of eco-friendliness, e.g. to significantly reduce fuel consumption and NOx and CO2 emissions. These goals address the stage of operation of regional aircrafts. When taking a look from demonstrator level (like in GRETEL) to serial production, the next level of addressing sustainable aircrafts is to assess and improve the whole life cycle of such kind of aircrafts. This comprises questions of e.g. material choice with respect to the carbon footprint, manufacturing processes with respect to energy and CO2 consumption and also the degree of recyclability. This can be achieved by establishing sustainable measures directly from the beginning in the design phase. The methodology of choice is to perform a continuous lifecycle assessment, which supports the product development process towards circular thinking respective ecologically optimized design decisions. The assessment of how sustainable a product is and whether ecological and social standards have been met, is currently only possible with a huge effort. A transparent and tamper-proof exchange of information with respect to materials and energy used/needed, process and product details, quality, maintenance and recycling forms the basis for the effective design and control of a resource-efficient economy. Using the benefit of blockchain technology within product development processes e.g. sustainability-oriented engineering, ensuring compliance with social and environmental standards, transparent and secure data exchange between actors in the supply chain, tracking of selected materials across the entire value chain and finally the savings in manual labor for data collection within a lifecycle assessment allows OEM to develop sustainable solutions for future aircraft. Using inputs from several national and european R&D projects it will be made clear how first stepd towards circular economy in aerospace look.

An efficient optimization scheme for the preliminary sizing of composite aircraft wings

Mr. Spyridon Kilimtzidis (University of Patras), *Athanasios Kotzakolios, Vassilis Kostopoulos*

Over the past decades the ever-growing aeronautics transport sector posed challenges to the scientific community, rendering the design of air vehicles a matter of intensive scientific studies. In that regard, a plethora of multi-fidelity design tools, able to capture the whole spectrum of phenomena that may rise during flight, has been developed. Commonly, the three-stage design process that spans the development of an aircraft, namely the conceptual, the preliminary and the detailed one, dictate the use of each tool. Since historically the majority of the design effort is put into the conceptual and preliminary design phases and any design change among them could be costly, enhancing the current low-fidelity models could steer towards a more reliable decision-making process and provide a wider understanding of a candidate design. On that end, and in the field of structural analysis, the well-established FEA method has been vastly utilized to model structures and to predict their response. However, the generation of FEA models composed of numerous components drastically raises the computational time, due to the number of associated D.O.F ‘s involved. Likewise, detailed FEA models are also avoided in the early design stages. Alternatively, equivalent models can be used to model the behavior of a structure. Referring to aircraft wings, two simplified modeling approaches can be followed, the equivalent beam and the equivalent plate. The former represents the wing box as a beam of equivalent properties along a reference axis, while

the latter one considers the aircraft wing to behave as a plate. The beam model is well-suited to high aspect ratio wings, while the plate is more accurate for low to medium aspect ratio wings. On that end, a novel optimization scheme for the preliminary sizing of composite materials aircraft wings is proposed herein. Replacing traditional 3D FEA models commonly present at this design stage, a computationally efficient model of the wing under consideration is initially developed based on the well-established Equivalent Plate Method (EPM). The efficiency and accuracy of the method is put into test by means of comparison to a 3D FEA model developed in NASTRAN. The promising results lead to the development of an optimization scheme, capable of preliminarily sizing the structural components of the wing, aiming at a minimum total mass design while simultaneously satisfying static strength, stiffness and dynamic aeroelastic design requirements. The straightforward coupling of the EPM model of the wing with external aerodynamics codes allows on the one hand the aerodynamic load introduction to the structure, as well as the examination of any aeroelastic dynamic instabilities present, by means of flutter velocity, of each candidate design. Results obtained from the EPM linear static solution are further exploited and the static strength of each component of the wing is evaluated using the maximum stress criterion.

Instrumentation and Ground Testing of a Composite Elastic Wing Wind Tunnel Model

Mr. Ralf Keimer (DLR), *Johannes Riemenschneider, Efthimis Giannaros, Spiridon Kilimtzidis, Athanasios Kotzakolios, Vassilis Kostopoulos*

The Goal of the Project GRETEL is to build a composite elastic wing wind tunnel model. This model incorporates morphing aerodynamical structures and is to be delivered for testing in the Large Low speed wind tunnel Facility (LLF) of German-Dutch Wind Tunnels (DNW). In order to be allowed to be tested in a wind tunnel, a ground test is required to assure the integrity of the design of the wing. In this paper a short introduction to the overall setup of the model is given including an overview of integrated sensors. A short introduction into the different configurations of the wing to be tested is given as well as the rationale for the derived test-matrix of the ground tests. The mechanical setup for the ground tests is described. There are two main tests done, on the one hand the static tests of the wingbox, on the other hand the dynamic tests for determination of modal parameters of the model in its different configurations. The static tests are done to identify mechanical properties of the model as built and compare them to the predictions of the finite-element simulations. The method to derive the boundary conditions, i.e. loads and deformations, for the static tests from the simulation is documented and discussed. The static tests are also used to calibrate the integrated strain gauges to enable load monitoring in the wind tunnel tests. First experimental results from the ground tests are shown and discussed, comparing them to predictions from the simulation.

An efficient optimization scheme for the preliminary sizing of composite aircraft wings

Mr. Spyridon Kilimtzidis (University of Patras), *Athanasios Kotzakolios, Vassilis Kostopoulos*

Over the past decades the ever-growing aeronautics transport sector posed challenges to the scientific community, rendering the design of air vehicles a matter of intensive scientific studies. In that regard, a plethora of multi-fidelity design tools, able to capture the whole spectrum of phenomena that may rise during flight, has been developed. Commonly, the three-stage design process that spans the development of an aircraft, namely the conceptual, the preliminary and the detailed one, dictate the use of each tool. Since historically the majority of the design effort is put into the conceptual and preliminary design phases and any design change among them could be costly, enhancing the current low-fidelity models could steer towards a more reliable decision-making process and provide a wider understanding of a candidate

design. On that end, and in the field of structural analysis, the well-established FEA method has been vastly utilized to model structures and to predict their response. However, the generation of FEA models composed of numerous components drastically raises the computational time, due to the number of associated D.O.F 's involved. Likewise, detailed FEA models are also avoided in the early design stages. Alternatively, equivalent models can be used to model the behavior of a structure. Referring to aircraft wings, two simplified modeling approaches can be followed, the equivalent beam and the equivalent plate. The former represents the wing box as a beam of equivalent properties along a reference axis, while the latter one considers the aircraft wing to behave as a plate. The beam model is well-suited to high aspect ratio wings, while the plate is more accurate for low to medium aspect ratio wings. On that end, a novel optimization scheme for the preliminary sizing of composite materials aircraft wings is proposed herein. Replacing traditional 3D FEA models commonly present at this design stage, a computationally efficient model of the wing under consideration is initially developed based on the well-established Equivalent Plate Method (EPM). The efficiency and accuracy of the method is put into test by means of comparison to a 3D FEA model developed in NASTRAN. The promising results lead to the development of an optimization scheme, capable of preliminarily sizing the structural components of the wing, aiming at a minimum total mass design while simultaneously satisfying static strength, stiffness and dynamic aeroelastic design requirements. The straightforward coupling of the EPM model of the wing with external aerodynamics codes allows on the one hand the aerodynamic load introduction to the structure, as well as the examination of any aeroelastic dynamic instabilities present, by means of flutter velocity, of each candidate design. Results obtained from the EPM linear static solution are further exploited and the static strength of each component of the wing is evaluated using the maximum stress criterion.

Manufacturing, Assembly and Integration of a Large Scale Composite Wing Wind Tunnel Model and the Design and Implementation of an associated Measurement System

Jan Baucke, Stefan Steeger, Ralf Keimer, Michelangelo Giuliani

Building a wind tunnel model with an innovative aerodynamic design including a laminar airfoil concept and morphing parts requires a suitable manufacturing and assembly plan to transfer the virtual model to concrete reality. The contribution of the INVENT GmbH within the GRETEL consortium is the manufacturing of the main structural components of the Wing and the integration of the Wind Tunnel Model. To realize such a precise projection, the main approach is to implement a high overall accuracy of the later model by realizing a low percentage of geometry deviation already on piece part level. Beginning with a material dedicated tool design concerning cure cycle parameters and induced strain effects, for aspects of geometrical manufacturing accuracy, also suitable inspection techniques, regarding the verification of structural requirements and material conditions are implemented in the integration process at specified steps. REDAMs contribution to the structural components was focused on the wing model ribs and their internal parts. For these items FDM additive manufacturing technologies have been integrated with traditional manufacturing techniques after specific trade studies on weight, mechanical performance and cost features. A further part of the integration process of the GRETEL Wind Tunnel Model is the installation of application-related measurement equipment. The Institute of Composite Structures and Adaptive Systems of the German Aerospace Center (DLR) is responsible for the design and realization of such a project customized measurement concept. For the measurement of the pressure distribution along the profile contour with various angles of attack and wing configurations during the testing, the wing is equipped with several pressure taps. Further, the measurement equipment spectrum covers also the registration of acceleration forces and mechanical loads of the inner wing structure

components. This concept creates a holistic picture of the coherences between aerodynamical and mechanical dimensions for each tested configuration. The implementation of all aforementioned aspects into the large-scale model is elucidated and discussed in the light of morphing parts of the model being delivered by another project. The integrated equipment is described and the impact of the integration into the design and assembly of the overall model is illustrated.

HYFLEXFUEL project

Session Chair : Dr. Valentin Batteiger, Bauhaus Luftfahrt, Germany

The HyFlexFuel project: A perspective to flexible production of sustainable jet fuel from a broad feedstock base

Mr. Valentin Batteiger (Bauhaus Luftfahrt), *Christina Penke, Leonard Moser, Andreas Sizmann*

Europe's aviation sector recently announced the vision to eliminate net CO2 emissions by the year 2050[109]. It is evident that such targets can only be achieved by a transition from crude-oil based jet fuels to renewable energy carriers over the next decades. Current aviation biofuels are mainly produced from lipid feedstock (oils and fats). In the future, it will be important to produce advanced biofuels from a much broader and more sustainable feedstock base. The EU-Horizon 2020 project HyFlexFuel[110] addresses this challenge by demonstrating the main process steps along an advanced biofuel pathway that can convert various types of organic feedstock via hydrothermal liquefaction. The context and scope of the collaborative research project is reviewed by summarizing the main results from the research and development efforts on the individual process steps. Special emphasis is put on the HTL conversion step. HyFlexFuel partner Aarhus University has established a pilot-scale research plant to investigate HTL in industrially relevant conditions (continuous plug-flow reactor with efficient heat exchange)[111]. Several feedstock, including wet waste streams, such as sewage sludge and food waste, agricultural residues, such as different types of manure or straws and cultivated biomass in form of the lignocellulosic energy crop miscanthus and the micro-algae Spirulina, have been processed to intermediate HTL biocrudes. The resulting biocrudes can be further upgraded to liquid transportation fuels via hydrotreatment. By providing an overview about the HFF project, this contribution introduces to a session that addresses important aspects of HTL fuel production in detail, namely:

(i) The potential availability of waste and residues feedstock that are suitable for HTL conversion across Europe, presented by Franz-Fabian Bellot (DBFZ)

(ii) The upgrading of HTL biocrudes to transportation fuels via hydrotreatment, presented by Daniele Castello (Aalborg University)

(iii) Pre-screening analyses of kerosene samples to pave the way for an approval of future fuels for civil aviation, presented by Bastian Rauch (DLR)

(iv) System analyses to quantify the techno-economic and environmental performance of HTL fuels, presented by Christina Penke (BHL)

Acknowledgement: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 764734.

[109] www.destination2050.eu

[110] www.hyflexfuel.eu

[111] K. Anastasakis, Continuous Hydrothermal Liquefaction of Biomass in a Novel Pilot Plant with Heat Recovery and Hydraulic Oscillation, Energies 2018, 11, 2695; doi:10.3390/en11102695

Quantification of European biomass potentials and identification of preference regions for sustainable aviation fuel production

Mr. Franz-Fabian Bellot (DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH)

Anthropogenic climate change and staggering greenhouse gas (GHG) emissions are essential topics of our time, and the implementation of emission reduction activities play an essential role in the fruition of counter-measures. The transport sector, as one of the main contributors to human-induced emissions, also presents significant GHG reduction potentials. Especially the generation of biofuels based on hydrothermal liquefaction (HTL) constitutes a key technology for sustainable and economically competitive transportation. Therefore, understanding the distribution of biomass feedstocks is of high importance for the identification of HTL preference regions and planning of emission reduction activities. We used weighted kernel density estimations (wKDE) based on spatially disseminated geographic datasets to quantify and model the distribution of 11 agricultural and urban residues within EU-28 countries. The spatially explicit analyses reveal that an annual potential between 115 and 293 Mt DM is available from the aggregation of all considered biomasses. Preference regions for HTL plants and hence, the generation of sustainable aviation fuels (SAF), predominately concentrate in northern Italy, the Netherlands, Belgium as well as large parts of France and Germany (Figure 1). In addition to that, the generation of biomass supply curves for specific locations indicate area-specific feedstock compositions and therefore, allow a detailed quantification of the surrounding residue potentials within a certain threshold distance. Geographic information systems (GIS) were used to quantify the biomass potential for multiple point of maximum potential (PMP) sites. The results show a maximum feedstock aggregation potential between 1.5 and 2.4 Mt DM within a maximum threshold distance of 50 km at the most feasible single location within Europe.

From biocrude to sustainable aviation fuel components: challenges, successes and perspectives

Dr. Daniele Castello (Aalborg University), *Muhammad Salman Haider, Stefano Chiaberge, Lasse Aistrup Rosendahl*

Hydrothermal liquefaction (HTL) is establishing itself as one of the key technologies for the production of bio-fuels, including novel sustainable aviation fuel (SAF) components. This process is able to convert virtually any kind of biomass feedstock, without limitations due to high moisture or low lipid content, into an energy-dense viscous product called “biocrude”. This product can be in turn refined to produce drop-in biofuels, which are chemically equivalent to commercial fuels and can therefore represent a ready-to-use alternative. Biocrude upgrading can be successfully achieved by means of catalytic hydrotreating, involving the reaction of biocrude with hydrogen at high temperature and pressure, in the presence of a proper catalyst. This process results in a dramatic change of biocrude properties, reducing its viscosity, density and boiling point distribution and removing the undesired heteroatoms (oxygen, nitrogen and sulfur). The upgraded product can be then distilled to obtain a number of different fuel products, among which promising SAF components. In this work, we show the successful results of long-run continuous hydrotreating campaigns, carried out on biocrudes from diverse origins: algae, sewage sludge and straw. In all cases, a careful, case-specific choice of catalyst and process conditions determined the success of the operations. The kerosene-range fractional cut was also obtained by distillation and characterized, revealing its compliance with most parameters in ASTM D4054 Tier 1. As a final demonstration, a blend of the HTL-derived jet fuel component with commercial aviation fuel was fed to a lab-scale aviation engine, showing the potential of this new candidate SAF.

System design and performance evaluation of jet fuel production by hydrothermal liquefaction

Ms. Penke Christina (Bauhaus Luftfahrt e. V.), *Moser Leonard, Özal Göksu, Batteiger Valentin*

Within the EU Horizon 2020 project HyFlexFuel, the hydrothermal liquefaction (HTL) fuel production chain, from different feedstock types to an upgraded kerosene product that meets most jet fuel specifications, has been demonstrated successfully. However, when designing a commercial HTL process, the utilization of by-products such as the carbon-rich process water and the provision of the required process heat must be taken into account as well. Now the question arises which HTL system design is associated with the lowest environmental impact and production costs. The contribution addresses this research question by establishing a comprehensive process model for different feedstock (sewage sludge, straw, miscanthus and microalgae) based on experimental biocrude production and upgrading campaigns in pilot and laboratory scale. This model enables evaluating different process configurations in terms of energy efficiencies and serves as basis for subsequent system analyses by applying techno-economic and life cycle analyses (TEA and LCA). The results show that an energetic use of the by-products and intensive heat recovery encompassing the entire HTL process chain are key parameters for low-cost and low-emission HTL fuels. Upgraded biocrude using sewage sludge, representing a waste stream in wastewater management, can be produced at near-competitive price levels. Compared to conventional jet fuel production, greenhouse gases are reduced significantly. However, sewage sludge is a limited resource and only limited amounts of jet fuel could be substituted. Feedstock such as straw or miscanthus are available in larger quantities and provide the opportunity to produce larger amounts of sustainable aviation fuels at moderate costs. This way, the HTL process offers the potential to substitute significant jet fuel quantities and may thereby contribute to an eco-efficient aviation in the future.

The JETSCREEN fuel prescreening process to support development of innovative Sustainable Aviation Fuels

Dr. B. Rauch (DLR), *S. Blakey, C. Lewis, M. Fortunato, M. Sicard, P. Le Clercq*

In December 2020, the EU Green Deal announced the need to reduce transport emissions by 90% by 2050 (compared to 1990 levels). This requires the production and deployment of sustainable aviation fuels, which offer one effective way to mitigate both CO2 and non-CO2 impacts on the climate as well as improving airport local air quality. While regulatory frameworks like CORSIA aim to reduce the price difference by offsetting CO2, there is a broader need to develop and approve a variety of fuel production pathways that permit the utilisation of a wider range of feedstocks. However, substantial investments of time and finance are currently needed to support these fuels through the current ASTM D4054 international evaluation process. A key JETSCREEN enabler is the ability to predict a wide range of fuel performance based on low cost, and volume, fundamental analytical testing that in the past would have not been possible without high tier testing to assess performance, with all the cost, time, and efforts that this would entail. A two-tired process to prescreen candidate fuels before they enter ASTM D4054 fuel evaluation was developed jointly with the US National Jet Fuel Combustion program (NJFCP). The resultant fuel prescreening methodology provides essential feedback about the suitability and improvement potential of candidate fuels to innovative fuel producers. During the project, JETSCREEN provided its prescreening services to five innovative fuels producers in two iteration loops. It was shown that by providing this earlystage feedback, even fuels that initially did not conform to aviation fuel requirements could be massively improved and become aviation fuel worthy candidate fuels within few

months. In consequence, JETSCREEN tools are lowering cost of SAF candidate fuel evaluation and de-risk/optimise the product prior to entry into the approval process.