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THE FLIGHT DYNAMICS SYSTEM FOR THE CONTROL OF THE SIRIO SPACE-CRAFT DURING ITS OPERATIONAL LIFE.

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CNUCE

Divisione Servizio Elaborazione Dati

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CNUCE - Istituto del CNR
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I would like to express my congratulations to everyone at CIA, Telespazio and CNUCE who has contributed to the realisation of the ground system which will control SIRIO during its operational life and in particular to the authors of this paper who have been responsible for designing that part of the system which involves data processing activities for the SIRIO flight dynamics control and which is described here.

This paper presents the results of a very sucessful effort in which a team of data processing and applied software experts from CNUCE have collaborated with a group of NASA mission support experts and have been able to accumulate the specific applied experience necessary for operating SIRIO.

One of the most important results of this cooperation is that the Telespazio and CNUCE teams operating on the implementation of the ground system support have demonstrated that they are able to determine S/C orbits with a higher precision than that originally planned by NASA.

This is a remarkable achievement which reduces costs for S/C control and makes the ground support system designed by SIRIO team completely independent from NASA support.

As SIRIO Project Manager, I am confident that the system described in this paper is the best solution possible to satisfy all the needs of the SIRIO mission.

Abstract

This publication describes the Flight Dynamics System for the control of the SIRIO mission in its geostationary phase. Because we now are several months ahead of the mission execution schedule, the Flight Dynamics System is already being implemented. The design of the system described in this publication is subject to revision on the revealing of new requirements or improvements.
In section 1 a general survey of the mission is given; in section 2 the FDS itself is described; in section 3 the programs which pursue the main objectives of the FDS are detailed; in section 4 both hardware and software computing supports are presented; in section 5 the evolutions and improvements planned for the FDS are considered.
The reader of the present note is presumed to be familiar with the VM/370 Control Program and Conversational Monitor System, with the System/370 Operating System and with the CNUCE computing facilities.

Contents

LIST OF ABBREVIATIONS

- ADP - ATTITUDE DETERMINATION PROGRAM
- AMP - ATTITUDE MANEUVER PROGRAM
- ASP - ATTITUDE SIMULATOR PROGRAM
- CIA - COMPAGNIA INDUSTRIALE AEROSPAZIALE
- CMS - CONVERSATIONAL MONITOR SYSTEM
- CP - CONTROL PROGRAM
- CPU - CENTRAL PROCESSING UNIT
- FDCG - FLIGHT DYNAMICS CONTROL GROUP
- FDS - FLIFHT DYNAMICS SYSTEM
- GH - GIGA-HERTZ
- I/O - INPUT-OUTPUT
- IBM - INTERNATIONAL BUSINESS MACHINE
- K - KILO
- LCP - LINK CONTROL PROGRAM
- M - MEGA
- MCR - MISSION CONTROL RESPONSIBLE
- NASA - NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
- OCG - OPERATIONS CONTROL GROUP
- ODP - ORBIT DETERMINATION PROGRAM
- OMP - ORBIT MANEUVER PROGRAM
- OS - OPERATING SYSTEM
- PCM - PULSE CODE MODULATION
- PEMOS - REMOTE OPERATING SYSTEM
- RSCS - REMOTE SPOOLING COMMUNICATION SUBSYSTEM
- S/C - SPACECRAFT
- SHF - SUPER HIGH FREQUENCES
- SIOCC - SIRIO OPERATIONAL CONTROL CENTER
- TCU - TRANSMISSION CONTROL UNIT
- TDP - TELEMETRY DISPLAY PROGRAM
- TPP - TELEMETRY PREPROCESSOR PROGRAM
- VHF - VERY HIGH FREQUENCES
- VM - VIRTUAL MACHINE
- VS - VIRTUAL SPACE

1. Introductory remarks

1.1 Mission profile

SIRIO is a project sponsored by the CNR (Italian National Research Council) having as principal goals:

- -1- the performing of a number of scientific experiments in the field of telecommunications. The most remarkable is the propagation experiment at 18 GH;
- -2- the designing of a spacecraft capable of fulfilling the requirements of the experiments;
- -3- the stimulating of the electronic and mechanical industries in Italy by committing them to the construction of the subsystems of which the S/C is composed;
- -4- the concentrating of, in the CIA (an organisation set up for the SIRIO project with the support of some of the most qualified mechanical and electronic industries in Italy), the responsibility and know-how for integrating and testing the S/C;
- -5- the implementing of a ground control system for operating the S/C during its operational life;
- -6- the creating, within the CNR, of a know-how on S/C mission planning and execution.

SIRIO S/C is now in an advanced state of realization; the launch is scheduled to take place at Cape Kennedy, Florida, the 10th of August 1977, with a McDonnell and Douglas 2313 launcher provided by NASA. NASA is also encharged with the control of the mission, under CNR responsibility, until the geostationary scheduled position has been reached. After reaching the the target station point:

- longitude: 15 degrees West ± 1 degree
- height: 42166 km from the center of the earth
- orbital plane inclination: 0.3 degrees
- spin axis inclination: 1 degree within the negative orbit normal,

the S/C and the SIOCC (SIRIO Operation Control Center which is located at Fucino, 50 miles from Rome) will both be checked out. At that point, NASA will pass the control of the S/C to SIOCC. This is likely to be approximately thirty days after launch and is the beginning of the two year period of operational life of the S/C. During this period, all the experiments will be performed. In concurrence with

the experiments or with short interuptions of them, all necessary operations will be performed to the S/C in order to maintain it within the specified tolerances and to check its health.
In particular, the position of SIRIO in its orbit will be checked regularly as well as the inclination of the spin axis. As soon as the position of the S/C is found to be going out of tolerances, maneuvers will be planned to bring the S/C back in its target position.
Particular operations will also have to be performed within the Spring and Autumn equinox periods in order to prevent the S/C being damaged by low temperatures occurring during the sun eclipses. A series of checks of the most critical subsystems of the satellite will also be performed on a regular basis.
At the completion of the two year period, a decision will be taken as to whether to keep the S/C and the experiments operating as long as everything is functioning well or to let the S/C drift away from its target position.

1.2 Organization for mission control

The CNR has the full responsibility for the mission execution through the Mission Control Responsible (MCR). The Polytechnic of Milan is responsible for the scientific coordination of the experiments.
Telespazio has been committed by CNR to perform all the operations on the S/C; CIA (the firm who designed and assembled the S/C) is responsible for the know-how on the S/C.

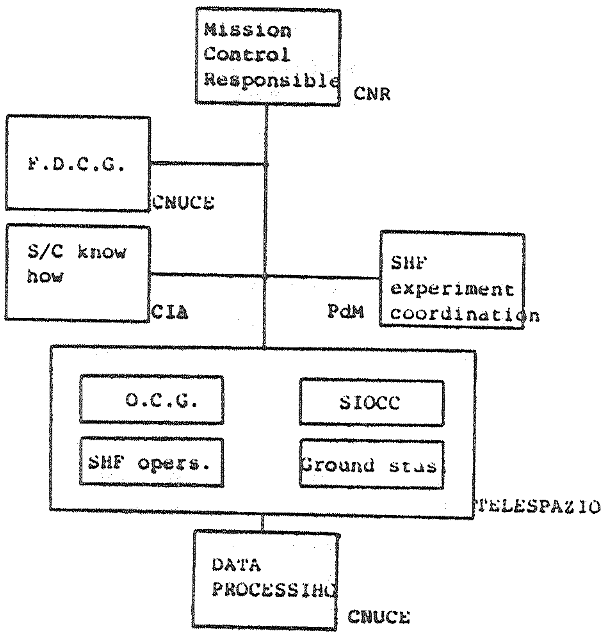

Fig. 1 - Organization for mission control

A pictorial view giving a simplified scheme of the main functions to be performed, is given in fig. 1.
CNUCE, on behalf of the CNR, has been assigned the task of assisting the MCR for the flight dynamics aspects of the mission with a Flight Dynamics Control Group (FDCG); CNUCE is also the data processing center running all the programs that, because of their dimension, can not be run on the PDP-11/70 of SIOCC. These programs constitute the Flight Dynamics System which is described in this publication.
CIA covers two main tasks by monitoring the S/C health status through a team of Flight Conductors which operate at SIOCC and by providing, on request from CNR, flight data analysis for inflight performance evaluations of the S/C subsystems.
The Polytechnic of Milan performs coordination functions among the experimenters in order to submit their requests to the operational group.
Telespazio takes care of coordinating the operations on the S/C through the Operations Coordination Group (OCG). The SIRIO Operation Control Center (SIOCC), located at the Telespazio ground station of Fucino, is the location where all the operations are actually performed. At Fucino (41.5 lat. N; 13 long. E) the primary ground equipment for SIRIO control is located i.e. SHF antenna and VHF antenna.
Another SHF antenna is located at the Telespazio ground station of LARIO (Northern Italy).

2. FDS General Description

2.1 FDS overall

The Flight Dynamics System for the control of the SIRIO Spacecraft during its operational life, is not an operating system in the strictest sense of the word. It is rather a mechanism by which the mission dependent set of stand-alone programs can execute together in the same computer and can communicate with each other exchanging data. The primary function of the FDS is to provide the FDCG (Flight Dynamics Control Group) and the OCG (Operations Control Group) with a flexible tool to elaborate the telemetry data transmitted from the SIRIO spacecraft and the tracking data acquired by the Fucino and Lario ground stations.
Four main areas of operations are covered by the FDS software:

- orbit determination
- attitude determination
- orbit control
- attitude control

For each one of these main tasks, a computer program has been developed in accordance with the FDS prime requirements i.e. flexibility in hardware support and simplicity in its use.
Because of the amount of computer core needed by these programs due to the large amount of data processed, and to the great quantity of analytic computations, the FDS software has been implemented on the IBM 370 computers at CNUCE in Pisa and a communication link has been established between the PDP 11/70 of SIOCC and the CNUCE computers to allow the data flow from the Fucino ground station to the CNUCE computing center.
Data flow from SIOCC to CNUCE is in real-time even if a reasonable delay of time is allowed between data acquisition and data processing during the SIRIO spacecraft geostationary phase.
This is done primarily in order to speed up the operations during the execution of the station keeping procedures and also to allow the acquisition and the monitoring of the telemetry data in the CNUCE remote station during the critical phases of the SIRIO mission. Data coming from the Fucino ground station to CNUCE are stored on magnetic disk to be processed with a minimum delay of one hour by the FDS programs.
Data processing is performed at different levels in the sense that orbit determination and attitude determination programs directly perform computation on tracking and telemetry data, even if already preprocessed, while orbit control and attitude control programs require the results of the previous programs as input data. Thus, the orbit

determination and attitude determination programs can be executed at the same time. The orbit control and the attitude control programs can also be executed concurrently but it is not possible to execute determination programs and control programs at the same time using data relating to the same epoch.
The results which are obtained from the execution of these programs and which are of primary importance to the FDCG and the OCG are as follows:

- the ORBIT FILE which contains the Keplerian orbital elements of the SIRIO orbit at a given epoch;

- the ATTITUDE FILE which contains the right ascension and the declination of the SIRIO S/C at a given epoch;

- a command sheet either from orbit control or attitude control programs, detailing a requested maneuver to be performed on the SIRIO S/C.

All the FDS programs, except for the Orbit Determination Program which runs in batch mode under OS-VS2, are running under the VM/370 Control Program (CP) and the Conversational Monitor System (CMS) in an interactive way.
Each program consists of several logic units devoted to the execution of the different phases of the process. The logic units in a program are of the following two different types:

- logic units devoted to the computations needed for the solution of given problems.
- logic units devoted to the management of the I/O files and, more generally, to the management of the entire system.

The main characteristic of the system is to allow the interaction between the user and the computing process at a certain number of points corresponding to the start and/or the end of each logic unit, during the execution of a program. This operating philosophy allows the user to affect the process by changing the sequence of the operations on the basis of the results of the previous steps. Furthermore, the automatization of the data management makes the use of the system easy for the user who, even though he may be an expert in the field of flight dynamics is not required to have a great know-how on computing techniques.

2.2 When FDS is used

As has already been said, SIRIO S/C, after handover, will be located in its target geostationary position at a longitude of 15 degrees W ± 2 degrees of tolerance at the height of 42,166 kms from the center of the earth. The orbit plane will have an inclination on the equator below 0.3 degrees. The satellite spin axis will be located within 1 degree of negative orbit nominal. The described position is actually not stationary because there is a number of perturbing forces which move the spacecraft away from its position. The most strongly influencing forces, due to celestial mechanics are:

- tesseral accelerations due to the non-sphericity of the earth;
- lunar-solar attraction;
- solar pressure.

The Auxiliary Propulsion System installed on the satellite, which is composed of two axial and two radial jets, allows for the compensating of the influence of these forces. Because the axial and radial jets fire in directions which also have non-axial and non-radial components, maneuvering the satellite implies modifications of the spin axis position.
Once the actions and the reactions which may be applied to the S/C are known, it is possible to estimate the usage of the FDS during SIRIO operational life.
The spin axis, as already said, has to be maintained within 1 degree of negative orbit nominal. The forces that perturb the spin axis position are the solar radiation and the torques caused by jet firing. Although a prediction of the frequency of spin axis correction is difficult (the torques given by the jets are, at a rough estimate, comparable to the ones due to solar radiation but may act in different planes), it is planned to perform two or three maneuvers of this kind every year. The Attitude Maneuver Program will be used for computing the maneuver. The position of the spin axis will, however, have to be checked regularly to determine the on-board SHF antenna coverage. The spin axis position will also be checked after each maneuver and before each experiment requiring this information. The Attitude Determination Program will be used to compute the attitude of the spacecraft. This program has, as basic input, the telemetry data coming from the sensors. These data will be transmitted from SIOCC to CNUCE following the procedure described in the next paragraph.
The longitude of the sub-satellite point has to be maintained between 14 and 16 degrees W. The main force causing a drifting of the space-craft towards West is that produced by the tesseral acceleration. A sensible action is also due to the lunar-solar attraction which is changing with a daily and yearly cycle. The position of the S/C will be checked regularly by using the Orbit Determination Program. Once the ODP has detected that the S/C has drifted out of tolerance limits, the Orbit Maneuver Program will be executed in order to compute a maneuver which will be

performed with radial jets and will cause the S/C to drift back toward East. The drift rate, due to the maneuver, will decrease until the S/C again starts to drift West because of the tesseral acceleration. It is planned to perform orbital maneuvers to correct the longitude every three or four months. The orbit will have to be checked frequently, at least twice each month, and after each maneuver.
Another constraint on the S/C positioning is the inclination of the orbit which has to be maintained below 0.3 degrees. The movement of the orbital plane is mainly due to the lunar-solar effect and is estimated in the period of the SIRIO mission in and out of plane of about 0.75 degrees per year. It is then planned to perform two North-South maneuvers yearly using the axial jets. The OMP will be used to compute the maneuvers. After any maneuver is performed, the S/C data, e.g. fuel weight, jet calibration, inertial data, etc. will be updated in order that the FDS may compute the next maneuver.
The FDCG will run a Telemetry Display Program (TDP) that will allow the telemetry to be displayed on a video terminal whenever the link with SIOCC is active. The execution of this program will not be dependent on operative reasons but will be activated for monitoring the S/C status.
From an operative point of view, all the activities related to the inflight control of SIRIO will be planned with monthly general schedules and weekly schedules that will be updated during the mission with the real data coming from the S/C.

2.3 How to operate FDS

Whenever one of the conditions specified in the previous paragraphs arises, the entire FDS or a part of it is executed in order to obtain information on how to operate the S/C.
In fig. 2, the nominal configuration of the FDS operations is shown.
As appears from the figure, the end users of the FDS are resident at the remote stations of the FDS network described in paragraphs 4.1.3 and 4.1.4.
In order to operate the FDS, the users have to set up a communication link and access the computers of the CNUCE Computing Center by means of an RSCS task (see paragraph 4.2.3) and/or by logging in a virtual machine, depending on the peripheral device used. It should be noted that, as said in paragraph 4.2.3, RSCS permits data transmission between the Central Processing Units and a remote station only for batch processing, thus, only the Orbit Determination Program can be executed using an IBM 3780 Remote Station; this device is to be used primarily by the Operations Control Group to obtain the output of the FDS programs in station.
Up to three virtual machines can be used to operate the FDS. The SIRSYS virtual machine is the most important because it

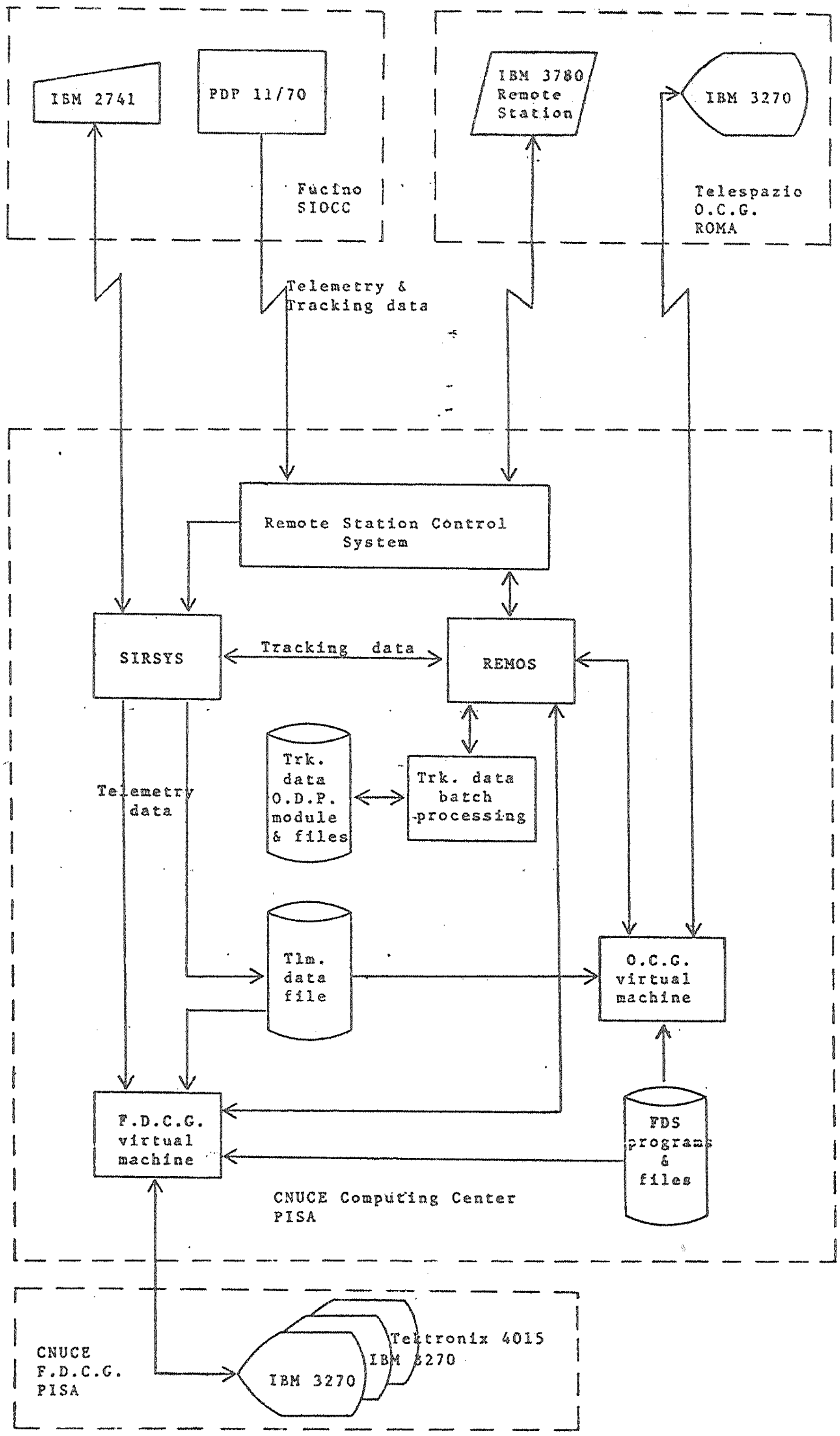

Fig. 2 - Nominal Configuration for FDS Operations

works as a system machine, controlling the FDS programs and data flow (see fig. 3).
For this machine, two disk units are defined as follows:

- the disk correspondent to the virtual address 191 is devoted to the Telemetry Data File written by the Link Control Program.

- the disk correspondent to the virtual address 192 contains the executable modules of the FDS programs and the permanent files needed for their execution.

Both disk units are linkable in read-only mode by the FDCG and OCG user virtual machines, so that the FDS programs can be executed.
It should be noted that, because the Orbit Determination Program can execute only in batch mode, the load module and the data sets pertinent to this program are stored on a disk unit which cannot be accessed by any virtual machine; its execution can be started from a virtual machine only by means of REMOS and cannot be controlled by the user until completion.
The focal point in operating FDS is the communication link between SIOCC and CNUCE Computing Center because it allows the input data, on which the FDS programs operate, to be available to the programs themselves.
The input data are of the following two different types:

- tracking data for orbit determination
- telemetry data for attitude determination.

The tracking data consist of angular data acquired from both Fucino and Lario ground stations and ranging data acquired from the Fucino ground station alone; the data are preprocessed on the PDP 11/70 computer before being transmitted to the CNUCE Computing Center using the communication link. The telemetry data are received from the SIRIO S/C by the TLM data handling system of the SIOCC, in real time, through the VHF or SHF link. When a telemetry frame is completely acquired, i. e. every 16 seconds, it is elaborated on the PDP 11/70 and presented to the user on three display units; at the same time, the entire frame is transmitted to the CNUCE Computing Center using the same communication link as for the tracking data.
Following the weekly detailed schedules of the mission operations, the SIOCC operator accesses the CNUCE Computers by logging in the SIRSYS virtual machine from an interactive terminal and asks the CNUCE operator to start the RSCS task devoted to the controlling of the data transmission from SIOCC to CNUCE; the SIOCC operator then starts both the execution of the Link Control Program and the transmission from PDP 11/70. Data are received by RSCS and transmitted, via a channel-to-channel link, to the SIRSYS virtual machine where the Link Control Program recognizes the type of data.

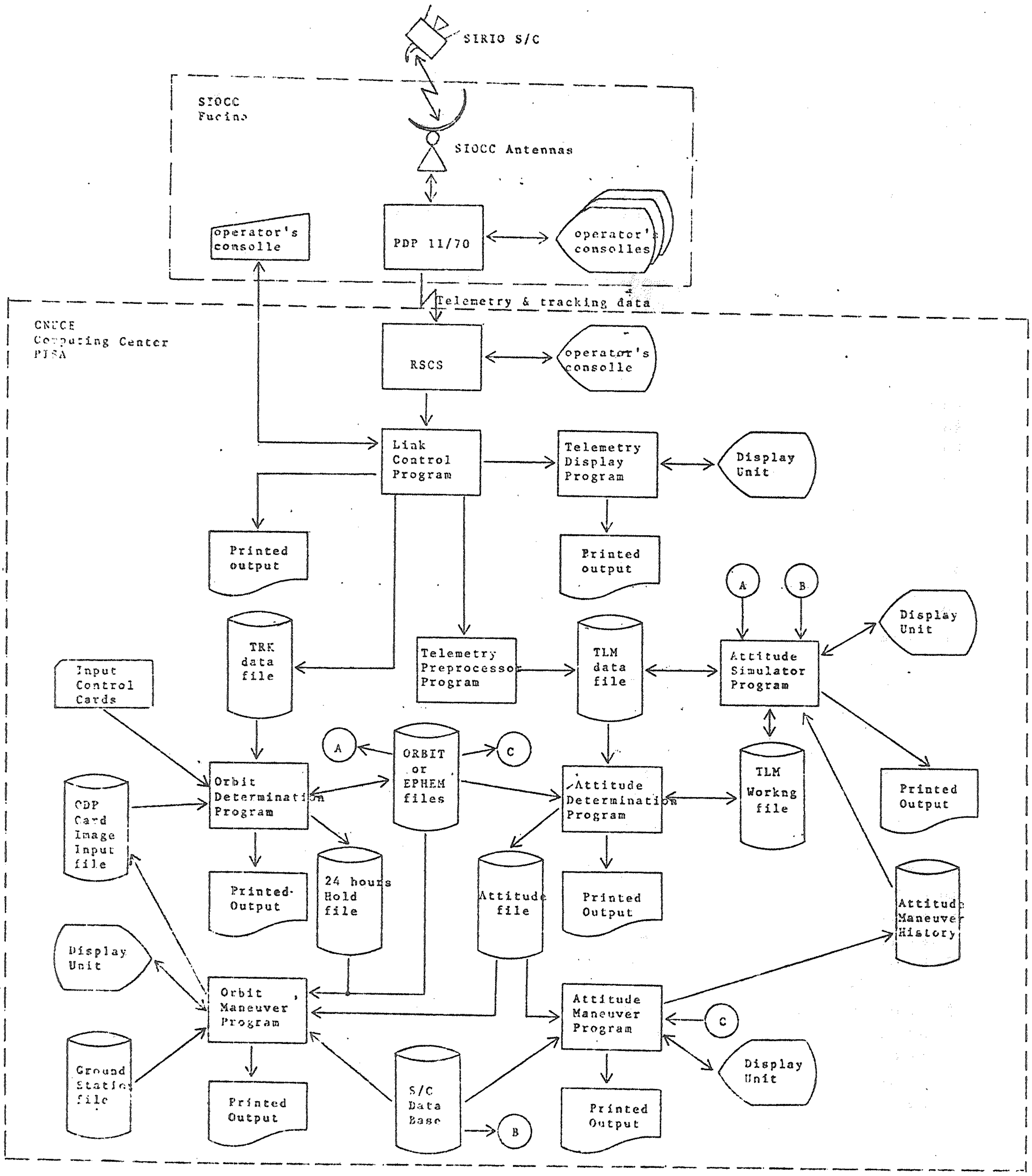

Fig. 3 - FDS Data Flow

The tracking data are transmitted from SIRSYS to REMOS(*), and from there to the tracking data batch processing which stores them on disk in the Tracking Data File.
Once the data acquisition has been completed, the Flight Dynamics Control Group personnel access the computers of the CNUCE Computing Center by means of the FDCG virtual machine and execute the Orbit Determination Program via REMOS, using one of the display terminals at its disposal.
On the other side, the Operations Control Group personnel can perform the same operation by using a Terminal Display Unit and the OCG virtual machine or start directly the Orbit Determination Program from an IBM 3780 Remote Station via FSCS and REMOS. The results, computed by the Orbit Determination Program, can be either in Orbit File format or in Ephem File format and are stored on disk or on tape to be accessed by the other programs of the FDS.
When the option disk is chosen, a procedure must be activated to transfer those files to a disk available for the user virtual machines.
The telemetry data are transmitted in real time from SIRSYS to the FDCG virtual machine which should execute the Telemetry Display Program. Each time a telemetry frame is received it is elaborated as on the PDP 11/70 and the data are presented on a Terminal Display Unit to the Flight Dynamics Control Group personnel. At the same time, the telemetry frame is passed to the Telemetry Preprocessor Program, which is part of the Link Control Program. The TPP retrieves the information from the time channels and stores them on disk in the Telemetry Data File.
After each hour of telemetry data acquisition, the Telemetry Data File is updated by the Link Control Program which then sends a brief summary describing the operation to the SIOCC operator on an interactive terminal. The new data inserted in the Telemetry Data File are made available to the users while the LCP continues to receive data from SIOCC for the subsequent hour. The Flight Dynamics Control Group and the Operations Control Group personnel can execute the Attitude Determination Program by using their own virtual machines and can compute the attitude of the S/C. The results of the execution of the Attitude Determination Program are then stored on the Attitude File.
Because the ADP may be executed at the same time by the FDCG and the OCG personnel, in order to avoid possible interference on the execution of the programs, the Attitude File is stored on the disk unit where the working files and the printer files of the single virtual machine are stored.
For the same reason, either the Orbit File or the Ephem File as well as the output files from the maneuver programs are stored on the same disk units.

(*) REMOS is a virtual machine set up to control the exchange of data between OS and VM systems.

Once the orbit determination and the attitude determination have been made and if a maneuver has been scheduled or is to be set up on the basis of the previous results, the FDCG and the OCG personnel can execute either the Orbit Maneuver Program or the Attitude Maneuver Program using their own virtual machines.
Taking into account the S/C parameters influencing the flight and the maneuver specifications made by the users, the maneuver programs perform a detailed computation of the maneuver and print out a command sheet to be translated by a S/C analyst into the appropriate command string to be transmitted to the S/C.

3. Mission dependent software

All the programs used for SIRIO mission support are written in ASSEMBLER/370 and FORTRAN languages and designed to run on the IBM 370/168 of the CNUCE Computing Center under VM/370 except for the Orbit Determination Program which is running on the IBM 370/158 under OS/VS2.

3.1 LCP - Link Control Program.

The Link Control Program is not a mission dependent program in the strictest sense of the word because, in fact, it is not affected by any of the mission dependent parameters. Rather, it can be seen as a real time data acquisition system. The reason why it is considered a mission dependent program, is that its use at CNUCE Computing Center is strictly connected with FDS of which it is a critical node.
The main purpose of the LCP is to make available to the other FDS programs the tracking data and the telemetry data received from the SIOCC. A baseline diagram of the Link Control Program is shown in figure 4. A general description on this program is presented in section 2. of the present note; more detailed information is given in reference 6.

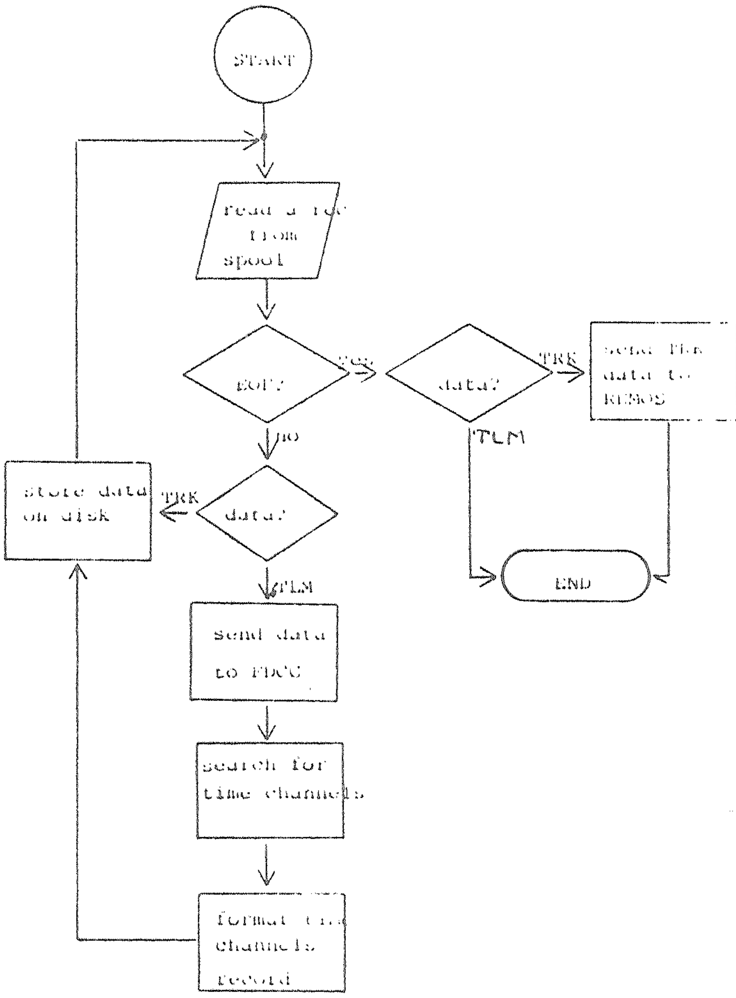

Fig. 4 - LCP baseline diagram.

3.2 TDP - Telemetry Display Program

The Telemetry Display Program is designed to run on the FDCG virtual machine in conjunction with the LCP while

receiving telemetry data from SIOCC. The main purpose of the TDP is to allow the monitoring of the S/C status by displaying the telemetry data received in real-time from the S/C itself.
The TDP starts by displaying the nominal values expected from the telemetry channels and then waits for a telemetry frame to be transmitted by LCP.
Once the transmission process from LCP to the reader spool area of the FDCG virtual machine has begun, the TDP refreshes continuously the data displayed with the new data read in from the spool area. When a channel goes out of the proper range, a string of stars is displayed instead of its numerical value.
Depending on the number of users logged in the computer, it may happen that data are transmitted by the LCP at higher speed than they are elaborated by the TDP.
If this is the case, more than one telemetry frame at a time is written on the reader spool area of FDCG virtual machine between two continuous refreshments of the data displayed. In this case, the TDP reads from the spool area the last telemetry frame transmitted and purges the previous ones in order to refresh the data with the last updated values. The process continues until the data transmission is held up. In figure 5, a baseline diagram of the Telemetry Display Program is shown.

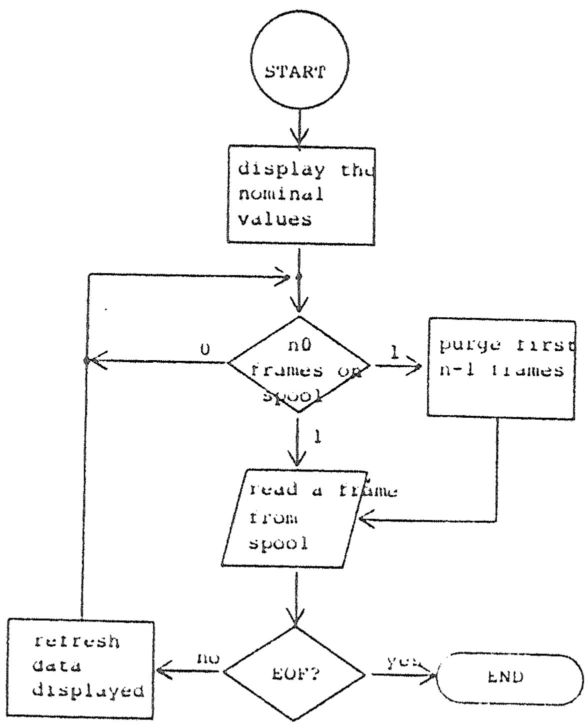

Fig. 5 - TDP Baseline diagram

3.3 ODP - Orbit Determination Program

The Orbit Determination Program is primarily used, during mission support, to perform the determination of the orbit of the S/C starting from the trajectory data observed by one or more ground stations. As so far described, for the SIRIO mission support the input data to the program are the SHF antenna pointing angular data acquired at Fucino and Lario ground stations and the ranging data acquired by the SHF ranging equipment of the Fucino ground station.
The output of the program can be either an Orbit File containing the Keplerian orbital elements at a given epoch or an Ephem File containing the ephemerides of the S/C in a given time span.
The ODP has also been designed to cover a wider area of computational requirements for mission support, mission analysis and research and development studies.
To accomplish these objectives, the ODP is built up as a series of related computer programs, each one devoted to cover a specific orbit determination requirement. For a detailed description of the entire program see the Orbit Determination Program user's guide. A general description of the main tasks covered by the program follows.
The Differential Correction Process is the most important part of the ODP used for SIRIO mission support. Its purpose is to estimate the values of a set of parameters, called solve-for variables, in a mathematical model for celestial bodies motion. The solve-for parameters are those which are implicit in the equations of motion, i.e. the S/C epoch, the aerodynamic force parameter, the scale factor on the solar radiation acceleration, etc.
The parameters are estimated so as to minimize the sum of the squares of the differences between computed and observed trajectory data while constraining the parameters to satisfy their a priori initial estimates within a specified uncertainty. The trajectory data required by the programs are supplied by the users on the Tracking Data File.
A second important objective pursued by the ODP is the computation of the time history of the S/C trajectory from a given set of initial conditions. Typical output is in the form of Keplerian orbital elements at various times during the trajectory.
For the use of the ODP for research and development studies, a Data Simulator Process has been designed in order to output a simulated observation file for the space-craft and a given set of stations.
These observations are the output of a function of an input tracking schedule and the stations observing the satellite. Because the observations are computed with the same model as the Differential Correction Process, the observation file can be used as input to the ODP itself for pre-launch testing and analysis.
Another important function performed by the ODP is to retrieve data from the ODP files to create temporary working

files of data to be used by subsequent ODP runs.
When executing the ODP in any one of the possible ways, files of program results may be generated and saved for later use, external to the ODP, or for subsequent use by another ODP run.
The most useful data files contain the satellite ephemerides which are needed by the Attitude Determination Program and by the maneuver programs.

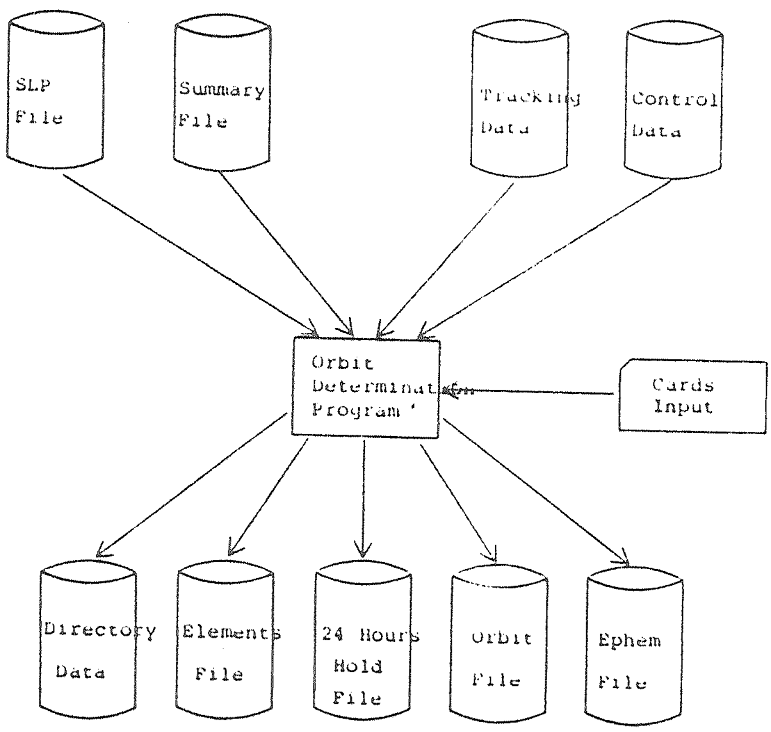

Fig. 6 - SIRIO Orbit Determination Program
Principal External Interfaces.

3.4 ASP - Attitude Simulator Program

The Attitude Simulator Program is designed to work in conjunction with the Attitude Determination Program for testing purposes, prelaunch analysis and training mission support personnel.
The main purpose of the ASP is to generate simulated telemetry data in any of two different formats. Data may be stored on disk in a Telemetry Data File similar to that created by the LCP in order to enable the user to run FDS in simulation mode. Data may be generated also in the format of the Telemetry Working File of the ADP to be used primarily for analytical studies or for testing the ADP when perfect simulated data is required with no telemetry quantization errors. Telemetry data can be simulated by means of the spacecraft attitude and spin rate, either as constant values or as linearly varying quantities obtained from the Attitude History File generated by the Attitude Maneuver Program being used as input to the program. Options are also provided to apply noise, quantization errors, bit errors and biases.
The user may interrupt the simulation at any time in order to change simulation parameters and to pass from constant to varying attitude so that all the phases of the SIRIO operational life can be simulated.
Figure 7 is an overview of ASP illustrating the major modules and the principal I/O interfaces.

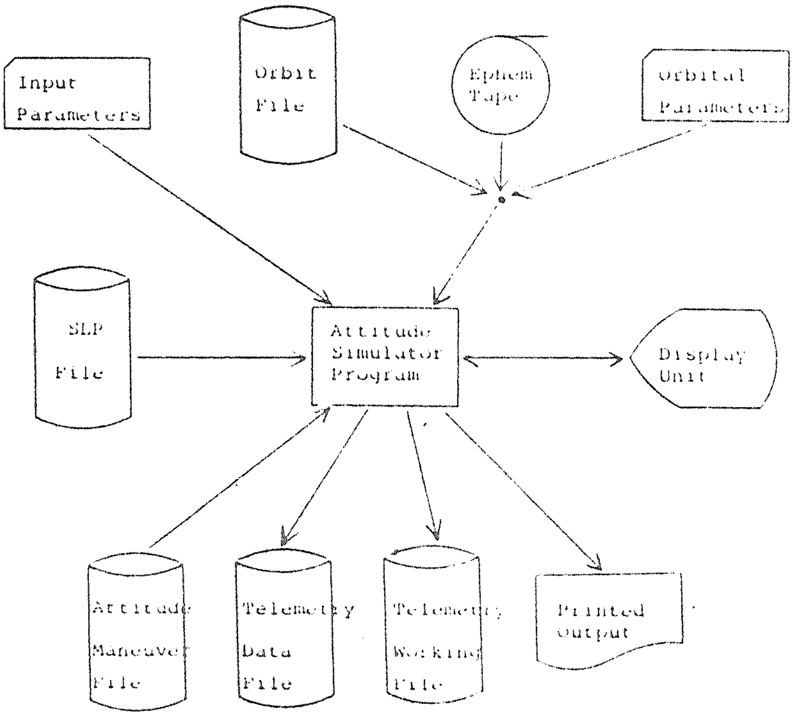

Fig. 7 - SIRIO Attitude Simulator Program
Principal External Interfaces.

3.5 ADP - Attitude Determination Program

The Attitude Determination Program has been developed to satisfy the attitude determination requirements of the SIRIO S/C.
The ADP retrieves the attitude of the spacecraft from the time channels information inside the telemetry frames acquired during an entire orbit.
Not all the frames acquired need to be processed by the ADP. It is estimated that not more than 300 frames distributed through the same orbit are necessary in order to satisfy the attitude determination requirements. The distribution of the frames to be processed is directly dependent on the geometric configuration given by the relative position of the sun, earth and S/C and which varies through the orbit. For this reason, several options are provided to combine the data to be passed to the deterministic processing: options are provided to select every ith frame from the Telemetry Data File or to smooth blocks of n consecutive frames to generate a single smoothed frame. Options for several data smoothing techniques are also provided to reduce random noise and the effects of telemetry granularity and possible nutation. Before performing the attitude determination, an option is provided to store on the Telemetry Working File the smoothed data for analytical study purposes.

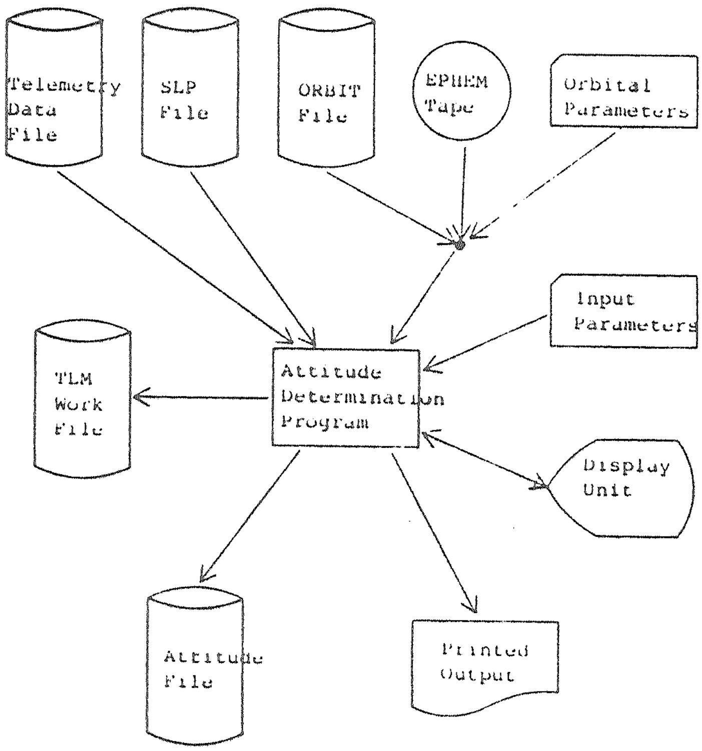

Fig. 9 - SIRIO Attitude Determination Program
Principal External Interfaces

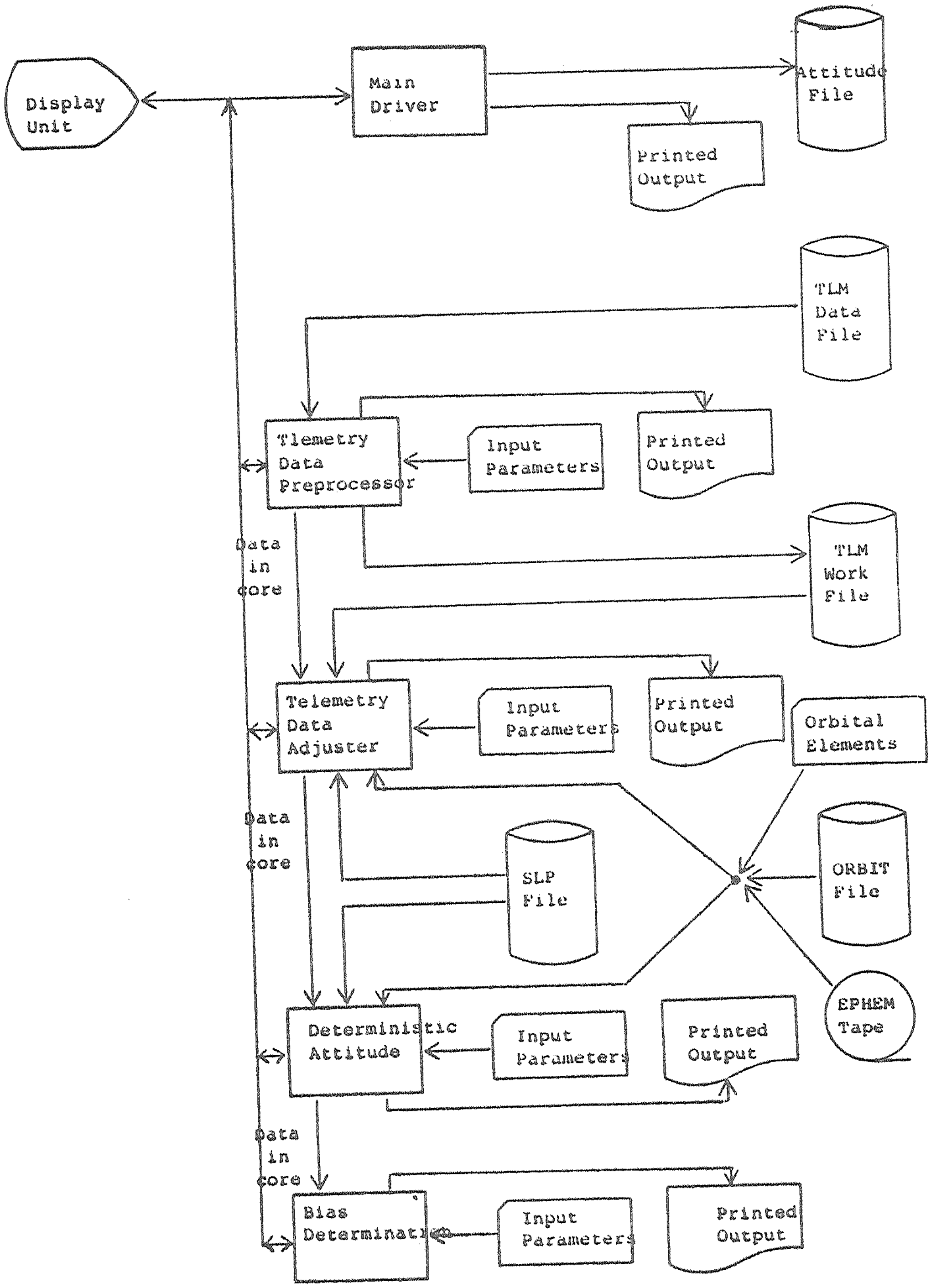

Fig. 8 - SIRIO Attitude Determination Program
Baseline Diagram

The deterministic attitude process computes attitude from each frame of smoothed data using up to eleven methods.
Because each method yields two possible ambiguous attitudes, a block averaging procedure is required to resolve the ambiguity in each attitude solution and to compute a weighted average of the unit spin axis vectors.
The results consist of a combined average attitude for all the eleven methods and individual average attitudes for each method; these are stored on the Attitude File.
Because it is possible that no solutions are obtained from the deterministic process for a significant part of the data pass due to the systematic or random errors, a bias determination technique has also been implemented on the ADP in order to handle errors resulting from sensor misalignment or hardware specifications.
Once the biases are known, they can be used as a priori values on the smoothing techniques in order to reprocess the data to be passed to the deterministic process.
Figure 8 shows the principle I/O interfaces, in figure 9 an overview of ADP illustrating the major modules is given.

3.6 OMP - Orbit Maneuver Program

The Orbit Maneuver Program has been designed to provide the SIRIO mission support personnel with the possibility of computing and achieving desired on-station orbital maneuvers. Specifically, the OMP is able to compute the detailed maneuver scenarios and jet firing tables necessary to perform out-of-plane corrections, East-West station keeping maneuvers, and simultaneous in-out-of-plane corrections.
To achieve these goals, different targeting schemes have been implemented in the program together with a model of both propulsion and attitude control.
The most important targeting schemes available in the ODP are:

- East-West station-keeping maneuvers targeting on longitude drift rate or semi-major axis

- East-West station-keeping maneuvers targeting on longitudinal constraints

- North-South station-keeping maneuvers targeting on inclination and/or node

- Simultaneous in-out-of-plane maneuvers targeting on multiple maneuver goals.

By means of a particular targeting scheme and using the model of the spacecraft, it is possible to obtain and verify the end conditions of a maneuver including predicted changes in orbit, attitude, spin rate and fuel tank status. In

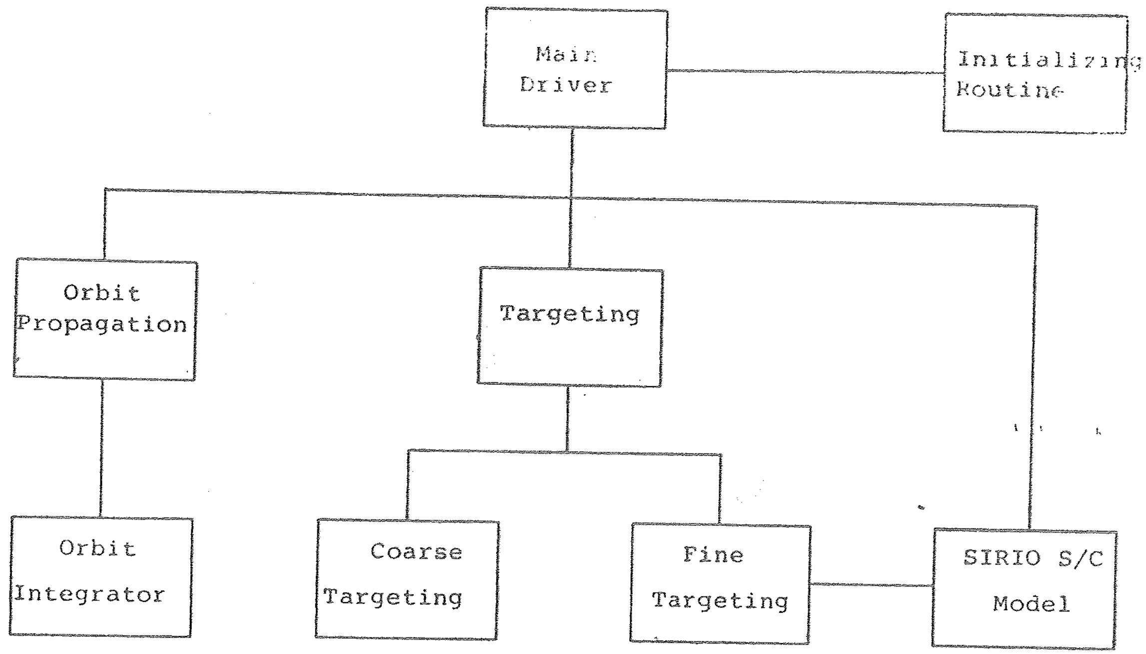

Fig. 10 - SIRIO Orbit Maneuver Program Overall Design

addition, it is possible to reconstruct any maneuver given the jet firing sequence. This allows the calibration of maneuvers already performed or the fine tuning of proposed maneuvers.
An overall design of the ODP is given in fig. 10 and a description of the principal I/O interfaces is presented in fig. 11.

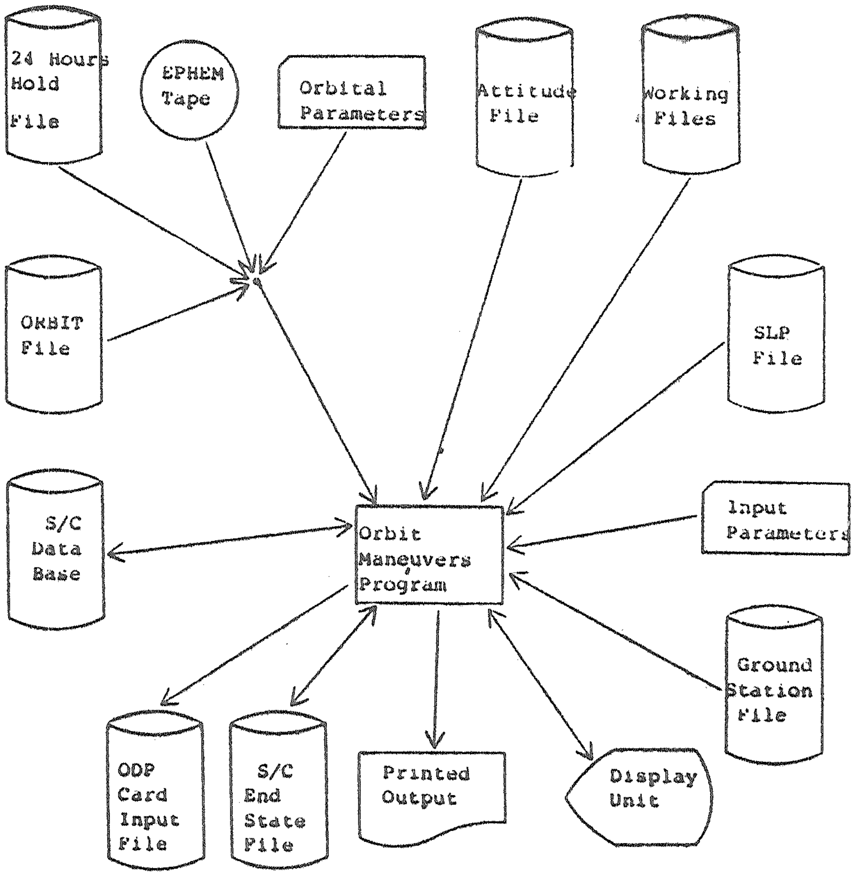

Fig. 11 - SIRIO Orbit Maneuver Program
Principal External Interfaces

3.7 AMP - Attitude Maneuver Program

The Attitude Maneuver Program is able to compute attitude reorientation maneuvers of the SIRIO S/C in anyone of four arthogonal directions having a phase angle to a reference vector.
The targeting scheme available in the AMP is a reorientation maneuver targeting on right ascension and declination from an initial attitude and spin rate.
The maneuver can be optimized so that either the minimum fuel consumption or the maximum Earth Coverage can be achieved. In addition, for the OMP it is possible to reconstruct any maneuver given the jet firing sequence and the start and end conditions of the S/C.
Because several constraints must be satisfied during attitude reorientation, i.e. antenna coverage must be maintained at all times and spin axis Sun angle must remain within 90 degrees ± 23 degrees, the geometry can be optionally tested for all these conditions.
The results of the execution of the AMP are the commands and the associated data and details necessary for practical execution of the reorientation with a time response of the S/C spin axis and other meaningful parameters such as Sun angle, station aspect angle and sensor coverage throughout the maneuvers. A baseline diagram of the Attitude Maneuver Program is shown in fig. 12.

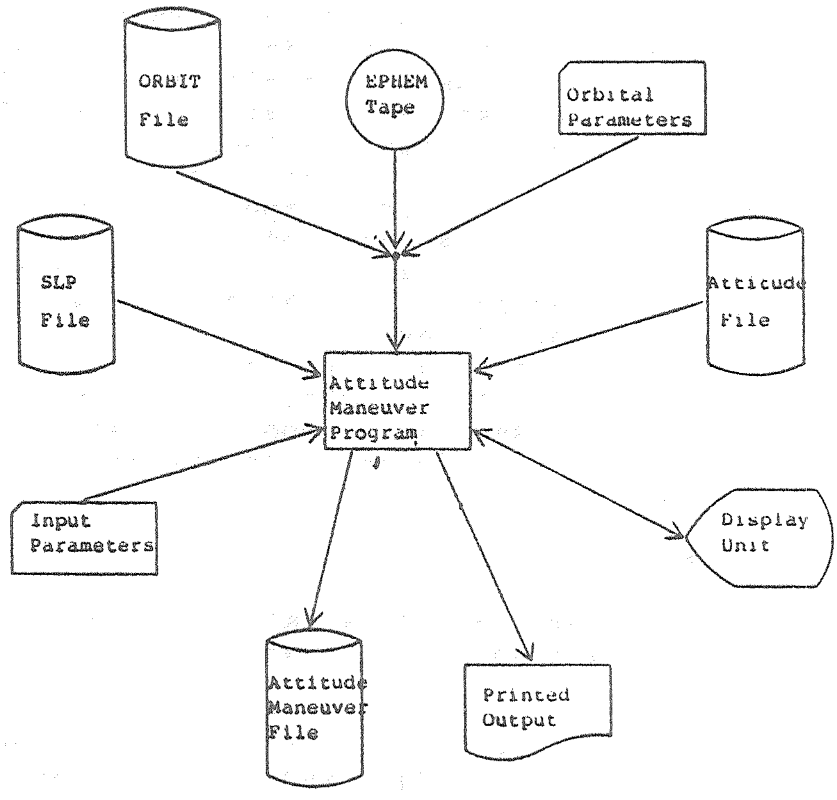

Fig. 12 - SIRIO Attitude Maneuver Program
Principal External Interfaces

4. Computing support

4.1 Hardware configuration

4.1.1 CNUCE Computing Facilities

As shown in fig. 13, the CNUCE Data Processing Service is based on the use of two Central Processing Units (CPU) as follows:

- IBM 370/168 mod.1 with a 4 Mbytes core;
- IBM 370/158 mod.1 with a 3 Mbytes core.

The on-line storage capabilities, which are up to 3700 Mbytes for the 168 model and up to 2500 Mbytes for the 158 model, are completely based on the use of direct access storage units. Different types of card readers, printers, terminals etc. are available to the users for both batch and interactive processing. The remote entry is assured by means of standard telephone lines from 110 to 40800 bps, handled by Terminal Control Units (TCUs).
An IBM 2914 switching unit, which connects the CPUs with the TCUs, enables a great number of I/O devices to be connected to either of the CPUs in order to change from the nominal hardware configuration when operating necessities require this.
The 168 CPU model is normally devoted to the interactive service while the 158 CPU model works in batch mode;however, it is possible to invert the use of the CPUs when only a few users are working in interactive mode in order to allow a better batch throughput by using the higher power of the 168 while switching the interactive service to the 158 which still provides a very good response time.
The hardware configuration described has been designed by the CNUCE Data Processing Service experts in order to match the reliability of the system required for the SIRIO control and to maintain a high flexibility in hardware support required by the many users of the CNUCE systems working in different fields of applied research.
In fact, the hardware configuration is symetric in all its components, except for the CPUs, and therefore CNUCE facilities have to be seen as a pool of peripheral units which can be connected indifferently to either of the CPUs.

4.1.2 SIOCC Computing Facilities

The SIOCC system is composed of a Data Processing System, a Telemetry Data Handling and some Data Communication Interfaces.
The Data Processing System is based on a PDP 11/70 computer with 96K words of core memory, on two disk cartridge drives, with 1.2 M words per cartridge, and on two magnetic tape units. Three alphanumeric displays are used by the operators

to monitor the telemetry data in real-time and to send commands to the spacecraft. A line printer, a card reader and an operator console complete the system. The Telemetry Data Handling is composed of two DCM decoding chains which decode the SIRIO telemetry data received either via VHF link or SHF link. Each chain consists of a bit conditioner which receives the PCM signal, a frame Synchronizer, which finds the synchronism and supplies data to the computer through DMA channel and a PCM simulator which generates a PCM signal to test the chain.
The Data Communication Interfaces are used to connect the SIOCC to other data processing facilities. This allows the PDP 11/70 to be connected to the SHF experiment data logger, located in the Fucino SHF station, to the Lario SHF Data-Processing System (PDP 11/45) and to the CNUCE Computing Center.

4.1.3 Remote Stations

By remote stations we mean any kind of hardware devices, physically located anywhere, capable of being connected to a Central Processing Unit by means of data communication links.
In this sense, a conversational terminal not directly connected with the Central Processing Unit is to be considered a remote station.
By means of a remote station, a general user can communicate with a computer, executing programs and obtaining as output the results of the computations on a type of support compatible with the equipment of the remote station itself.
The general definition of remote station applies to the CNUCE facilities when connecting a peripheral device to the central computers; this can be done by using either the virtual machine concept facilities provided by the VM/370 Control Program or the Remote Spooling Communication System of CNUCE.
Both of these facilities are used to connect the remote stations dedicated to the SIRIO mission control and included in the SIRIO Flight Dynamic System Network as explained in 4.1.4.
For the control of the SIRIO S/C during the geostationary phase of the mission, four different remote stations have been installed to match the Flight Dynamic System Operations.
The first one of the remote stations is located at SIOCC and is equipped with the PDP 11/70 of the SIOCC itself which is seen as a remote terminal by the Central Processing Unit of CNUCE during tracking and telemetry data transmission from the Fucino ground station to the CNUCE Computing Center.
Another remote station is located at SIOCC and consists of a printing interactive terminal used primarily by the SIOCC operators to run the LCP. This station has been set up with the purpose of minimizing the communications needed between

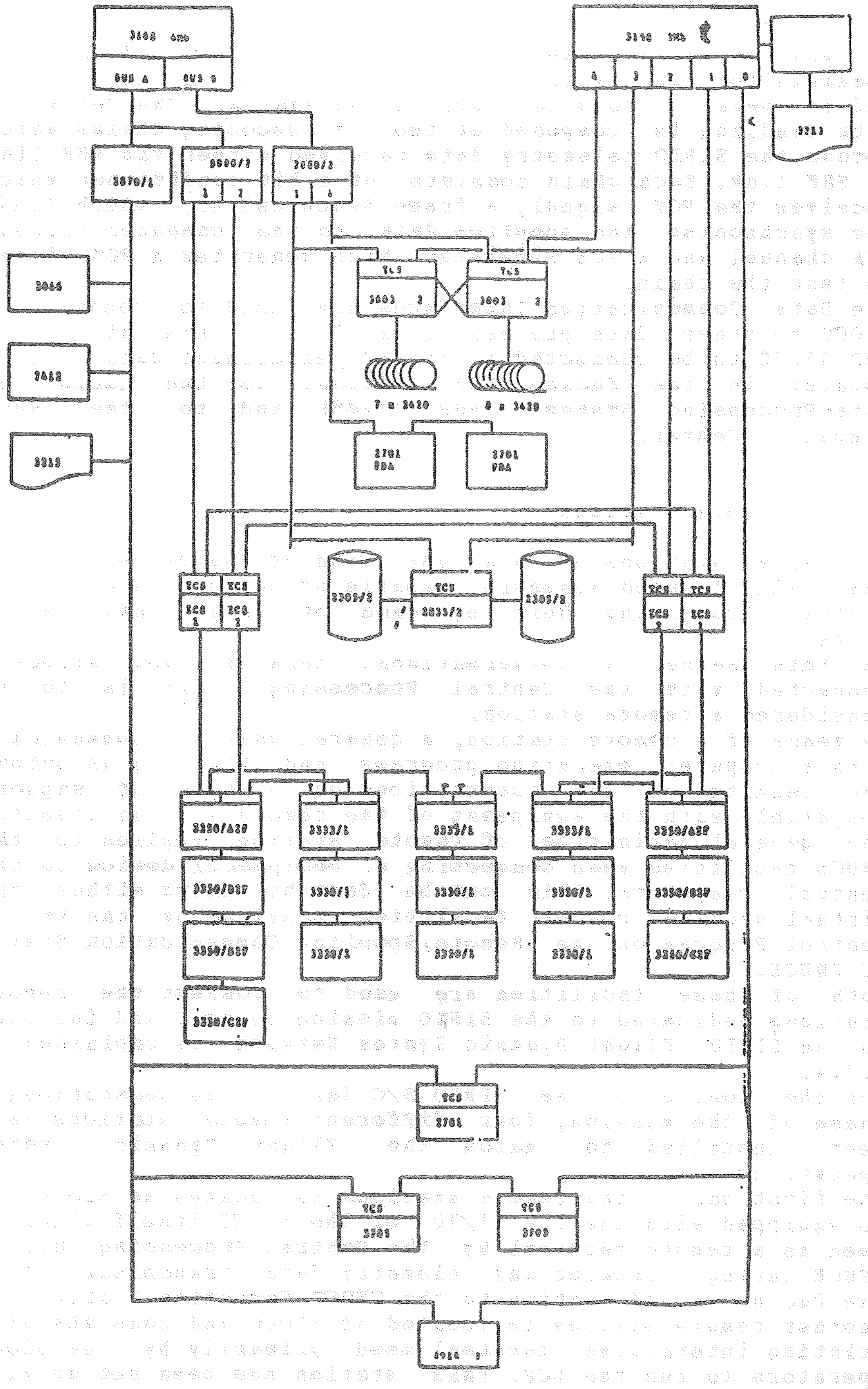

Fig. 13 - CNUCE Hardware Configuration

CNUCE and SIOCC operators.
The third remote station of the FDS network is used by the FDCG personnel in Pisa and is equipped with two terminal display units and one graphic display terminal.
The display units are normally used to execute the FDS programs during scheduled operations; the graphic display terminal is primarily used by the FDCG personnel to execute programs devoted to studies on FDS improvement and evolution and to graphic applications as well as the standard FDS programs.
The fourth remote station is located in Rome at the Telespazio Spa building and is equipped with one terminal display unit and with one IBM 3780 reader and printer; this staion is used by the OCG personnel during scheduled operations to execute the FDS programs.

4.1.4 Network

All the software and hardware resources so far described are assembled together in the Flight Dynamics System Network which allows the exchange of information between the Central Processing Units of the CNUCE Computing Center and the remote stations.
A baseline diagram of the network is shown in fig. 14.
The link between the SIOCC computer and the CNUCE Computing Center is half duplex, at 1200 bit/sec and is supported by a standard telephone line. Data are sent out on the communication link by PDP 11/70 by means of Synchronous Line Interface DU11. From the other side, the communication link is controlled by a Terminal Control Unit handled through the Remote Spooling Communication System of CNUCE.
Because the data transmission is one way, from SIOCC to CNUCE, any request of repetition of an information block by RSCS is ignored and the information itself is lost. However, the probability of loss of information due to errors in transmission for this type of communication link is negligible in percentage if this is compared with the amount of data to be transmitted and to the needs of input data for orbit determination and attitude determination programs.
The interactive terminal of SIOCC is connected to the CNUCE Computing Center by means of full duplex communication link, at 135 bit/sec. Executing the Flight Dynamics programs from this terminal implies a long period of connection time because of the low transmission rate of the line and the amount of data to be printed at the terminal.
The remote station of Telespazio is connected to the CNUCE Computing Center with a full duplex communication link, at 4800 bit/sec, which allows the Display Unit and the IBM 3780 to be connected at the same time at 2400 bit/sec of transmission rate.
This line more than satisfies the needs of the operations to be performed in this station.

FDS. It has to be mentioned that such a critical link has been implemented with the highest reliability.

- Pemote Stations: Keeping in mind that the stations have to be considered as components of FDS, the following cases of failure of hardware of the stations have to be considered:

  - FDCG station in Pisa: the station is fully redundant

  - DCG station in Rome: the OCG personnel is given the possibility of receiving the FDS outputs in case of failure of one or the other terminals because the outputs may be sent on the running unit from the FDCG station via the spool area.

  - First SIOCC station: all the main units of the PDP 11/70 have back-up except for the Central Processing Unit which is of the highest reliability. If the CPU should fail, no input data can be sent to CNUCE.

  - Second SIOCC station: the only task of this station is to activate the Link Control Program. If the interactive terminal should fail, the LCP may be activated from any other terminal at CNUCE.

- CNUCE Computing Center: As said in paragraph 4.1.1, the hardware configuration can be seen as a pool of peripheral devices which can be connected indifferently to both CPUs by means of the 2914 unit.
  This allows the modification of the configuration of both computers in a very flexible way.
  From this it results that:

  - failure of a single device is not critical because it is always possible to replace the unit with another one from the same pool

  - in case of failure of one of the CPUs all the units connected to it can be switched to the other CPU.

  - the disk units, where the FDS programs and files are stored, are, at fixed times, copied to other similar units, not on-line, which can replace the on-line units if these should fail.

4.2 Operating Systems

4.2.1 VM/370 Control Program and Conversational Monitor System

Virtual Machine Facility/370 is a system control program that manages a real computing system so that all its resources are available to many users at the same time. Each

user has at his disposal the functional equivalent of a real, dedicated computing system. Because this functional equivalent is simulated for the user by VM/370 and does not really exist, it is called a virtual machine.
VM/370 has two major elements:

- The control program (CP),which controls the resources of the real computer in order to provide multiple virtual machines.

- The Conversational Monitor System (CMS), a subsystem giving users a wide range of conversational, time sharing facilities, including creation and management of files, and compilation, testing and execution of problem programs.

While the control program of VM/370 manages the concurrent execution of the virtual machines, it is also necessary to have an operating system managing the work flow within each virtual machine.
For conversational users, the work flow for a virtual machine is managed by the CMS facilities; it is however possible for each virtual machine to use different operating systems or different releases of the same operating system.
CP provides each virtual machine with virtual device support and virtual storage; the operating systems themselves execute as though they were controlling real devices and real storage.

4.2.2 System/370 OS/VS2

The System/370 Operating System consists of a control program (a supervisor, master scheduler and job scheduler) together with a number of optional processing programs such as the language translator, utility programs etc. The processing programs are designed to help the user program solutions to problems and design new applications. They do this by giving the programmer a combination of programming aids, services and precoded routines that can use with appropriate language statements. Although the control program also assists the user, its primary functions are to efficiently schedule, initiate and supervise the work performed by the computing system.
The supervisor is the service and control center of the operating system. Its primary function is to perform a variety of services requested by the user's program, such as allocating storage space, performing I/O operations, loading programs into main storage and initiating the execution of programs.
The programs that are serviced by the supervisor can be either optional processing programs or user application programs. User-designed programs are usually intended for specific applications, and are normally prepared and

scheduled for execution using the supplied processing programs which provide the means by which programmers can use the supervisor services.
Among the processing programs, the master scheduler and the job scheduler are particularly relevant because together with the supervisor, they make up the control program, which to a large extent determines the basic nature of each operating system configuration. The master scheduler controls the overall operation of the computing system-operating system combination. The job scheduler enters job definitions into the computing system, schedules, and then initiates the performance of work under control of the supervisor.

4.2.3 Remote Spooling Communication System

The Remote Spooling Communication Subsystem is a component of VM/370. Together with the control program of VM/370, it controls telecommunication I/O devices and lines used to automatically transfer files between:

- VM/370 users and remote stations;
- Remote stations and other remote stations;
- VM/370 users and remote batch systems;
- Remote stations and remote batch systems;
- Remote stations and a CMS Batch virtual machine.

RSCS consists of a multitasking supervisor, system control tasks and line driver tasks.
The RSCS supervisor supports multiple system control and line driver tasks that may be active at any one time. This include multitask dispaching, the management of virtual I/O devices used by RSCS and the management of virtual storage required by each task.
The system control tasks provide common services to the line driver tasks and provide communication with the RSCS operator. These services include command execution, message distribution, program check handling, VM/370 spool system interface, and communication line allocation.
Each line driver task manages the transmission of files to and from a single remote station and provides a communication link for remote station operator commands. Due to functional and hardware differences in terminal equipment, each line driver is written to support a specific class of remote stations.

5. FDS forecasted evolutions

The description of FDS given in the previous paragraphs is actually the design of a system which is now in an advanced state of implementation. There are many reasons why, in the future, FDS could undergo changes or improvements. Some of these are described below:

- Changes in hardware or in operating systems at CNUCE: CNUCE is a computing center serving a large number of users working in many different fields of applied research. SIRIO represents for CNUCE a remarkable percentage of the load of the center and has high priority because of the responsibilities involved, because the time schedules may never be considered flexible and because the quality of the service required is the highest. However, the necessities of other users, changes in the hardware or software available on the market, price considerations or other reasons could cause the direction of CNUCE to modify the configuration of the Center as it is forecasted to be operating during the SIRIO mission period. In this case it will be necessary to take into account these changes and to adapt the system to the new configuration.

- Improvements to FDS data flow: It may happen that during the testing of FDS and during flight simulation it is found possible to make improvements. Especially as far as the data flow efficiency is concerned, we expect to see the possibility of optimizations.

- Upcoming requirements: New requirements for FDS could arise in connection with modifications of the ground system back-up or modifications of the mission plan. Provided that the proposed modifications do not imply conflicts in schedules, they will be implemented before the mission; otherwise, the modifications could be implemented on an experimental system and inserted in the prime system only when sufficiently tested.

- Evolutions of the System output requirements: During the operational life of the S/C, it may happen that the conversational output of FDS is required to be changed for the better understanding of the results, or for condensing them based on the needs of the software operators and analysts. These kind of changes are easily implemented and will be inserted in the system continuously.

- Enrichment of the system with storing and retrieving facilities of historical data: It will be easy to enrich the system with the possibility of storing data concerning the history of the various parameters which constitute the inputs or the outputs of FDS. Depending on the analysis that will be planned of the historical data, programming tools will be implemented in order to allow the analyst to search, retrieve, correlate or weight mediate the data he wants. These tools will have to be designed some months in advance before they are needed.

6. References

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