GALILEO MISSION ANALYSIS

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ABSTRACT

This is the report of the work done by the author in preparation and during his visit at the German Space Operation Center (GSOC) in Munich.
Two space missions have been considered in order to test SOAP (Satellite Orbit Analysis Program, by "The Aerospace Corporation"), have a first training with it and analyze how it could be used for successive studies. The GSTBV2 mission is defined as first step of the Galileo constellation. Agile is an Italian Low Earth Orbit satellite.
The work proceeded with the Galileo mission analysis. I evaluated each orbital perturbation alone and comparing the results with a reference case.
The last step was the study of GSTBV2 in-orbit maneuvers. At this point some problems, possible bugs, of the software were met.
The main results have been:
1) Preliminary SOAP results agree with the documented ones
2) Galileo out-of-plain maneuvers, the most expensive, can be excluded if the starting orbital parameters are carefully adjusted
3) The efficiency of GSTBV2 in-orbit maneuvers can be increased, if we spread the burn in subsequent orbits, as quasi-impulsive steps. In this way the total burn time reduces from 2.4/2.5 to 2.3/2.4 hours.

1 INTRODUCTION

The present document is divided in four sections.

The first part reports about preliminary tests of SOAP (Satellite Orbit Analysis Program, by "The Aerospace Corporation"). I have considered two space missions: GSTBV2 and Agile.
The GSTBV2 mission will have a Galileo type orbit in order to characterize MEO orbit environment, secure frequency filings and enable early experimentations. The present document gives a brief reconstruction of some orbital parameters and how they evolve in time. The starting osculating elements were: a =29601.297 km, e =2 E-03, i = 56 deg, RAAN = 150 deg, Argument-Perigee = 0 deg, Mean-Anomaly = 0 deg, Epoch = 18 Oct 2005.
AGILE is a Small Scientific Mission dedicated to high-energy astrophysics. The mission requirements impose a circular low Earth orbit. The nominal conditions are set to 550 km with 0.6° inclination. This document shows a preliminary analysis of the star sensor

obscuration periods. This happens when the Earth enters the star sensor field of view, it is a critical condition that must be predicted carefully.

The third section shows a Galileo mission analysis. The Galileo constellation will be formed of 27 satellites in a Walker 27/3/1 configuration at 23616km altitude and 56deg inclination. Three satellites will be injected in each orbit as spares.

SOAP includes as orbit perturbations: Earth gravity harmonics, Sun and Lunar third body gravities, atmospheric drag and solar pressure. Easy check boxes, into the Low Thrust Platform "*Perturbations*" menu, allow switching on or off each perturbation. The starting epoch was defined as 21 March 2003, mass 630kg and surface 2m^2.

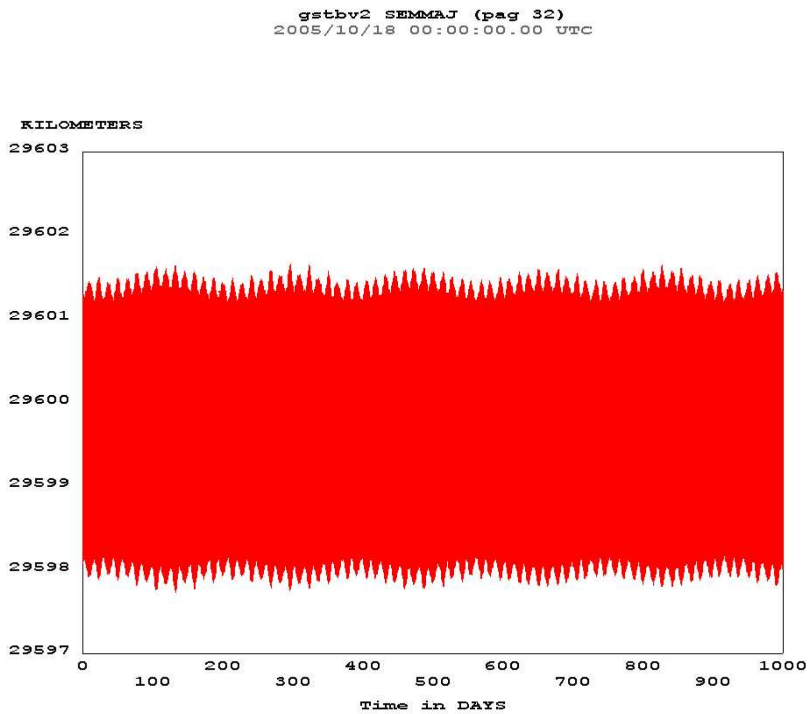
For the fourth and last part I have calculated the 180° drift maneuver, necessary to change the spacecraft in-orbit phase, of the GSTBV2 mission. I have analyzed first how make maneuvers with SOAP and then some possible implementations of the drift burns.

2 GSTBV2 TEST

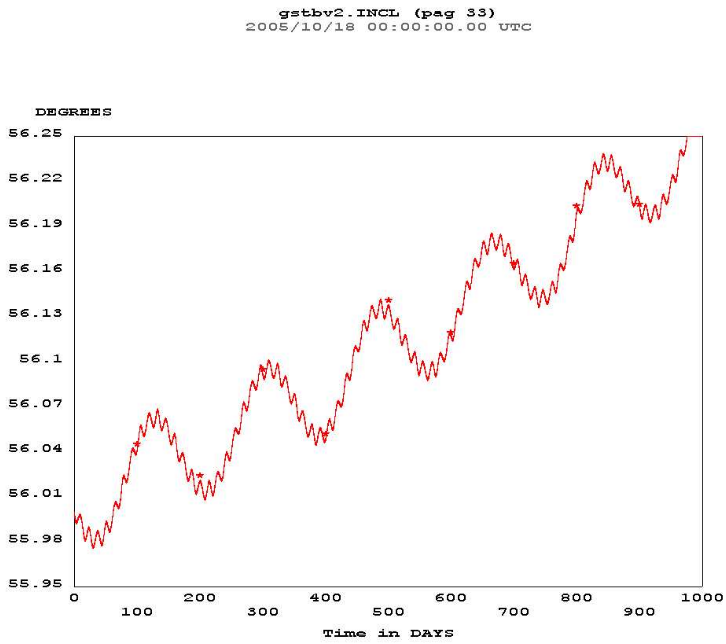
The following pages show some plots concerning time evolutions of the main orbital parameters obtained with SOAP.

Time evolution of semimajor-axis, inclination, right ascension and perigee altitude are reported for a three years mission. Then, using SOAP functions, the software can calculate some critical parameters as Earth and Moon eclipses and telemetry distance and coverage.

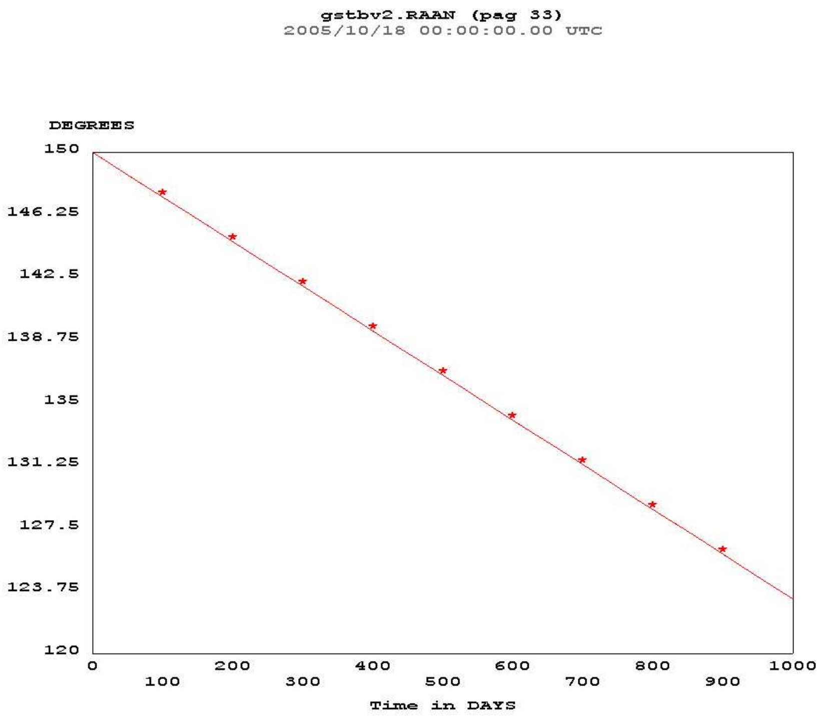
-Semimajor Axis



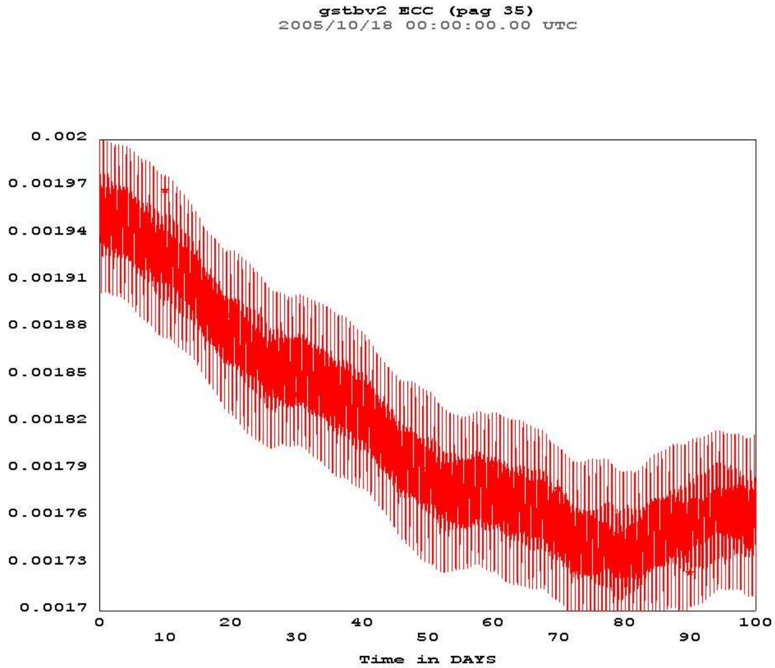
-Orbit Inclination



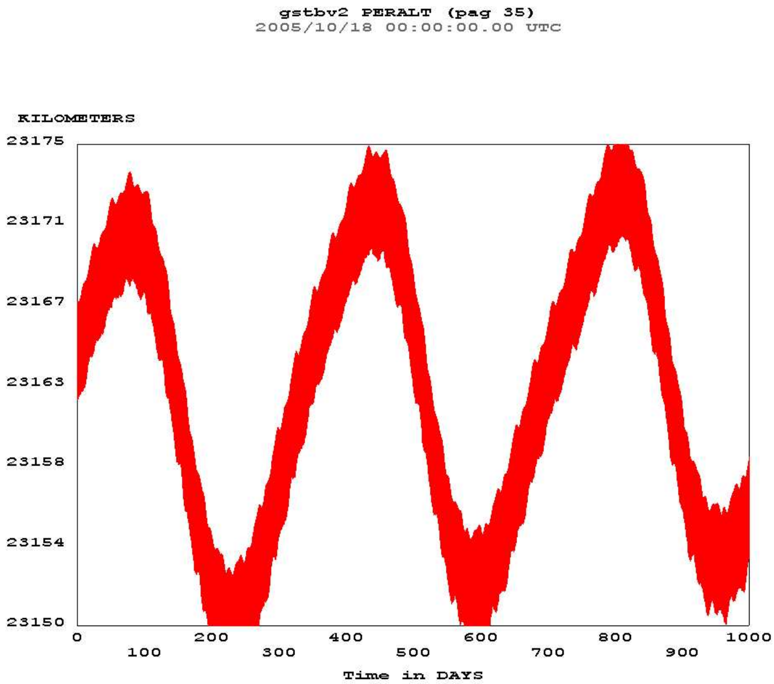
-RAAN



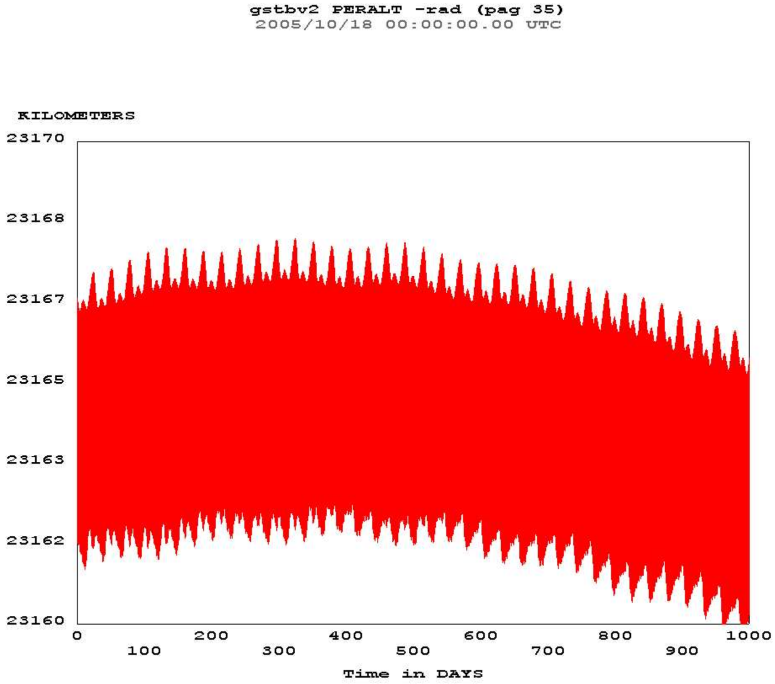
-Eccentricity



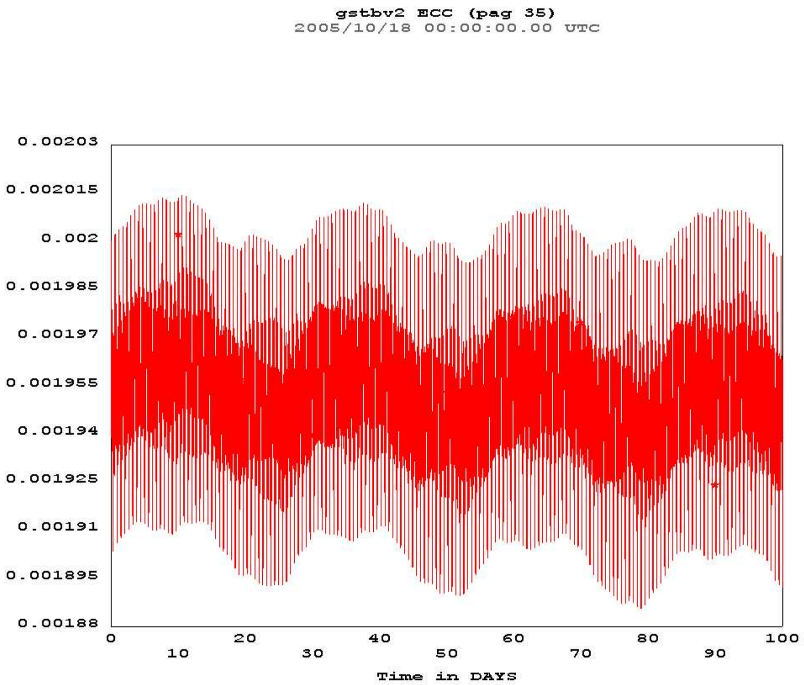
-Perigee altitude



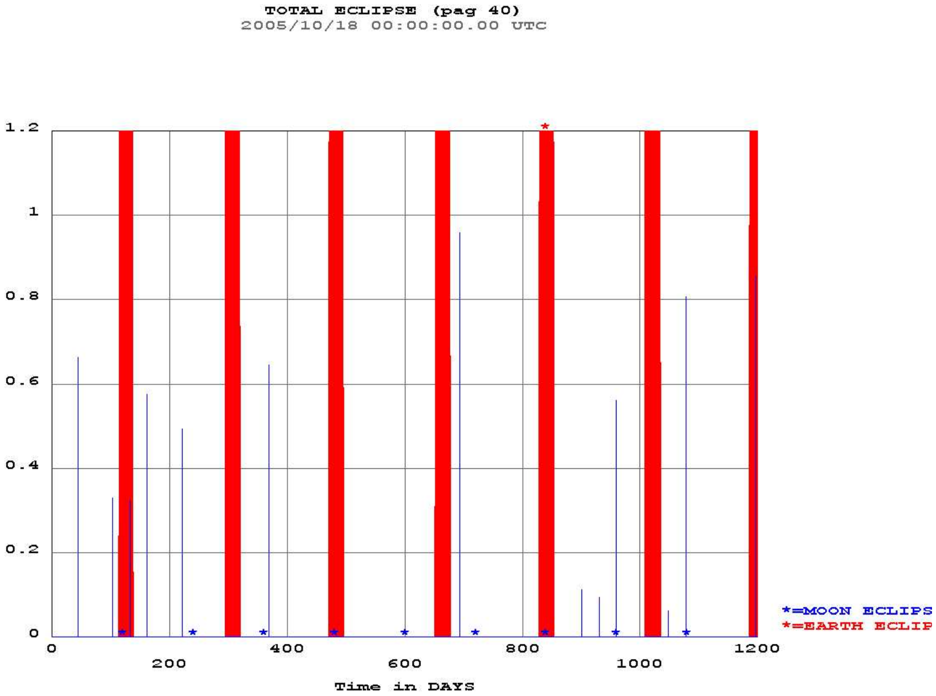
-Perigee altitude, without solar radiation pressure:



-Eccentricity, without solar radiation pressure:



-Eclipses by Earth (red) and Moon (blue)



The eclipse and umbra periods used the algorithms reported at pag213 of the SOAP manual. The shadow *Expression Analysis* was defined as:

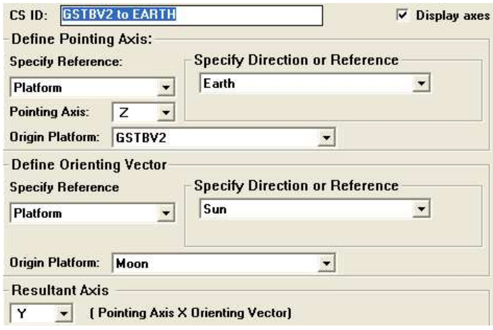
0.5+("SDMOON"-"SBTEND")/(2*"SDSUN")
0.5+("SDEARTH"-"SBTEND2")/(2*"SDSUN")

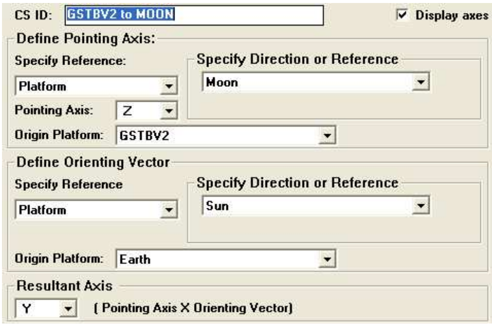
and SDMOON, SDSUN AND SDEARTH *Expression Analysis* were:

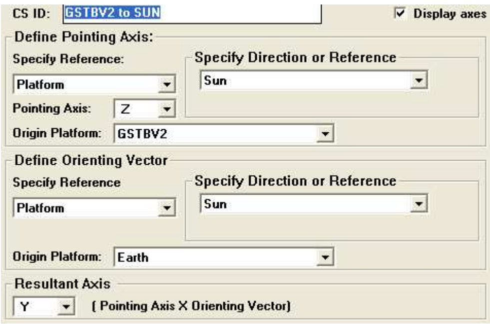
asin("RMOON"/"RGM")
asin("RSUN"/"RGS")
asin("REARTH"/"RGE")

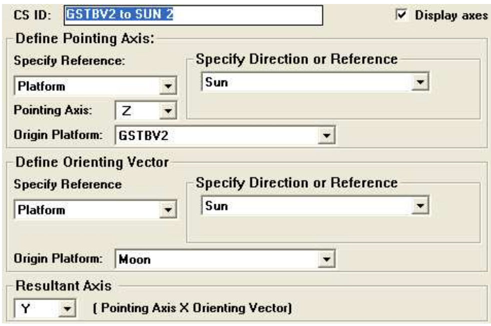
RGM was a Cartesian Position Analysis of the type RANGE_MAGNITUDE with GSTBV2 as platform1 and Moon as platform2. RMOON is the radius of the Moon. SBTEND is an Angular Position Analysis of the type INCLUDE_ANGLE with "*GSTBV2 TO Moon*" as CS1, "*GSTBV2 TO Sun*" as CS2, Moon as ORIGIN1 and Sun as ORIGIN2.
The Coordinate system "*GSTBV2 to Moon*" was defined, with Moon as "*Specify direction or reference*" of the "*Define Pointing Axis*":

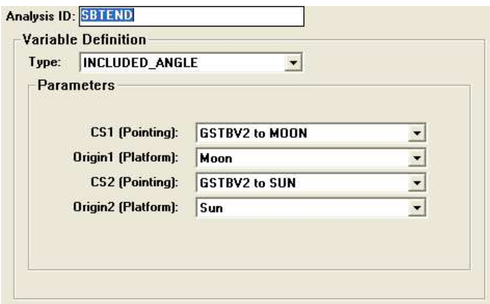
- Examples of SOAP Expression Analysis used studying the eclipse periods:

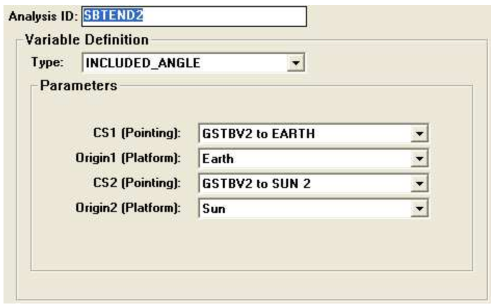




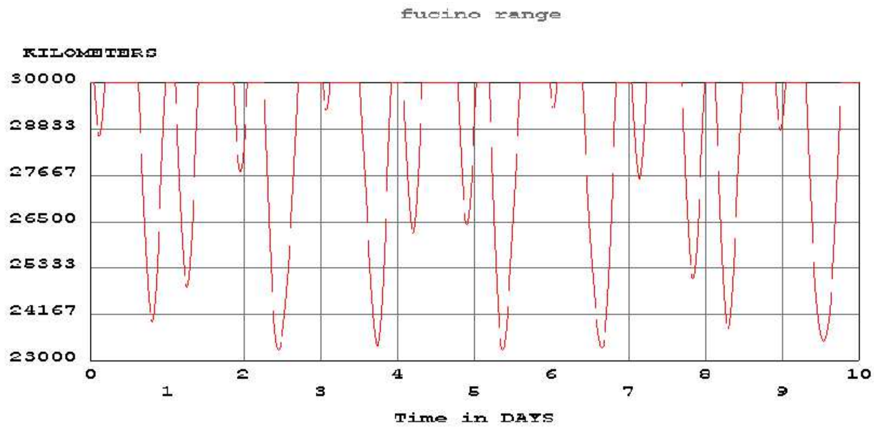


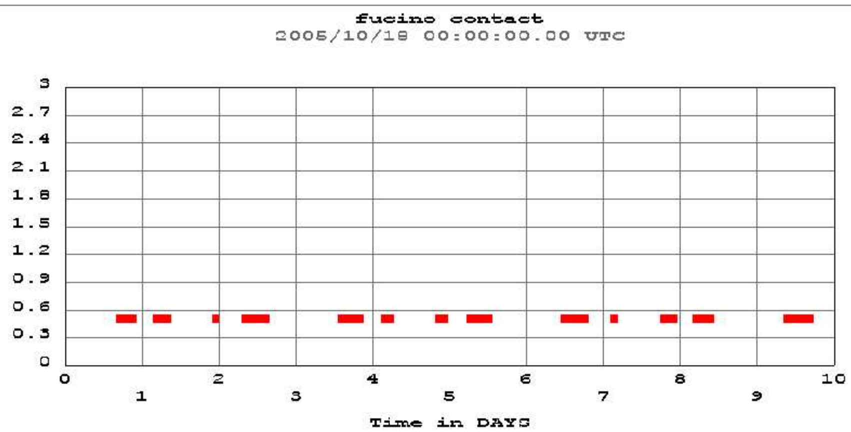






-Fucino Telemetry Center *Range* and *Coverage*

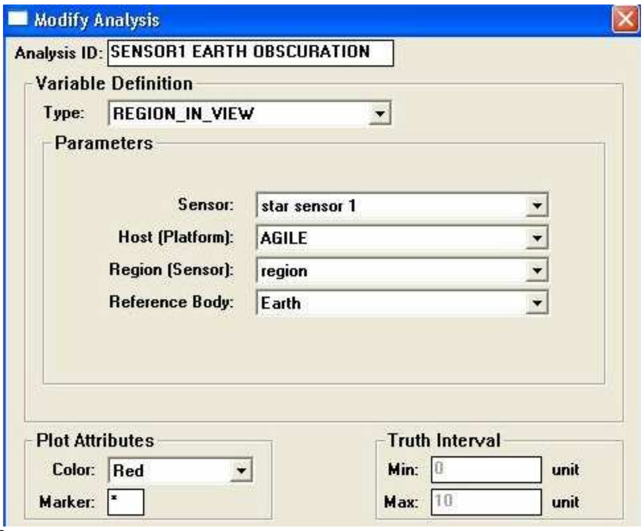


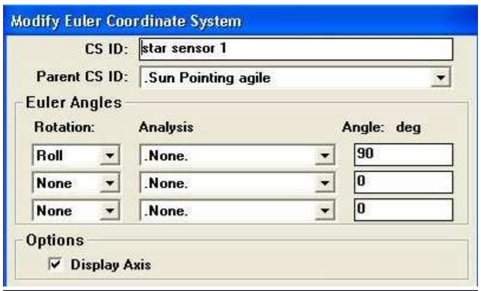


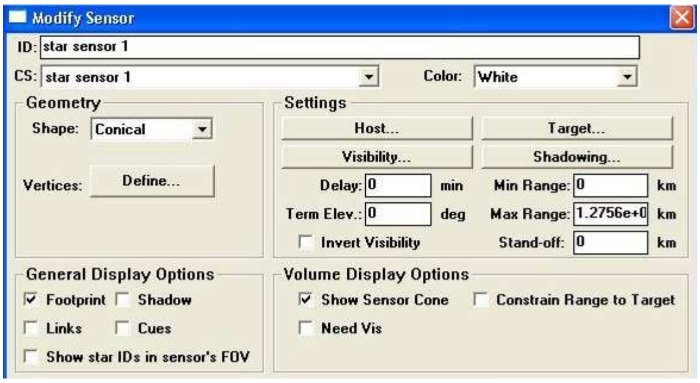
3 AGILE TEST

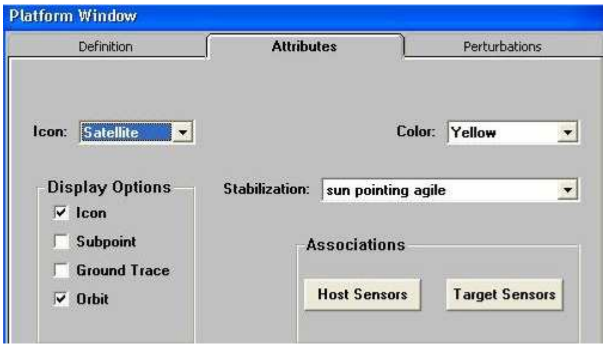
The spacecraft attitude was defined as *SunPointing*, to maintain the solar panels towards the Sun. The two sun sensors were defined with a roll inclination of 90 and 270° by defining two appropriate *CoordinateSystems*. The next pictures show the SOAP *Functions* defined to solve the sensor obscuration problem. The results are reported by the last image. The red line represents the time interval when the Earth is inside the field of view of the star sensor. When this happens the sensor does not work properly.

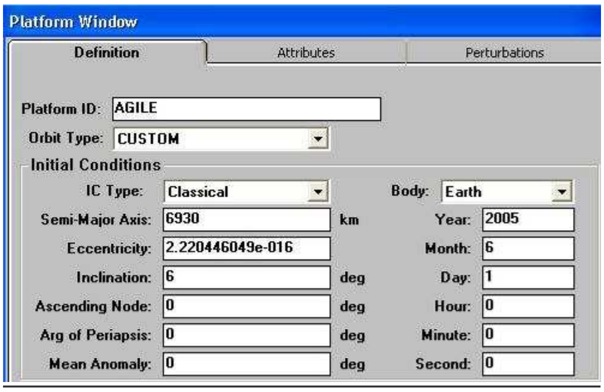
- SOAP *Functions* defined to compute the star sensor obscuration problem:



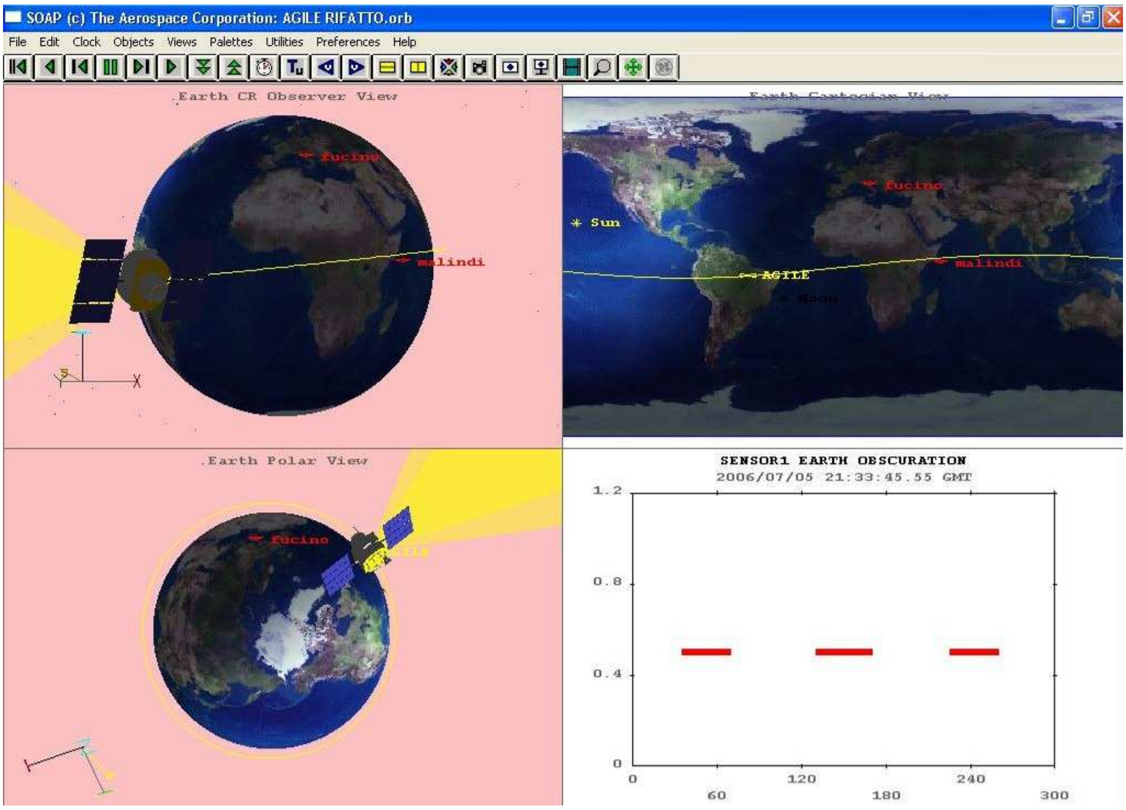








- Example of SOAP output for the Agile mission analysis:



4 GALILEO ORBIT PERTURBATIONS

In order to facilitate the comparison of different effects of the orbit perturbations, a reference case has been defined which includes only the zonal perturbation terms in the Earth potential. This is done by making the "*GAL01 ref*" Low Thrust Platform, where only the "*oblateness (j2…)*" perturbation is switched on into the "*Perturbations*" menu.
The orbital parameters were plotted using Orbit Paramiters Analysis like "*GAL01 ref.INC*" where the platform "*GAL01 ref*" has been selected via "*Satellite*" pull-down menu and "*Inclination*" with "*Type*" pull-down menu.
The orbital Phase was constructed as ω+τ (where ω is the argument of the perigee and τ the true-anomaly) using Expressions Analysis, where the previous formula can be written directly; for example the phase for "*Gal01 ref*" satellite:

> *("GAL01ref.ARGPERAPS"+"GAL01 ref.TRUEAN")-((("GAL01ref.TRUEAN" + "GAL01ref.ARGPERAPS")>=6.2832*"[Rad]")*6.2832*"[Rad]")*

This expression was necessary to normalize the angle between 0 and 2π. "*GALxx.TRUEAN*" and "*GALxx.ARGPERAPS*" are Orbit Parameter Analysis of the Low Thrust Platforms *GALxx*.

The phase differences were normalized between -π and π whit expressions like:

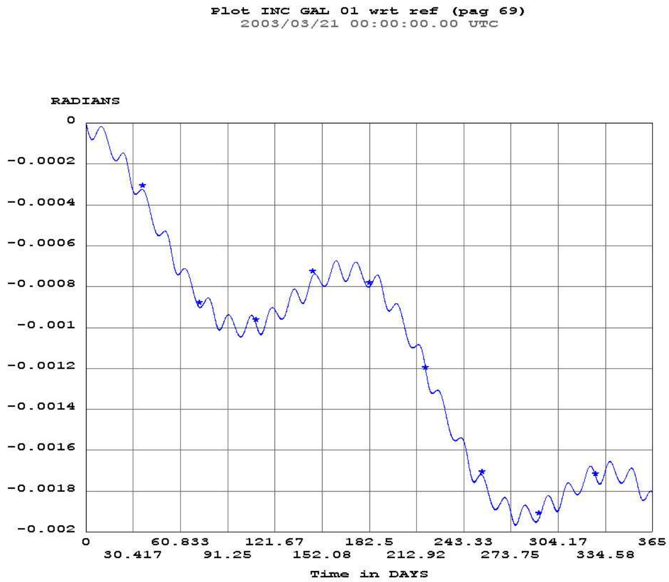
> *"GAL 01 ref+sunlungrav PHASE" - "GAL 01 ref PHASE"-(abs("GAL 01 ref PHASE" - "GAL 01 ref+sunlungrav PHASE")>3.1416*"[Rad]")*6.2832* "[Rad]"*abs("GAL 01 ref PHASE" - "GAL 01 ref+sunlungrav PHASE")/("GAL 01 ref PHASE" - "GAL 01 ref+sunlungrav PHASE")*

As starting parameters we have considered:
Sma=29995.51km, Ω=0, ω=0, e=0.002, i=56deg, mean=0deg

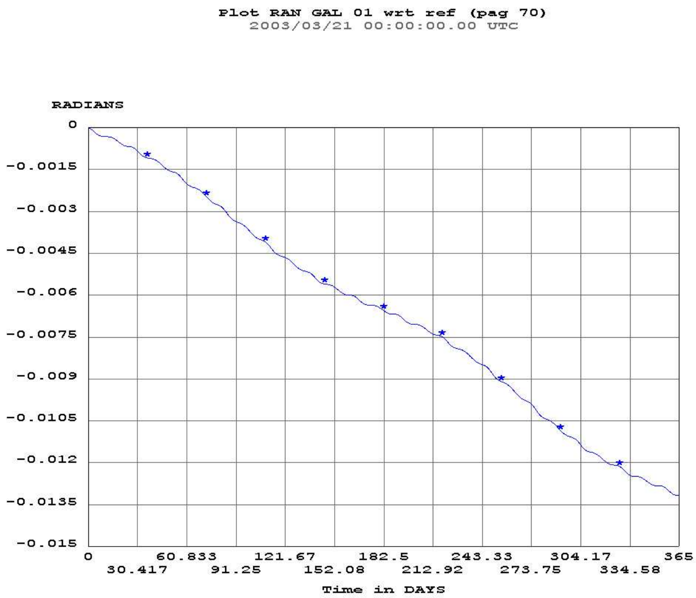
4.1 Sun and Moon Gravity Perturbation

The Low Thrust Platform "GAL 01 ref+sunlungrav" has been defined. The oblateness, lunar third body and solar gravity perturbations were switched on.

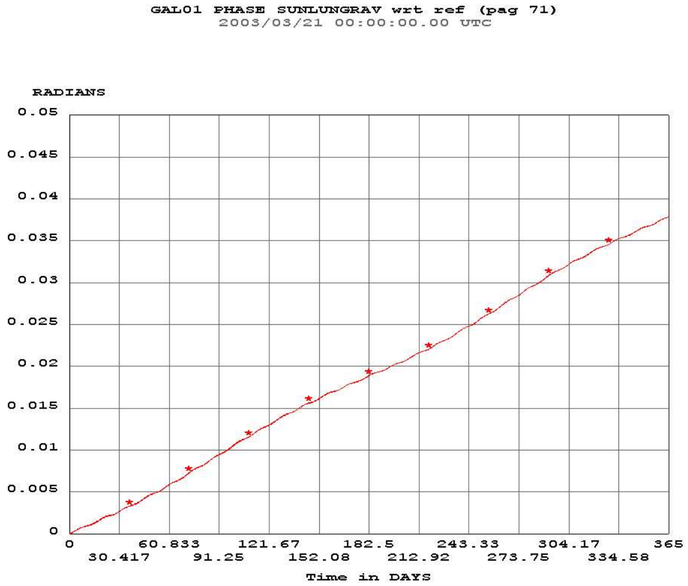
- Difference in inclination wrt the ref case



- Difference in RAAN wrt the ref case



• Difference in phase angle wrt ref case

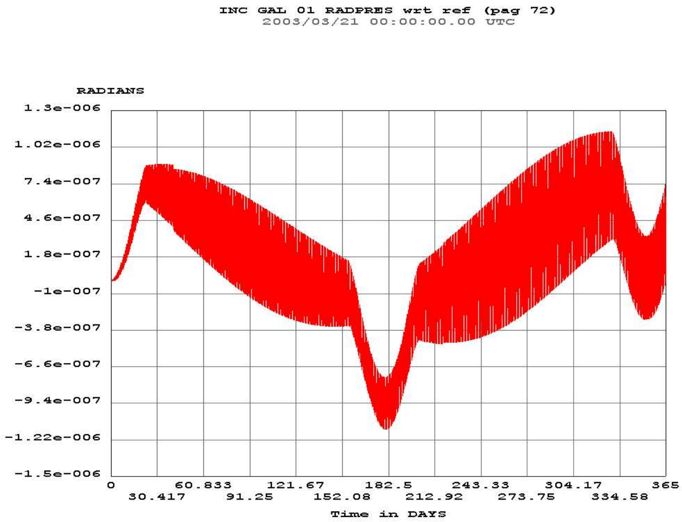


4.2 Solar Pressure Perturbation

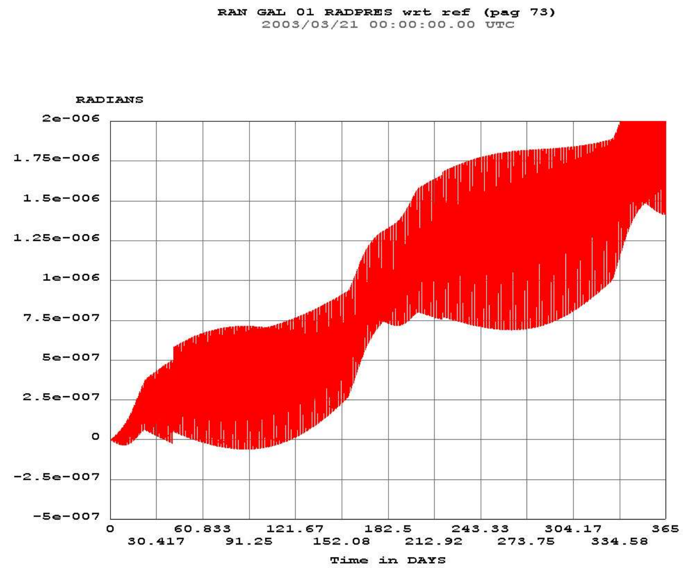
The Low Thrust Platform "*GAL 01 ref+radpres*" has been defined. The oblateness and solar radiation pressure perturbations were switched on. Considering eccentricities lower than 0.0001 the phase daily oscillations were removed. The best reconstruction of the reported graphs was made with reflectivity of zero. Solar pressure perturbation computed by SOAP doesn't take into account solar flux F10.7 variations.

4.2.1 Spacecraft Attributes: reflectivity = 1 (totally reflecting body)

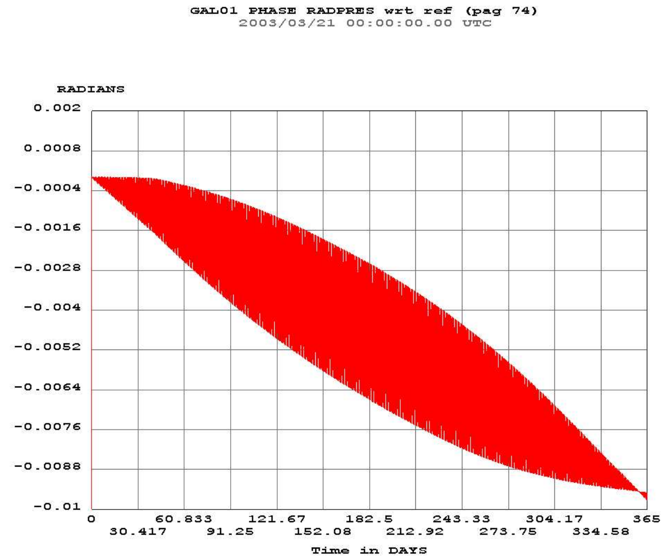
- Difference in inclination wrt ref case



- Difference in RAAN wrt ref case

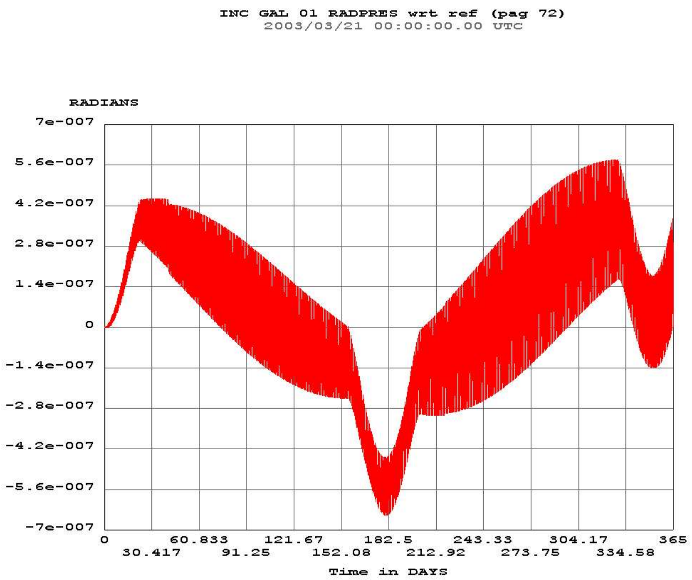


- Difference in phase angle wrt ref case

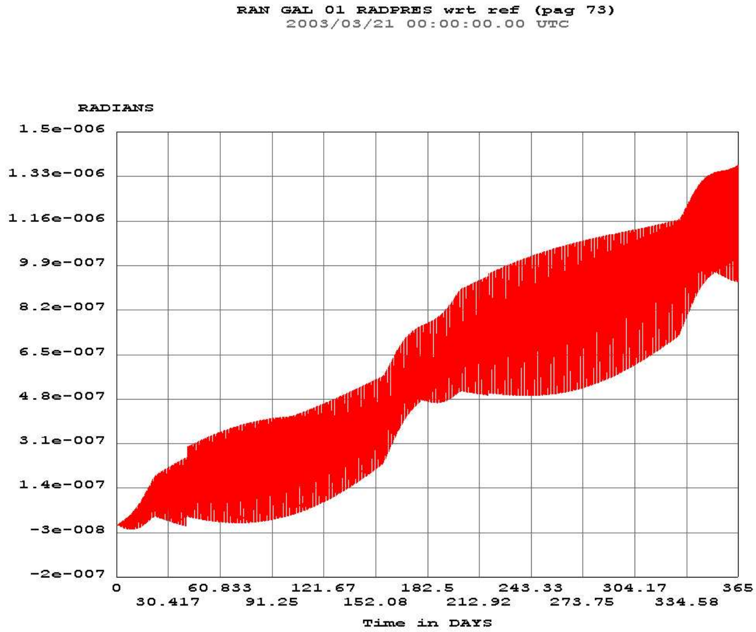


4.2.2 Spacecraft Attributes: reflectivity = 0 (totally absorbing body)

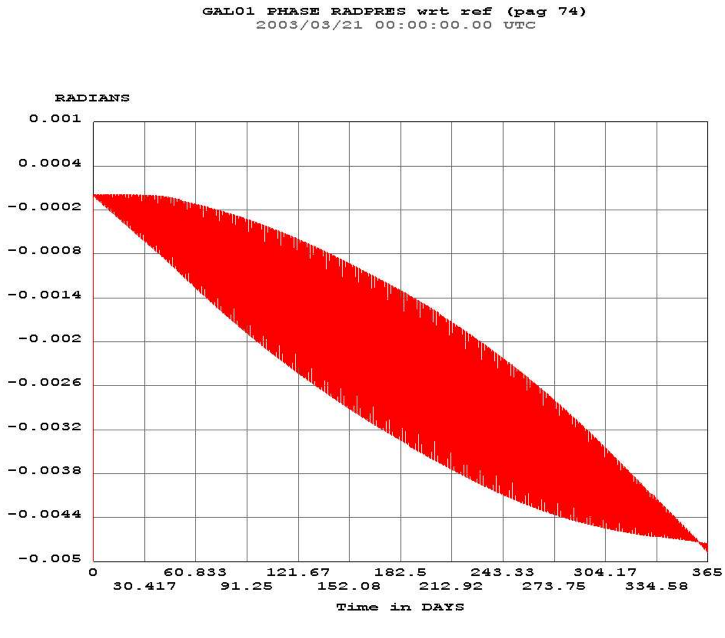
- Difference in inclination wrt ref case



• Difference in RAAN wrt ref case



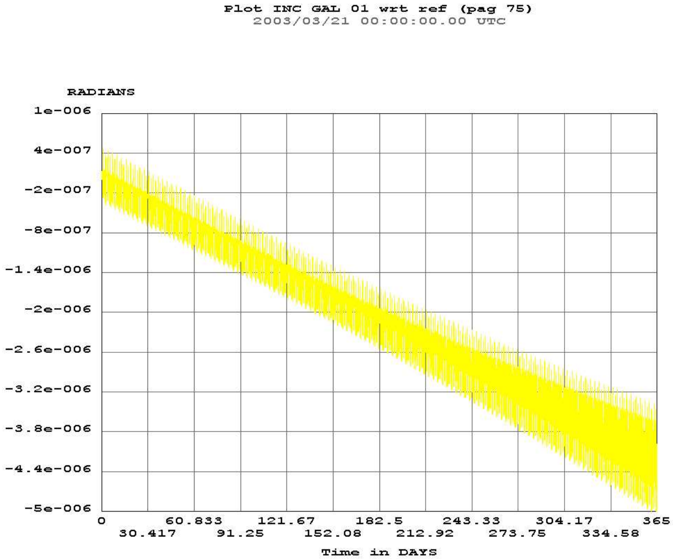
• Difference in phase angle wrt ref case



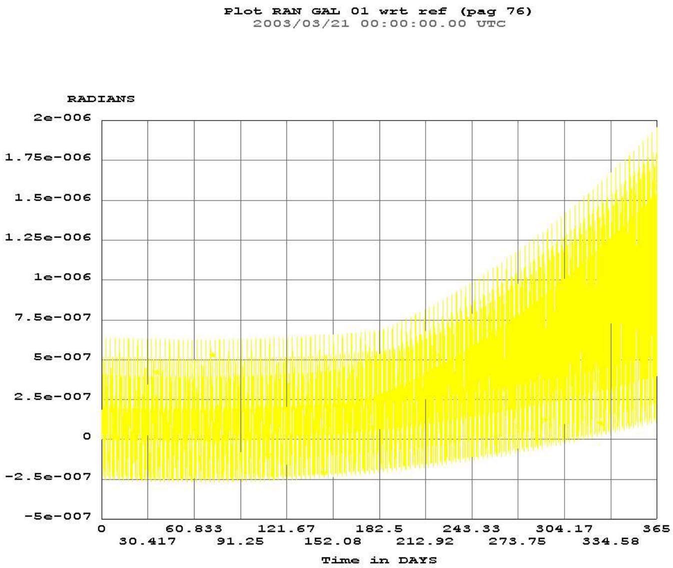
4.3 Tesseral Perturbation

The Low Thrust Platform "GAL 01 ref+tess" has been defined. The oblateness and tesseral gravity perturbations were switched on.

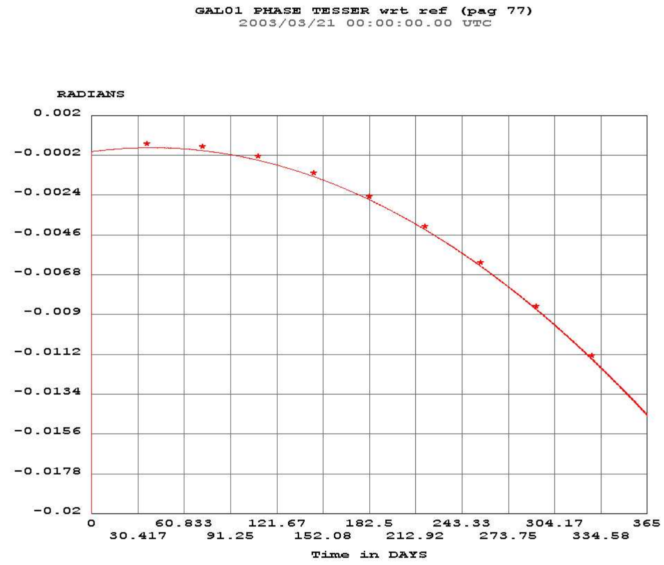
- Difference in inclination caused by tesseral terms in Earth gravity field wrt ref case



- Difference in RAAN wrt ref case



• Difference in phase angle wrt ref case

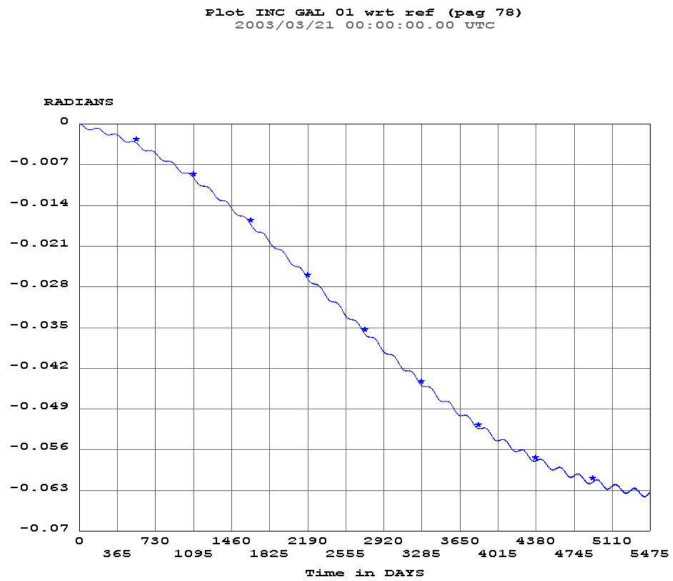


4.4 Total perturbation

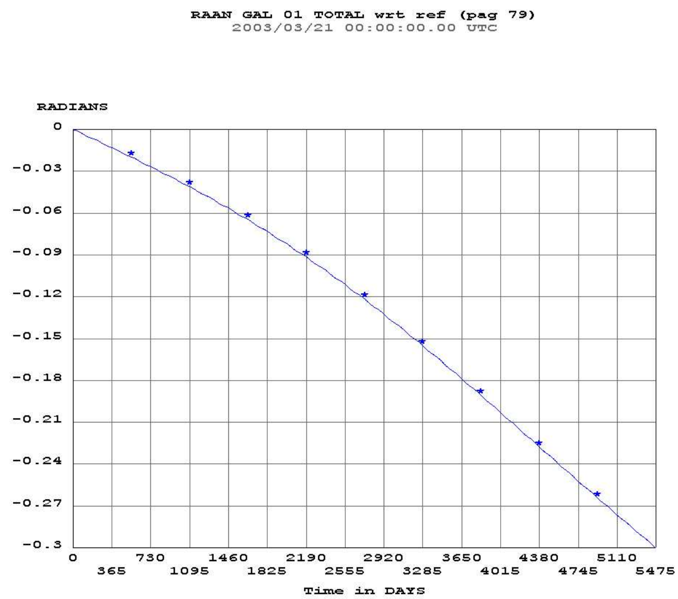
The Low Thrust Platform "*GAL 01 LT*" has been defined. All the perturbations were switched on excluded only air drag, which has a negligible effect at the considered altitudes. The spacecraft reflectivity has been defined as 0 (totally absorbing body)

4.4.1 Starting parameters: Sma=29995.5km, Ω=0°, ω=0°, e=0.002, i=56°, mean=0°

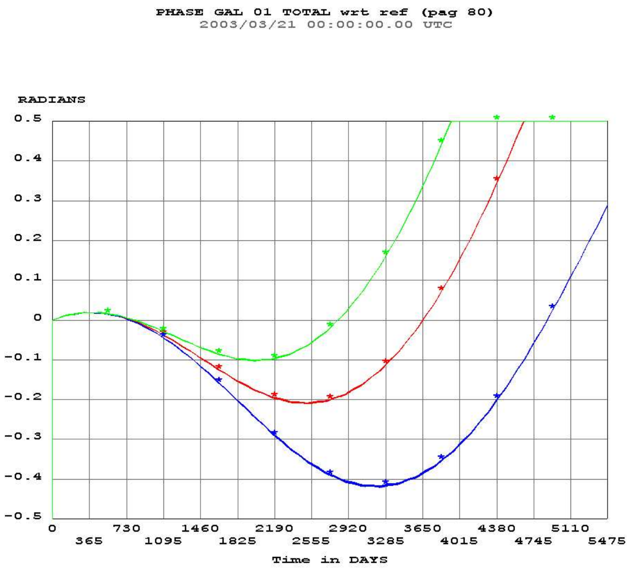
• Difference in inclination wrt ref case



• Difference in RAAN wrt ref case



• Difference in Phase wrt ref case



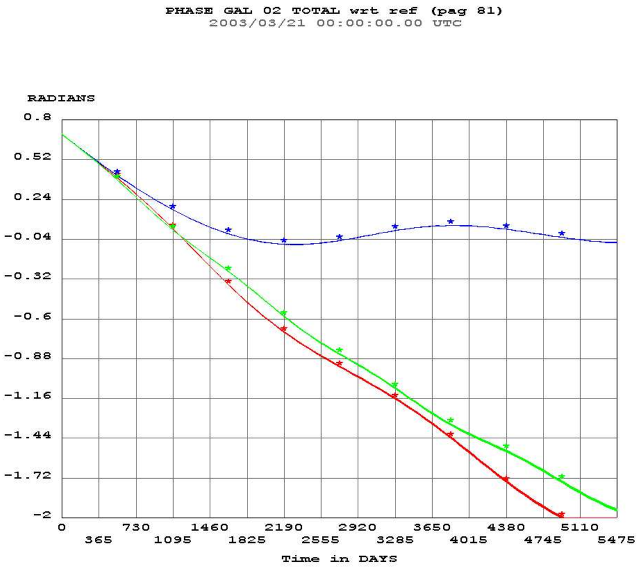
The blue line is computed using reference and perturbed cases with sma=29995.3km, the green one has sma=29995.7km. Big differences can be seen with little variations in starting semimajoraxis.

The platforms "*Gal01.3 LT semmajvar*" and "*GAL 01.3 ref*" and the analysis "*GAL01.3 xxxx*" and "*GAL 01.3 ref xxx*" have been defined where the only variation is the starting sma.

4.4.2 Starting parameters: Sma=29995.5km, Ω=0°, ω=0°, e=0.002, i=56°, mean=40°

The Low Thrust Platform "*GAL 02*" has been defined as previously done for "*GAL 01 LT*"

• Difference in phase angle wrt ref case ("*GAL01 ref*"), totally perturbed

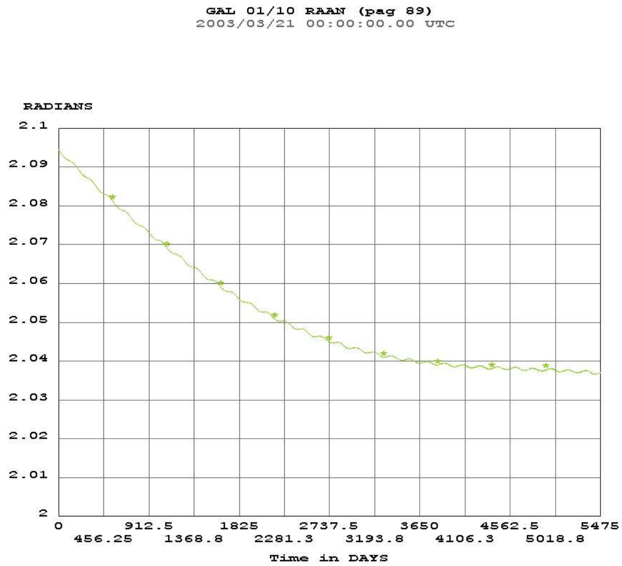


The blue function was computed using starting sma of 29994km instead of 29995.51, for both reference and perturbed platforms. The geen line has sma=29997. The Low Thrust Platforms "*GAL02.5 lt*" and "*GAL02.6 lt*" were realized.

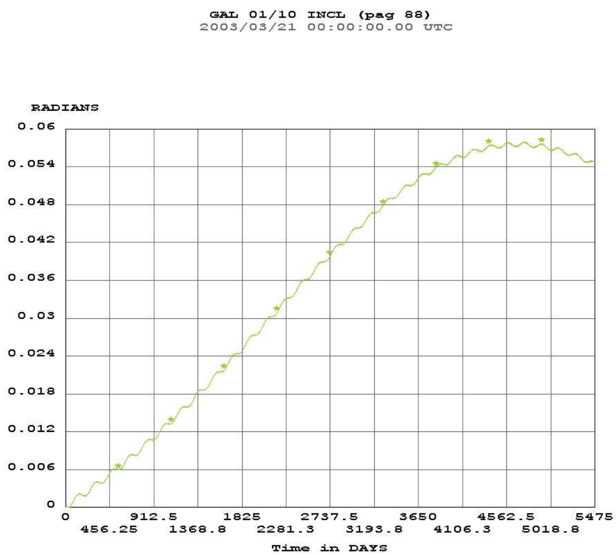
4.4.3 Starting parameters: Sma=29995.5km, Ω=120°, ω=0, e=0.002, i=56°, mean=13.3°

The Low Thrust Platform "*GAL 10*" was defined as previously done for "*GAL 01 LT*"

- Difference in RAAN wrt ref case (*GAL01 ref*), totally perturbed



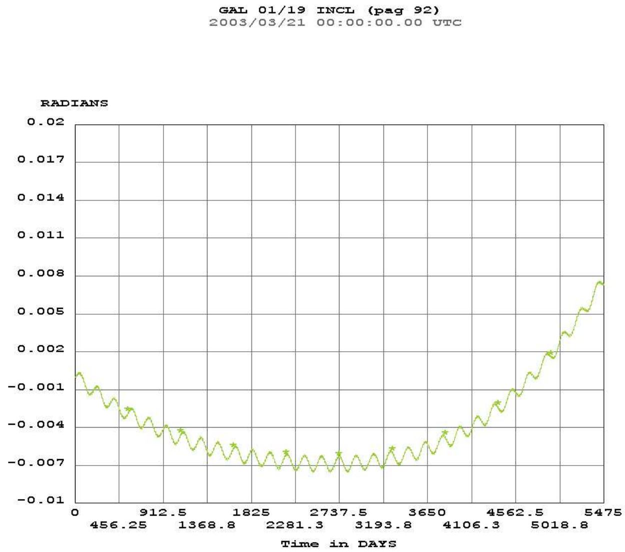
- Difference in INCL wrt ref case (*GAL01 ref*), totally perturbed



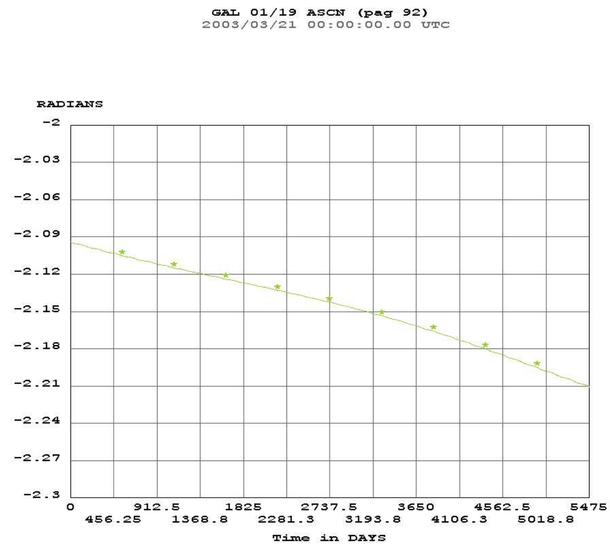
4.4.4 Starting parameters: Sma=29995.51km, Ω=240°, ω=0°, e=0.002, i=56deg, mean=26.66°

The Low Thrust Platform "*GAL 19*" was defined as previously done for "*GAL 02 LT*"

• Difference in INCL wrt ref case (*GAL01 ref*), totally perturbed



• Difference in RAAN wrt ref case (*GAL01 ref*), total perturbation



4.5 Optimization of starting inclination and RAAN

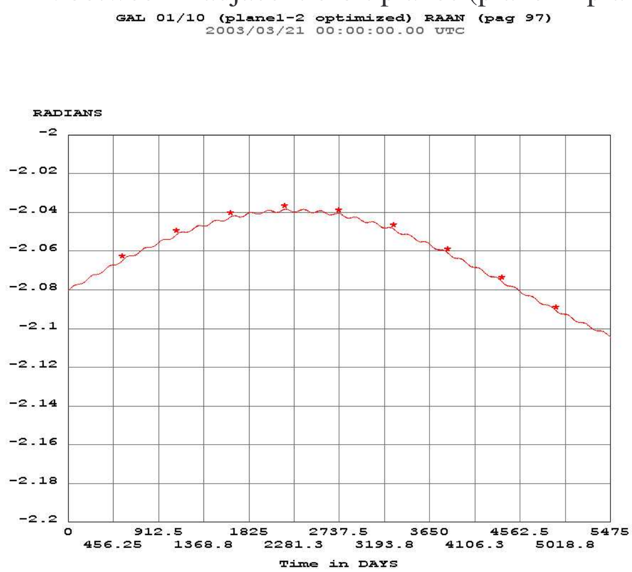
The requirements for orbit keeping are +/- 2 deg for inclination, +/-2deg for relative spacing of nodal lines and +/-3deg for relative phasing of adjacent satellites in one orbit. These conditions should be obtained by using appropriate starting values for inclination, RAAN, semi-major-axis and phase. <u>In this way out of plane maneuvers could be avoided</u>. The reported optimal starting values for each plane are:

Plane	Inclination (deg)	RAAN (deg)
1	55.8	5.3
2	52.4	124.5
3	53.9	243.9

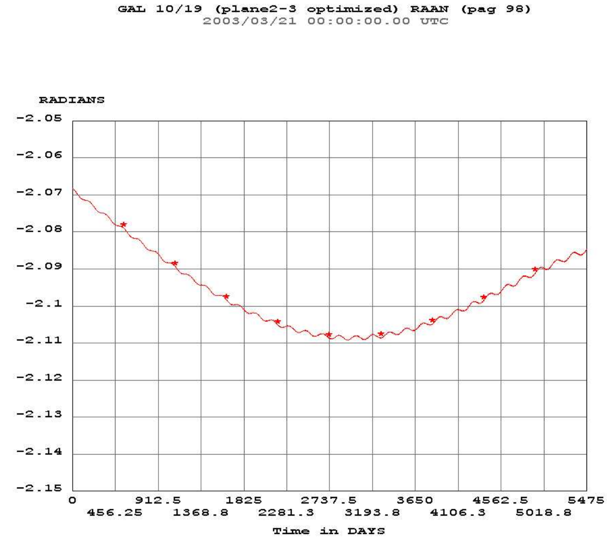
Low Thrust platforms "*Galxx lt (optimum)*" have been defined with these parameters.

The computed variation of difference in RAAN showed a maximum around 2 deg from the starting value, 6-8 years after launch:

- Difference in RAAN between 2 adjacent orbit planes (plane1 - plane 2)

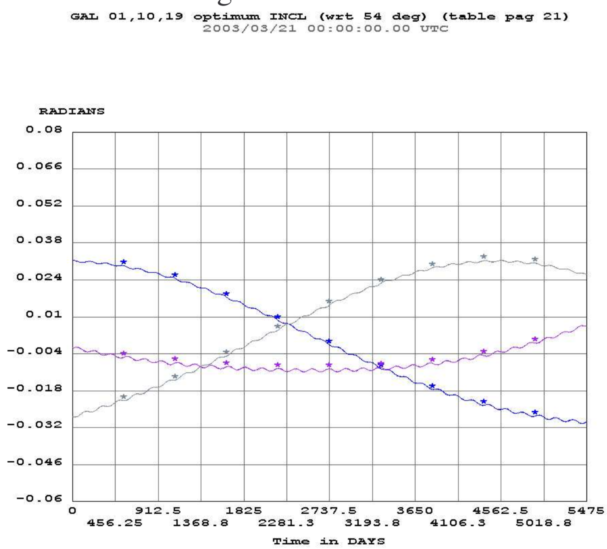


• Difference in RAAN between 2 adjacent orbit planes (plane2 - plane 3)



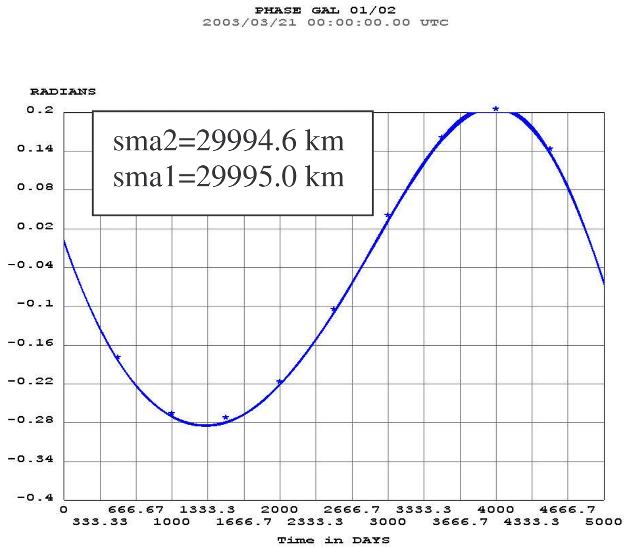
The variations of inclination are less than 2 deg:

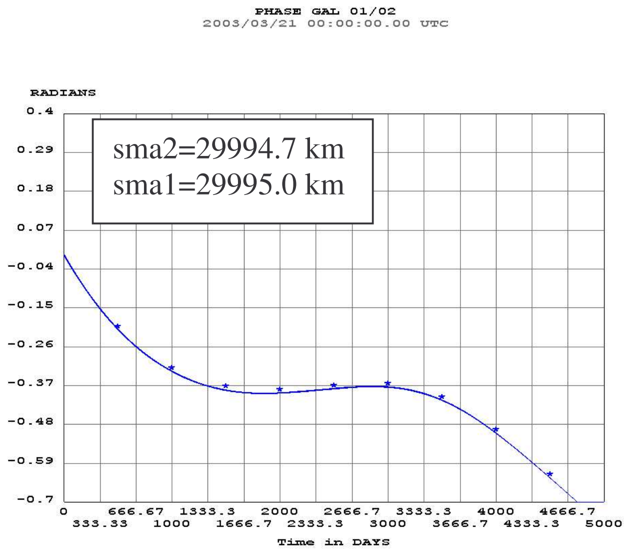
• Inclination bias wrt nominal 54 deg



In orbit relative phase variations need a starting sma and phase optimization to be minimized. Here I report examples of phase difference variations for different starting semi-major-axis:

- Phase difference variation, wrt nominal 40 deg, for satellites "*GAL 01*" and "*GAL 02*" (plane 1, starting phases: 0 and 40 deg).





Examples of maximum phase excursions (deg) for Sma1=29995.3km :

Sma2	29994,5	29994,6	29994,65	29994,7	29994,8	29995	29995,5	29996
$\|\Delta\Phi_{max}\|$	1,9	0,5	0,7	0,9	1,1	1,3	2,8	4

5 GSTBV2 DRIFT MANEUVER

This section is a brief example of how the drift maneuvers, considered for the mission GSTBV2, can be analyzed using Soap. It is divided into 3 paragraphs:

- Hohmann transfer computation with Delta-Vs (impulsive maneuver): a preliminary example used to test the Soap performance and define methods.
- 180deg Gstbv2 drift with Delta-Vs: the most costly drift maneuver is simulated using the impulsive method.
- 180deg Gstbv2 drift using Low Thrust platform: the same case using finite burn analysis.

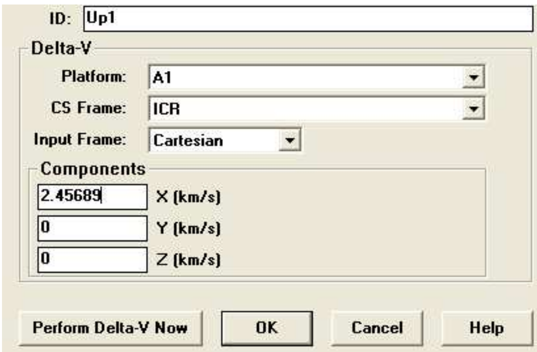
5.1 Hohmann transfer

5.1.1 Calculations

A simple Hohmann transfer is here performed in order to test the SOAP Delta-Vs output. The start and final circular orbits have 6570 and 42160 km radius. Computing their velocity ($V_c^2=\mu/r$, $\mu=398600{,}5$ km^3/s^2) we obtain: $V_{c1}=7{,}78908$ and $V_{c2}=3{,}07481$ km/s. The transfer orbit has $V^2=2\mu/r-\mu/a$ and $2a=r_1+r_2=24365$ km, so at perigee the velocity is 10,24597 km/s and at apogee it is 1,59668 km/s. The first Delta-Vs will be 2,45689 km/s and the second 1,47813 km/s.

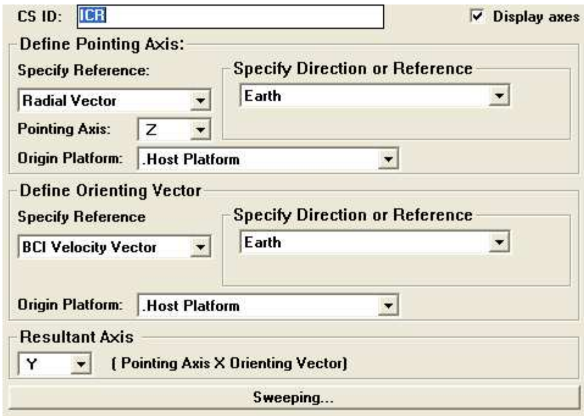
5.1.2 Simulation

The first burn can be performed by the Delta-Vs menu as follow:



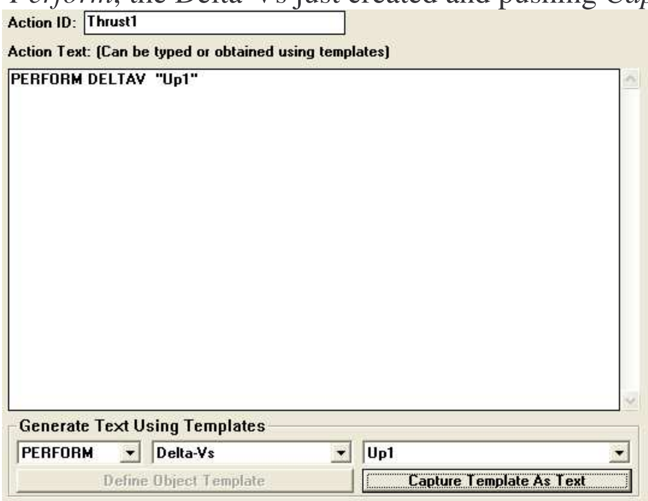
The *Platform* and the Ref System must be chosen. Then the thrust can be applied defining its Cartesian components.
Note that the *Platform* pull-down menu should have all the satellites previously defined as *Keplerian*, *Low Thrust* and *Norad*, where the Delta-Vs should be applied (as defined by the Soap Manual chapter19, pag294) but the Low Thrust Platforms are not present. So only Keplerian Platforms can be considered.

The ICR (*Intrack Crosstrack and Radial*) reference system must be used in order to define the thrust vector to respect the platform velocity. In the present example the reference system is defined using the *Coordinate Systems* menu as shown:



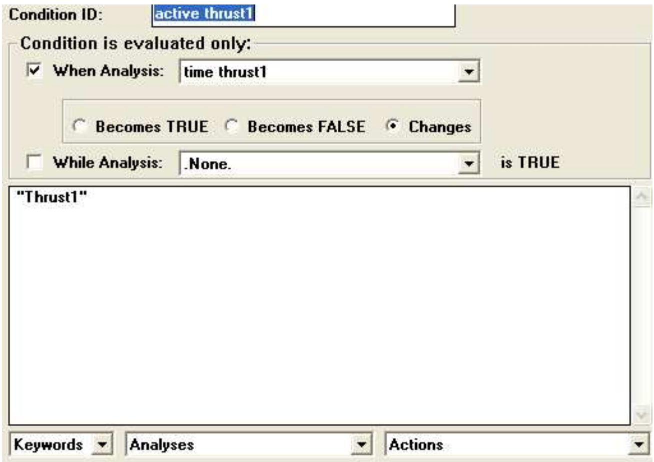
Note that the *Z* axis will be along the radial vector to respect the Earth but the *X* axis will be defined as the cross product of the *Pointing Axis* and the *Orienting Vector* (see Soap manual chapter 8, pag132) and so it will be oriented along the platform velocity only for circular orbits or at perigee and apogee of an elliptical orbit.

Then the Delta-Vs *Action* must be created using the pull-down menu on the left of the window, choosing: *Perform*, the Delta-Vs just created and pushing *Capture as text*.

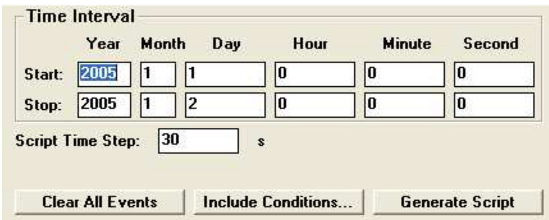


Now we must define the *Condition* that will be used for the maneuver. Time based conditions are used in the examples of Soap manual and Libraries. First an *Elapsed_time* Analysis must be defined:

This function will become true at the indicated time.
After this step the *Condition* is computed:



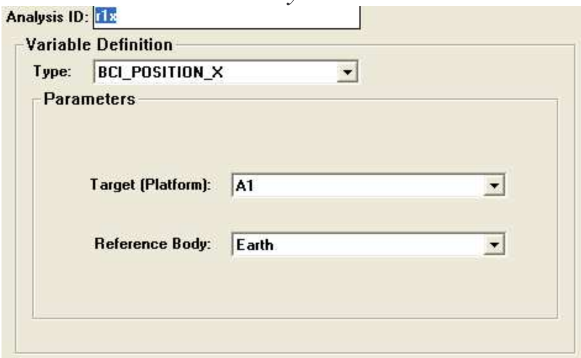
and a *Script* created using the *Utilities* Soap menu:



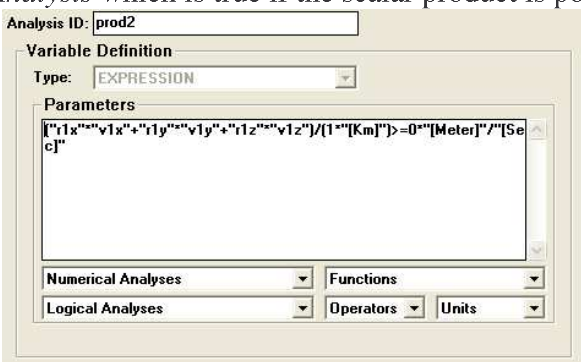
Note that the activation time must be inside the *Start* and *Stop* interval. By the *Include Conditions* menu the activation condition is chosen and then the *Generate Script* button pushed.

The <u>second burn</u> can be defined using the same method. After a semi period a second maneuver can be performed defining a new Elapse_time *Analysis*.

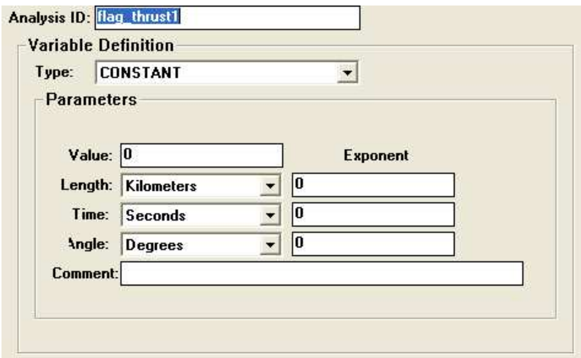
Another way is let Soap to understand when the apogee of the transfer orbit is reached. The scalar product of the satellite radius and velocity vectors will pass from positive to negative values at apogee. In this way the transfer orbit can be moved changing only the Elapsed_Time of the first burn, the second one will be changed consequently.
First the radius and velocity vectors components (r1x, r1y, r1z, v1x, v1y and v1z) must be defined as *Cartesian Position* and *Velocity*:



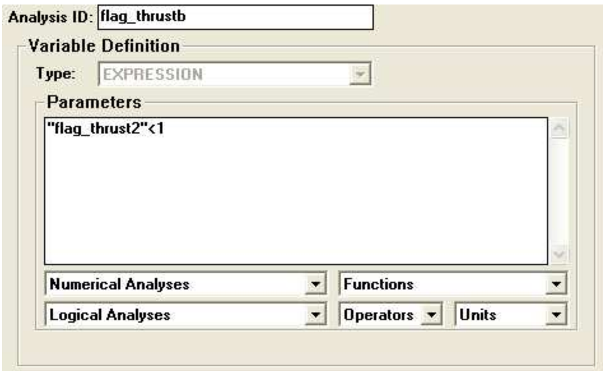
Then an *Expression Analysis* which is true if the scalar product is positive:



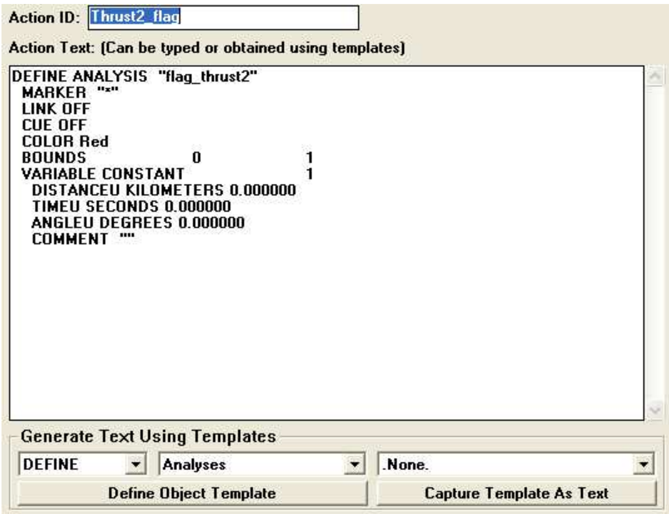
The *Delta-Vs* Up2 is defined as done for the Up1; the Flag_Thrust1 and Flag_Thrust2 are defined as *Constant Analysis* and will change values if the burns have been done (1) or not (0):



Now two *Expression Analysis*: Flag_Thrusta, true when the first burn will be done and Flag_Thrustb, false when the second burn will be done.

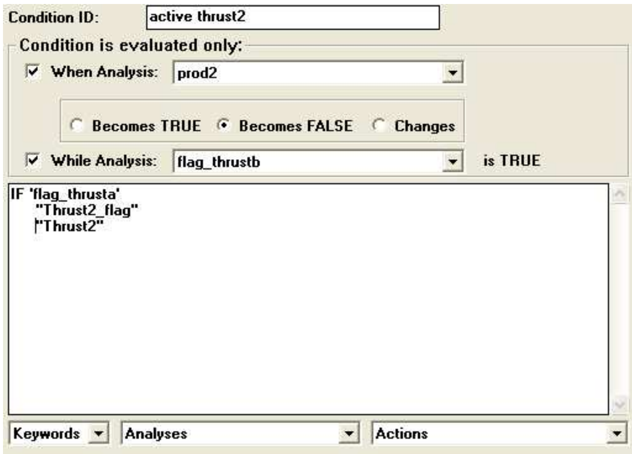


Finally the *Actions* must be defined. When the burn conditions are reached the Delta-Vs is performed and the flag redefined. This is done by two *Actions*. Thrust2_Flag redefines the flag as after burn value (1) using *Define*, *Analysis*, *Define Object* and *Capture Template* menus:

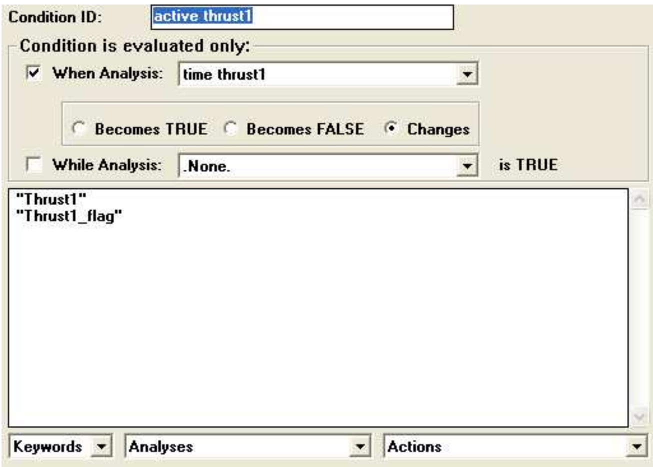


Thrust2 performs the *Delta-Vs* (made as previously done for the Thrust1 *Action*). An *Action* called Thrust1_Flag is done like the Thrust2_Flag.

The *Condition* for the second burn will be defined as follow:

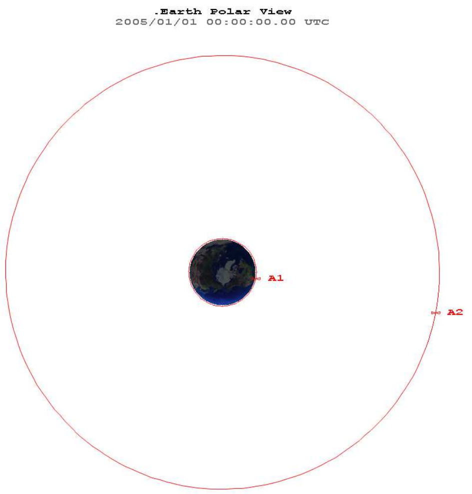


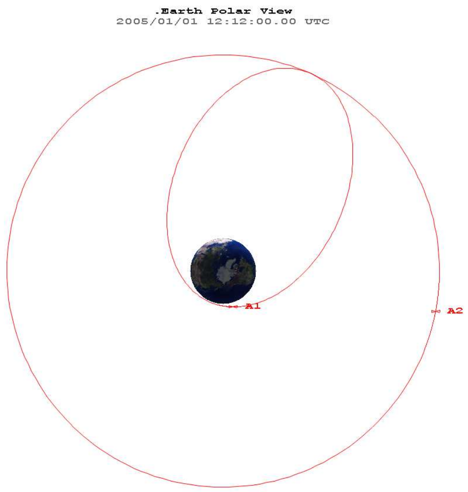
And the *Condition* Active Thrust1 is redefined as follow:

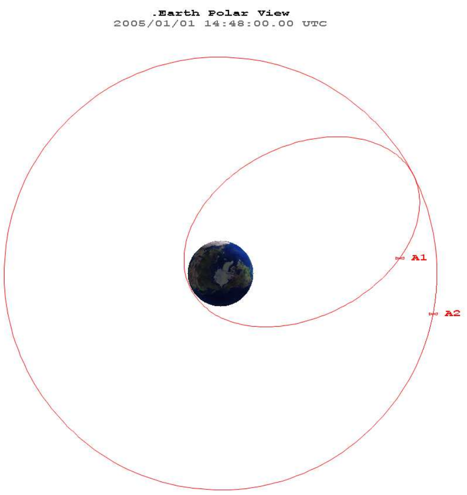


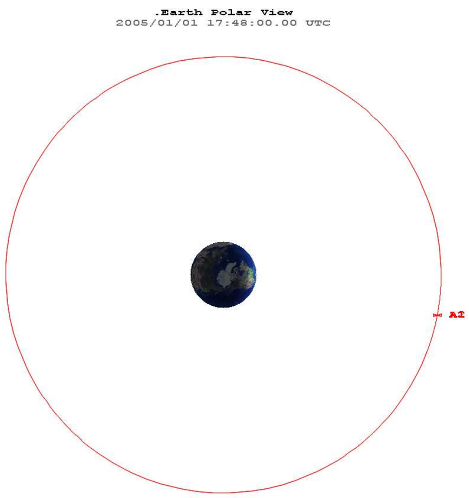
The Active Thrust2 Condition must be put inside the script as previously done for the Active Thrust1.

5.1.3 Results


.Earth Polar View
2005/01/01 00:00:00.00 UTC
A1
A2


.Earth Polar View
2005/01/01 12:12:00.00 UTC
A1
A2


.Earth Polar View
2005/01/01 14:48:00.00 UTC
A1
A2


.Earth Polar View
2005/01/01 17:48:00.00 UTC
A2

5.2 180° Impulsive maneuver

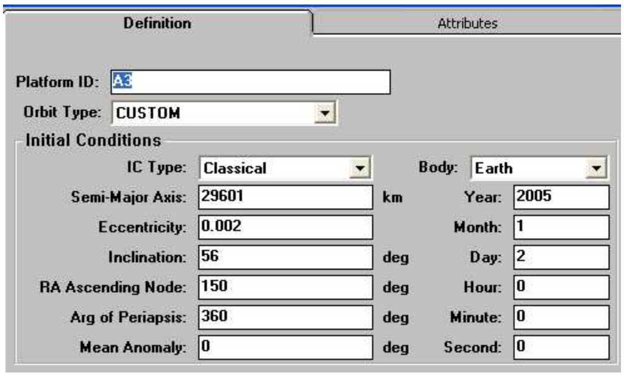
5.2.1 Calculations

The 180deg drift maneuver must be performed in 30 days. Two impulsive maneuvers are taken into account, both made at perigee. The first will change the orbit increasing the radius, the second, after about 30 days, will give to the satellite the starting semimajoraxes, but different phase.
Starting from the Gstbv2 orbit (29601, 0.002, 56, 150, 0, 0) the perigee and apogee radius are a(1±e) and so 29541.8 and 29660.2 km. The period is $T^2=2\pi a^3/\mu$ so 50683.5 sec. The perigee velocity ($V^2=2\mu/r-\mu/a$) is 3.677 km/s.
During 30 days the satellite will do about 51.1 orbits. It means that the drift trajectory must perform 50 orbits while the starting one will have done 50.5 rotations. In this way, at the end of the drift, the satellite will be shifted of a half orbit and so 180 deg.
The 50.5 unperturbed periods, divided for 50, gives a drift orbit period of 51190.3 sec from which the semimajoraxis is 29797.78 km. Now the drift orbit perigee velocity can be obtained: 3.6889 km/s. The *Delta-Vs* is 0.0119 km/s.

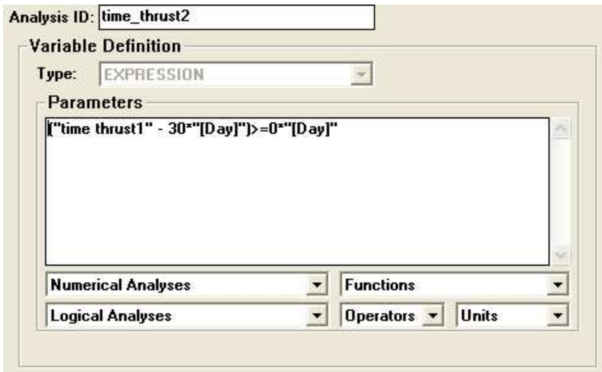
5.2.2 Simulation

The simulation can be done using the same method used for the Hohmann trajectory. See file *gstbv2 180deg impuls.orb*.

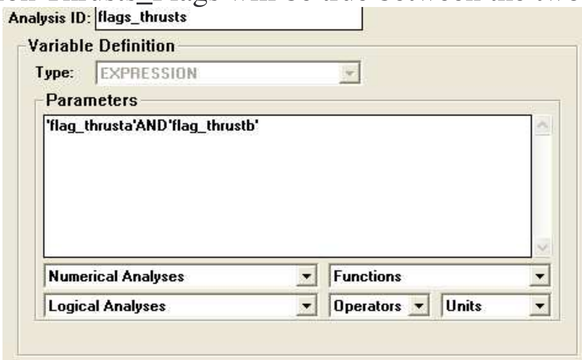
The *Platform Keplerian* A3 is defined:



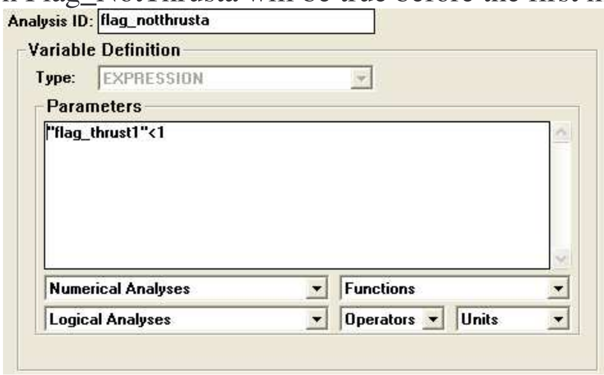
The *Delta-Vs* and the *Actions* are defined as for the Hohmann file (only the ΔV values are different). The Time_Thrust1 *Analysis* is made considering as *Relative Date* 02/Gen/2005 00GMT. An *Analysis Expression* function called Time_Thrust2 is defined that will be true 30 days after the first maneuver:



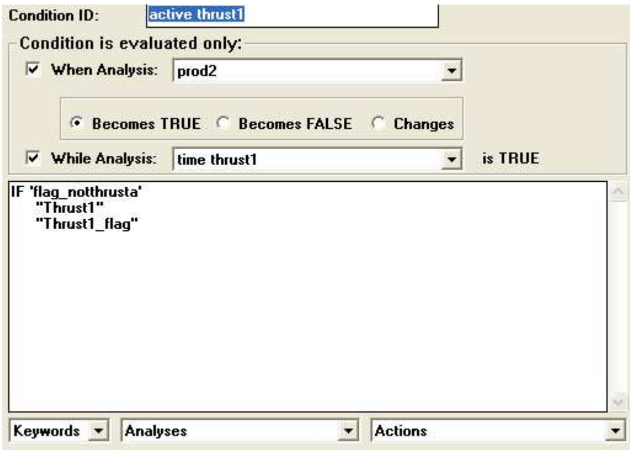
The analysis Expression Thrusts_Flags will be true between the two maneuvers:



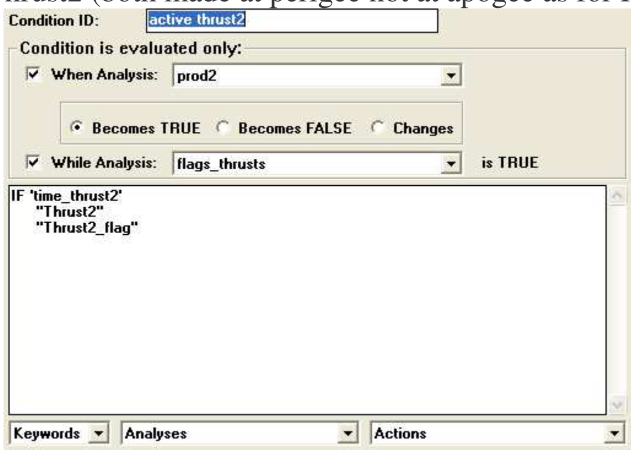
Similarly the function Flag_NotThrusta will be true before the first maneuver:



The Active_Thrust1 *Condition* is:

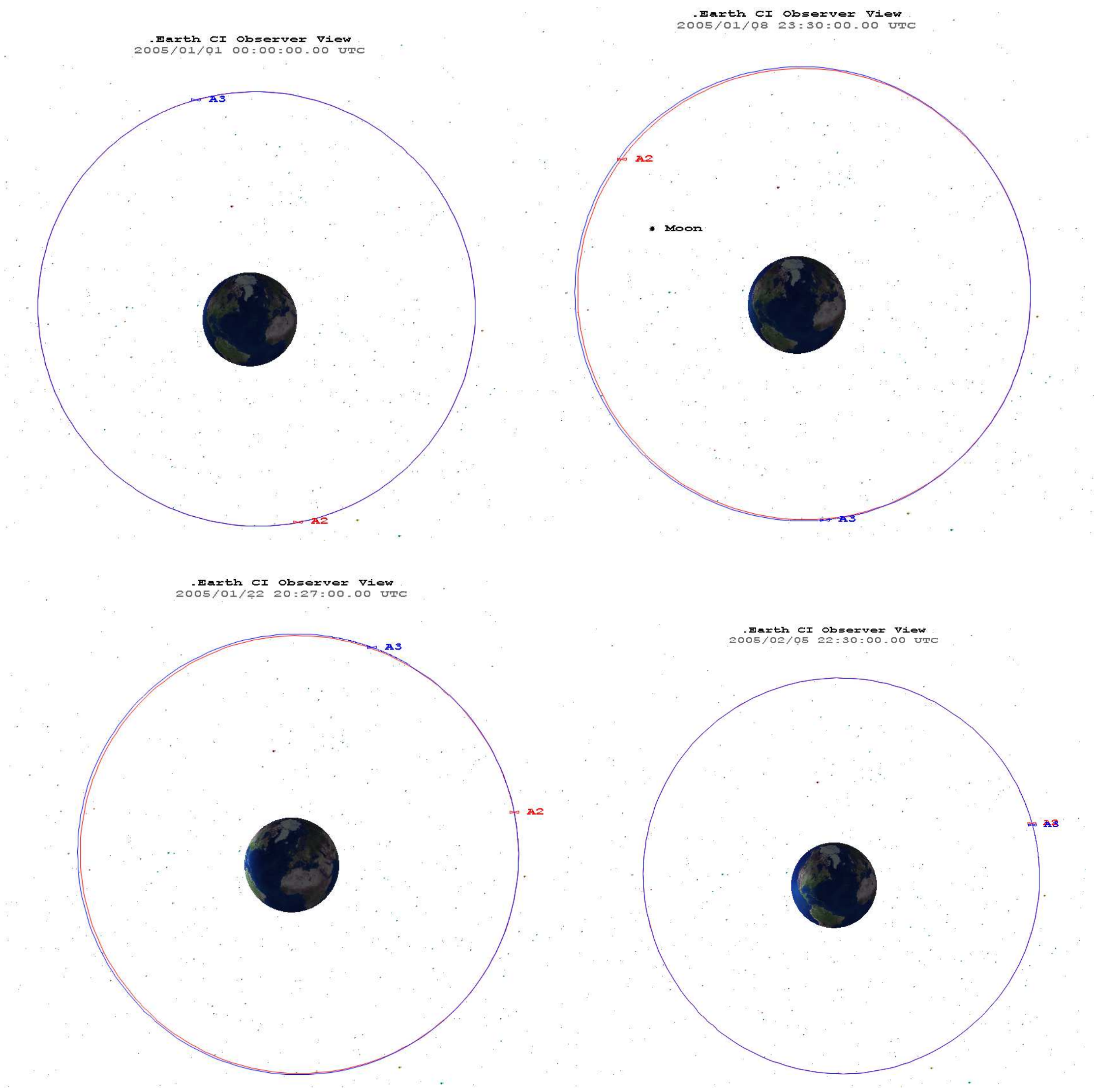


While the Active_Thrust2 (both made at perigee not at apogee as for Hohmann):



Then using the *Utilities* and *Script* menu the two actions must be inserted into the script, using the *Include Conditions* menu and taking care that the *Stop Interval Time* must be not less than 3 February 2004.

5.2.3 Results

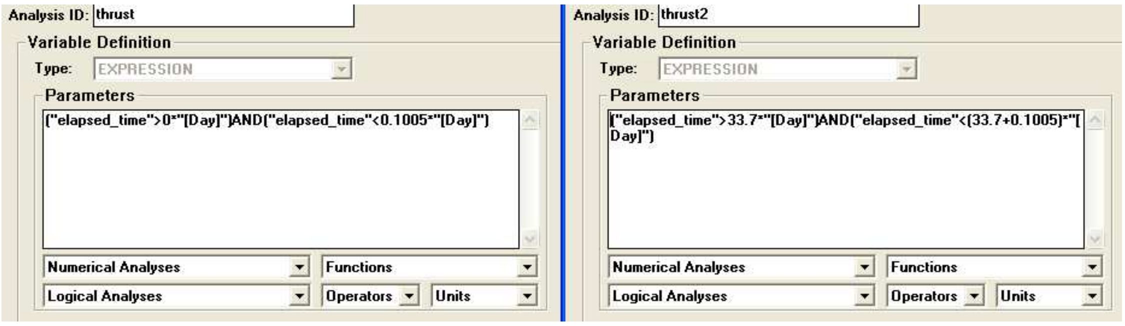


After the drift maneuver the two satellites, separated by a 180° phase difference, are overimposed.

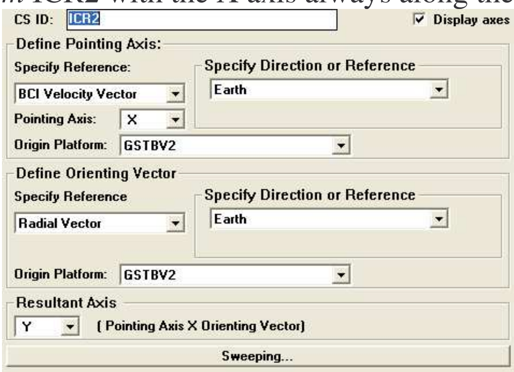
5.3 180° Not Impulsive maneuver

5.3.1 Time Controlled

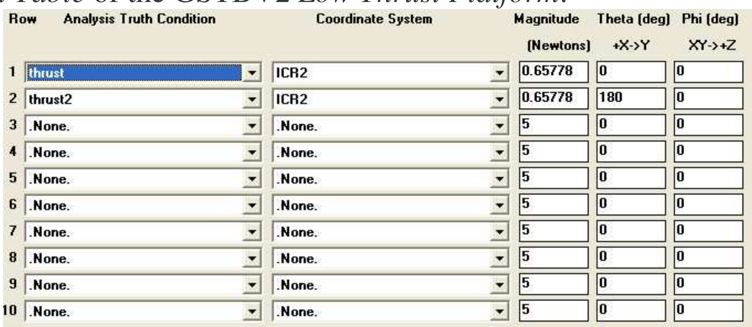
The simplest method, which can be used, is a time function that will be true when the thrust must be performed, until the sma defined by the documentation (29770km) is reached. The *Expression Analysis* Thrust and Thrust2 were defined for thrust duration of about 2.5 hours, note that the second maneuver is performed 33 days after the first:



A new *Coordinate System* ICR2 with the X axis always along the velocity vector:



And the *Thrust Table* of the GSTBV2 *Low Thrust Platform*:

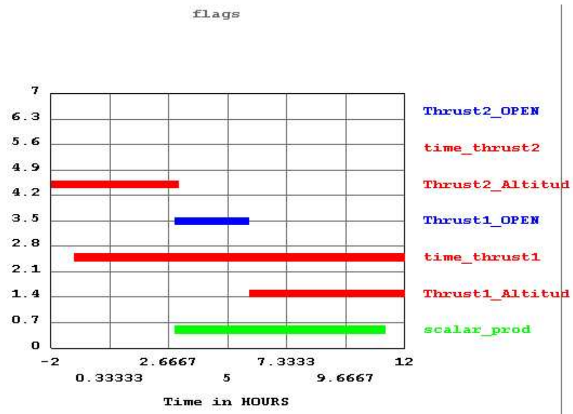


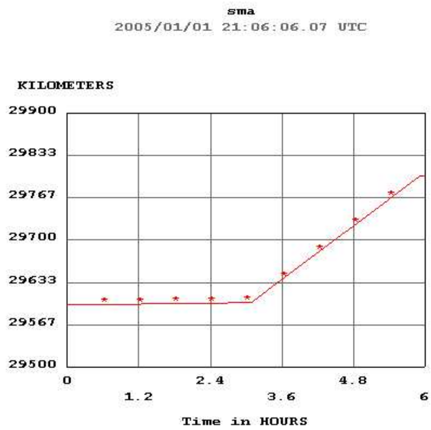
Row	Analysis Truth Condition	Coordinate System	Magnitude (Newtons)	Theta (deg) +X->Y	Phi (deg) XY->+Z
1	thrust	ICR2	0.65778	0	0
2	thrust2	ICR2	0.65778	180	0
3	.None.	.None.	5	0	0
4	.None.	.None.	5	0	0
5	.None.	.None.	5	0	0
6	.None.	.None.	5	0	0
7	.None.	.None.	5	0	0
8	.None.	.None.	5	0	0
9	.None.	.None.	5	0	0
10	.None.	.None.	5	0	0

5.3.2 Altitude Controlled

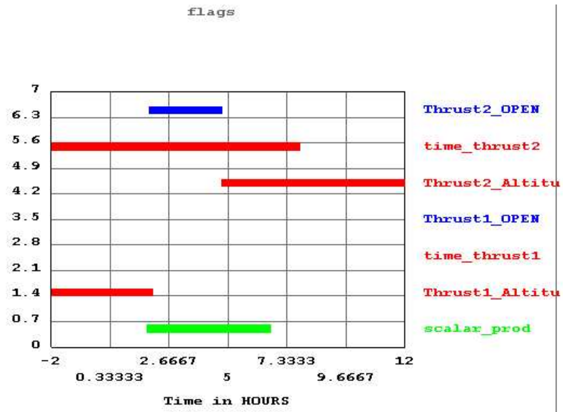
Another method is switching off the thrust automatically when the desired semimajoraxis (29797km) is reached.

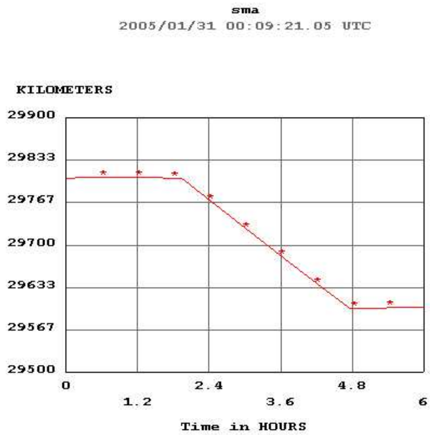
First maneuver:



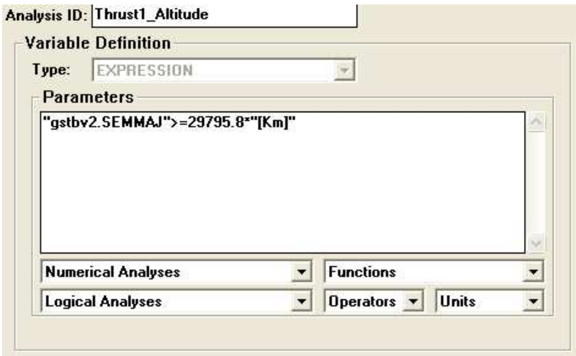


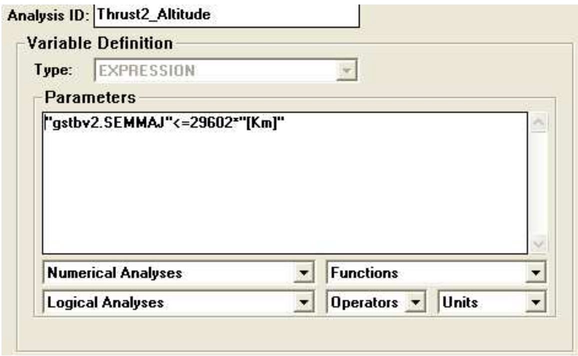
Second maneuver:

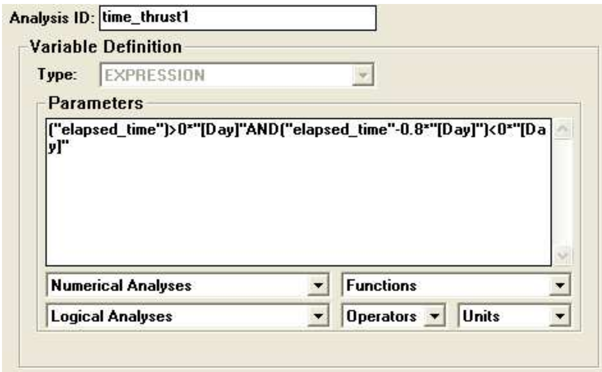


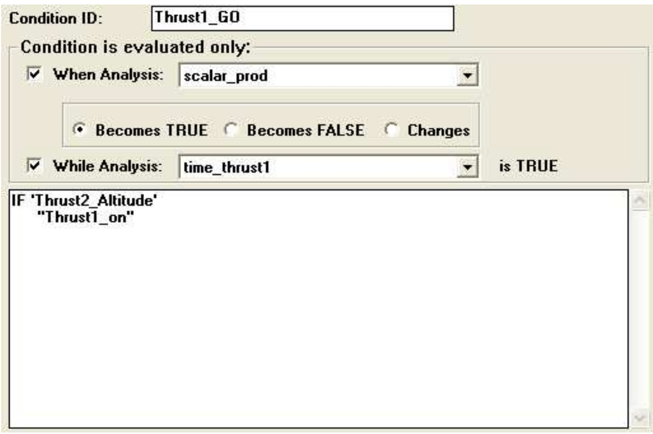


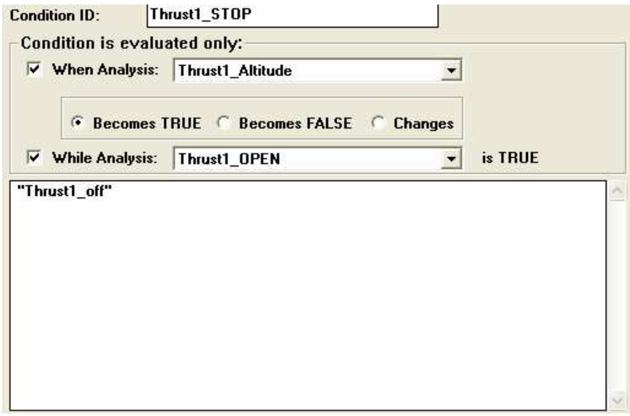
The first maneuver (blue function) is performed starting at perigee (ascending front of the scalar_prod analysis, green) when time_thrust is true (*Expressione Function* which define the time interval when the burn must be done) and thrust_altitude2 is true (red function which defines when the sma is below 29600km). The thuster is shitched off (Thrust1_STOP *Condition*) when the desired sma is reached (about 29797km) and Thrust1_altitude becomes true.
In the same way the second maneuver is done after 30 days and until the sma goes below 29600km (Thru2_OPEN and Thrust2_STOP *Conditions*).


Analysis ID: Thrust1_Altitude
Variable Definition
Type: EXPRESSION
Parameters
"gstbv2.SEMMAJ">=29795.8*"[Km]"
Numerical Analyses
Functions
Logical Analyses
Operators
Units


Analysis ID: Thrust2_Altitude
Variable Definition
Type: EXPRESSION
Parameters
"gstbv2.SEMMAJ"<=29602*"[Km]"
Numerical Analyses
Functions
Logical Analyses
Operators
Units


Analysis ID: time_thrust1
Variable Definition
Type: EXPRESSION
Parameters
("elapsed_time")>0*"[Day]"AND("elapsed_time"-0.8*"[Day]")<0*"[Da
y]"
Numerical Analyses
Functions
Logical Analyses
Operators
Units

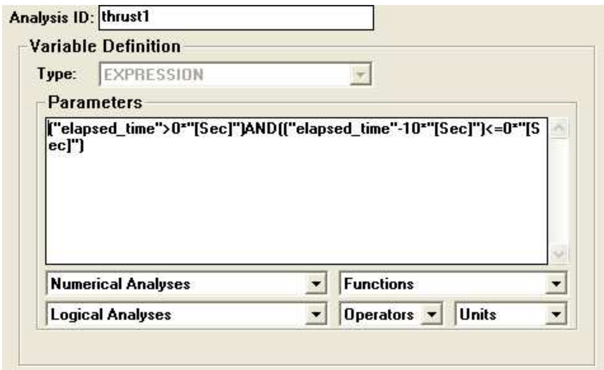

Condition ID: Thrust1_GO
Condition is evaluated only:
When Analysis: scalar_prod
Becomes TRUE
Becomes FALSE
Changes
While Analysis: time_thrust1
is TRUE
IF 'Thrust2_Altitude'
"Thrust1_on"

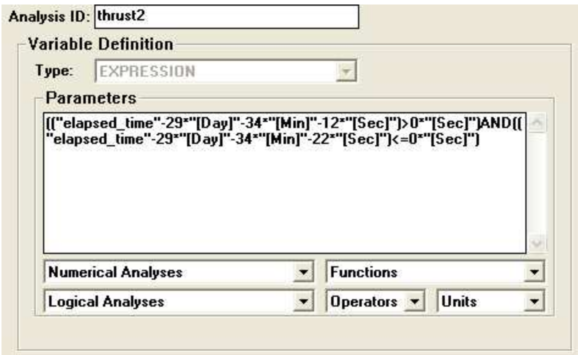


<u>Note that the windows are sometimes not correctly refreshed.</u> <u>The user must do it.</u>
Remember to use *Genetare Script* function in *Utilities*, *Script* menu before start simulation.

5.3.3 Near Impulsive Maneuvers

A method to force Soap using impulsive maneuver can be: use high force for a short time interval, near the integration time step. Considering constant force F and mass m for a time interval Δt it means: $F*\Delta t=m*\Delta V$. The speed jump is the previously defined 12m/s and mass is around 540kg, for example the force will be 647N for 10sec. Optimized, to reach the target position at perigee after 30 days, with 665N.
The Thrust *Expression Analysis* are:

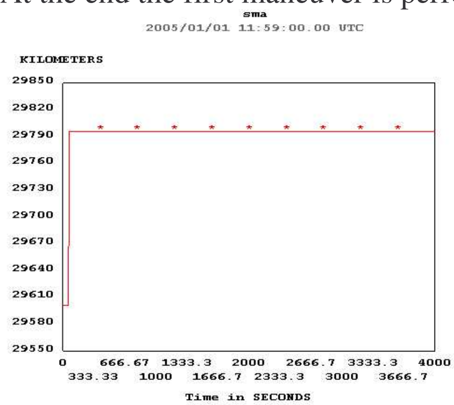


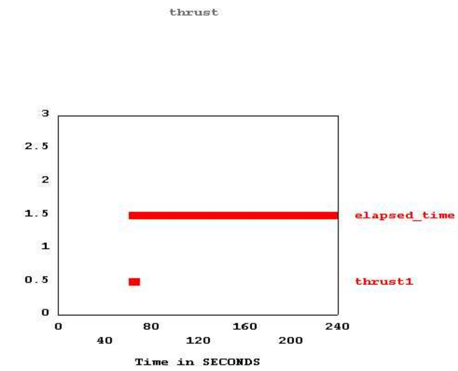


And the *Low Thrust Platform*, *Thrust Table*:

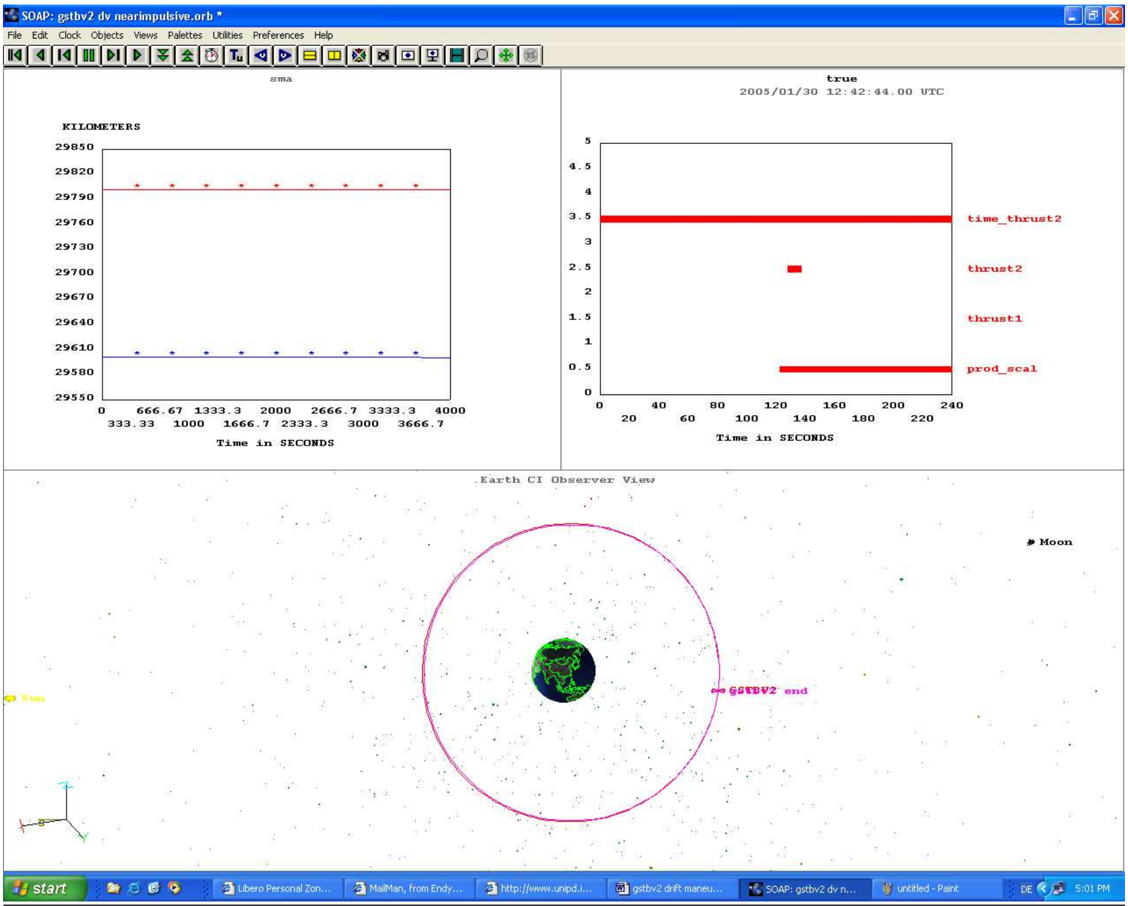
Row	Analysis Truth Condition	Coordinate System	Magnitude (Newtons)	Theta (deg) +X->Y	Phi (deg) XY->+Z
1	thrust1	ICR	650	0	0
2	thrust2	ICR	650	180	0
3	.None.	.None.	5	0	0
4	.None.	.None.	5	0	0
5	.None.	.None.	5	0	0
6	.None.	.None.	5	0	0
7	.None.	.None.	5	0	0
8	.None.	.None.	5	0	0
9	.None.	.None.	5	0	0
10	.None.	.None.	5	0	0

At the end the first maneuver is performed:





<u>Note that the second one, implemented at the perigee 29 days and 34 minutes after, is not performed by Soap.</u> <u>When the second thrust should be done (around 30 gen 2005) the functions seam correctly defined, but nothing happens.</u>

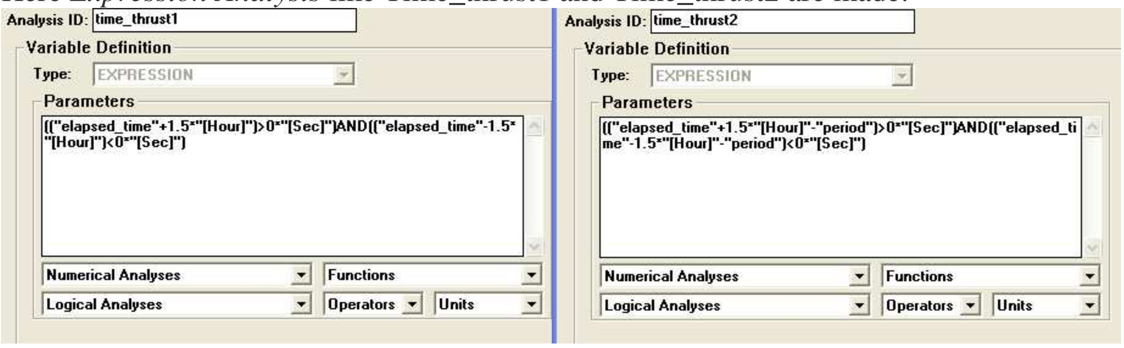


The Thrust2 function becomes true and the satellite is above the target one, but the semimajoraxis (left) doesn't change. If you use thrust duration around 350 sec and intensity of 5 N the maneuver is done.

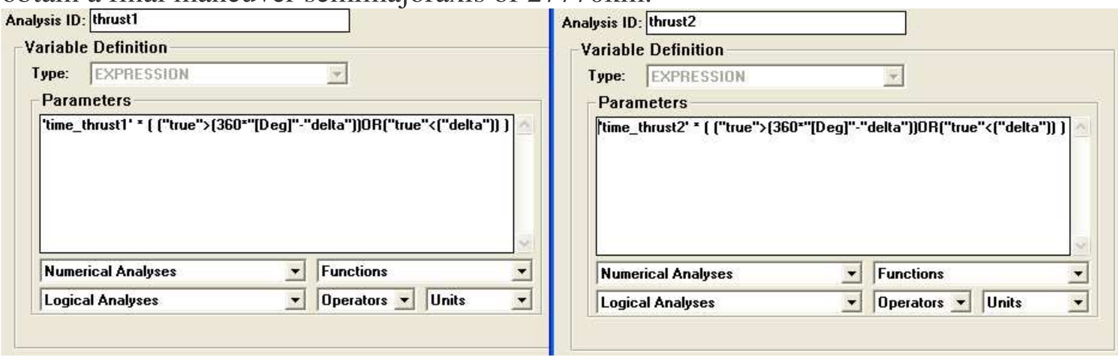
5.3.4 Step Maneuvers

The most realistic approach is consider a group of finite burn maneuvers made at the perigees of successive orbits, instead of a unique one. The simulation is made by the file *gstbv2 drift steps.orb* and only for the first maneuver.

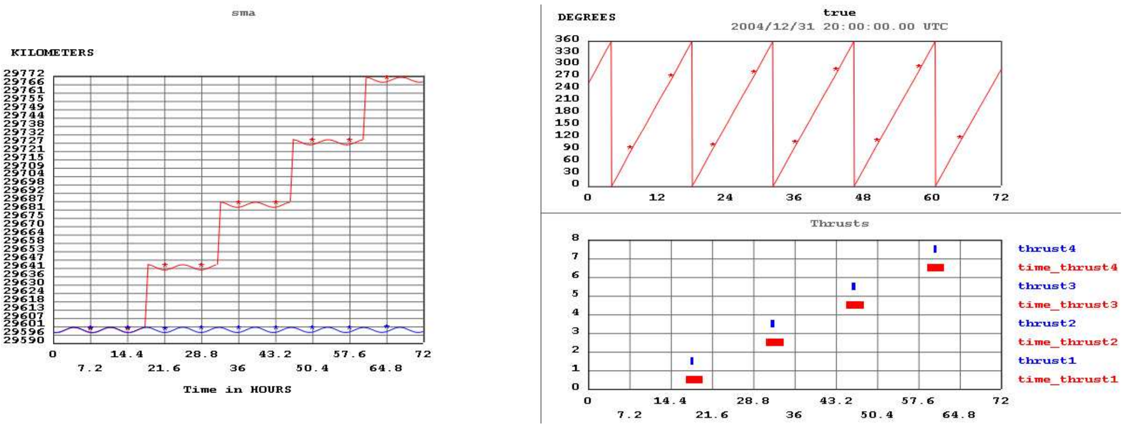
Here *Expression Analysis* like Time_thrust1 and Time_thrust2 are made:



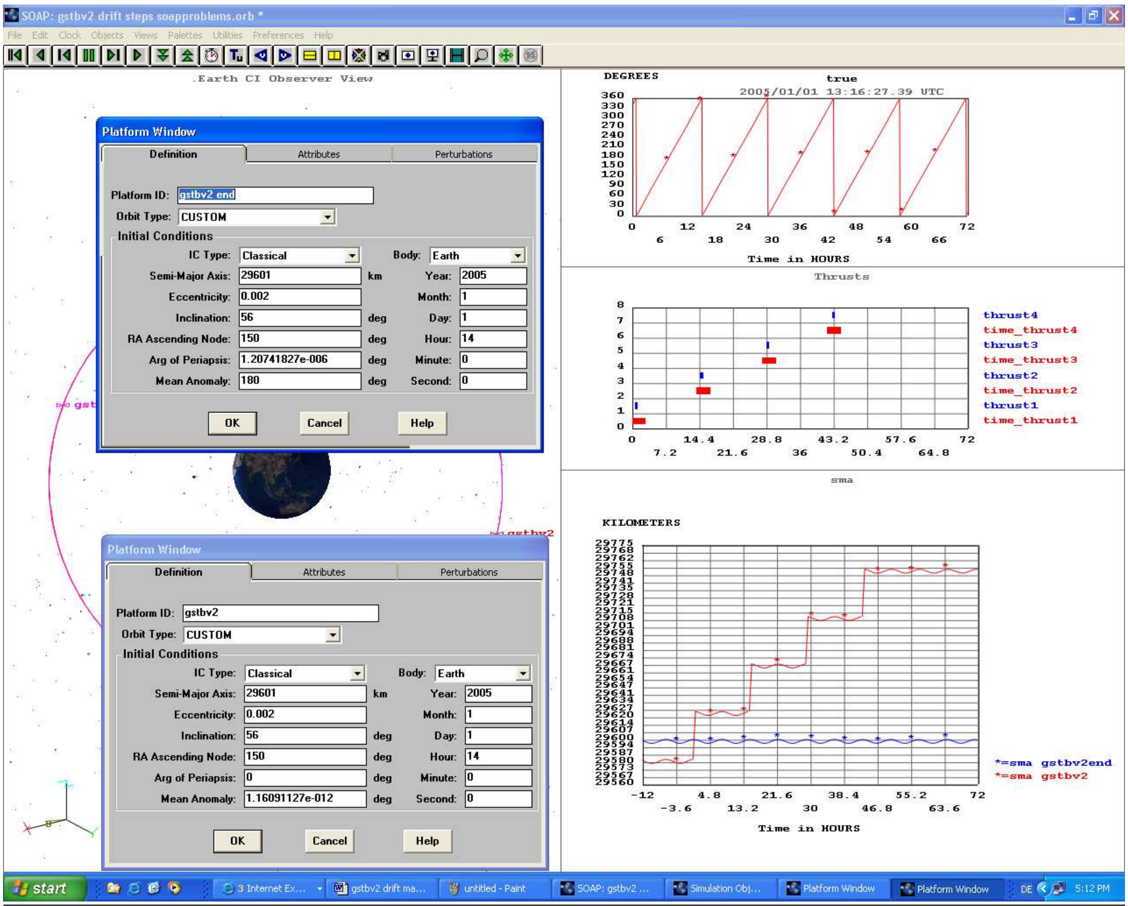
and *Expression* like Thrust1 and Thrust2 perform the maneuver when the true_anomaly is symmetric wrt the perigee (zero). The *Constant Analysis* Delta is defined in order to obtain a final maneuver semimajoraxis of 27770km.



The result is 4 burns maneuver of about 0.56-0.6 hours each (2.3-2.4 hours total). It can be compared with the *gstbv2 dv simmetricwrtperigee.orb* scenario, where the unique burn lasts 2.4-2.45 hours and it is made with same starting and final sma: 29600, 29770 km. This worst case considers thrust activated around 15 deg before perigee and switched off around 15 deg after it. In fact the efficiency should go like the cosinus of the maximum distance from perigee: cos(15deg) = 0.965, it means an efficiency loss around 4%.



Note that problems have been met when the burn is performed near the epoch of the perigee passage, as define in the *Low Thrust Platform* menu. See file *gstbv2 drift steps soapproblems.orb*:



Here the starting semimajoraxis changes into the graph right, but it dosen't agree with the value used for the *Low Thrust Platform* definition menu.

6 CONCLUSIONS

- ✓ The Galileo evolution of inclination and RAAN for adjacent planes is confirmed to have around +/- 2 deg maximum variation from the nominal values (54 and 120 deg). The reported optimized starting inclination and RAAN were used (as starting osculating values) and a life-time of 15 years assumed. This excludes the necessity of out-of-plane maneuvers when the starting values are properly chosen.
- ✓ The Galileo requirement of +/- 3deg for relative phasing of adjacent satellites in one orbit could be obtained by using optimized starting semi-major-axis and phases. The relevant variations encountered for phase difference between adjacent in orbit satellites ("*Gal01 LT*" and "*Gal02 LT*") using small starting semi-major-axis variations, admit this possibility.
- ✓ A GSTBV2 single burn maneuver will last around 2.5 hours (same consideration for 1 month later second maneuver)
- ✓ A GSTBV2 4 burns maneuver can reduce the burning time for the considered case from 2.4 to 2.32 hours: single burn 4% efficiency reduction.

Some Soap (or user) problems have been met:

a) The *Delta-Vs* impulsive maneuvers can't be used for the *Low Thrust Platforms*
b) The semimajoraxis of the transfer orbit, for a 30 days 180 deg drift maneuver, could be something more than the reported 29770km. Around 29790km?
c) Sometimes Soap doesn't refresh correctly the windows. If you double-click the window and click *OK* the refresh will give the correct graph, but if you do not do it or you trye to do it later the error will not be corrected.
d) The low duration finite burn maneuver, used forcing Soap to apply impulsive maneuvers for *Low Thrust Platforms*, sometimes is not performed. Problems with the integration time step? Wrong definition of thrust analysis?
e) Maneuvers made near the perigee passage time defined for *Low Thrust Platforms* menu could give problems

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