GRAVMOD-2: A NEW TOOL FOR PRECISE GRAVITATIONAL MODELLING OF PLANETARY MOONS AND SMALL BODIES

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ABSTRACT

This paper describes the ESA gravity modelling tool GRAVMOD-2, its main functionalities, ongoing studies and expected evolutions. GRAVMOD-2 is the follow-up and extension activity of the GRAVMOD-1 tool.

GRAVMOD-2 is a software tool developed by Astos Solutions and GMV for ESA. It adds guidance analysis and on-board manoeuver capabilities to the gravitational modelling core of GRAVMOD-1 originally developed by DEIMOS. The unique mathematical models and architecture make it particularly suitable for the modelling of the gravity field of highly irregular bodies such as asteroids or comets.
GRAVMOD-2 is composed of two main modules:
1) A Gravity Modelling module: containing mathematical algorithms able to compute gravity fields as Spherical Harmonics Model (SHM) or Multiple Point Masses Model (MPMM), using as input gravity accelerations provided or computed from other gravity fields (as PANGU model, polyhedron model, and ellipsoid model, along with the already mentioned SHM and MPMM). This module allows also comparing two different gravity fields, analyzing the accelerations produced or propagating a trajectory.
2) An Orbit Propagation and Determination module: set of methods and algorithms allowing the propagation of a trajectory, generation of measurements, and optimal estimation of a gravity field once a mission around a body is known. It also allows the computation of stable orbits based on simplified dynamics models including the restricted three body problem.
As a part of this tool also a GNC propagator has been developed for on-board applications.
GRAVMOD-2 allowed producing a series of gravity models for ESA internal purpose. Those models have been made available via the ESA Planetary Database (PDB). PDB has been extended and which provides now capabilities to plot GRAVMOD-2 gravity fields and trajectories(using a simplified version of the GRAVMOD-2 propagator).
The paper will conclude with the current status of ongoing studies and expected mid-term evolutions.

1. INTRODUCTION

All the main functionalities of the tool will be addressed in the next paragraphs, trying to give an overview of all the possible different applications of the software.
For this reason, instead of focusing on the theory behind, some test cases and screenshot will be shown and discussed for all the main functionalities. The results will be analyzed and at this purpose, the plotting capabilities of the tool will be used when possible.

2. GRAVITY MODELLING MODULE

<u>This Module is able to compute gravity fields not considering time as part of the input data</u>, as performed by the Orbit Propagation and Determination module.
The gravity modelling module is able to:

- for a given gravity field provided as input, *compare two different gravity field models*, in terms of accuracy and computational effort. The following models are considered:
  - Spherical Harmonics;
  - Multiple Point Mass Model;
  - Geometrical Models.

  The SHM allows representing especially regular bodies (like planets), while MPMM and geometrical models should better described more irregular bodies (as asteroids).
  The Geometrical models implemented are: PANGU Model [1], Polyhedron Model [2] and Ellipsoid Model.
- *compute the gravity field that best fits with a given set of distributed (real or simulated) external measurements*. Only the MPMM and SHM model can be produced. For the MPMM generation this is done by sequentially running two sub-processes: initial guess generation and adjustment through a least squares / NLP approach. The SHM generation is performed analytically.

Since this module does not consider time as part of the input data, the provided measurements must be directly related to the concerned gravity field. This means that only accelerations and gravity gradients generated by the gravity field at certain locations can be used, but not tracking data. Therefore, the measurements provided cannot be time-dependent and must be given in the relative reference frame.

2.1. Gravity Model Identification

The user can provide as input any of the gravity models already mentioned in chapter 2. For each of them, a SHM or MPMM can be generated.
For the generation of a MPMM a grid of points has to be provided. It is used to compute the reference accelerations, used to run the NLP solver, in order to get the most suitable MPMM. As alternative, a set of accelerations can be directly used as input instead of a gravity model. This is not possible for the SHM generation, since it makes use of analytical algorithms to produce the spherical harmonics. These algorithms are based on the estimation of the volume and of the distribution of the mass.
For this task, three test cases are reported here.
In the first two tasks the asteroid Eros (433) is used.

Figure 1 Eros image taken by the NEAR Shoemaker spacecraft [4]

In the first one a MPMM is produced for the Eros (433) asteroid using as input a polyhedron model [3].
The obtained MPMM is reported in the following table:

Table 1 MPMM for Eros (433). The positions are given in the Planet Center-Planet Fixed (PCPF) Reference Frame (RF)

X-PCPF [m]	Y-PCPF [m]	Z-PCPF [m]	Mass [kg]
-14787.5	-1217.4	6.4	143615369396901
11249.1	-4605.1	317.6	402802331947232
-11810.7	212.1	337.3	652647755794170
8063.1	-1346.8	225.6	1.34593390519967e+015
-5291.6	1932.0	85.1	1.39284929626184e+015
1347.5	791.2	-404.1	1.30129161958909e+015

The gravitational constant obtained is 449659.2 m^3/s^2, while the original polyhedron model gravitational constant is 450001.4 m^3/s^2, which gives an error of just 0.08%. In the MPMM plot each point mass is represented by a sphere whose volume is proportional to its mass. This graphical representation reveals the obtained shape and its similarity with the real asteroid:

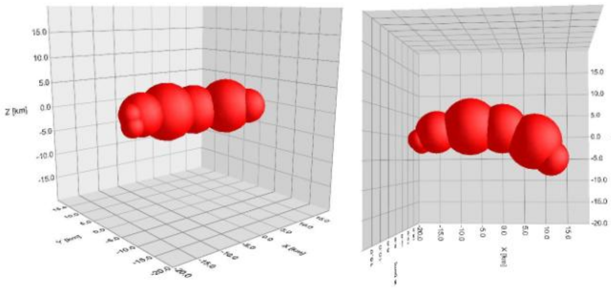

Figure 2 Eros MPMM obtained by GRAVMOD-2

In the second test case, a SHM is generated from the same polyhedron model used in the previous test. In this case the obtained gravitational constant is 453580.1 m^3/s^2 (error of 0.8%). The SHM produced is shown in the next figure (equipotential surface):

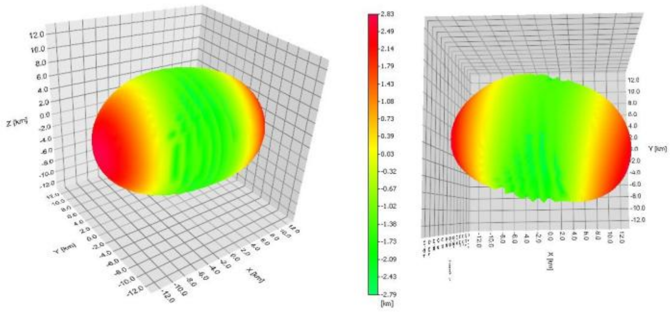

Figure 3 Eros SHM shape plotted by GRAVMOD-2

The shapes obtained (Figure 2and Figure 3) are quite similar, if the differences between the two gravity models are taken into consideration. In both cases an elongated shape, similar to the real one (see Figure 1), is obtained.
The two obtained gravity models will be compared in the next section.

In the last test case, a SHM is computed using as input an ellipsoid model of the Earth (X-axis = Y-axis = 6378137.0 m, Z-axis = 6356752.3142 m).

The SHM produced is shown in the next figure:

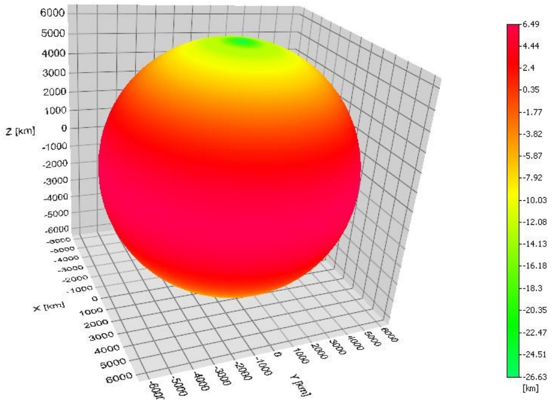

Figure 4 SHM shape plot

The ellipsoidal shape obtained perfectly represents the input model. Only the zonal terms are significant, the other harmonics are indeed zero (that explains why the colours are uniform in the direction of the latitude). This is the consequence of choosing an ellipsoid model as input.
In the next paragraph the two models obtained for the Eros asteroid will be compared.

2.2. Gravity Models Comparison

The comparison between two gravity models can be performed propagating the same initial state and then comparing the obtained states, or defining a reference grid and comparing the local accelerations.

The SHM and MPMM obtained for Eros (433) in paragraph 2.1 will be compared here.
Three different trajectories will be propagated for one day:

1. Polar circular orbit with Semi-Major Axis (SMA) of 50 km
2. Polar circular orbit with SMA of 30 km
3. Inclined (60°) circular orbit with SMA of 30 km

The first two orbits are perpendicular to the major axis of the asteroid (in the x-z plane), for this reason the effect of the asymmetries and of the peculiarities of the gravity fields should not be so evident in the trajectory propagation. They should not lead to big differences in the propagated trajectories, in particular the first one having larger SMA. The main differences will be in the direction of the motion (longitudinal).
The third orbit will explore also the latitudinal direction, leading to bigger differences between the propagated trajectories.

In the next three figures, on the left side the differences in positions obtained by propagating each of these orbits around the MPMM and SHM are shown and on the right side the propagated trajectories are plotted (the black trajectory is obtained with the MPMM and the white one with the SHM). The x-y-z axes are oriented as shown in Figure 2 and Figure 3.

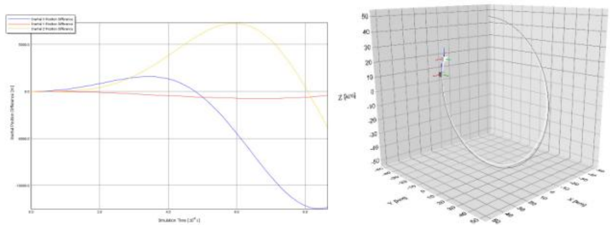
Figure 5 Position Differences Orbit 1

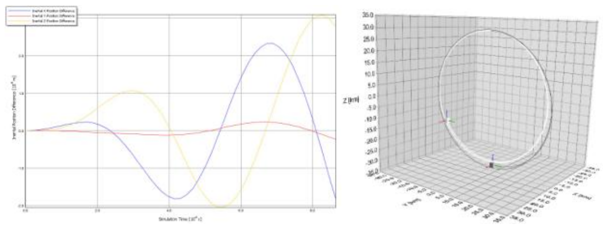
Figure 6 Position Differences Orbit 2

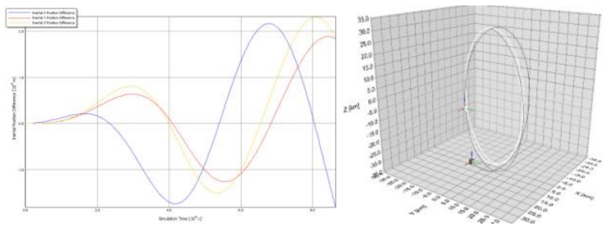
Figure 7 Position Differences Orbit 3

As expected, the first two orbits show very small differences in the y-component (the orbital plane of the selected polar orbit lays in the x-z plane); while the third orbit experiences the difference of the gravity models also in this component. The differences are bigger in the last two orbits since they are closer to the central body (SMA 30 km vs 50 km).

3. ORBIT PROPAGATION & DETERMINATION MODULE

<u>The Orbit Propagation and Determination module is dealing with two different functionalities: precise orbit propagation, and gravity field estimation from satellite tracking data through a filtering scheme</u>.

For the second of these purposes, it also implements a measurements generation mode that feeds the filtering process. In a certain way, this module completes the Gravity Modelling Module since here also the evolution in time of the involved variables is considered for the gravity identification.

Four different main modes/tasks can be distinguished:

- *Trajectory Propagation*. Its main purpose is the propagation of an initial state (position and velocity) in the presence of a certain (user configurable) dynamic environment, and of the initial covariance matrix (uncertainties) if specified by the user. Two different propagators can be used: the Mission Analysis Propagator (for planetary or interplanetary missions) that allows the propagation of the S/C trajectory, and the HIgh-FIdelity (Hi-Fi) Asteroid Propagator (for missions around asteroids) that allows the propagation of the S/C and of the asteroid trajectories.

- *Measurements Generation*. It allows the generation of measurements to feed the estimation process. These measurements are generated by taking the dynamic variable of interest from the Trajectory Propagator and adding the previously user-configured errors affecting the measurements. This mode can be executed independently, in order to generate a set of measurements, or can be called by the higher-level mode devoted to the determination process. It makes use of the Trajectory Propagation module to compute the set of measurements that shall be afterwards used by the orbit and gravity field determination module.

- *Trajectory Determination Mode (and Monte Carlo Simulation)*. This mode is responsible for the optimal determination of the involved parameters of the problem, typically the satellite orbit and the gravity field under study (but also other dynamical parameters can be estimated), by using a least-square method. This mode makes use of the Trajectory Propagation (it can be run with both the propagators) and Measurement Generation modes. On top of it a Monte Carlo Simulation can be run. In that case the orbit determination process is repeated many times changing the values of some dynamical parameters.
- *Stable Orbits Determination Mode.* The objective of this mode is to provide the user with a set of initial conditions, in terms of initial state vector or orbital elements for which the orbit of a spacecraft under certain asteroid environment will remain stable. Due to the perturbations in the vicinity of the asteroids there are no closed orbit solutions, therefore, the stability criteria is defined in terms of time in which the spacecraft is enclosed within a given boundary. The approach follows a two step procedure. In the first step, simplified (though complex) dynamical models are used to described the environment of a single or binary asteroid. At this stage a search for candidate orbits is carried out, using state-of-the-art methods reported in the literature. The second step consists of checking the validity of the previously selected solution and if this fulfils the bound conditions in the complete scenario.It is very important to understand that, from the point of view of the subsequent filtering process, a (simulated or external provided) gravity field must exist a priori. The reason is clearly defined by considering the only alternative option: providing to the filtering process measurements gathered by a certain (real or simulated) mission: in this case, any computation process would always miss the accuracy estimation of the selected determination method. A gravity field would then be computed, but nothing would be known about how good or bad it is.

3.1. Trajectory Propagation

In this paragraph no test case will be shown, but only the main capabilities and features of the GRAVMOD-2 propagators. It is very difficult to choose one or two test cases able to represent all the different models implemented. Since the propagator is a “basic” functionality used in almost all the other functions of the software (as in the comparison task), in this paragraph just an overview of it will be given.

The trajectory propagators are very flexible due to many different models and reference frames implemented. They propagate the trajectory of the spacecraft, while the Hi-Fi propagator can propagate also the motion of the central body (asteroid).
The implemented Equations Of Motion (EOF) can be propagated (in Inertial J2000 or True Of Date frame). In the next table, all the available propagator modes are listed:

Table 2 Propagator Modes implemented

Mode	*Spacecraft*	*Spacecraft attitude*	*Central body*
3DoF	X		
3DoFTor	X	*	
6DoF	X	X	
3DoF+CB	X		X
3DoFTor+CB	X	*	X
6DoF+CB	X	X	X

*Only the torques are computed

All the EOM can be integrated using Cartesian or Equinoctial elements.
Several perturbation models are available. The implemented EOF and models per each propagator are summarized in the following table:

Table 3 EOF and Models implemented

	Mission Analysis	*Hi-Fi*
EOM available	3DoF, 3DoFTor, 6DoF	All
Specific Peturbations	Atmospheric drag*, Ocean tides (only for Earth as part of SH)	Outgassing, Yarkovsky, Relativistic effects
Common	Solar radiation pressure, Solar wind, 3rd Bodies perturbation, Longwave radiation,	

Perturbations	Albedo, Impulsive Maneouvres

*the standard, exponential and Jacchia-Bowman (2006 and 2008) atmospheric models have been implemented.

Also different integrators have been implemented and they are summarized in the next table:

Table 4 Implemented Integrators

Integrator	**Single/Multi-Step**	**Step-Size**	**Order differential equations**
Runge-Kutta 45	single	variable	1^{st}
Dormand Prince 8	single	variable	1^{st}
Runge-Kutta 853	single	variable	1^{st}
Runge-Kutta 4	single	fixed	1^{st}
Gauss-Jackson 8	multi	fixed	2^{nd}
Runge-Kutta-Nystrom 1110	single	variable	2^{nd}
Odex 2	extrapolation	variable	2^{nd}

GRAVMOD-2 has also plotting capabilities to visualize the results of the trajectory propagation task. 2-D plots are able to visualize any variable (perturbing acceleration, state, orbital element, etc.) versus time.
In addition, also 3-D animations are available in two different views: the *Central Body View* (see Figure 8), showing only the spacecraft and the central body and the *Interplanetary View* (see Figure 9), able to show also all the other celestial bodies relevant for the trajectory.

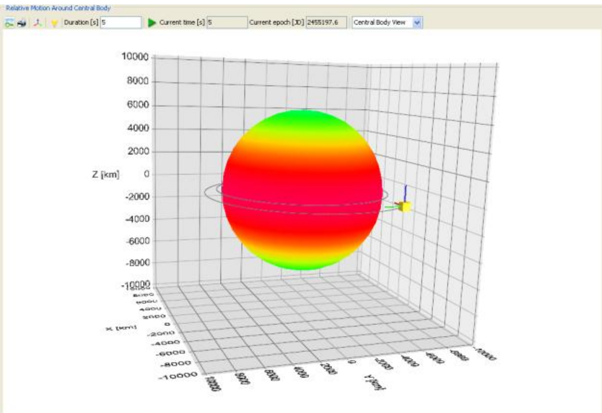

Figure 8 GRAVMOD-2 Central Body View

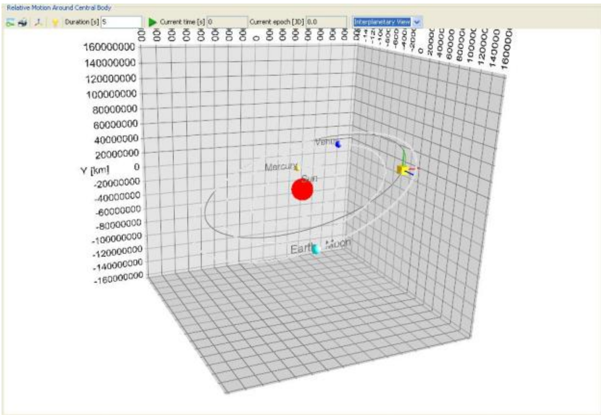

Figure 9 GRAVMOD-2 Interplanetary View

3.2. Measurements Generation

The GRAVMOD-2 measurements generation function is an extension of the propagator task allowing generation of the following types of measurements:

- Accelerometer
- Doppler
- Differential One-Way Ranging (ΔDOR)
- GPS Measurements
- Gradiometer
- Optical Camera Measurements
- Range

A database of ground stations is present in GRAVMOD-2 and user-defined ones are also allowed. The measurements can be generated including noise (Gauss and Iess noise models are implemented). Several parameters of the instruments (antenna, camera) can be customized.
All the results are printed into output files and displayed in 2-D plots (measurement vs. time).

For radiometric measurements, which require the definition of ground stations, the elevation and azimuth (including their rates) are plotted versus time, as shown in the next figure:

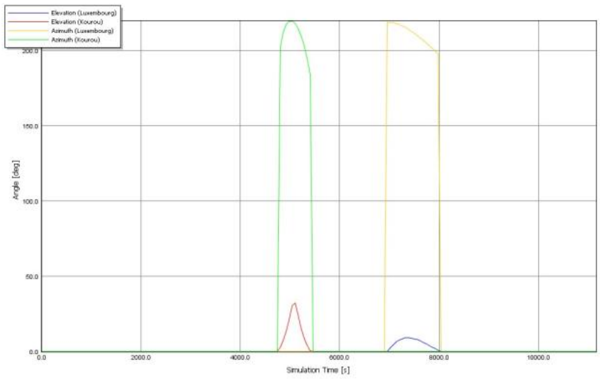

Figure 10 GRAVMOD-2 plot: ground station angles vs. time

3.3. Orbit Determination

The orbit determination task allows determining the initial states of a trajectory based on "real" observations of the trajectory itself. It estimates the initial conditions of the nonlinear system of differential equations of motion using nonlinear measurements relative to the state. The error in the initial state is estimated by using the observation residuals, which are the observed measurements minus those computed from the reference orbit.
Many different orbit determination methods have been used in the past. The weighted least-squares method allows correcting the parameters of a reference trajectory in order to find the trajectory that best approximates the observations, considering the least-squares of the residuals between the actual observation and the predicted ones. The estimated weighted least-squares trajectory will be the best function that approximates the real measurements.
This technique can be applied not only to the initial states, but also to other dynamical parameters as those related to the gravity field (gravitational parameter and spherical harmonics).
The orbit determination process assumes that the user knows perfectly the dynamics of the problem, as well as all the other parameters involved (spacecraft parameters, perturbations, central body information, etc.). Most of these parameters are not only unknown, but also their uncertainties might be even related to each other. For this reason, on top of the orbit determination process, GRAVMOD-2 provides a Monte Carlo simulation feature. It runs many times the same orbit determination process changing some parameters within their uncertainties. It is also possible to run a Monte Carlo simulation without estimating any parameter.

For this task no specific plot is created, but all the plots created for the propagation and measurement generation tasks are available also here.

3.4. Stable Orbit Determination

The search for stable orbits in the vicinity of minor bodies has motivated a large number of studies. Nevertheless, neither of them provides a general method to deal with the problem. The main rationale for the lack of a general approach lies in the complexity of the dynamics. In this sense, the list of arguments in (9) to argue that the design of a space mission to small asteroids is challenging turns out to be revealing: 1) small bodies have large ranges in crucial physical parameters; 2) among this range of small body parameters, each set can have close proximity dynamics that are difficult in and of themselves; 3) spacecraft designs and mission operation concepts can be driven in very different directions as a function of this close proximity dynamical environment; 4) crucial small body parameters may not be known prior to rendezvous; and 5) it is likely that vehicle designs and operations concepts that fit one small body may not fit another.
The available tools to study the stability of the dynamical environment can be categorized into two groups: tools of Dynamical Systems and numerical analysis. The former usually requires the identification of a solution known for all time, such as an equilibrium point or a periodic orbit. In order to obtain such a solution, it is usually needed to simplify the dynamical model doing suitable assumptions. Moreover, the stable orbit function is aimed to search for "practical" stability, which is less restrictive than the Dynamical Systems approach.
In turn, the numerical exploration of the minor body environment does not present restrictions on the dynamics to be considered. The complete set of perturbing accelerations can be taken into account at this stage. Nevertheless, a finite group of initial conditions are needed to perform the numerical exploration, and, therefore, an a priori qualitative knowledge of the dynamical environment is required.
Having in mind the previous discussion, the architecture of the stable orbit function presents a two-level structure: a first step which uses the principles of the analysis of dynamical systems and a second step in charge of performing a numerical exploration.
The first level would use simplified models to perform a complete dynamical analysis of the asteroid environment while the second level would use the complete model of the dynamical environment. This separate approach in two levels, named simplified and complete models, allows us to obtain different information from each one: an approximate global qualitative dynamical behaviour from the first and the quantitative evolution of a particular trajectory in the second. This approach would also result robust in the sense that permits a directed and thorough exploration of the trajectories of the vicinity of the minor body.

3.4.1. Simplified Models

Depending on the type of orbit to be analysed, the shape of the asteroid and the available data, three different models of an asteroid are considered:

- point mass model,
- ellipsoid model
- and two point masses model.

Each of these models is more suitable for analysing specific aspects of the motion around small bodies and allows us to obtain qualitative and quantitative information as regards as the stability of particular trajectories.
The minor body is modelled as a point mass, and therefore, its gravitational potential is spherical. The

approach fits the CR3BP, and the system is constituted by Sun-Asteroid.
This system can also be used to analyse binary systems if they are assumed to be a unique rigid body with the joint mass aggregated at the barycenter of the system. The simplicity of this model, and the presence of the Sun as one of the primaries of the CR3BP, permits to include the Solar Radiation Pressure in the analysis. The results would, in general, be more accurate away from the proximity of the asteroid gravitational potential in the degree this potential differs from a punctual mass potential.
The types of trajectories that can be investigated with this model are: Lagragian points (see next figure) and Halo and Lissajous orbits around them, the influence of the SRP in the location of this Lagrangian points and the Self-Stabilized Terminator Orbits (SSTO).

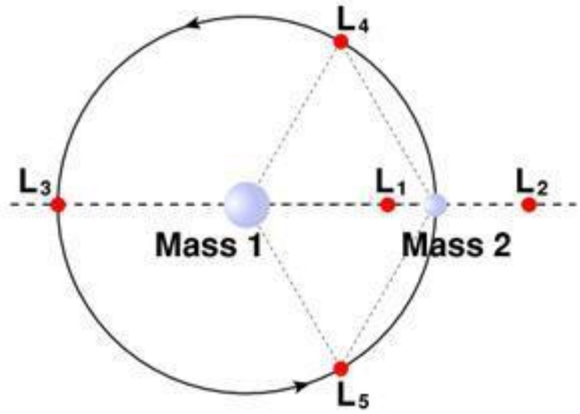

Figure 3-11: Lagrangian Points Location

The second available simple model is the ellipsoid. The minor body is modelled as an ellipsoid with a second order gravitational potential, i.e., the coefficients C20 and C22 are, in general, different from zero. The approach is the same as in (9). The z-axis corresponds to the rotational axis. Assuming a constant density model, those coefficients are function of the inertia moments of the ellipsoid, which are functions of the axes size of the ellipsoid. A numerical integration of the non dimensional equations in the rotating asteroid frame is performed and its size-shape stability is studied. The main advantage of this approach is that reduces the number of parameters that are involved in the motion to two and, therefore, allows us to tabulate the results as a function of only two parameters. In addition, the size-shape stability is defined in a practical or engineering way, considering as stable all the trajectories whose eccentricity is kept below a threshold (0.2) during longer than tens of orbits. The function will return the values of the semimajor axis within the user specified limits that are stable.
As seen in the figure below, the results obtained with GRAVMOD models, match the benchmark provided in (9) quite well.

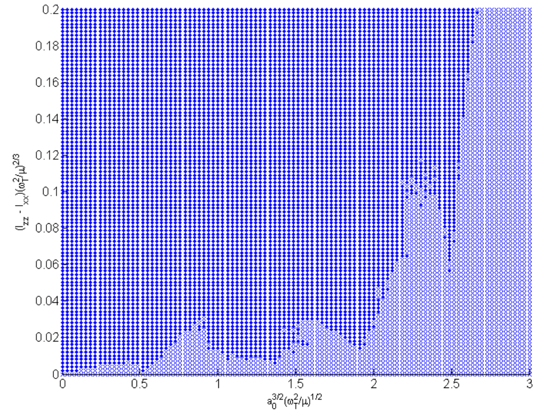

Figure 3-12: Equatorial orbits stability analysis performed with GRAVMOD models.

The two-point mass model is the last of the simplified models included in GRAVMOD. This model is specially intended for the analysis of asteroid binary systems under the assumption of the circular restricted three body problem (CRTBP), but also allows accounting for asphericity in the case of a single asteroid.
The reference frame which has been used for this analysis is either the synodic frame for the binaries or the rotating frame in the case of a single asteroid. The types of trajectories that can be investigated with this model are: Lagragian points and Halo and Lissajous orbits around them, the influence of the SRP with limiting hypothesis in the location of this Lagrangian points. The analysis of each of these trajectories, as for the single point mass model, is made following the general guidelines exposed in (9).
At this level of the stable orbit function, only the location of the equilibrium points is computed since the stability depends on a number of parameters and their relative importance as it was shown by internal GMV's studies.

3.4.2. Complete Model

At this level, the GRAVMOD High-Fidelity propagator is used to investigate the evolution of the initial conditions provided by the previous level.
These conditions are provided automatically by the tool depending on the user selection of the gravity model.
A Monte Carlo simulation can be performed for a set of initial conditions that vary from the nominal (provided by the previous level) in a range defined by the user. The dynamical model is complete in the sense that the user would also be able to select the perturbing accelerations to be considered in the Monte Carlo propagations.
The complete model then outputs the statistical summary of the major relevant state variables in the best reference frame, i.e. inertial, Sun-synodic, system-synodic.

The tool allows also the output of each one of the trajectories of the Monte Carlo either in the reference frame in which the initial guess is computed or in the inertial frame used for the integration.

4. GNC-PROPAGATOR

The GNC propagator is targeted for an implementation on a generic GNC simulator for a planetary or interplanetary mission, suitable for an on-board implementation. Therefore, the on-board propagator cannot include the same models as the ground propagators, either for mission analysis or for orbit determination. This is due to the computing limitations of the on-board processors, that constraint the amount of operations to be performed during the time slot of the propagator.

There is another constraining point for the on-board propagator models, the maximum memory allocated. It refers not only to the executable or object files but also to the size of the required model parameters. For instance, a point mass model might have to consider a reduced number of points, or the number of 3rd bodies to be included shall be limited to avoid the storage of a large ephemeris file.

This reduced order models will introduce propagation errors bigger than the ground-based propagators. This is not critical since on-board propagations are typically used for shorter propagation times than in ground control centres.

All these aspects have been considered and the experience gained in previous projects by GMV, such as

- ANTT (7), which analyzed the influence in the total acceleration of the different sources in four different segments in the Rosetta mission, which considered all the different configurations that were expected. This also provided great insight in the modelling of the gravity assist of the bodies.
- Projects related to the analysis of far and close phase approaches to the minor bodies (8). This study showed that very accurate and satisfactory results may be achieved by just considering a simplified dynamics based on the central gravity of the minor body, the third body perturbation of the Sun modelled as a gravity gradient as major contributions, the leakages and the solar radiation pressure where included as process noise during the state propagation. This approach was considered appropriate due to the size of the solar arrays, but in case these are large enough an explicit contribution may be also considered, adding an ECRV to account for the uncertainties and simplifications of the models.
- Several ESA funded projects analysed as well the GNC system during the in-orbit phase, either for orbits around planets or minor bodies, where the proper solar radiation perturbation model might play an important role depending on the target orbit.

As stated in the SW requirements, the propagator considers the state propagation as well as the covariance matrix propagation. Attitude propagation is understood as out of scope of the on-board GNC propagator, since the solution provided by the star-tracker (attitude sensors) is quite accurate and when the availability of STR's cannot be granted due to dazzling by the Sun or by lit areas of the asteroid, or because of occultation of stars by the asteroid.

The dynamic models considered in the GNC propagator are based on simplification of the perturbations models of the high fidelity trajectory propagator. These simplifications are required because of the limitation of the CPU capabilities of the on-board processors, mainly memory and clock frequency. Moreover, much of the parameters described above are not directly observable, and therefore they cannot be estimated within the determination process. The perturbation models include: central body gravity, third body gravity, non-spherical gravity field, solar radiation pressure, impulsive and low-thrust manoeuvres and noise model errors. These last ones may be composed either of biases or exponentially correlated random variables. The covariance of these variables is also propagated together with the covariance of the state vector, since those parameters are considered in the augmented state vector.

For the expression of the state vector of the S/C, position and velocity, the Cartesian representation has been chosen. Among the reasons for this choice are:

- Most accurate solution
- Flexibility to adapt to different mission phases
- Flexibility to include different thrust types and laws (applicable to different missions and spacecraft)
- Allows accurate long propagation for guidance purposes
- Reliable and robust existing formulation

On the other hand, the numerical effort is slightly higher than other formulations, especially for the computation of the covariance, which is this case, is made through central differences.

The on-board GNC propagator has been developed in standard C code, and therefore may be compiled in practically any OS. Depending on the OS and the system requirements, the on-board GNC propagator can compiled as:

  - Dynamic Library Link in Win32 O/S
  - Static Library
  - Together with program application using the On-board GNC propagator source code

The On-board GNC propagator has been successfully tested in a Leon-III card.

5. EXTERNAL INTERFACES

Since the main application of this tool is the

identification of gravity models, GRAVMOD-2 is able to export/import the generated gravity models to the ESA Planetary DataBase (PDB) [5]. On one hand this allows keeping the PDB updated and, on the other hand, it allows to directly use the gravity models already available in PDB importing them directly into the current workspace. Within PDB the same plots as shown in Figure 2 and Figure 3 are available for the stored gravity models.
Moreover, a simplified GRAVMOD-2 propagator has been also incorporated into PDB allowing the propagation of trajectories around celestial bodies modelled with a MPMM, SHM o PANGU model. PDB has now also the capability to plot these propagated trajectories independently of GRAVMOD-2.

Furthermore the gravity models created by GRAVMOD-2 can be exported into the ASTOS software (AeroSpace Trajectory Optimization Software). This will allow more complex analysis involving optimization of trajectories, mission parameters, etc.

6. CONCLUSIONS

GRAVMOD-2 results to be a very flexible tool, due to all the different functionalities and models implemented. It allows gravity modelling, mission analysis and trajectory simulations. If used in combination with ASTOS, it could handle also optimization problems.
It makes use of a user-friendly GUI that helps the user to set-up the problem in combination with the detailed Software User Manual.
It has been designed in order to be used within Concurrent Design Facilities (CDF) for missions involving asteroids, but its flexibility allows its use also in other domains.

7. REFERENCES

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