DESEO – DESIGN ENGINEERING SUITE FOR EARTH OBSERVATION

F. Letterio [1], S. Tonetti [2], S. Cornara [3], G. Vicario [4]

DEIMOS Space S.L.U., Ronda de Poniente 19, Edificio Fiteni VI, 2-2, 28760 Tres Cantos, Madrid, Spain,
[1] Email: federico.letterio@deimos-space.com
[2] Email: stefania.tonetti@deimos-space.com
[3] Email: stefania.cornara@deimos-space.com
[4] Email: gonzalo.vicario@deimos-space.com

ABSTRACT

DESEO (Design Engineering Suite for Earth Observation) is a software toolkit to support mission analysis and preliminary system/subsystem design activities of Earth Observation (EO) missions.
DESEO has been designed to be used by mission and system engineers throughout all phases of an EO mission (from Phase 0 to Phase E), whenever they need accurate and fast quantitative results to support design trade-offs and assessment analyses.
DESEO has been designed to be a modular, flexible and self-standing application, to provide the user with a comprehensive set of mission-related and system-related computation modules and with visualization capabilities to yield meaningful numerical and graphical results.
DESEO has been conceived as a tool in continuous evolution, suitable to be upgraded with further modules and capable to be interfaced with external software.
DESEO currently embeds 38 different modules in a Graphical User Interface (GUI), an EO mission data repository and a result visualization module (3D interactive visualisations, Gantt charts, Cartesian plots, cartographic maps representations and tables).

1. INTRODUCTION

The commercial market and the European Space Agency (ESA) offer a wide set of tools and libraries in order to help the space engineers in their everyday work, in both fields of mission and system analyses for EO missions. Nevertheless, none of the available tools merges together all and only those capabilities necessary for accomplishing the above-mentioned task.
The natural consequence for a user is the burden of dealing with a large set of different software tools, often supported by external post-processing instruments, and with evident drawbacks in terms of interface compatibility.
DESEO is a software toolkit, developed under an ESA contract, aimed at providing a unique instrument for supporting the everyday work of system and mission analysts.
The underlying idea of DESEO is to ease the user experience in its work, focusing the software design on the specific tasks it has been conceived for.
DESEO thus collects a decennial experience in system and mission analysis for EO missions, gathering in one tool the best practices matured in more than 20 mission studies, covering from Phases 0 to Phases D.
The objective of this paper is to describe the toolkit, both in terms of its capabilities and its field of applicability.
DESEO is the follow-on activity of SMAT (System and Mission Analysis Toolkit), representing its upgrade and extension. Its first version is under development, with the objective of increasing some computational capability, consolidating the GUI and guaranteeing full functionality under both Windows and Mac OS X operative systems.

2. TOOLKIT HERITAGE

Mission and system analysis are continuously evolving disciplines, strictly connected with the technical evolution of the EO missions concepts.
In these disciplines a key asset is the analyst expertise: the expert shall be able to dynamically interpret new requirements and propose a feasible solution through effective analysis approaches.
A very large background of analyses in those fields allowed the experts to define best practices and optimal approaches to face a large number of recursive problems.
DESEO is thus born as a software tool that aims at implementing all those best practices, in order to provide the analyst with assessment and design means tailored on the basis of his/her specific needs.
In order to take into account this expertise in the user requirements definition, a comprehensive analysis of the DEIMOS analysts' know-how matured in more than 20 mission studies has been carried out. The result has been an exhaustive knowledge map that, opportunely filtered, has brought to the fore the impact and criticality level of more than one hundred possible analyses that could be executed in the fields of **system and mission analysis**.
An attentive down-selection of all the possible analyses that could have been implemented in DESEO led to the selection of the currently implemented capabilities. The main criterion for this selection has been creating a tool able to cover the most common and recursive analyses that system and mission analysts deal with in their

everyday work in EO missions.
Beside the company expertise, the EO Customer Furnished Items (CFIs) have been another key asset for the DESEO development. In fact, some of the ESA EO CFIs functionalities (i.e. orbit propagation, satellite attitude modes and some pointing laws) have been integrated in the computational chain of DESEO, thus joining the powerful computational capabilities of the ESA-maintained EO libraries with DESEO well-structured processes aimed at providing complex analysis results, with the support of a GUI.
Beside the above-mentioned inheritances converged in DESEO (i.e. analysts' know-how and EO CFIs), there is another extremely important component that defines the backbone of the toolkit. In fact, DESEO collects the methodologies and algorithms retrieved from multiple DEIMOS (DMS) internal tools, the so-called "EO Mission Analysis and Simulation Suite". It represents a key added value for DESEO: those methods and algorithms represent in fact the state-of-the-art expertise in the mission analysis field and at the same time they are very robust, since they have been applied and tested in a large number of analyses and in a wide spectrum of EO missions.

3. SOFTWARE ARCHITECTURE

DESEO has been developed following the principles of **flexibility and modularity**, in order to guarantee reduced maintenance and upgrading efforts.
Moreover, since DESEO inherited already robust algorithms from a heterogeneous set of different tools, a deep work of re-engineering has been conducted in order to allocate a large number of different analysis concepts seamlessly in a unique but modular architecture.
The overall architecture has been designed in order to identify clear interfaces, both between analysis modules and GUI and among the modules themselves.
The design approach has been based on an **Object-Oriented (OO)** approach, supported by the Unified Modelling Language (UML).
For the interfaces definitions, an extended use of **XML Schema Documents (XSD)** has been done, making their modifications very agile.
The result has been a very flexible infrastructure, able to integrate in a unique paradigm a large number of different analyses, thus enabling an easy extension of the tool capabilities and, hence, being prone to future improvements and enhancements.
As depicted in Fig.1, the user can operate DESEO both via a GUI and also via command line. Moreover, the analysis modules are integrated in the overall high-level architecture by means of well-defined interfaces, so that they can be extended (both in number and functionalities) with a plug-and-play approach.

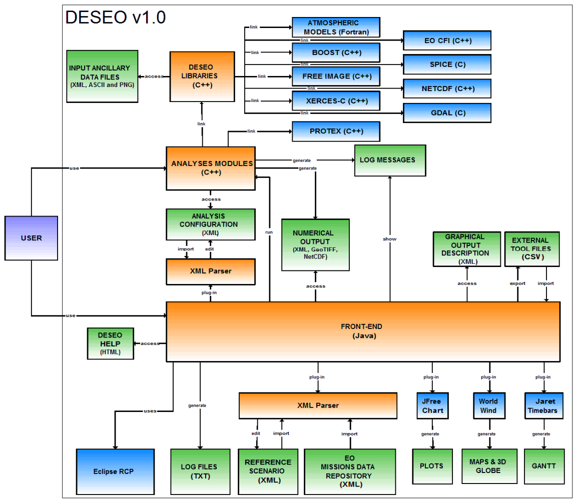

Figure 1. High-Level System Decomposition

4. ANALYSIS CAPABILITIES

DESEO provides the mission and system analyst with a wide set of assessment and design tools, which span from complex simulation-based computations to fast auxiliary analytical models.
The 38 different analysis modules embedded in the toolkit are intended to yield a powerful instrument for the analysis processes, as well as to support the everyday analyst work by means of fast and precise computations.
The following sub-sections briefly outline the DESEO analysis capabilities.

4.1. Orbit Propagation

DESEO implements several propagation methods, which can be used as standalone analyses or as backbone for all those analyses that foresee orbit propagation. Moreover, the propagators can be used both for short-term propagations (e.g. for generating a reference orbit) and for long-term propagations (e.g. for studying the behaviour of a perturbed orbit). The available propagation methods encompass:

- **Numerical propagation**, aimed at short-term precise propagations (Fig. 2);
- **EO CFI propagation**, giving access to all the EO CFI propagation methods (Fig. 2);
- **Semi-analytical propagation**, aimed both at short- and long-term propagations (Fig. 3);

Along with the orbit propagation methods, some other analyses relying on them are provided:

- **Attitude computation**, implementing different attitude laws and giving access to the EO CFI attitude computation methods (Fig. 4);
- **Atmospheric analysis**, computing atmospheric characteristics, using different atmospheric models (Fig. 5).

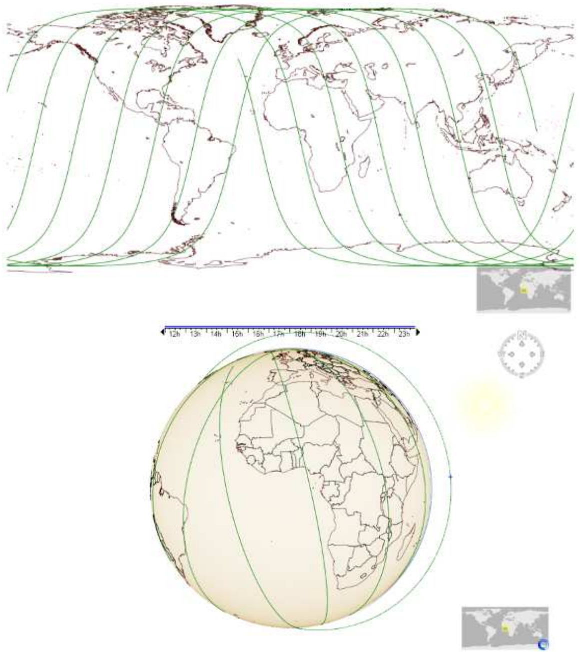

Figure 2. Propagated Orbit: Map Projection (above) and 3D View (below)

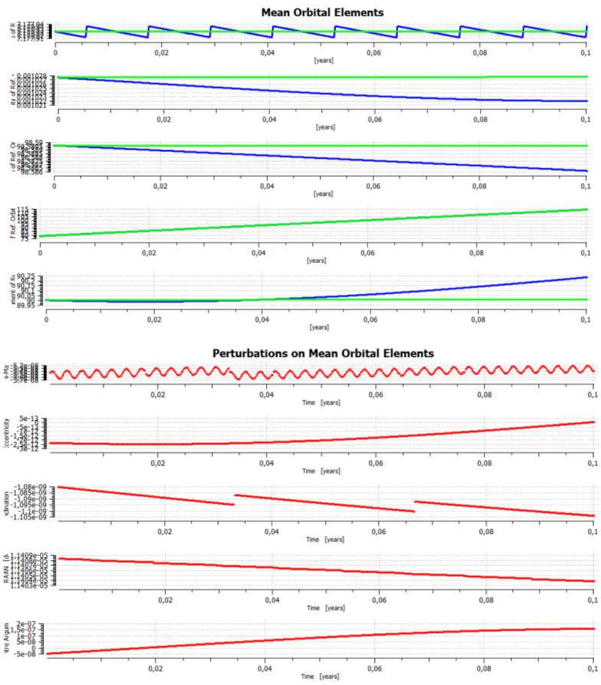

Figure 3. Propagated Mean Elements (above) and Relative Perturbations (below)

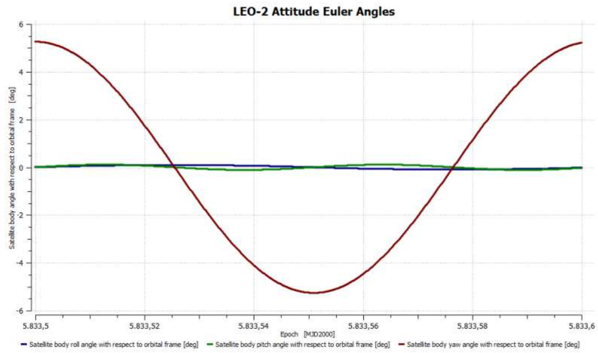

Figure 4. Attitude Computation

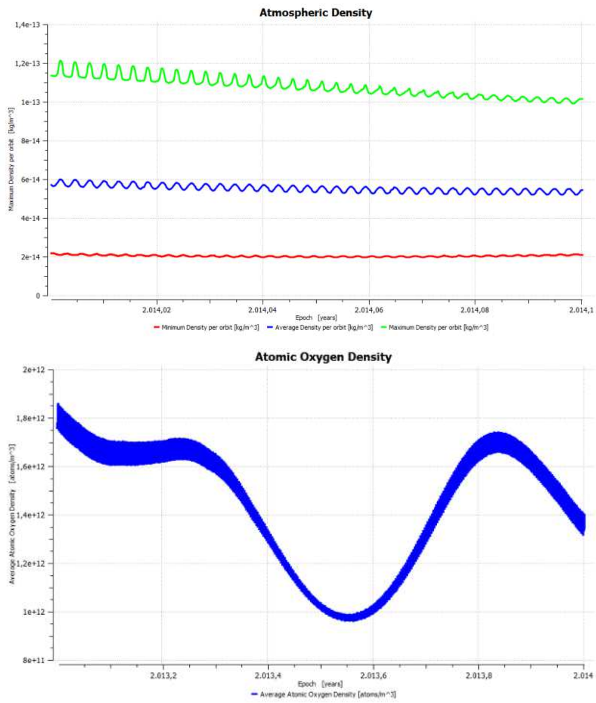

Figure 5. Atmospheric Density (above) and Atomic Oxygen Density (below)

4.2. Coverage Analyses

Based on short-term orbit propagation, DESEO provides algorithms to compute information about the zones observed by a defined on-board payload (P/L). The coverage analysis is highly customizable, both in terms of payload and maps definitions.

The instruments can be designed taking into account classical constraints for e.g. optical and radar instruments (e.g. field of view, incidence angles/observation-zenith angles, sun-zenith angle, sun-glint, etc.).

The maps identifying the areas of interest for data acquisition can be thematic (e.g. terrain, water, ice) or polygonal maps.

Among the wide set of computed outputs, there are **revisit time** (Fig. 6), **coverage** and **P/L duty cycle**.

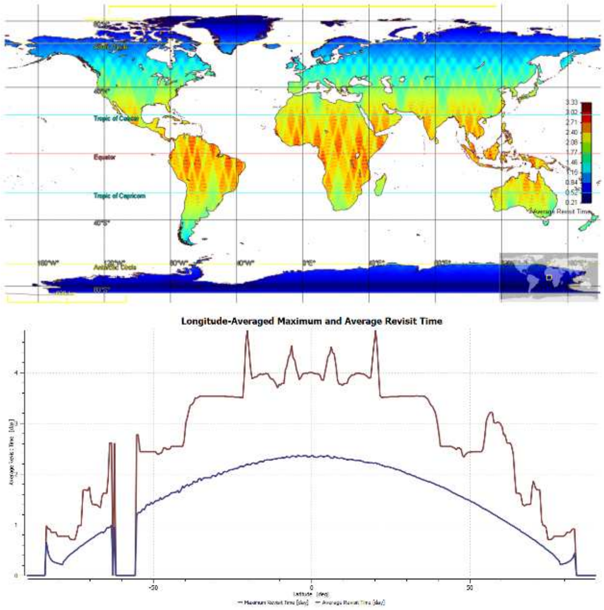

Figure 6. Revisit Time Map (above) and Revisit Time Longitude-Averaged Values (below)

4.3. Ground Station Contact Analyses

DESEO provides a set of analyses focused on the relationship between the space and ground segments. It enables the computation of the visibility geometry and contact statistics of a spacecraft with respect to different ground stations. It is also possible to solve conflicts that arise when a spacecraft has contemporary access to multiple ground stations.
The timeliness analysis then provides a powerful instrument to compute the latency of acquired data, given a ground station (GS) network.

- **Ground station visibility**, computing the visibility intervals between S/Cs and GSs (Fig. 7 and Fig. 8);
- **Ground station conflicts**, solving possible ground station access conflicts (Fig. 7 and Fig. 8);
- **Timeliness analysis**, assessing the time from instrument data acquisition to their delivery as data product to the user segment interface (Fig. 9).

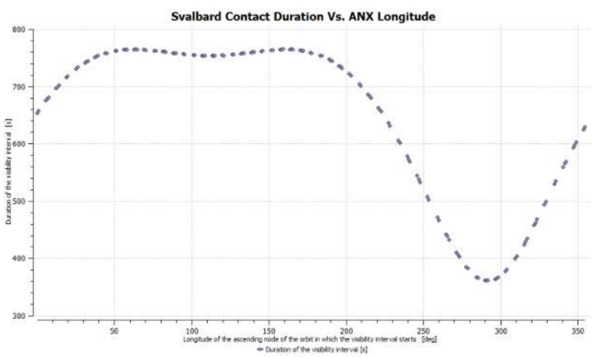

Figure 7. GS Contact Duration vs. Ascending Node Crossing Longitude

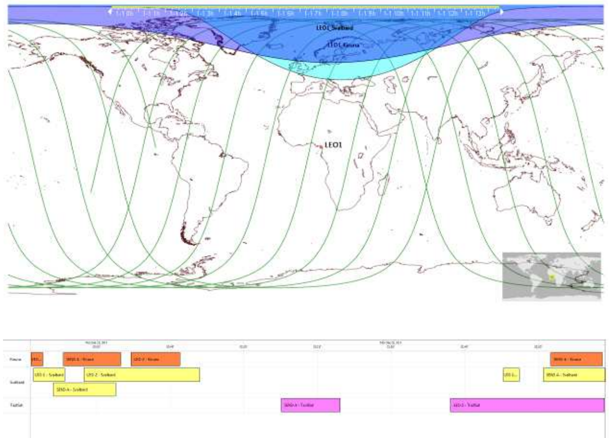

Figure 8. GS Visibility Map (above) and Contacts Gantt Chart (below)

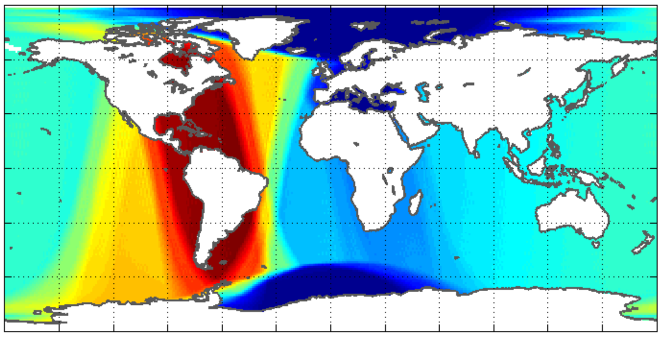

Figure 9. On-Board Data Latency Map

4.4. Orbit Control Analyses

A comprehensive set of analyses is dedicated to computing the ΔV and fuel necessary to maintain an orbit, given a control strategy. DESEO provides several control laws, stand-alone or combined. It also implements an analytical formula for estimating the ΔV and fuel necessary to control a loose formation in master-drone configuration.
The results of the Orbit Control analyses could be further used to compute the overall mission ΔV and fuel budget, along with other orbit manoeuvre contributions.
The set of orbit control analyses encompasses:

- **Altitude control** (Fig. 10)
- **Inclination control**
- **Equator ground track control**
- **Altitude and inclination control**
- **Equator ground track and inclination control**
- **Master-drone control**

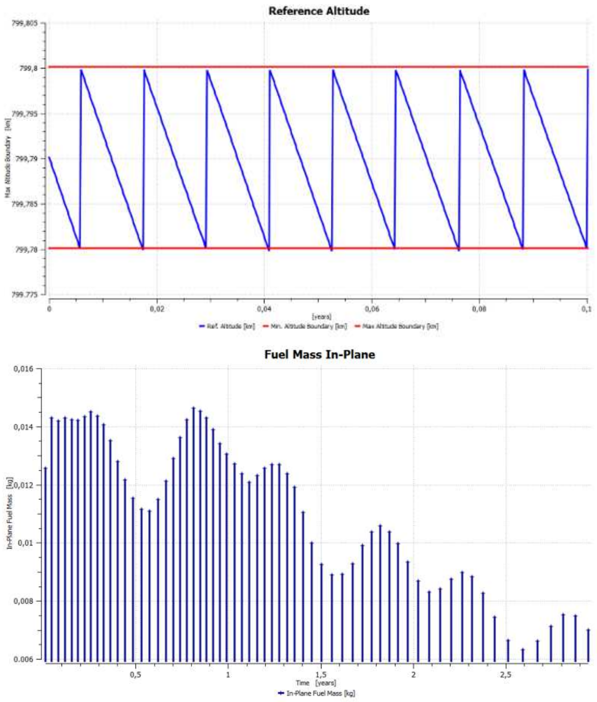

Figure 10. Altitude Control (above) and Firing Fuel Mass History (below)

4.5. Delta-V and Fuel Budget Analyses

This system analysis is aimed at providing the user with a powerful instrument for evaluating the overall mission ΔV and fuel budget.

- **Injection errors correction**, computes the ΔV for correcting launcher dispersion errors;
- **Collision avoidance**, computes the ΔV for the collision avoidance manoeuvres estimated over the mission lifetime (to avoid collisions with catalogued debris objects);
- **Orbit transfer**, computes the ΔV for possible orbit transfer manoeuvres;
- **End-of-life (EoL) decay analysis**, computes the ΔV for the EoL re-entry manoeuvre (Fig. 11). This analysis fully implements the ESA guidelines on ΔV and fuel budget calculation [1].

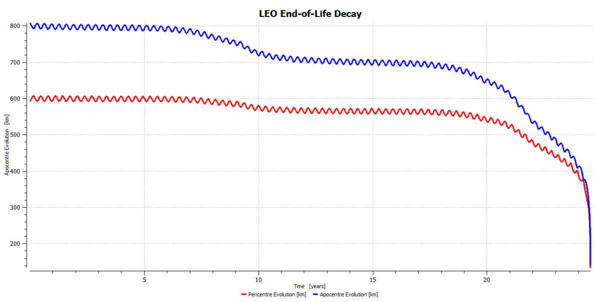

Figure 11: Apogee and Perigee Evolution during the EoL Re-Entry Phase

4.6. Power Budget

The Power Budget analysis is a complex system analysis that can be exploited both for sizing the power subsystem (by means of a parametric approach) and for assessing S/C sub-system design.
This analysis takes into account the S/C attitude, the orientation of the solar panels (that can be fixed or with a degree of freedom) and a model of the losses both in terms of batteries and solar panels (Fig. 12).

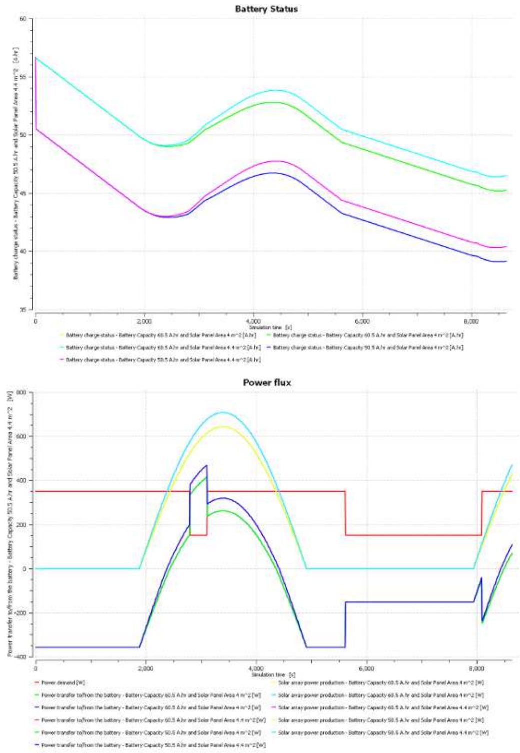

Figure 12. Battery Status (above) and Power Fluxes (below)

4.7. Mass Memory Occupation Analysis

This system analysis couples the information conveyed by the payload duty cycle with the GS visibility contacts, generating the timeline of the on-board mass memory occupation (Fig. 13).

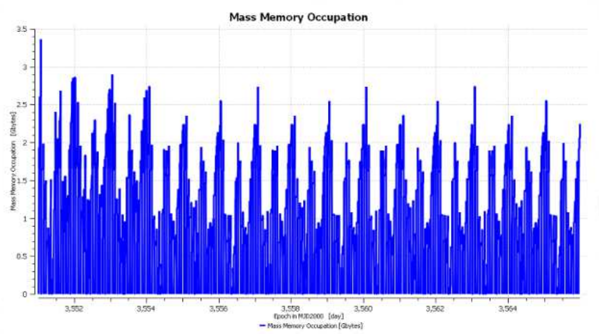

Figure 13. On-board Mass Memory Occupation

4.8. Orbit Selection

The Orbit Selection analyses embed a series of tools aimed at helping the mission analyst in identifying the candidate orbits for a specific mission.

- **Orbit wizard**, provides an orbit state vector based on high-level orbit definitions;
- **LEO selection**, provides a set of orbits given certain requirements, along with ancillary information for the reference orbit selection (Fig. 14);

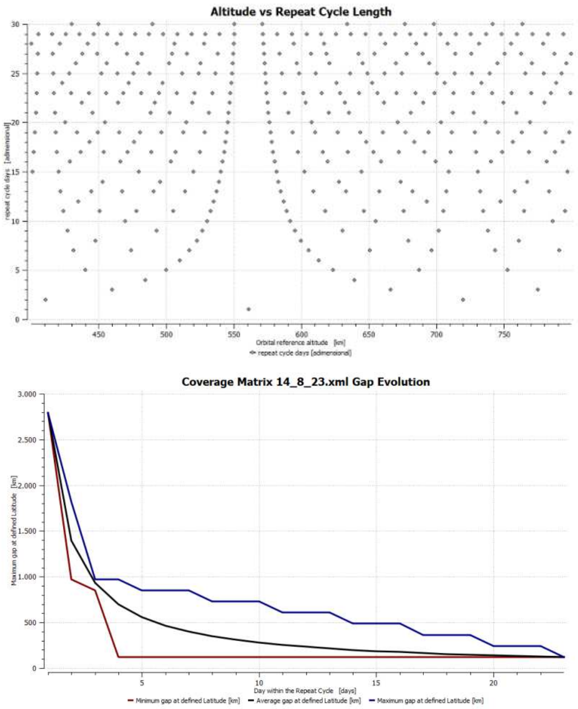

Figure 14. Altitude vs. Repeat Cycle Map (above) and Gap Evolution Graph (below)

- **SSO inclination**
- **Frozen eccentricity**
- **Right Ascension of Ascending Node (RAAN) drift rate**

4.9. Generic Geometric Analyses

The Generic Geometric Analyses collect a series of analyses providing geometric information about a space system.

- **Ground illumination**, provides a map or 3D view of the Earth illumination at a given epoch;
- **Time transformations**, implements transformations between different time reference frames;
- **Coordinates transformations**, implements transformations between different coordinate reference frames and coordinates systems;
- **Basic swath geometry**, computes geometrical information of a simple swath model;
- **Geodetic distance**, computes the geodetic distance between two points on ground;
- **Sun-zenith angle**, computes the sun-zenith angle within a swath generated by a space-borne sensor;
- **Observation-zenith angle**, computes the incidence angle within a swath generated by a space-borne sensor;
- **Swath computation**, computes the geometric characteristics of the swath generated by a space-borne sensor (Fig. 15);

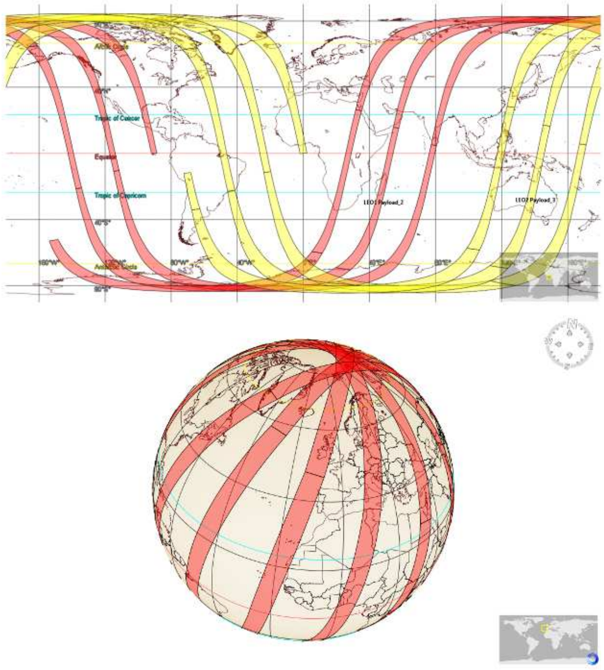

Figure 15. Swath Maps (above) and Swath 3D View (below)

- **Pointing analysis**, performs parametric analyses based on the EO CFIs Pointing library, applying constraints on the orbit segments;
- **S/C topocentric coordinates**, visualises the spacecraft orbit in a topocentric coordinates system (Fig. 16);

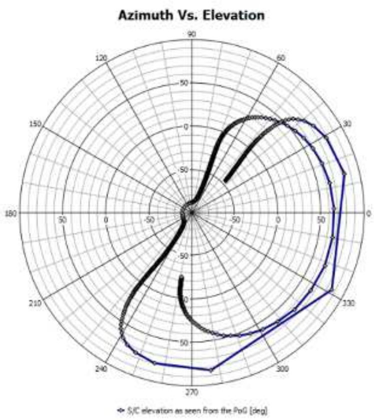

Figure 16. Azimuth-Elevation Polar Plot

- **Sun-synchronous beta angle**, computes the Sun β-angle during a year for a sun-synchronous orbit;
- **Sun-synchronous eclipse**, computes the eclipse durations during a year for a sun-synchronous orbit (Fig. 17).

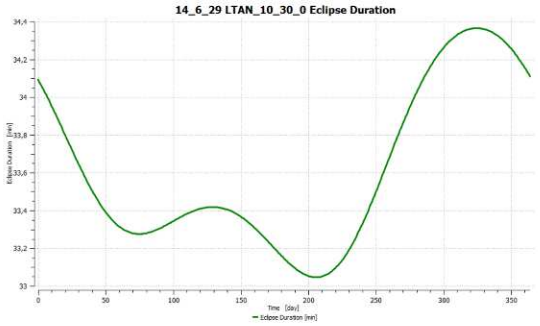

Figure 17. Eclipse Yearly Evolution

5. DESEO APPLICABILITY TO EARTH EXPLORERS PHASE A STUDIES

As introduced in Sec. 2, one of the drivers in the DESEO user requirements definition was creating a tool able to cover the most common and recursive analyses a system and mission analyst encounters in his/her everyday work.

An opportunity to prove the applicability of DESEO to a classical mission analysis study was provided by the Earth Explorers (EEs) Phase A/B1 studies, since DEIMOS was at the same time involved in the DESEO development and in the EEs Phase A/B1 Studies as mission analysis responsible.

A traceability matrix between the DESEO implemented analyses and the EEs Mission Analysis Reports (MAR) produced by DEIMOS has been generated.

The outcome of this exercise has highlighted that DESEO has been able to cover almost all the analyses required for the chosen EO missions. There are 12 analyses that were not strictly performed for the EEs mission analysis, but that are implemented and distributed within DESEO.

Moreover, together with mission analysis tools, DESEO implements computation capabilities that are commonly handled by system engineers and, thus, they are not applied in the EE MARs, e.g. attitude analyses and power budgets (in bold in the Tab.1).

A very interesting aspect of the analysis of DESEO applicability to the EEs Phase A/B1 studies is the inverse traceability matrix, i.e. detecting which analyses performed in the scope of the EEs Phase A/B1 studies are actually covered by DESEO: almost all the analysis necessary for the EE MARs are covered by DESEO.

It is possible to see that there are only few analyses DESEO covers with some constraints: some refinements are present in the EEs MARs that cannot be performed by the current DESEO version (refined analyses are highlighted with a star (*) in Tab.1).

Moreover, the only analyses of the entire three EE Phase A/B1 studies analysed not covered at all by DESEO are associated with very specific computations that had to take into account not-generic characteristics of the payload or the mission. However, four of them could be retrieved with an opportune post-processing of the available data generated by DESEO (i.e. formation, GS interference, duty cycle and data latency analyses) and three of them could be performed with very simple extensions of the toolkit capabilities (i.e. sunglint and orbit control analyses).

Summarising, only two analyses of the whole set of three EEs Phase A/B1 studies taken into account are out of the scope of DESEO, being very mission-specific (i.e. interferometry and reflectance sensor levels related analyses). The cases not fully covered by DESEO are then mainly related with level of detail of Phase B1.

Analysis	CarbonSat	FLEX	Biomass
Orbit Propagation	Orbit Altitude Evolution	Formation Flying Stability (*)	Orbit Altitude Evolution
Attitude	N/A	N/A	N/A
Coverage	Coverage, Sunglint Tracking (*)	Coverage, Duty Cycle	Coverage, Duty Cycle (*)
Ground Stations Visibility	GS Network	GS Network, Interference (*)	GS Network LEOP
Ground Stations Conflict	GS Network	GS Network	GS Network LEOP
Timeliness	N/A	On-board Timeliness	Data Latency (*)
Swath Properties	Coverage	Coverage	Coverage
Sun-Zenith Angle	Coverage	Coverage	N/A
Observation-Zenith Angle	Coverage	Coverage	Coverage
SC Topocentric Coordinates	GS-to-S/C Viewing Geometry (*)	GS-to-S/C Viewing Geometry	N/A
Pointing Analysis	N/A	N/A	N/A
Semi-analytical Propagation	Delta-V Budget	Delta-V Budget	Delta-V Budget
Atmospheric Properties	Atmospheric Density Profile Delta-V Budget	Atmospheric Density Profile Delta-V Budget	Atmospheric Density Profile Delta-V Budget
Altitude Control	Delta-V Budget	N/A	N/A
Inclination Control	Delta-V Budget (*)	N/A	Delta-V Budget
Eq. Ground Track Control	N/A	GTE Control (*)	Delta-V Budget
OA + OI Control	N/A	N/A	N/A
EGT + OI Control	N/A	N/A	Delta-V Budget
EOL Decay	Delta-V Budget	Delta-V Budget	Delta-V Budget
Beta Angle	Beta Angle	Beta Angle	Beta Angle
Eclipses	Eclipse	Eclipse	Eclipse
Ground Illumin.	N/A	N/A	N/A
Time Tran.	N/A	N/A	N/A
Coordinates Tran.	N/A	N/A	N/A
Injection Errors Correction	Delta-V Budget	Delta-V Budget	Delta-V Budget LEOP
Collision Avoidance	Delta-V Budget	Delta-V Budget	Delta-V Budget
Orbit Transfer	N/A	Formation Acquisition	Orbit re-positioning
Master-Drone Control	N/A	Formation Control (*)	N/A
Orbit Wizard	N/A	N/A	N/A
LEO Selection	Orbit Selection	N/A	Orbit Selection
SSO Inclination	N/A	N/A	N/A
Frozen Eccentricity	N/A	N/A	N/A
RAAN Drift Rate	N/A	N/A	N/A
Basic Swath Geometry	Orbit Selection	N/A	N/A
Geodetic Distance	N/A	N/A	N/A
ΔV & Fuel Budget	Delta-V Budget	Delta-V Budget	Delta-V Budget
OBDH	N/A	N/A	Data Volume
Power Budget	N/A	N/A	N/A

Table 1. DESEO vs. EEs MARs Traceability Matrix

This example shows the capability of the toolkit of covering a classical mission analysis with its set of implemented tools. Nonetheless, DESEO has wide margins of upgrade and enhancement, both in terms of mission analysis (by means of more complex and detailed analyses) and system analysis (with dedicated tools to cover the whole field of possible analyses).

6. FLYING DEMONSTRATION CASE: DEIMOS-2 MISSION

The DEIMOS-2 mission has been launched in June 2014 and consists in an agile mini-satellite for high-resolution EO applications. The agile spacecraft can be steered to accurately point the pushbroom-type optical payload, which can provide 75-cm pan-sharpened and 4-m multi-spectral image with a swath of 12 km at nadir, at an orbit altitude between 590 km and 640 km. It is currently operating nominally and it is a Third Party Copernicus mission.

The whole mission analysis and some system analyses of the DEIMOS-2 mission have been performed using DESEO.

The objective of this section is to provide a comprehensive overview of the DEIMOS-2 mission design process undertaken using DESEO, in order to show the degree of compliance of the toolkit with the actual needs of the DEIMOS-2 mission.

Starting with the reference orbit design and characterisation, this section encompasses the injection orbit selection, the coverage and ground station contact performance, the Sun geometry analysis, the assessment of the impact of free orbit decay on the mission return, the manoeuvre implementation scenario and the complete mission ΔV and fuel budgets.

6.1. Orbit Selection

The key drivers for the DEIMOS-2 orbit selection were the optimisation of the revisit time over the Earth surface with the nominal Field of Regard (FoR) (±30º) and the extended FoR (±45º), the image resolution obtained and the mission robustness (mainly in terms of orbit decay) with respect to potential failure scenarios (launcher injection errors, propulsion system availability and reliability).

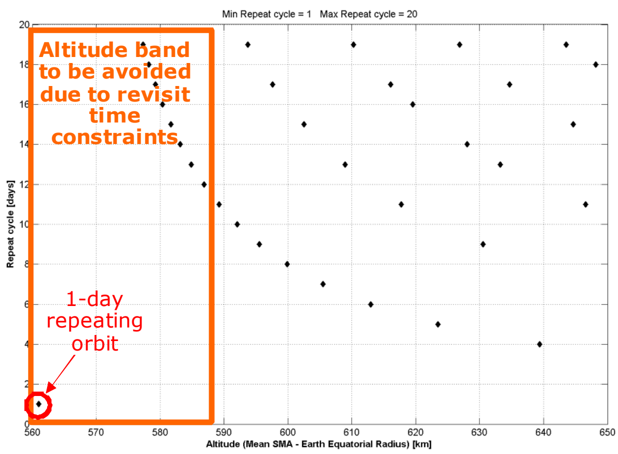

Figure 18. SSOs Repeating Orbits Plot

The mission has been designed to be feasible and fulfil the mission requirements even in case of launcher injection errors and/or failure of the main on-board propulsion system within certain acceptable margins. The orbit decay without applying any control has been designed to be compatible with the mission success, i.e. without drastically jeopardising the mission feasibility.

Figure 18 displays the repeat cycle length as a function of the reference altitude for a wide set of candidate orbits in the altitude range of interest, retrieved with the LEO Selection Analysis. Figure 19 highlights the orbits allowing global coverage in a given number of days with a given FoR.

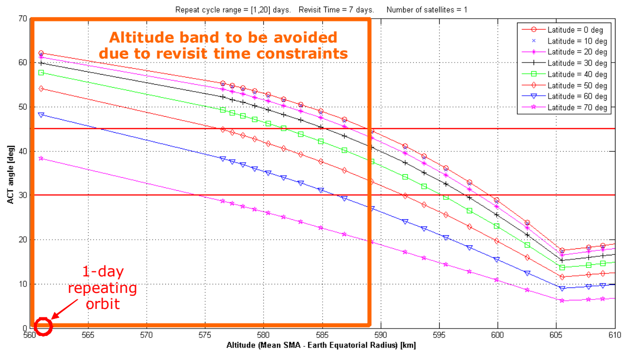

Figure 19. Required Across-Track Angle for Global Coverage

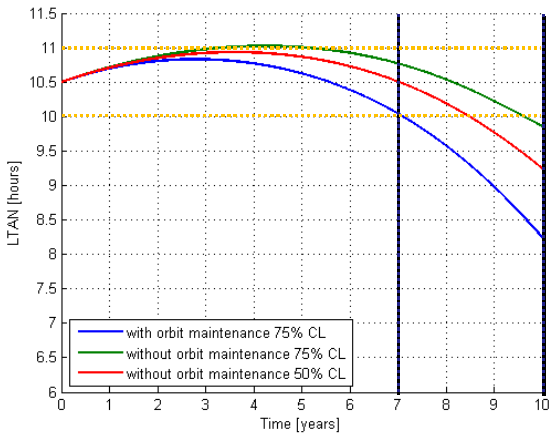

Figure 20. Mean LTAN Evolution

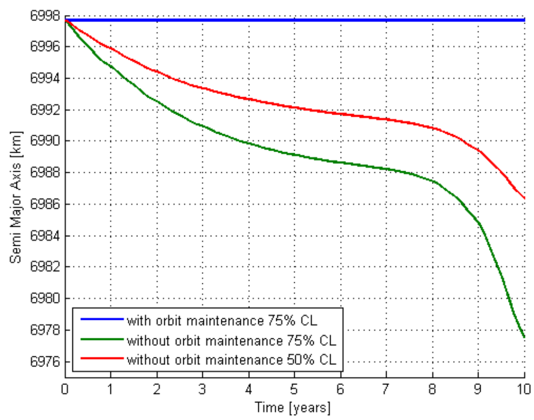

Figure 21. Mean Semi-major Axis Evolution

The mission analysis addressed the orbit evolution assessment, in order to evaluate the impact of a

uncontrolled orbit on the mission performances, and the planning and implementation of the orbit manoeuvres (correction of launcher injection errors, orbit maintenance, collision avoidance and end-of-life disposal). Mission scenarios with orbit maintenance during the mission lifetime and with free-decaying orbit have been analysed and the corresponding impact on the mission return has been assessed (Figure 20 and Figure 21).
Once the reference orbit has been selected, a set of dedicated and detailed orbit analyses is performed to fully characterise the mission profile and performances, e.g. beta angle and eclipse duration evolution (Figure 22).

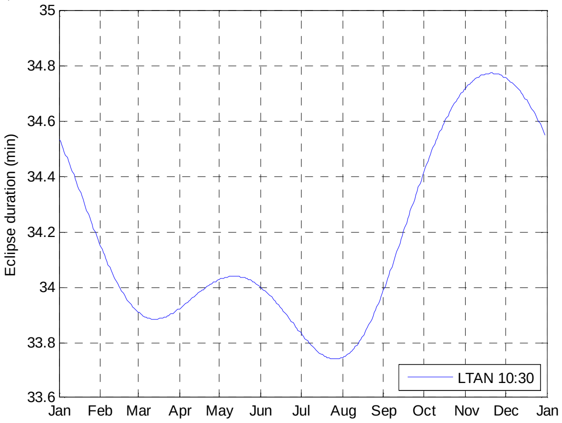

Figure 22. Yearly Evolution of Eclipse Duration

6.2. Coverage

To exhaustively characterise the mission performance, extensive coverage analyses have been carried out, encompassing such figures of merit as revisit time, number of acquisitions, observation viewing geometry, cumulative coverage vs. time (Figure 23).
Moreover the geometry of observation has been assessed with detailed analyses of swath properties in terms of width and Observation-Zenith Angle.

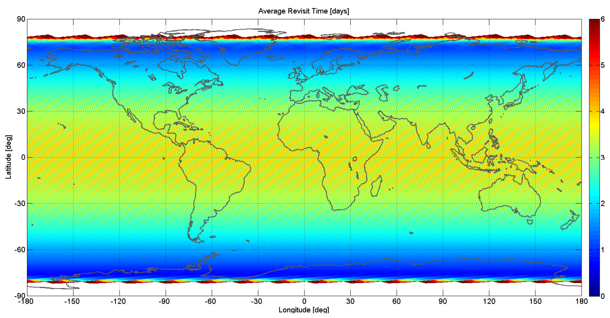

Figure 23. Avg. Revisit Time after a Repeat Cycle

6.3. Ground Station Contact Analysis

The definition of the operations scenario has been also driven by the contact opportunities with the primary ground station (Puertollano), and with the secondary ground station (Svalbard) used to enhance the available data download time (Figure 24).

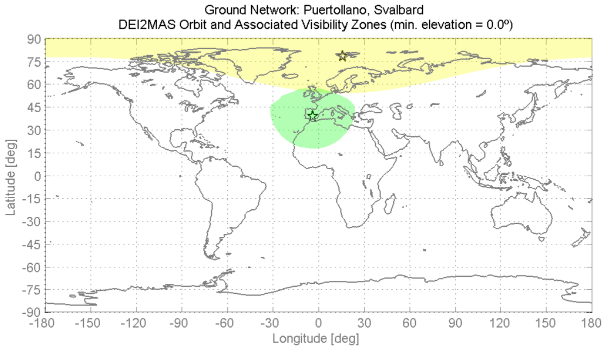

Figure 24. Coverage Zone of Svalbard (yellow) and Puertollano (green)

6.4. System Budget Analysis

The volume of images collected and the ground delivery intervals, combined with the on-board mass memory and data transmission rate, have a key impact on the mission capacity and exploitation. Comprehensive on-board data memory occupation analyses have been performed to assess the memory sizing (Figure 25).

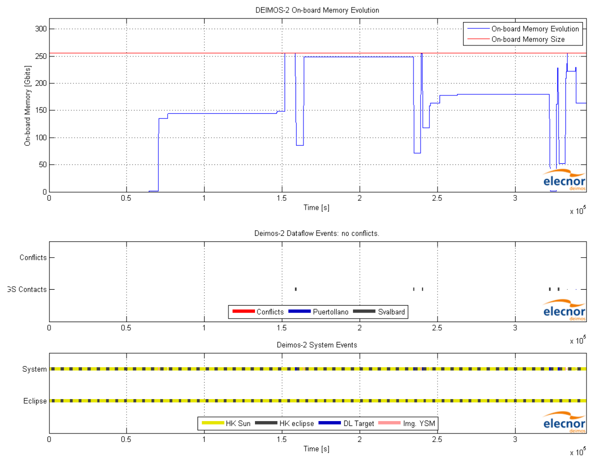

Figure 25. Memory Occupation Analysis

The overall ΔV and fuel budgets have been computed embedding the contributions for initial orbit acquisition, orbit maintenance, collision avoidance and EOL disposal. The main ΔV contributions are due to initial orbit acquisition and EOL disposal manoeuvres (Table 2).
Extensive power budget analyses have been also carried out in order to assess the platform capacity to support a complex series of operations encompassing continuous attitude manoeuvres, data acquisition and download, eclipses and battery charges (Figure 26).

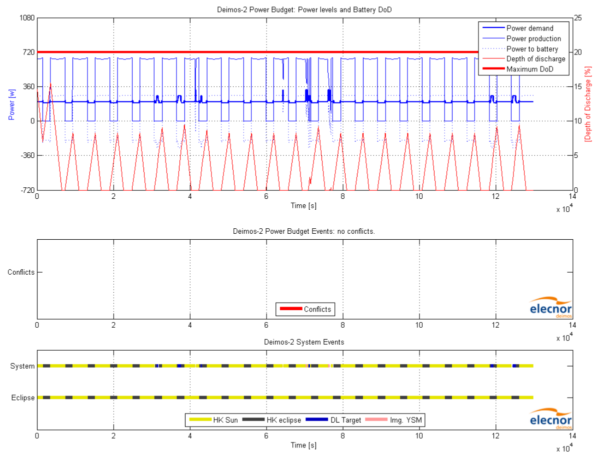

Figure 26. Power Budget Analysis

Manoeuvre	ΔV [m/s]	Fuel Mass [kg]
Initial Orbit Acquisition		
Injection Error Correction	**18.6**	**0.6**
In-plane manoeuvres	5.4	0.2
Out-of--plane manoeuvres	13.2	0.4
Orbit Maintenance		
Tot in-plane orbit control	**5.6**	**0.2**
Average in-plane orbit control manoeuvre	0.002	0.0001
Collision Avoidance		
Tot in-plane collision avoidance	**3.8**	**0.1**
Average in-plane collision avoidance manoeuvre	0.54	0.02
EOL Disposal		
In-plane de-orbiting manoeuvre	**19.7**	**0.6**
Total Budget		
Total results	**47.6**	**1.5**

Table 2. ΔV and Fuel Budgets

Table 3 shows the very high compliance level of DESEO with the mission and system analysis needs of the DEIMOS-2 mission. Only few analyses (*) needed some post-processing of the DESEO outputs in order to cope with the advanced phases of the project (from A to E).

Analysis	DEIMOS-2	Analysis	DEIMOS-2
Orbit Propagation	Orbit Evolution	Beta Angle	Orbit Selection
Attitude	Agility (*)	Eclipses	Orbit Selection
Coverage	Coverage, Duty Cycle	Ground Illumin.	N/A
Ground Stations Visibility	GS Network	Time Tran.	N/A
Ground Stations Conflict	GS Network	Coordinates Tran.	Launch Scenario (*)
Timeliness	N/A	Injection Errors Correction	Delta-V Budget
Swath Properties	Coverage	Collision Avoidance	Delta-V Budget
Sun-Zenith Angle	Coverage	Orbit Transfer	Launch Scenario, Delta-V Budget
Observation-Zenith Angle	Coverage	Master-Drone Control	N/A
SC Topocentric Coordinates	GS Network	Orbit Wizard	Orbit Selection
Pointing Analysis	N/A	LEO Selection	Orbit Selection
Semi-analytical Propagation	Long-term Orbit Evolution	SSO Inclination	N/A
Atmospheric Properties	Atmospheric Density Profile Delta-V Budget	Frozen Eccentricity	N/A
Altitude Control	Delta-V Budget	RAAN Drift Rate	N/A
Inclination Control	N/A	Basic Swath Geometry	Orbit Selection
Eq. Ground Track Control	N/A	Geodetic Distance	N/A
OA + OI Control	N/A	ΔV & Fuel Budget	Delta-V Budget
EGT + OI Control	N/A	OBDH	Mass Memory Occupation (*)
EOL Decay	Delta-V Budget	Power Budget	Power Budget (*)

Table 3. DESEO vs. DEIMOS-2 Traceability Matrix

7. CONCLUSIONS

DESEO is a powerful toolkit, designed to supply an exhaustive set of functionalities and cover the most common and frequent analysis needs that a mission/system engineer faces in his/her everyday work. DESEO can be used by analysts whenever they need accurate and fast quantitative results to support trade-offs and internal analyses. Nevertheless, DESEO is also able to manage large analysis campaigns, as a complete EO mission Phase 0 or Phase A study.

Moreover DESEO has been designed taking into account progressive future developments. For this reason, a modular and generic architecture has been implemented, paving the way for future extensions.

The outcome is a very generic and modular software toolkit that, starting from the current SMAT tool, is undertaking incremental upgrades minimising the integration effort for new capabilities, both in terms of analysis modules and GUI functionalities. The wide margin of extendibility of DESEO covers both the increase of computation capabilities (especially the system analysis modules) and the consolidation of GUI for improving the user experience when operating it.

The DESEO development has been based on a comprehensive overview of the possible necessary analyses to be handled by the end-user in the frame of current and future EO missions outlining a large number of possible use cases. Many of them have been already integrated in the current toolkit version. Nevertheless, the other use cases represent a solid basis for starting the design of further upgrades, both in terms of implementation of new analyses and consolidation of the current ones.

The EO CFI library has been modularly and seamlessly integrated in DESEO. Its integration has been performed in order to have no implementation efforts whenever a newer version of the library will be available.

The ESA EE mission analysis activities, as well as the DEIMOS-2 ones, are showcases for the functionalities provided by DESEO and their reliability throughout all the phases of an EO mission (from Phase 0 to Phase E).

DESEO will be available for both Windows and Mac OS X platforms.

8. REFERENCES

[1] A. Gabriele, B. Carnicero, P. Bensi, B. Duesmann, I. Barat, “Guidelines for ΔV and propellant budget computation for spacecraft in LEO orbits”, EOP-SFP/2013-03-1705, 22/03/13.

[2] S. Cornara, B. Altés-Arlandis, M. Renard, S. Tonetti, F. Pirondini, R. Alacevich, A. Mazzoleni, “Mission Design and Analysis for the DEIMOS-2 Earth Observation Mission”, *63rd International Astronautical Congress*, Naples, Italy, 2012.