focussuite WHITE PAPER

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1. INTRODUCTION TO *FOCUSSUITE*

This section provides a general introduction to ***focussuite***, GMV's advanced off the shelf flight dynamics solution for satellite operations, and shows how our system provides the most complete solution to the needs of both end-user products and flight dynamics system developers. Our product addresses the specific requirements of satellite operators while at the same time providing a framework that allows further product development and evolution.

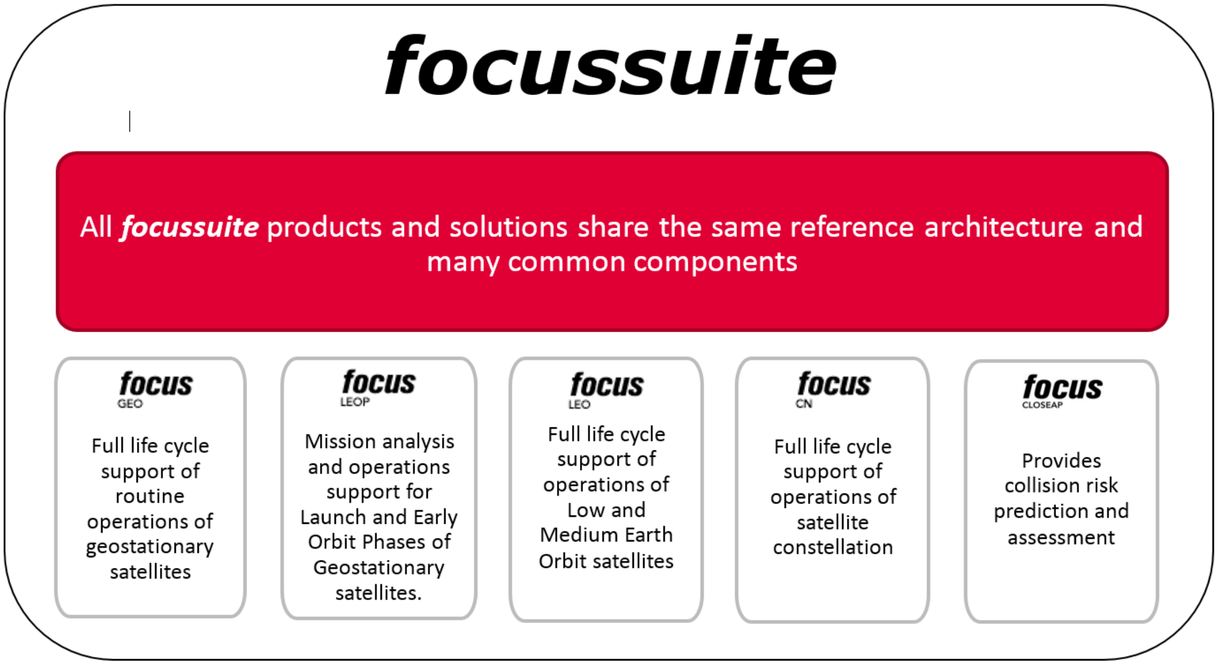
focussuite can therefore be regarded as a COTS product that can be customized to fit your needs, but also as a framework oriented to minimizing programme development schedule, costs and risks, and at the same time greatly improving the efficiency of operations (minimizing operations workload) and reducing the risk of human errors.

GMV acknowledges the fact that every customer has different needs and requirements when it comes to covering their flight dynamics needs. This reflection comes from our privileged position as the main European supplier of flight dynamics systems and services after almost two decades of uninterrupted successful services to a large variety of clients. Consequently and consistently with this we are pleased to offer to the market ***focussuite***, the ultimate flight dynamics solution for satellite operations. Our solution is characterized by the following unique high-level requirements:

- Advanced off-the-shelf, multi-mission, multi-satellite flight dynamics solution for flight dynamics satellite control that sets a new standard in functionality, reliability, flexibility and user friendliness.
- Capability to provide full lifecycle flight dynamics operations support through our unsurpassed collection of flight-proven mission independent and mission specific functionality. Flight-proven support of commercial satellite platforms is provided with accuracy fully consistent with native systems.
- Availability of a large collection of plug-and-play components providing unprecedented functionality and being able to customize the system to fit your specific needs. GMV provides custom solutions with strong customer focus and customer support.
- Provision of a generic framework that allows further product development and evolution, including the ability to integrate external applications with unprecedented ease. Our open framework dramatically boosts productivity, system usability, accessibility and stability.

focussuite has therefore been conceived as a real framework as it is demonstrated by its major functionalities: **a computation layer** based on the extensive reuse of existing and improved software, a **client/server architecture**, a **database driven** system, an **advanced GUI** (based on common applications philosophy: "*everything-in-one-working-area*" and "*all-one-click-away*" and using a GUI toolkit that allows a development of GUIs through configuration files rather than through code), procedures automation capability through the ***autofocus*** extension (based on a dedicated language **SOL** -Spacecraft Operations Language), advanced **graphical capabilities**, **portability** (e.g. Windows / UNIX / Linux/ Web) and **extensibility** (any extra functionality following certain I/O rules can be easily integrated via configuration files) .

focussuite includes a suite of generic operational flight dynamics systems. They share the same architecture and many common components. Each of them has a different computational layer, all of them based originally on flight proven ESA's packages like PEPSOC and NAPEOS. The following stand-alone products are included within ***focussuite***:



focussuite
All ***focussuite*** products and solutions share the same reference architecture and many common components
focus GEO
Full life cycle support of routine operations of geostationary satellites
focus LEOP
Mission analysis and operations support for Launch and Early Orbit Phases of Geostationary satellites.
focus LEO
Full life cycle support of operations of Low and Medium Earth Orbit satellites
focus CN
Full life cycle support of operations of satellite constellation
focus CLOSEAP
Provides collision risk prediction and assessment

Table 1-1 –*focussuite* operational Flight Dynamics Systems

The following paragraphs describes the overall structure of ***focussuite*** products and a more detailed description of the common components used by all the products within ***focussuite***, namely:

<u>On the client side</u>:

Component	Description
ebro	Generic Events Browser, shows a set of events in a Gantt chart. Self-contained tool, to be used in all ***focussuite*** products.
grafos	Generic plotting tool. Self-contained tool, to be used in all ***focussuite*** products.
focusclient	Client side of ***focussuite*** products, including the GUI and the communications layer
focusapi	API (Application Programming Interface) that can be used by external clients to interact with ***focusprocess manager***. In particular, it shall be used by **focusclient** and ***autofocus. It provides a REST API accesible through https in order to be used by third party services.***
autofocus	***focussuite*** Automation module.
focusframes	Stand-alone application used for conversion between different reference frames. This application has been provided by GMV in previous systems and shall be provided in ***focussuite*** products
focusaspect	Telemetry Monitoring tool
visualfocus	Visualisation tool providing 2D, 3D and Sensor's Views

On the server side:

Component	Description
focusprocess manager	Processing component in the Server Side of ***focussuite*** products.
focusdata manager	Manager of operational data files (including revision control), in the Server Side of ***focussuite*** products.
focusart	Optional component that provides Automatic Regression Testing functions, to let the developers or system administrators execute automatically a set of reference tests on the computation functions installed at the server side. It can alternatively be installed as a stand-alone tool that will use the same computation functions as the operational system.

On both sides:

Component	Description
tkforms / tkflib	Data access layer for computation programs and user interaction toolkit
focusevelog **(Events Logger)**	Generic logger of operational events. It is a generic client-server component, easily adaptable to ***focussuite*** products or any other system.
focusComm	Communications layer

At the same time, several **stand-alone products** based on ***focussuite*** infrastructure are available. A good example is ***focuscloseap***, a generic tool for automatic detection of close approaches between geostationary satellites and objects intersecting their orbit. An independent document providing complete information on ***focuscloseap*** is available at ***focussuite*** web page: http://focussuite.gmv.com/

Additionally, GMV has a long experience in developing customised ***focussuite*** -based solutions for specific needs. The existing framework and the multiple development tools associated to it make this process extremely efficient and reliable. GMV will be pleased to study with you ways to develop a ***focussuite*** -based solution for your own needs, both in operational and mission analysis contexts.

The next chapters provide a general description of ***focussuite*** and a high level overview of its main components.

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Ref.	Title	Code	Ver.	Date
[AD.1]				

Table 2–1: Applicable Documents

2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Ref.	Title	Code	Ver.	Date
[RD.1]				

Table 2–2: Reference Documents

3. ***FOCUSSUITE*** GENERAL DESCRIPTION

3.1. KEY REQUIREMENTS

Among others, the following key requirements have been taken into account in the design of the system:

- **Openness**: ***focussuite*** makes use of open standards such as XML for exchange of products and standard communication protocols with external systems. Moreover, it provides a well-documented API (Application Programming Interface) to enable execution of the system functions from external systems plus its unique capability of integrating external applications into the package without code modifications or software builds.
- **Portability (Windows / UNIX / Linux/ Web)**: All the technical solutions chosen for each part of the system are portable to these platforms. Operating system dependent modules have been minimised and encapsulated.
- **Client / Server**, both available in Windows, UNIX and Linux. Heterogeneous combinations (e.g. client in Windows connecting to server in UNIX) are supported. The web based client makes it available in any platform with a suitable browser, from mobile phones to desktop computers.
- **Flexible, expandable, scalable**: Ease of maintenance is a must; it is possible to perform quick updates of the system and inclusion of new modules without having to rebuild the system. The containerized deployment of the system provides the system great flexibility and scalability. It also allows to deploy it in different environments from cloud to on-site infrastructures. ***focussuite*** is based on different services that can be adapted and scaled according to each user requirements.

Ergonomic, Flexible and Visual GUI: multiple datasets, highly configurable, web based interface.

Full life-cycle support: Mission independent + mission specific functions, GMV's support for customisation.

Capability to support **multi-user, multi-satellite** and **multi-environment concepts**

Highly **efficient**: Automation capabilities

3.2. ***FOCUSSUITE*** PRODUCTS ARCHITECTURE

focussuite is a generic framework allowing the generation of a family of products that share the same architecture and infrastructure. They are systems built following a three-tier architecture (User Tier / Process Management Tier / Data & Computation Tier). The following figure shows this architecture.

The three-tier architecture is consistent with state-of-the-art trends in system design. It is a system design pattern that has been used successfully since the early 1990s on thousands of systems of various types. The three tiers in ***focussuite*** work as follows:

- The top tier, User Tier, provides services to the end-user, in particular everything related to presentation (user interface). It can be seen as the client-side in client-server architectures. Multiple clients may be running concurrently at a given time. This tier also provides a REST API available for integration with third party services or custom scripts. This tier is implemented as ***focusweb.*** This consist of a series of web services that interact with the underlying tiers providing the aforementioned API and also the web client used to interact with the system from any browser.

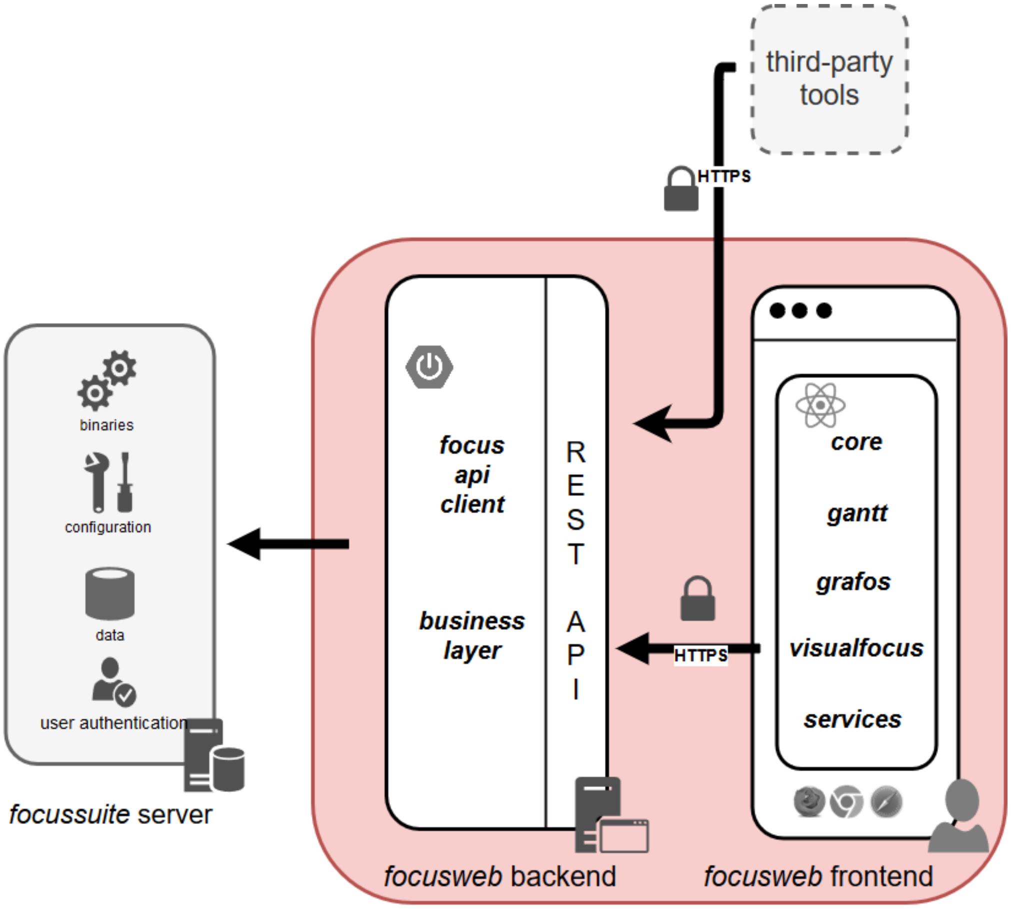


Figure 1 ***focusweb*** layer

- The middle-tier, Process Management Tier, handles the requests for data and process execution received from the clients. It is the heart of the system.
- The third tier (Data and Computation Tier) has two distinct layers or sub-tiers.
  - The **Data Management** Layer encapsulates all the data access (control of concurrent read / write requests coming from different users, data versions control to enable undo actions, etc). In the standard versions of ***focussuite*** the data are stored in a set of ad-hoc files. Potentially this layer could be upgraded to use a commercial database (a natural and feasible extension given the current architecture).
  - The **Computation Layer** hosts all the temporary processes that can be running concurrently at a given time, as a result of the execution of computation programs per user request. These processes act on temporary data retrieved previously from the Data Management Layer by the ***focusprocess manager***. This approach ensures that data will not be corrupted in case of process failure and enables concurrent processing.

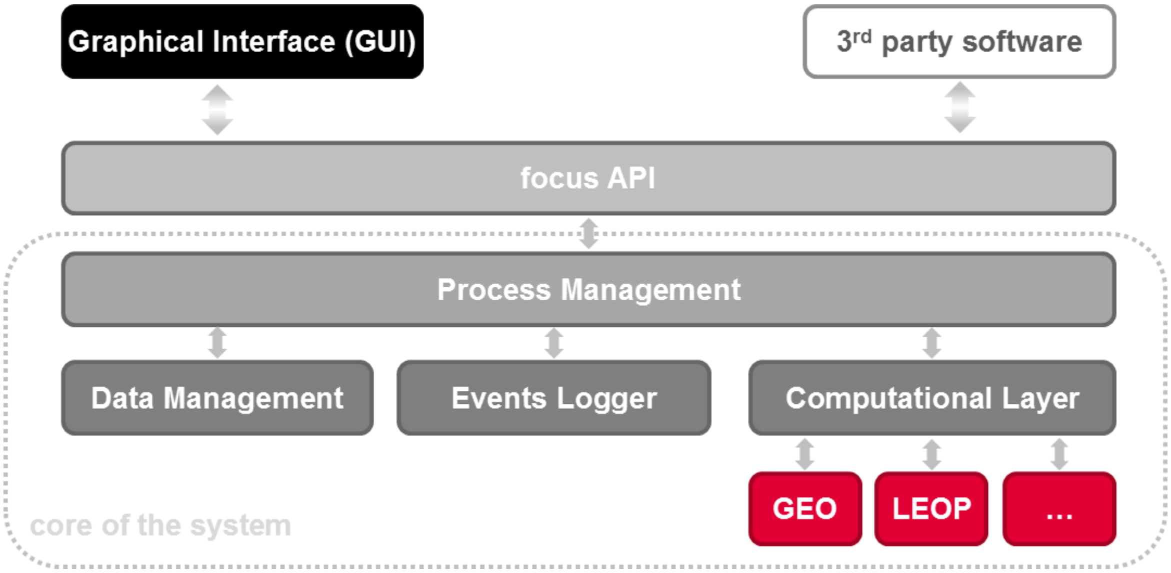


Figure 2: *focussuite* products structure as a high level architecture

Although the architecture has been defined as three-tier, this does not mean that three levels of hardware are needed. Nominally two levels (clients + servers) are foreseen. But as the client is a web application, it is served from the same server.

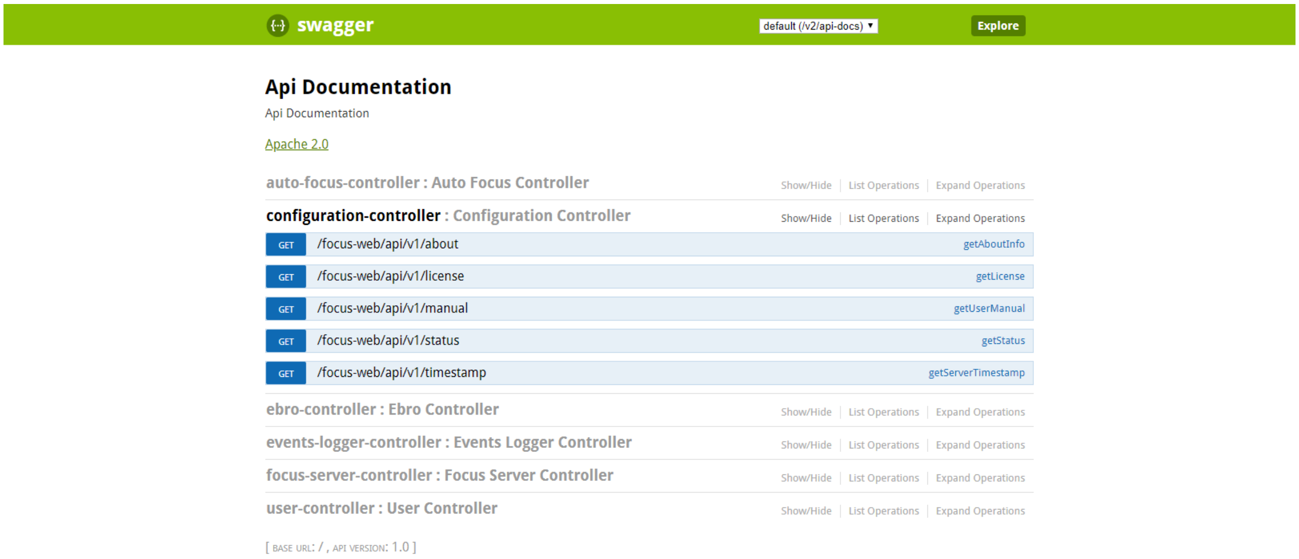
The client is a *javascript* single page application, developed using reusable React components and libraries. This ensures a great flexibility to the development of new features and the possibility to access the interface from different platforms such as mobiles, tablets or desktops.

This architecture provides components with separated concerns. The data management service providing the data management ensures that the rest of the services can be stateless, and therefore easily scalable. This also allows the containerization of the application, for example using Docker.

The application can be distributed as Docker images allowing easier flexible deployments and updates of the application different services. E.g. the ***focusweb*** server could be update independently of the rest of the services without downtime.

In the frame of ***focussuite*** products, the nominal configuration in terms of system deployment is to install the three layers in a set of servers, only needing a web browser on the client side. This architecture ensures the extensibility and scalability of the system. For example, the data management layer could be installed in a different machine for a large satellite constellation.

Many advantages derive from this architecture, in particular high performance (due to the higher distribution of the processing), flexibility, maintainability, reusability and scalability, by centralising process logic. Its management is a lot easier than in a general distributed system due to this centralisation.



Api Documentation

Api Documentation

Apache 2.0

auto-focus-controller : Auto Focus Controller — Show/Hide | List Operations | Expand Operations

configuration-controller : Configuration Controller — Show/Hide | List Operations | Expand Operations

GET	/focus-web/api/v1/about	getAboutInfo
GET	/focus-web/api/v1/license	getLicense
GET	/focus-web/api/v1/manual	getUserManual
GET	/focus-web/api/v1/status	getStatus
GET	/focus-web/api/v1/timestamp	getServerTimestamp

ebro-controller : Ebro Controller — Show/Hide | List Operations | Expand Operations

events-logger-controller : Events Logger Controller — Show/Hide | List Operations | Expand Operations

focus-server-controller : Focus Server Controller — Show/Hide | List Operations | Expand Operations

user-controller : User Controller — Show/Hide | List Operations | Expand Operations

[BASE URL: / , API VERSION: 1.0]

Figure 3 API documentation

In addition to the first decomposition of ***focussuite*** products, it is worth noting the following:

- ***focusapi***: This API lets any component interact with the ***focusprocess manager.*** It is used by the GUI and by ***autofocus*** procedures, but it could also be used by external systems to interact with ***focussuite*** products. The API includes a front-end and a back-end (the one that talks to the ***focusprocess manager***). This approach encapsulates the communications and allows easier integration. This way instead of an ICD, a documented API is provided. It is exposed as a well-documented REST API on the web server. This API provides an interactive swagger documentation.

- ***tkforms/tkfLib***: This toolkit or set of libraries provides all data access services including GUI panel edition and data access to/from computation programs. A common data file format (TKF) and the use of this toolkit improve commonality throughout the system and allows faster development of new components and an easier integration of new ones (such as new computation programs). The GUI, the ***focusdata manager*** and the Computation Programs use this toolkit. The format of this configuration files was specific for ***tkforms***, but recently, the format of ***tkforms*** has been replaced by a more standard format as XML. The content of the files is served in json format through the REST API.

- ***focuscomm***: *Communications Layer*. The purpose of this general use library is to encapsulate the communications between different components to make it possible to perform changes in the communications in future releases easily. Currently the server client communications are performed through safe, encrypted HTTPS connections.

- ***Revision controller***: This module supports the ***focusdata manager*** providing file revision control services. This function is needed to make it possible for the user to retrieve old versions of data files.

3.2.1. SECURITY

Providing a safe operation of the FDS is one of the main features of the suit of ***focussuite*** products. The external interfaces provided by the top layer follow the best practices for web standards, allowing its safe deployment either on isolated on-site facilities or on the cloud deployments.

- HTTPS, encrypted end to end communications.
- Secure cookie management.
- Local certificates.
- Easier to audit. (Tooling and best practices)
- HTTPS connections are easier to administrate. Firewall rules.
- Feasible to implement 2fa for critical functions.
- Besides our products are audited for security enforcement.

4. MAIN ***FOCUSSUITE*** COMPONENTS

This section provides a high level overview of the main components of ***focussuite***. Further sections provide more detailed descriptions on key components of the system such as the automation tools, plus an explanation on how to integrate external applications within ***focussuite*** framework.

4.1. GRAPHICAL USER INTERFACE

4.1.1. GENERAL

focussuite GUI is largely based on a proprietary toolkit for rapid GUI development called TkForms/TkfLib that has been developed by GMV. The TkForms/TkfLib toolkit is a piece of middleware that allows GUI development based on configuration files rather than on code (more details are provided in the following sections).

The most outstanding features of the ***focussuite*** GUI are:

- Efficiency and ergonomic: Current Flight Dynamics GUIs do not fully exploit capabilities for easing the access of the data and facilitating the use of the system. The figures below show a number screen shots of the ***focussuite*** GUI and highlight some of the advantages that the GUI brings.
- Additional functionality, reliability, efficiency: The new GUI not only brings substantial improvements in terms of efficiency and ergonomic but also provides additional functionality, including:
  - Detailed **Events Logging** mechanism including capabilities to visualise key results characterising the execution of the programs and therefore allowing for very efficient monitoring of station keeping planning procedure behaviour both in manual and automatic mode.
  - Advanced **data management** capabilities including the possibility to manage data sets (duplication, modification, deletion). The GUI includes the concept of private and public data sets thus reinforcing the reliability of the operations performed with the system and enabling far more efficient concurrent use of the system. Also capability for the user to perform on the fly duplication of operational data for performing trial executions before bringing data operational.
  - Improved mechanisms for work groups (**concurrent system access**), dramatically improved locking mechanisms.
  - Capability of **integrating new pieces of software** without the need of performing software rebuild, making maintenance a lot easier and dramatically less costly.
- Ease of use and learning curve: from the screen shots shown below it can be observed that the ***focussuite*** GUI represents a dramatic improvement in terms of ease of use and learning curve of the system. The system offers two levels of grouping of tasks that can be customised for each customer, therefore being capable of adapting to different operational approaches. Moreover, the system can be customised such that at any time the user is confronted with the normal sequence of operations making the system extremely easy to use.
- Additional **graphic capabilities** to the system will dramatically improve the productivity of the operations staff and provide a user-friendlier environment. A better output would also provide better view and better understanding of the results. In summary productivity and reliability will both be considerably improved. There several types of graphical information to be presented to the user, each of them visualised by a dedicated widget:
  - X-Y plots (for example orbital elements versus time or orbit determination measurements residuals)
  - Events (for example Orbital Events or a Timeline)
  - 3D/2D displays

4.1.2. USER LEVELS

The system administrator assigns each user a user level. The user level is shown in the title bar in the main window of the GUI.

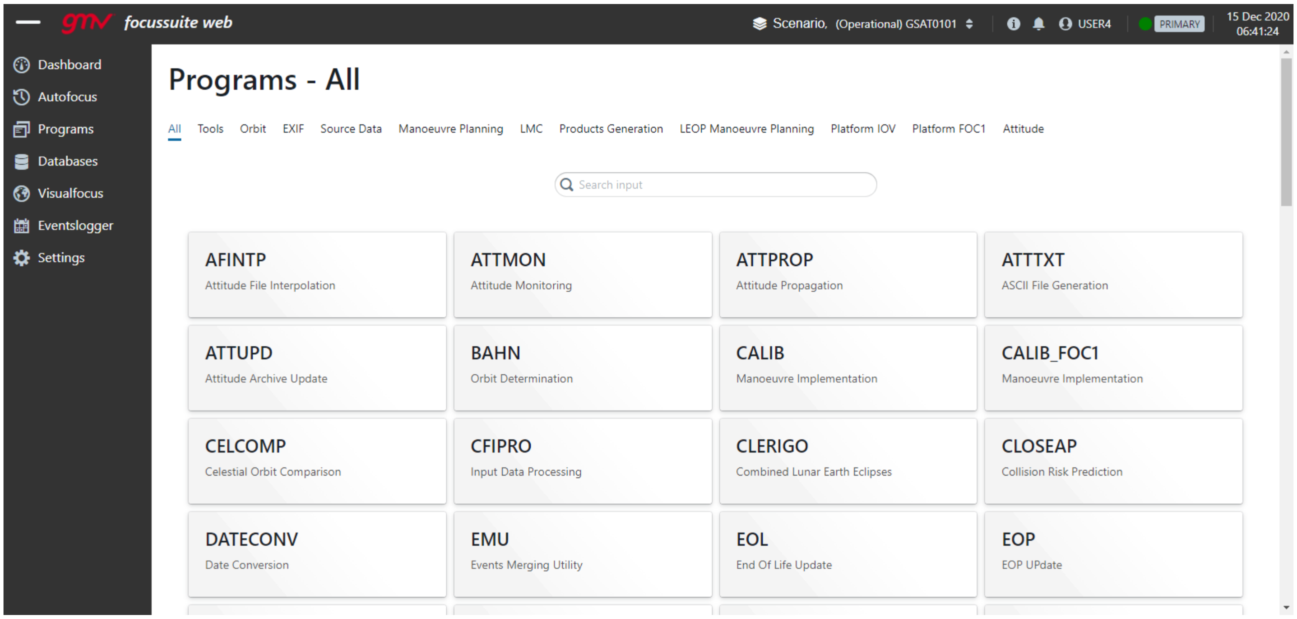
The number and names of the available user levels may vary depending on the customer. For example, the levels could be operator, expert and administrator. In the figure, a number is used as a user level.

The user level has an impact on the kind of actions that are authorised for each user (basically, process execution and dataset access). For example, the execution of a certain sensitive process may only be authorised to users at or above a given level. Another case is when the modification of a given dataset (either by edition or via the execution of a process) is restricted to a certain user level.

4.1.3. GUI OVERVIEW

focussuite client includes standard menu bar, tool bar and status bar from which the user can get access to a large variety of options. Providing flight dynamics engineers with powerful editing means representing a significant improvement in reliability and productivity.

focussuite client includes a system log (called ***focusevelog***) that is further described in a separate section.



AFINTP Attitude File Interpolation	ATTMON Attitude Monitoring	ATTPROP Attitude Propagation	ATTTXT ASCII File Generation
ATTUPD Attitude Archive Update	BAHN Orbit Determination	CALIB Manoeuvre Implementation	CALIB_FOC1 Manoeuvre Implementation
CELCOMP Celestial Orbit Comparison	CFIPRO Input Data Processing	CLERIGO Combined Lunar Earth Eclipses	CLOSEAP Collision Risk Prediction
DATECONV Date Conversion	EMU Events Merging Utility	EOL End Of Life Update	EOP EOP UPdate

Figure 4: Main window showing the different working areas

The main GUI also provides direct access to other components embedded in the package such as ***ebro*** (events browsing application), ***grafos*** (XY plots), ***frames*** (conversion between reference frames), ***focusevelog*** (standalone events logging client), new instance of the same client, ***autofocus*** (automation), ***focusaspect*** (telemetry monitoring and display), backup/restore facilities, etc.

The main GUIs are described further in the following subsections.

4.1.3.1. Login Window

To access the application, the user needs to specify a valid URL in web browser. Next step is to enter valid credentials to access the application. The application can use an OAuth2/OpenID identity and access management service such as keycloak in order to provide Single Sign On capabilities.

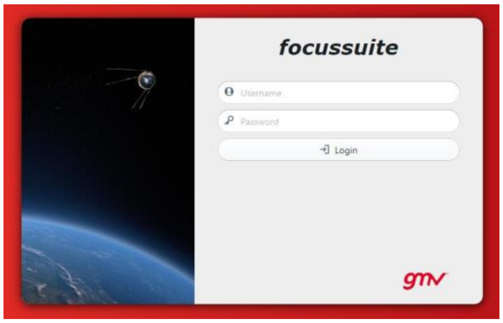


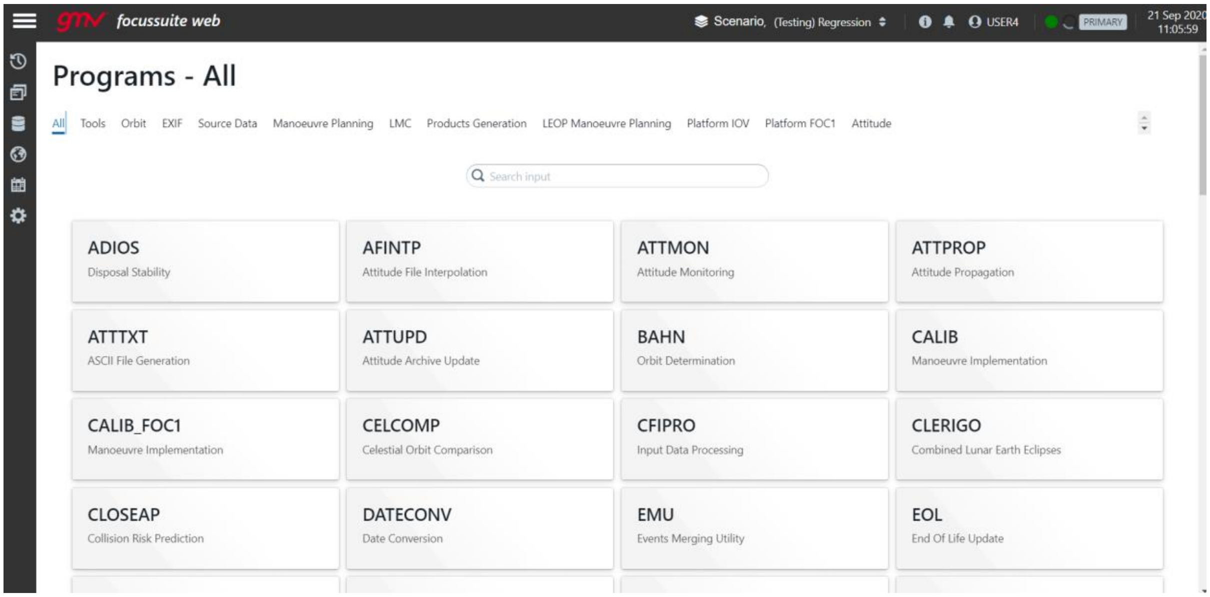
Figure 5: *focusweb* log-in window

4.1.3.2. Main View and Program View

After successfully logging into the system, the main window appears. ***focussuite*** MMI has been designed to have an 'all in one' working area and the overall GUI has been carefully designed to allow a high degree of efficiency and reliability.

The following HMI items are present:

- Component selection: Located in the left-hand vertical bar, it allows to switch among Programs, Autofocus, Events Logger, Visualfocus and Database.
- Scenario/workspace selection: Through a menu selector in the top horizontal bar.
- User information: Through a button in the top horizontal bar. It allows for logout.
- Miscellaneous information: Help menu, server connection status and system time is also deployed in the top horizontal bar.
- Computational programs: They are displayed in the main working area; the user can apply string-based filter selection or click on the upper tabs that group modules based on their functionality.

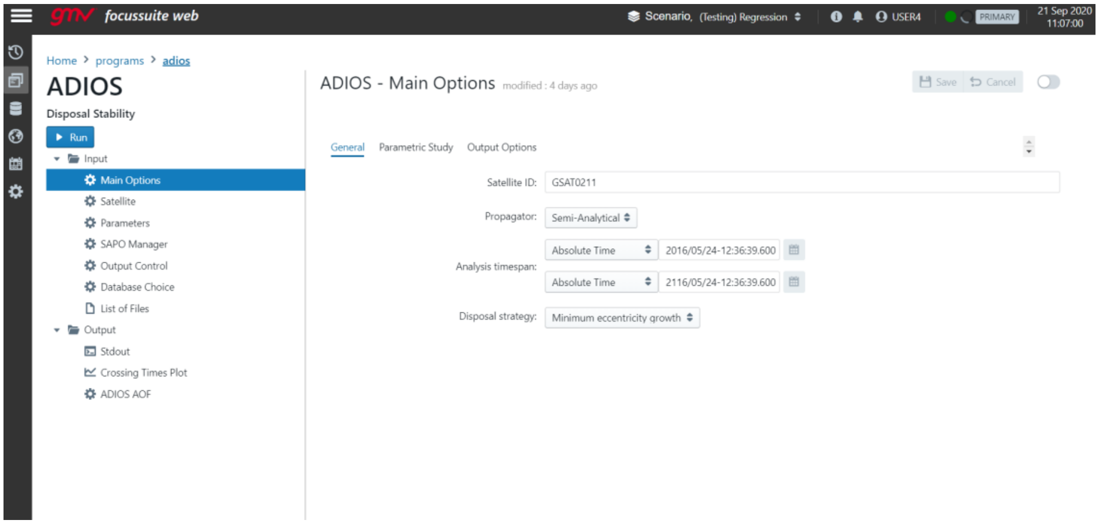


Programs - All

ADIOS	Disposal Stability
AFINTP	Attitude File Interpolation
ATTMON	Attitude Monitoring
ATTPROP	Attitude Propagation
ATTTXT	ASCII File Generation
ATTUPD	Attitude Archive Update
BAHN	Orbit Determination
CALIB	Manoeuvre Implementation
CALIB_FOC1	Manoeuvre Implementation
CELCOMP	Celestial Orbit Comparison
CFIPRO	Input Data Processing
CLERIGO	Combined Lunar Earth Eclipses
CLOSEAP	Collision Risk Prediction
DATECONV	Date Conversion
EMU	Events Merging Utility
EOL	End Of Life Update

Figure 6: *focusweb* main window

Once a program is selected, the following window is displayed:



ADIOS
Disposal Stability

ADIOS - Main Options modified : 4 days ago

Satellite ID: GSAT0211
Propagator: Semi-Analytical
Analysis timespan: Absolute Time 2016/05/24-12:36:39.600
Absolute Time 2116/05/24-12:36:39.600
Disposal strategy: Minimum eccentricity growth

Figure 7: *focusweb* program working area

In order to run a program the user shall simply presses the Run button from the corresponding panel. This initiates program execution through the corresponding Process Manager. Once the corresponding program has been initiated, the Run button becomes red and the legend changes to 'Stop' label, meaning that pressing it again will immediately abort program execution. At the same that the process is running, a run-time display is shown so that the user can easily monitor the execution of the corresponding function.

Basically, the ***focusweb*** MMI is a user-friendly interface that allows the user to

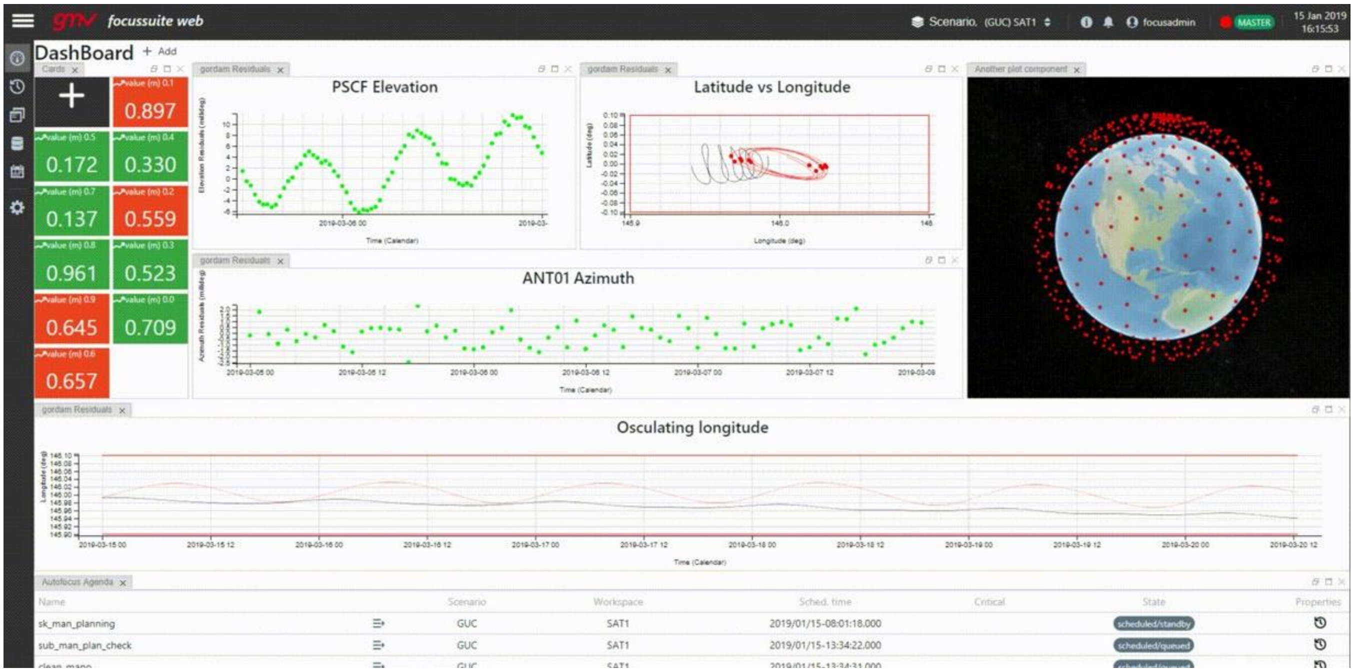
- Select the desired panel and tab of the selected program.

- Edit/save the panels.
- Open input/output files in a pop-up window (even without the need of blocking the panel).
- Open a list record in a pop-up window and move easily between records.
- Run the selected program.
- Display the program outputs (e.g. standard output, plots or Gantt diagrams)
- Download the standard output in the local machine.
- Export Test Program Data to generate a zip file containing the program data, configuration and/or binary.
- Import Test Program Data to ingest a zip file containing the program data, configuration, and/or binary. This data will be automatically imported into the selected program of the selected scenario/workspace.

4.1.3.3. Dashboard

The ***focussuite*** MMI includes a dashboard that allows the operator to get a quick view of the state of the fleet or a particular satellite. The dashboard is an user customizable set of widgets. These widget can be added by the user and arranged according to the operator needs. The Dashboard allows to include the following visualizations:

- ***Autofocus*** procedures agenda
- Plots generated by the different programs
- Tracking of different parameters in realtime
- 3D visualization of the fleet status



Name		Scenario	Workspace	Sched. time	Critical	State	Properties
sk_man_planning	≡›	GUC	SAT1	2019/01/15-08:01:18.000		scheduled/standby	⟲
sub_man_plan_check	≡›	GUC	SAT1	2019/01/15-13:34:22.000		scheduled/queued	⟲
clean_mano	≡›	GUC	SAT1	2019/01/15-13:34:31.000		scheduled/queued	⟲

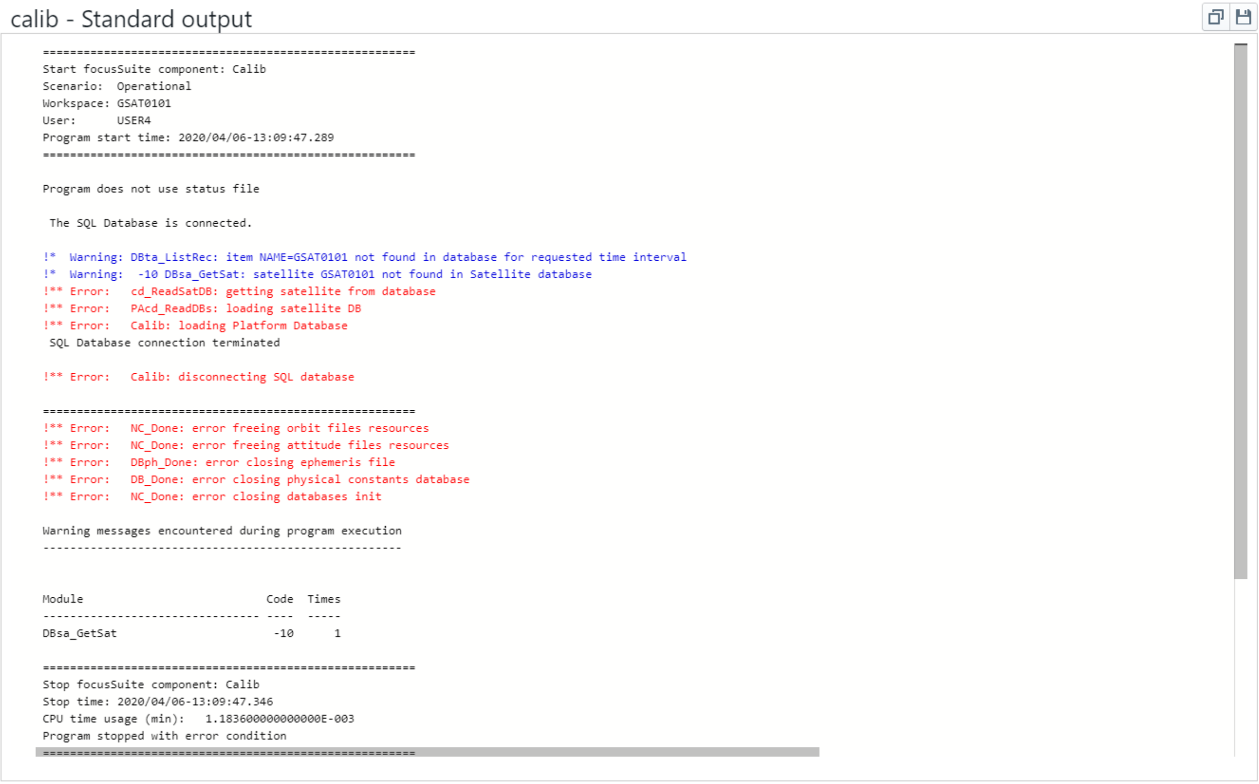
Figure 8: Dashboard view

4.1.3.4. Text (ASCII) Output

When the user selects the Stdout option in the Output from a Program command (programs tree) then the Output Area is filled with the corresponding text as shown in the figure below.

In addition it has to be noted that should an error occur during execution of any flight dynamics function, then the output area is split into two sections, one of them showing the standard output of the program and a second one showing the standard error.

The capability of the widget has been extended, supporting the highlighting of a program output, edition functions (copy, cut and paste), printing in colour and find. The widget takes in mind the large datasets used in some FDS applications and therefore is a high performant component capable of displaying large texts efficiently.



```
=======================================================
Start focusSuite component: Calib
Scenario:  Operational
Workspace: GSAT0101
User:      USER4
Program start time: 2020/04/06-13:09:47.289
=======================================================

Program does not use status file

 The SQL Database is connected.

!*  Warning: DBta_ListRec: item NAME=GSAT0101 not found in database for requested time interval
!*  Warning:  -10 DBsa_GetSat: satellite GSAT0101 not found in Satellite database
!** Error:   cd_ReadSatDB: getting satellite from database
!** Error:   PAcd_ReadDBs: loading satellite DB
!** Error:   Calib: loading Platform Database
 SQL Database connection terminated

!** Error:   Calib: disconnecting SQL database

=======================================================
!** Error:   NC_Done: error freeing orbit files resources
!** Error:   NC_Done: error freeing attitude files resources
!** Error:   DBph_Done: error closing ephemeris file
!** Error:   DB_Done: error closing physical constants database
!** Error:   NC_Done: error closing databases init

Warning messages encountered during program execution
-----------------------------------------------------


Module                          Code  Times
------------------------------- ----  -----
DBsa_GetSat                      -10      1

=======================================================
Stop focusSuite component: Calib
Stop time: 2020/04/06-13:09:47.346
CPU time usage (min):   1.183600000000000E-003
Program stopped with error condition
=======================================================
```

Figure 9: Example of highlighted text

4.1.3.5. Events Browser – Gantt Chart Output (***Ebro***)

Certain ***focussuite*** programs have the capability of generating an events file that can be visualized by the user in the form of a Gantt chart. As in the previous cases the Gantt chart is shown within the corresponding Output Area of ***focussuite*** GUI by means of a single click. This utility is called ***ebro***.

ebro is a generic, simple event browsing utility available for all ***focussuite*** products. ***ebro*** is fully integrated within ***focussuite*** products.

ebro supports changing the time scales, configuring events and managing event files.

When the cursor stays over an event, an event information window pops-up to display all the information about the event: Event type, event start and end times, event duration and comments section.

ebro provides the user with Events Files management capabilities such as:

Opening and Closing existing Events file

Browsing and navigating through the Gantt Chart Diagram

Setting options for the Gantt Chart diagram

- Event type configuration, to change the appearance of each type of event.
- Adding and deleting event types, new types of events can be added and configured according to user needs.
- Filtering events, allowing choosing the event types you want to display and their order along the vertical axis.

Zooming: there are four scales for the time axis: year, month, day and hour

Printing an event File.

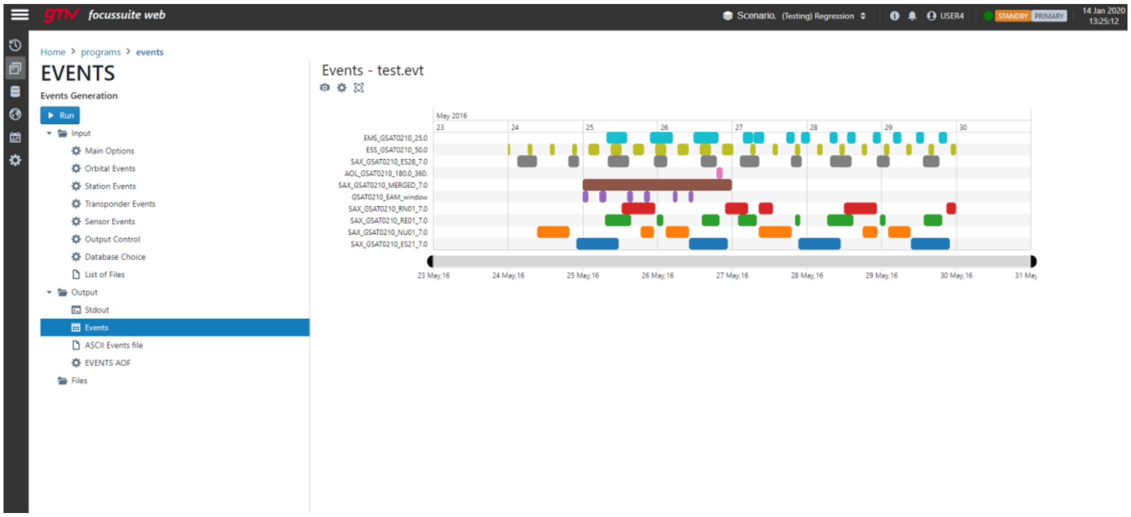


Figure 10: *focusweb ebro* widget

4.1.3.6. Graphics X-Y plots (*grafos*)

Certain ***focussuite*** programs have the capability of generating X-Y plots that can be visualized by the user through a dedicated plot facility. As in the previous cases the plots are shown within the corresponding Output Area of ***focussuite*** GUI by means of a single click.

grafos is a generic, simple, robust X-Y plotting facility and fully integrated module available for all ***focussuite*** products. ***grafos*** allows to generate a wide variety of X-Y plots like residuals, orbit comparisons, station-keeping analyses, etc., and basic image manipulation functionality like zooming, labelling, scaling and printing. ***grafos*** covers these requirements as an external application as well as an integrated widget in flight dynamic systems. The library uses GPU accelerated graphics in orther to allow the display of demanding data visualizations used in FDS applications.

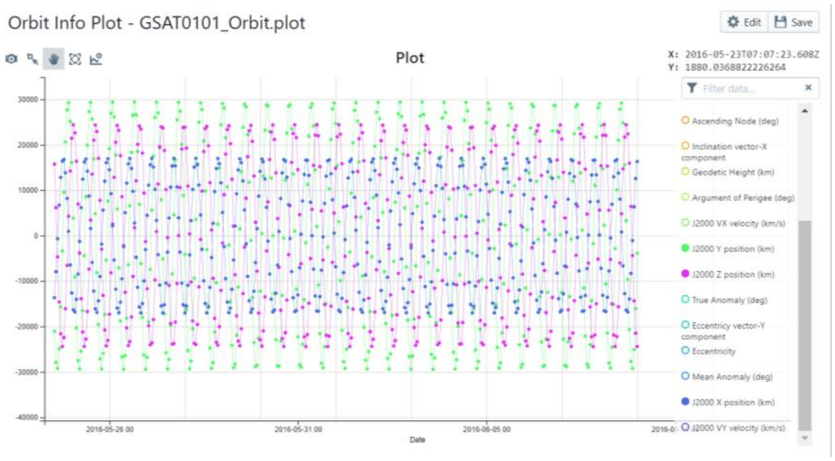


Figure 11: *grafos* Main Window

grafos provides the user with many plot manipulation capabilities such as:

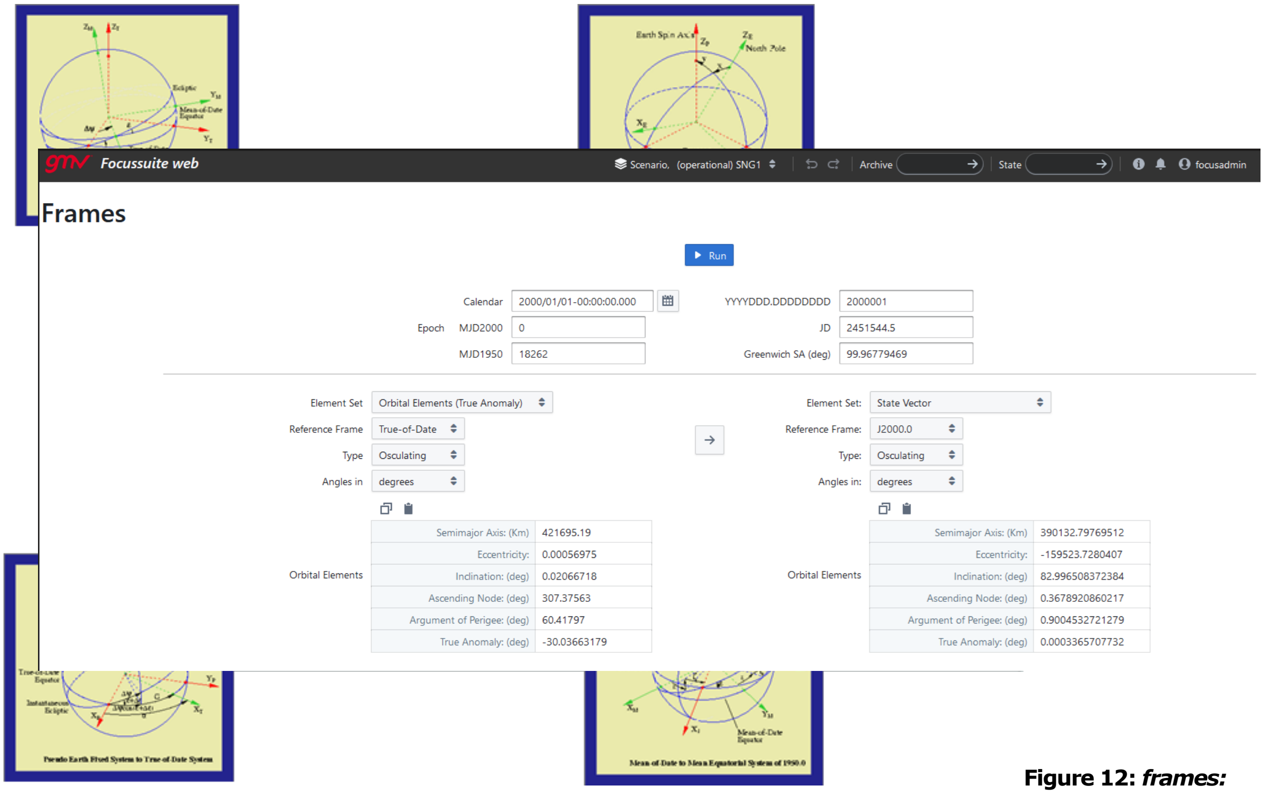
Creation of new plots through a series of dialogue windows and plot manipulation that allow the user to freely generate a new plot file.

- Adding or deleting sheets (tabs) in a plot
- Adding or deleting graphs (curves) in a plot
- Adding or deleting objects in a plot. The objects currently supported by ***grafos*** are text, lines, polygons and ovals.
- Clearing a Plot
- Setting options and properties: Setting options for each sheet (tab) through a configuration panel that allows setting the following options (fonts, colors, line widths and styles, etc.): general options (title, legend), axes options, attributes of the selected graph and attributes of the selected object.
- Changing the visualization window
  - Zoom In/Out: Allows you widen or narrow the x/y axis range
  - Shift left/right/up/down: Allows you move the x/y axis to subsequent or preceding values without changing the range.
- Deleting points from a graph
- Statistical analysis of the points in a graph, ***grafos*** shows the following information:
- Moving objects
- Working with multiple plots at once
- Deleting plots
- Saving plots
- Printing a plot File.

4.2. *FRAMES*: REFERENCE FRAME CONVERSION

frames is the reference frames and time formats conversion tool of ***focussuite.***

frames converts orbital elements between different formats and reference frames. It also supports the conversion between osculating and mean elements, conversion between different time formats, and conversion to and from TLE (two line elements).



Frames

Epoch

Calendar	2000/01/01-00:00:00.000	YYYYDDD.DDDDDDDD	2000001
MJD2000	0	JD	2451544.5
MJD1950	18262	Greenwich SA (deg)	99.96779469

Element Set	Orbital Elements (True Anomaly)	Element Set:	State Vector
Reference Frame	True-of-Date	Reference Frame:	J2000.0
Type	Osculating	Type:	Osculating
Angles in	degrees	Angles in:	degrees

Orbital Elements

Semimajor Axis: (Km)	421695.19
Eccentricity:	0.00056975
Inclination: (deg)	0.02066718
Ascending Node: (deg)	307.37563
Argument of Perigee: (deg)	60.41797
True Anomaly: (deg)	-30.03663179

Orbital Elements

Semimajor Axis: (Km)	390132.79769512
Eccentricity:	-159523.7280407
Inclination: (deg)	82.996508372384
Ascending Node: (deg)	0.3678920860217
Argument of Perigee: (deg)	0.9004532721279
True Anomaly: (deg)	0.0003365707732

Figure 12: *frames:* Reference frame conversion tool user interface

4.3. EVENTS LOGGER

focusevelog is a generic, flexible and extensible events logging facility available as either stand-alone or fully integrated module for all ***focussuite*** products. ***focusevelog*** is in charge of receiving, archiving, managing and distributing all information, warning or error messages to operators.

focusevelog implements a robust client-server solution composed of several modules:

- The server module is in charge of receiving the events from the emitters, archive them and broadcast to the clients, on both real-time or on demand. The server is also in charge of handling the alarm system.
- The emitting module is provided as a library that can be invoked by other processes (other ***focussuite*** components or third party application). It generates events to the Events logger.
- A variety of client modules, one of the most important being the ***focusevelog*** client.

The following figure shows the relationship between ***focusevelog*** and ***focussuite***.

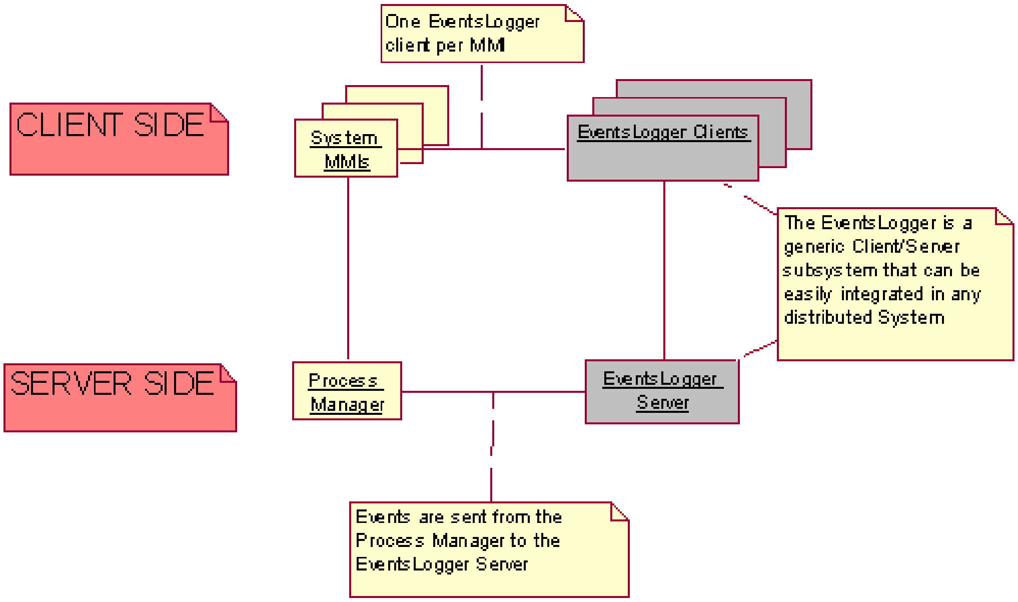
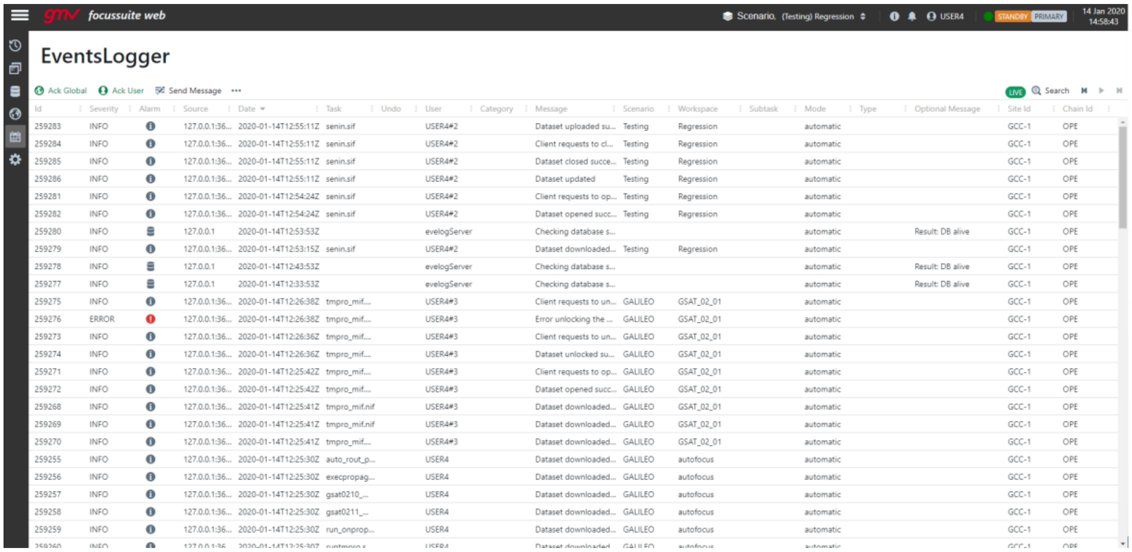

One EventsLogger client per MMI
CLIENT SIDE
System MMIs
EventsLogger Clients
The EventsLogger is a generic Client/Server subsystem that can be easily integrated in any distributed System
SERVER SIDE
Process Manager
EventsLogger Server
Events are sent from the Process Manager to the EventsLogger Server

Figure 13: evelog and its relationship with the rest of *focussuite*

focusevelog provides a user-friendly interface with the ability for handling real-time and archived messages, alarm notifications and acknowledgements.



EventsLogger

Id	Severity	Alarm	Source	Date	Task	Undo	User	Category	Message	Scenario	Workspace	Subtask	Mode	Type	Optional Message	Site Id	Chain Id
259283	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:55:11Z	senin.sif		USER4#2		Dataset uploaded su...	Testing	Regression		automatic			GCC-1	OPE
259284	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:55:11Z	senin.sif		USER4#2		Client requests to cl...	Testing	Regression		automatic			GCC-1	OPE
259285	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:55:11Z	senin.sif		USER4#2		Dataset closed succe...	Testing	Regression		automatic			GCC-1	OPE
259286	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:55:11Z	senin.sif		USER4#2		Dataset updated	Testing	Regression		automatic			GCC-1	OPE
259281	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:54:24Z	senin.sif		USER4#2		Client requests to op...	Testing	Regression		automatic			GCC-1	OPE
259282	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:54:24Z	senin.sif		USER4#2		Dataset opened succ...	Testing	Regression		automatic			GCC-1	OPE
259280	INFO	🛢	127.0.0.1	2020-01-14T12:53:53Z			evelogServer		Checking database s...				automatic		Result: DB alive	GCC-1	OPE
259279	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:53:15Z	senin.sif		USER4#2		Dataset downloaded...	Testing	Regression		automatic			GCC-1	OPE
259278	INFO	🛢	127.0.0.1	2020-01-14T12:43:53Z			evelogServer		Checking database s...				automatic		Result: DB alive	GCC-1	OPE
259277	INFO	🛢	127.0.0.1	2020-01-14T12:33:53Z			evelogServer		Checking database s...				automatic		Result: DB alive	GCC-1	OPE
259275	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:26:38Z	tmpro_mif....		USER4#3		Client requests to un...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259276	ERROR	❗	127.0.0.1:36...	2020-01-14T12:26:38Z	tmpro_mif....		USER4#3		Error unlocking the ...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259273	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:26:36Z	tmpro_mif....		USER4#3		Client requests to un...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259274	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:26:36Z	tmpro_mif....		USER4#3		Dataset unlocked su...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259271	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:42Z	tmpro_mif....		USER4#3		Client requests to op...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259272	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:42Z	tmpro_mif....		USER4#3		Dataset opened succ...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259268	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:41Z	tmpro_mif.nif		USER4#3		Dataset downloaded...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259269	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:41Z	tmpro_mif.nif		USER4#3		Dataset downloaded...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259270	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:41Z	tmpro_mif....		USER4#3		Dataset downloaded...	GALILEO	GSAT_02_01		automatic			GCC-1	OPE
259255	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	auto_rout_p...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE
259256	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	execpropag...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE
259257	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	gsat0210_...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE
259258	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	gsat0211_...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE
259259	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	run_onprop...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE
259260	INFO	ⓘ	127.0.0.1:36...	2020-01-14T12:25:30Z	runtmpro_s...		USER4		Dataset downloaded...	GALILEO	autofocus		automatic			GCC-1	OPE

Figure 14: *focusevelog* client main window

4.4. FOCUSPROCESS MANAGER

The ***focusprocess manager*** is the main “brain” of the system, centralising all the critical coordination tasks among the different components. Among others, it is responsible for the following tasks:

- **Handle requests for connection** from new clients (which shall include the userid, password, satellite family, satellite, environment and project corresponding to the connection), check the password and establish the connection or reject the request depending on the case.
- **Manage requests from clients for execution of computation layer processes**. Ensure that the client requesting the process is authorised (according to an external table). Assign a process ID. Check conflicting locks on data files. Send corresponding event to all clients acting on the same data area (with a process ID). Prepare the temporary environment, checking out the operational files from the configuration management repository, establishing the needed locks on them and creating the temporary copies on which the process shall act. Launch the process and monitor its execution. Enable the transmission of the output generated by the process to the corresponding client in real time. Check in the updated files in the configuration management repository and update the log of changes entering the ones associated to the process ID. Send event with exit status of process to clients acting on the same data area.
- **Receive requests from clients to stop an active process** (identified by its process ID). Check that the process is running and the client is authorised to stop it. Kill process and re-establish operational files in their original state, guaranteeing the integrity of the operational data. Send event to all clients acting on the same data area.
- **Send events to all the clients** corresponding to the relevant data area (combination of satellite family, satellite, environment and project). For this, the ***focusprocess manager*** needs to maintain a list of active clients and their corresponding data area. For example, if a client runs a process in a given data area, an event such as "Process X run by client Y" needs to be sent to all the clients using the same data area. This shall provide a common events log for all clients in each data area.
- **Send any type of data to a given client**. For example, send files for editing via the user's interface, whenever it is requested.
- **Update centralised data with data provided by a client**: For example, after the user has edited it and has decided to upload it so that it is stored in the central database.

4.5. FOCUSDATA MANAGER

The ***focusdata manager*** is the component that handles the data in ***focussuite***. This component receives the requests for data access from the ***focusprocess manager***, as needed depending on the needs of active processes and user requests (e.g., data edition).

The data is organised in a tree tier structure as follows:

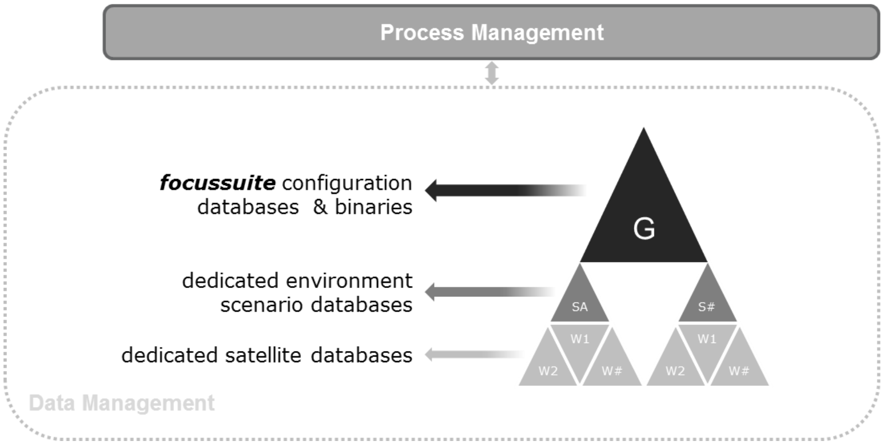

Process Management
focussuite configuration databases & binaries
dedicated environment scenario databases
dedicated satellite databases
G
SA
S#
W1
W2
W#
W1
W2
W#
Data Management

Figure 15: *focusdata* Manager Scenarios & Workspaces diagram

- A set of scenarios exist for a given ***focussuite*** server. A typical use of the scenario concept is to define a different one per environment (operational, simulation,). Another option is to define one per satellite platform, typical for operators that own big fleets.
- Each scenario includes a set of workspaces. A typical use of the workspace concept is to define a different one per satellite.
- Each workspace includes a set of datasets. A dataset is a group of data that are related somehow. In the standard products in ***focussuite***, a dataset maps to a file of any type (e.g. a plain ASCII file, a postscript file, an XML file, etc.) or a structured file in a standard format. An optional extension of the system, enabled by its overall architecture, is to plug a commercial relational database manager into the ***focusdata manager***.

When the user logs into the system, this can access only data from a single workspace. However you can have several clients open at the same time on a given machine, each working on a different workspace. The active scenario and workspace are shown in the title bar on the client GUI.

The **tree tier structure** makes it possible to define functions or data at a level higher than the workspace (e.g. scenario, or even global). They will be shared by all the workspaces under that branch. Therefore a certain function may be defined at the highest level (global), which means that all the workspaces in the system will share it.

Given that the system allows multiple users working at the same time, a system of locks is needed to avoid conflict due to concurrent access. This means that the system may tell you at some point that you cannot edit a certain dataset or you cannot run a certain process because of conflict with on-going tasks. For example, whenever there is another user editing that dataset or running a process that will modify it and therefore has set a lock on it.

4.6. COMMUNICATIONS LAYER

The purpose of this general-purpose library ***focuscomm*** is to encapsulate the communications between different components.

The functions available at ***focuscomm*** are grouped in two interfaces:

- ***focuscomm-Client:*** This interface includes all the services needed by any client component to start and stop a connection, send messages, upload and download files, ping the server, etc.
- ***focuscomm-Server:*** This interface includes all the services needed by any server component to be started or stopped, process incoming messages, etc.

5. *VISUALFOCUS*

visualfocus is a member of GMV's ***focussuite*** set of products and it is aimed to display the evolution of the satellite mission in realistic 3D environment and over a 2D earth projection.

visualfocus displays the flight of one or more satellites in real or simulated time. The configuration of the different displayed elements, input orbits and some more information is obtained from a configuration file stored in the ***focussuite*** server data structure. .

Every scenario contains a database and one or more configuration panels. The user can use all the available elements (planets, satellites, ground stations and sensors) defined in its scenario database for every configuration contained in that scenario. The modified databases and configurations are automatically saved in the server so other users may re-use them. When the configuration is ready, the user may launch the graphical tool and the graphical display is started.

The time evolution can be scaled to make the simulation run faster than real time (a time factor scale 1 means real time speed), and even to move backwards (negative time factor). This time factor can be also changed from the graphical windows once they are launched. It is also possible that ***Visualfocus*** reads the simulation time directly from the host machine's clock. In this case the simulation will progress at real-time rate, and it will also be synchronized with current time reference.

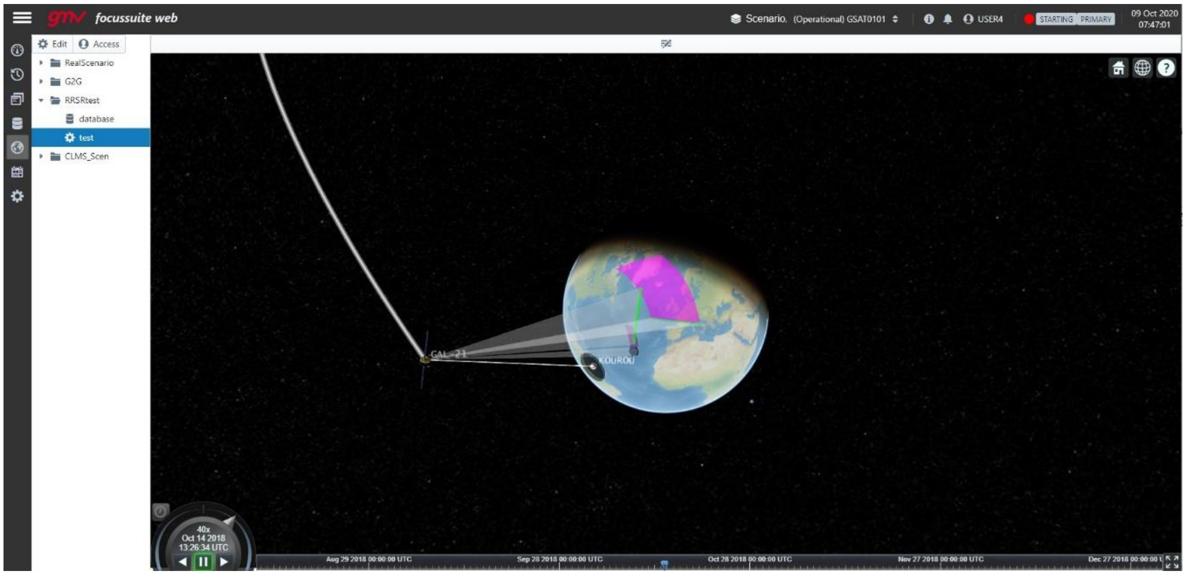


Figure 16 *focussuite* 3D view with visibilty contacts and sensor swaths

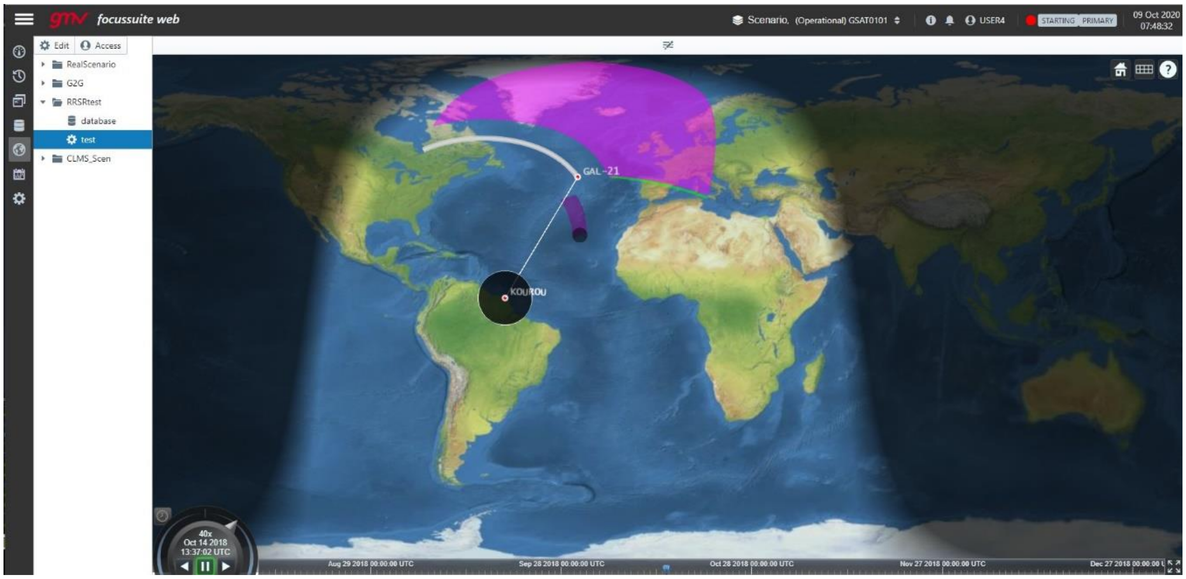


Figure 17 focussuite 2D view with visibilty contacts and sensor swaths

Graphical representation of selected elements is performed in 2D and 3D, with capability to switch between them during the simulation:

- **3D visualization tool:** This view supports/includes:
  - A three-dimensional view of the Earth and celestial objects (e.g. planets, Sun, Moon).
  - A 3D model of the satellite, optionally showing thruster firings and solar arrays attitude (SADM angle), taken from TM data.
  - Satellite orbits and attitude representation. Attitude can be provided from input file or from TM data.
  - Sensors field of view (conical/pyramidal/polygonal).
  - Ground stations, with visibility cone.
  - Station-satellite and satellite-satellite links.
  - The user can control the position of the camera.

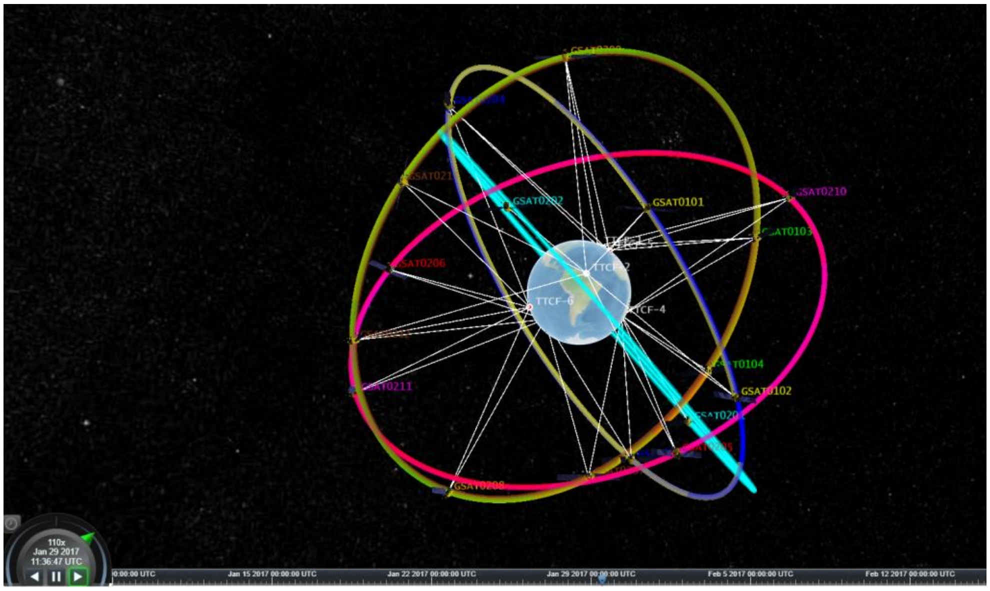


Figure 18: ***Visualfocus*** **3D Display (Earth-centred)**

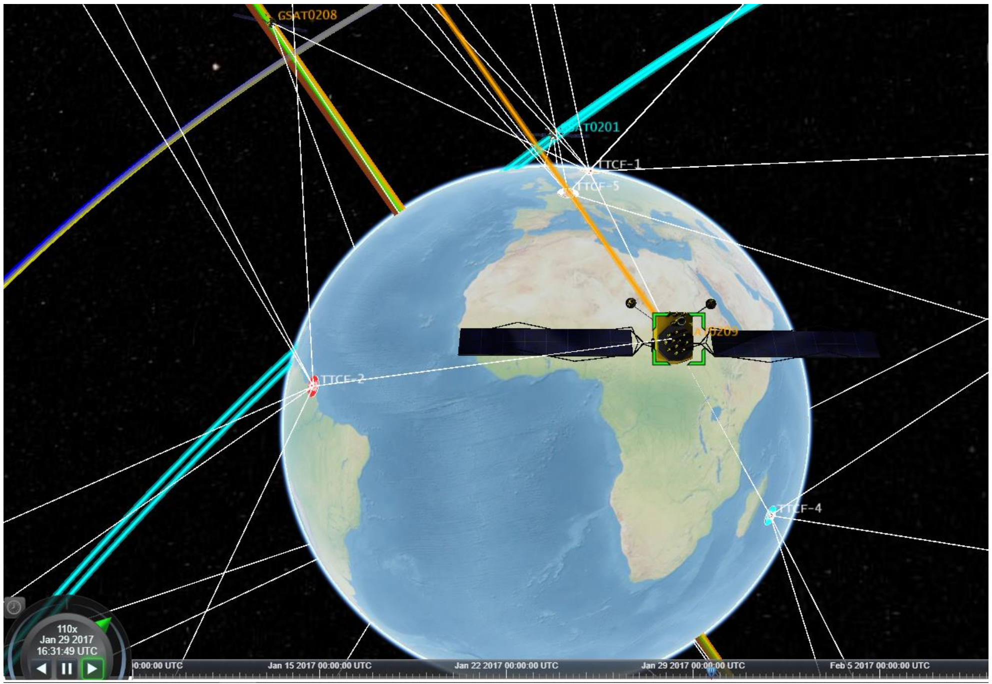


Figure 19: ***Visualfocus*** **3D Display (on-board camera)**

- **2D visualization tool:** This view supports/includes:
  - Ground-track of all active satellites and sub-satellite point.
  - Day/night terminator, eclipses, Moon shadow projection.

- Ground stations, their visibility areas and links to visible satellites.
- The swath of the sensors pointing towards the Earth.

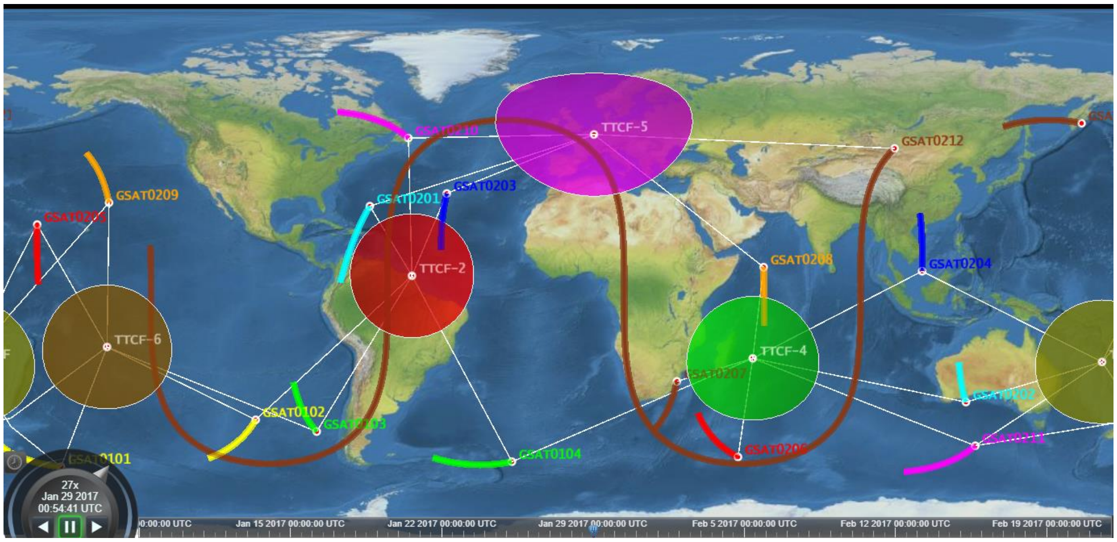
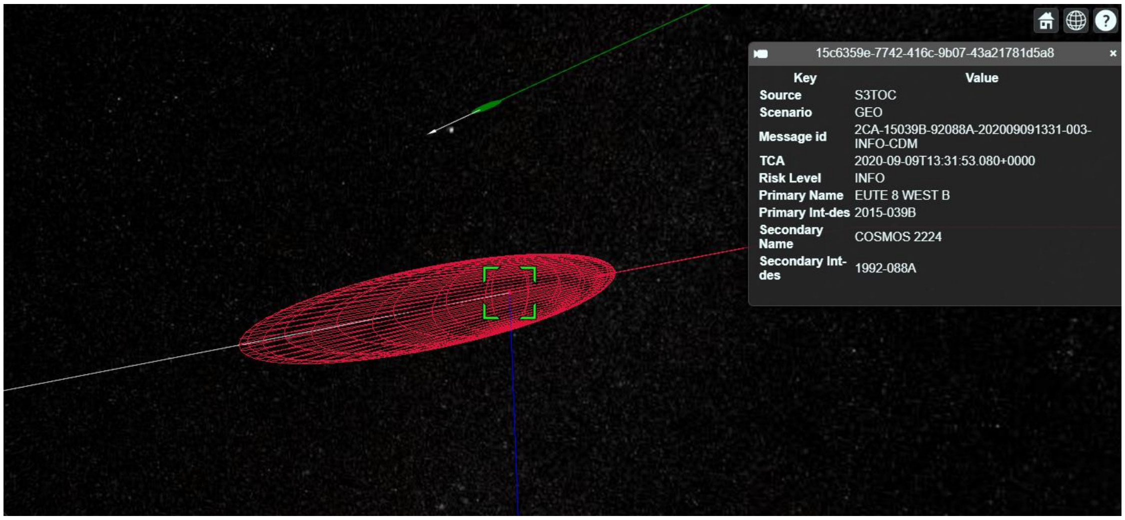


Figure 20: *Visualfocus* 2D Display

Among other features visualfocus supports:

- CDM and OEM formats that allows covariance ellipsoid representation (***focuscloseap***)



15c6359e-7742-416c-9b07-43a21781d5a8

Key	Value
Source	S3TOC
Scenario	GEO
Message id	2CA-15039B-92088A-202009091331-003-INFO-CDM
TCA	2020-09-09T13:31:53.080+0000
Risk Level	INFO
Primary Name	EUTE 8 WEST B
Primary Int-des	2015-039B
Secondary Name	COSMOS 2224
Secondary Int-des	1992-088A

Figure 21: *visualfocus* **CDM covariance ellipsoid representation**

- Connection with a TM server, to visualize TM data in Real Time
- Mobile elements: solar array rotation and thruster animation.

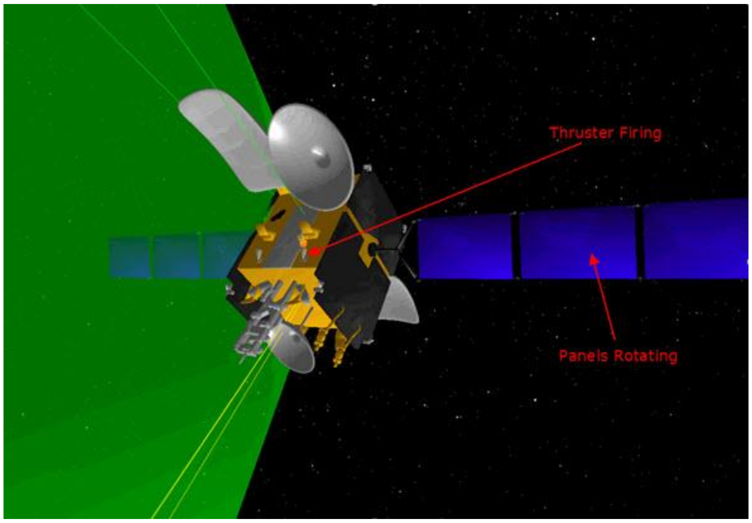


Figure 22: *visualfocus* **3D representation in real time including mobile elements**

- Grid sensors: contour lines footprint representing the antenna radiation.

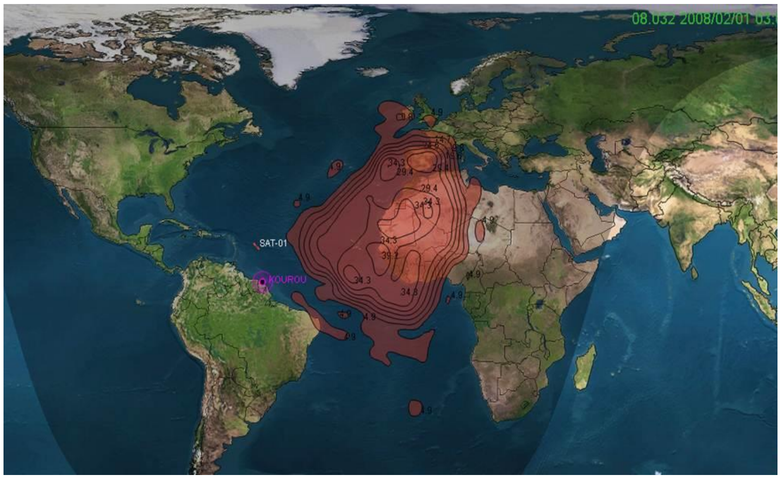


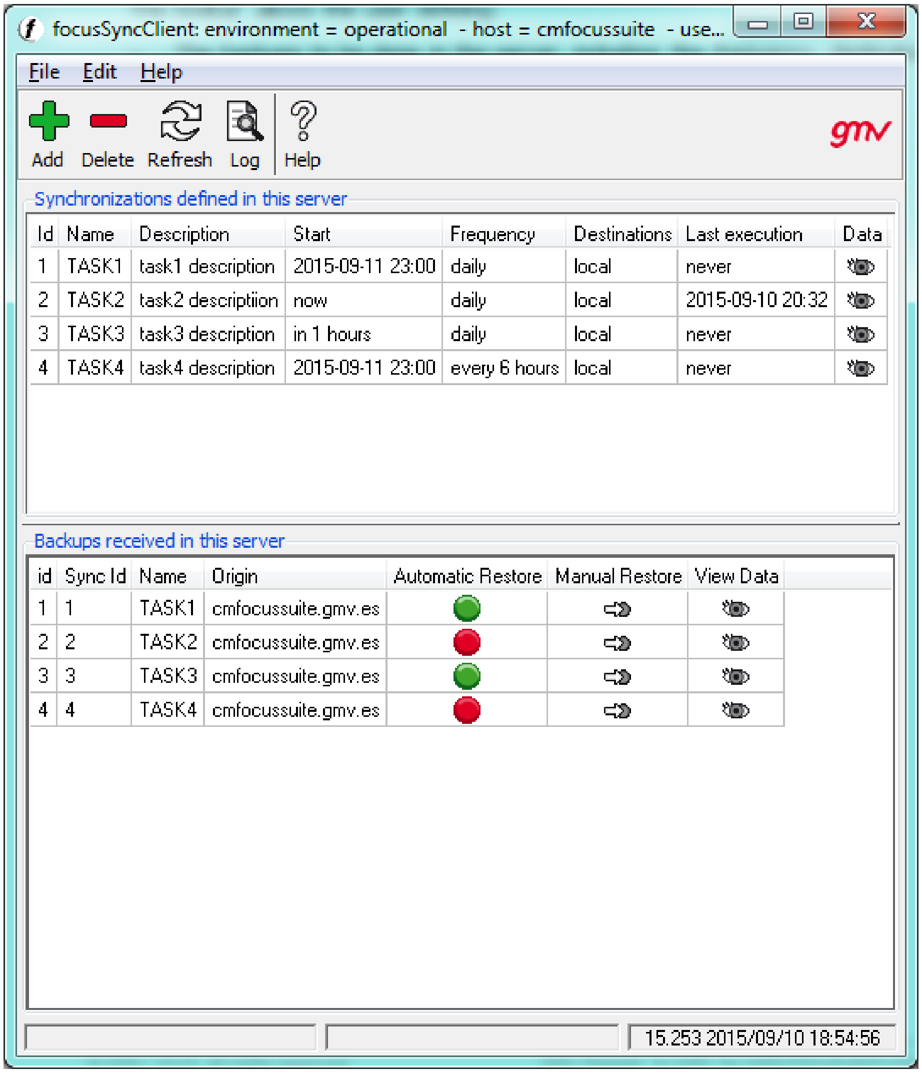
Figure 23: *visualfocus* **footprint for antenna radiation representation**

- Interface to retrieve TLE data from a database.
- Support for CCSDS data standard including the visualization of CDM, OEM, OPM and OMM outputs from programs in the main view

6. *FOCUSUITESYNC*

GMV offers the ***focussuite*** serves synchronization tool (***focussuitesync***) to maintain the servers with data aligned. ***focussuitesync*** is a client-server application:

- The server (***focussuitesyncserver***) schedules and executes backups of ***focussuite*** data as well as restores of these backups. Its main usage is to synchronize data between different servers, performing the backup on master server and restoring it in the slave server. The same backup can be sent to and restored in several slaves. It can be executed as a daemon.
- The client (***focussuitesyncclient***) is used to configure the server tasks. It provides a Graphical User Interface to configure the tasks to be executed in ***focussuitesync*** servers. It works as an external application that connects to servers. The following picture is the ***focussuitesyncclient*** main window, which is comprised of a menu bar, a toolbar and a working area.


focusSyncClient: environment = operational - host = cmfocussuite - use...
File
Edit
Help
Add
Delete
Refresh
Log
Help
gmv

Synchronizations defined in this server

Id	Name	Description	Start	Frequency	Destinations	Last execution	Data
1	TASK1	task1 description	2015-09-11 23:00	daily	local	never	👁
2	TASK2	task2 descriptiion	now	daily	local	2015-09-10 20:32	👁
3	TASK3	task3 description	in 1 hours	daily	local	never	👁
4	TASK4	task4 description	2015-09-11 23:00	every 6 hours	local	never	👁

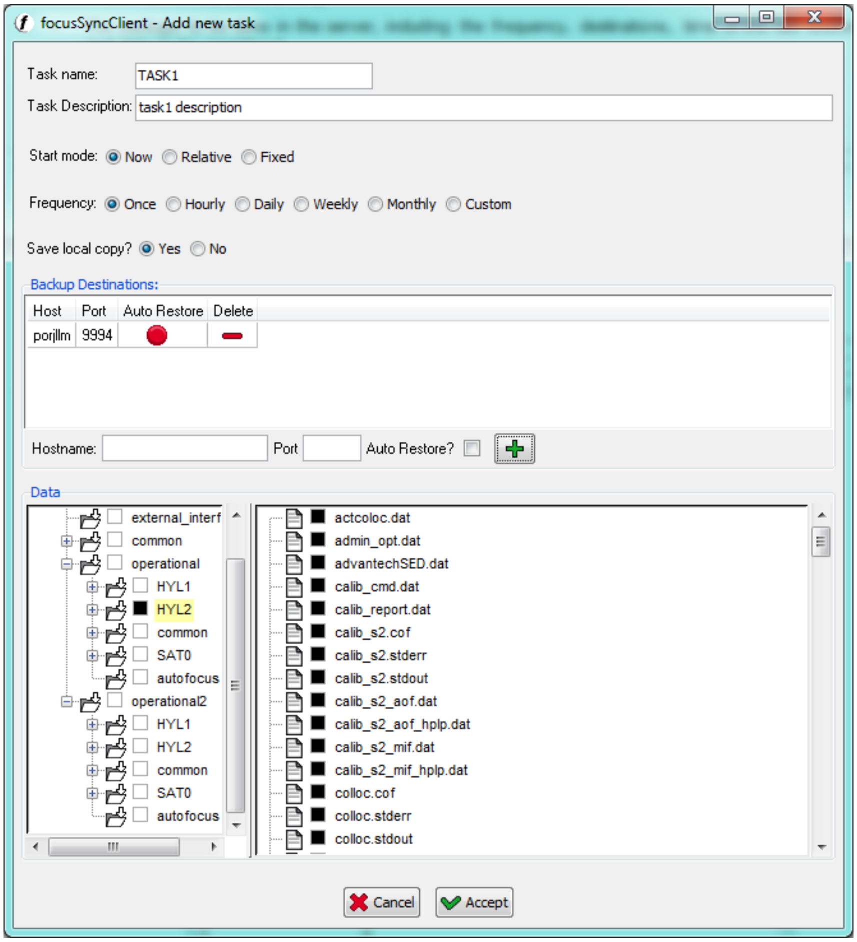
Backups received in this server

id	Sync Id	Name	Origin	Automatic Restore	Manual Restore	View Data
1	1	TASK1	cmfocussuite.gmv.es	🟢	➪	👁
2	2	TASK2	cmfocussuite.gmv.es	🔴	➪	👁
3	3	TASK3	cmfocussuite.gmv.es	🟢	➪	👁
4	4	TASK4	cmfocussuite.gmv.es	🔴	➪	👁

15.253 2015/09/10 18:54:56

Figure 24: *focussuitesync* Client Main Window

- The toolbar allows the user defining:
  - The backups to be done in the server, including the frequency, destinations (target servers), time of the last execution and data to be considered.



focusSyncClient - Add new task

Task name: TASK1

Task Description: task1 description

Start mode: ● Now ○ Relative ○ Fixed

Frequency: ● Once ○ Hourly ○ Daily ○ Weekly ○ Monthly ○ Custom

Save local copy? ● Yes ○ No

Backup Destinations:

Host	Port	Auto Restore	Delete
porjllm	9994	●	▬

Hostname: Port Auto Restore? □

Data

- □ external_interf
- □ common
- □ operational
  - □ HYL1
  - ■ HYL2
  - □ common
  - □ SAT0
  - □ autofocus
- □ operational2
  - □ HYL1
  - □ HYL2
  - □ common
  - □ SAT0
  - □ autofocus

- ■ actcoloc.dat
- ■ admin_opt.dat
- ■ advantechSED.dat
- ■ calib_cmd.dat
- ■ calib_report.dat
- ■ calib_s2.cof
- ■ calib_s2.stderr
- ■ calib_s2.stdout
- ■ calib_s2_aof.dat
- ■ calib_s2_aof_hplp.dat
- ■ calib_s2_mif.dat
- ■ calib_s2_mif_hplp.dat
- ■ colloc.cof
- ■ colloc.stderr
- ■ colloc.stdout

Figure 25: *focussuitesync* Client Main Window

  - The backups received in the server, including the origin, an automatic restore option or manual restore; and the data to be restored.

7. *FOCUSOC*

Focusoc is GMV's Conjunction Analysis and Collision Avoidance service, normally provided to commercial satellite operators, which is currently monitoring 80+ satellites in operations. It is mainly based on the screening of operational ephemeris including manoeuvres from the operator and owners against the following data sources, by means of the operational ***Focuscloseap*** tool:

- **High accuracy SP catalogue** from 18SDS, which includes ephemeris for all non-classified objects bigger than 10 cm.
- **Propagated orbits from 18SDS CDMs**, which can be directly ingested by the service from space-track.org, with no need of interaction from the operator. It is worth mentioning that CDMs generated by other sources could be ingested too.
- **Operational space-track public files**, including operational ephemeris for some operators such as SpaceX, OneWeb or Iridium.

Usage of the SP catalogue data requires for some clarifications. The service provides additional conjunction analysis based on SP catalogue, but raw orbits will not be used as they are. Instead, the SP catalogue data is extended to provide a better service, obtaining **GMV's extended catalogue**. It is remarked here that the **catalogue validity is extended**, by means of orbit determination and propagation, from usual 3-4 days to 7 days in LEO regimes, allowing earlier prediction of conjunctions and providing more time for monitoring and action-taking. It is worth mentioning that in the case of GEO orbits, the catalogue is extended up to 15 days.

In addition, the **extended catalogue presents covariance** evolution values, calculated based on the statistical comparison of the orbits generated by 18SDS in successive days, while the original SP catalogue is absent of covariance data needed to compute PoC in a close encounter. Then, ***Focusoc*** not only adds SP high accuracy data to the analysis, but also adds extended data obtained from exploiting the catalogue and its historical data.

The general functioning of the system is illustrated in the figure below:

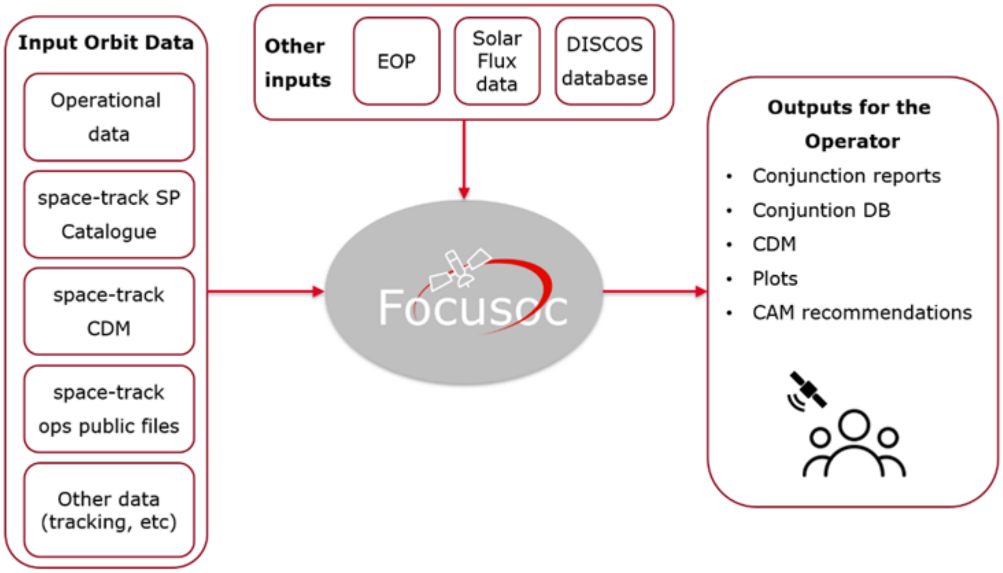


Figure 26: *Focusoc* overall functioning

Focusoc system also daily downloads and processes all the needed data for the computations (such as EOPs, Solar radiation, etc) and the contents of the DISCOS database, used to have an estimation of the size of each object for PoC computation. This process is completely automated and independent from the operator.

7.1. CONJUNCTION ANALYSIS AND COLLISION RISK ASSESSMENT

Conjunction Assessment in ***Focusoc*** is performed by means of GMV's ***Focuscloseap*** SW, which can be triggered up to three times using different data sources. First one for the screening comparing operational ephemeris with the orbits obtained from the CDMs, second one comparing operational data against the whole extended catalogue, and third one against the catalogue of operational public files. Each execution provides conjunction results, that they can be analysed together. This way, if the same conjunction is detected in more than one execution, it will be identified and the same event ID shall be assigned to both conjunctions, allowing easy data comparisons. Equally, if the same conjunction is detected in several executions over time, it will be identified as the same event too.

The conjunctions are classified depending on the assigned risk level, which is assessed as a function of the miss distance components and the PoC. These criteria are defined by each Owner or Operator with the consultancy and help of GMV when requested.

7.2. COLLISION AVOIDANCE MANOEUVRE COMPUTATION

After assessing geometry and collision risk for all the conjunctions, there might be some of them in which the relative position between both objects is very small or the collision probability is too high. ***Focusoc*** analyses the possibility of performing a Collision Avoidance Manoeuvre (CAM), in order to mitigate the risk of the event.

The service offers two options for CAM recommendations, which can be executed simultaneously. First option is to compute an **optimal CAM** in a fixed epoch, in the sense of looking for the optimal direction.

It is also possible to specify a certain range of epochs before the TCA, to look for the best candidate between those computed. The best one will be the closest manoeuvre to the TCA that fulfils the post-CAM probability threshold and input manoeuvre constraints, which shall be user-defined too. The algorithm implemented will perform an optimization process, in order to compute the collision avoidance manoeuvre with **minimum ΔV for which the PoC is reduced to the threshold value**. This is done by using the PoC-gradient method along the three directions at the point of the orbit in which the manoeuvre is to be performed.

The second option offered by the service is a parametric analysis where a range of delta-V values applied in the along-track direction are analysed at different epochs (both in the positive and the negative along-track direction).

The software then provides the **results of the whole parametric analysis**, and proposes a **manoeuvre recommendation** (best candidate) between all the manoeuvres computed during the parametrical analysis.

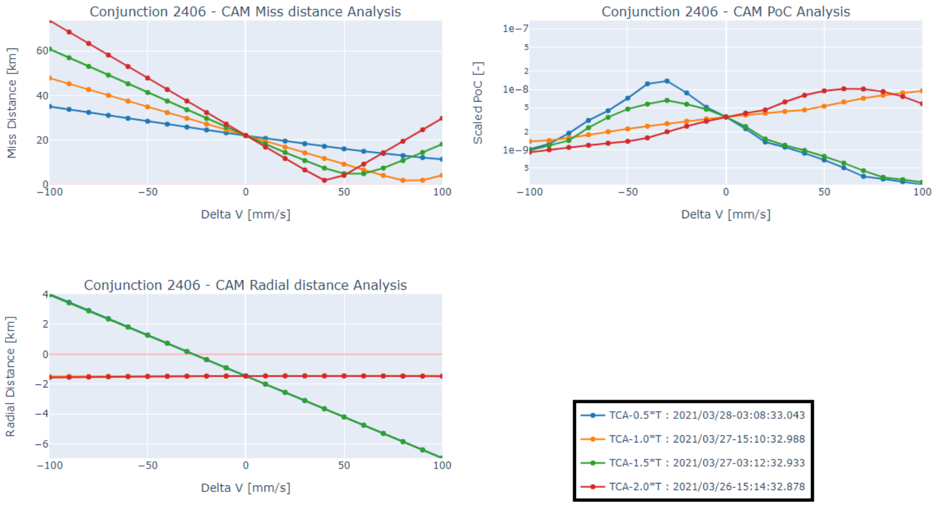


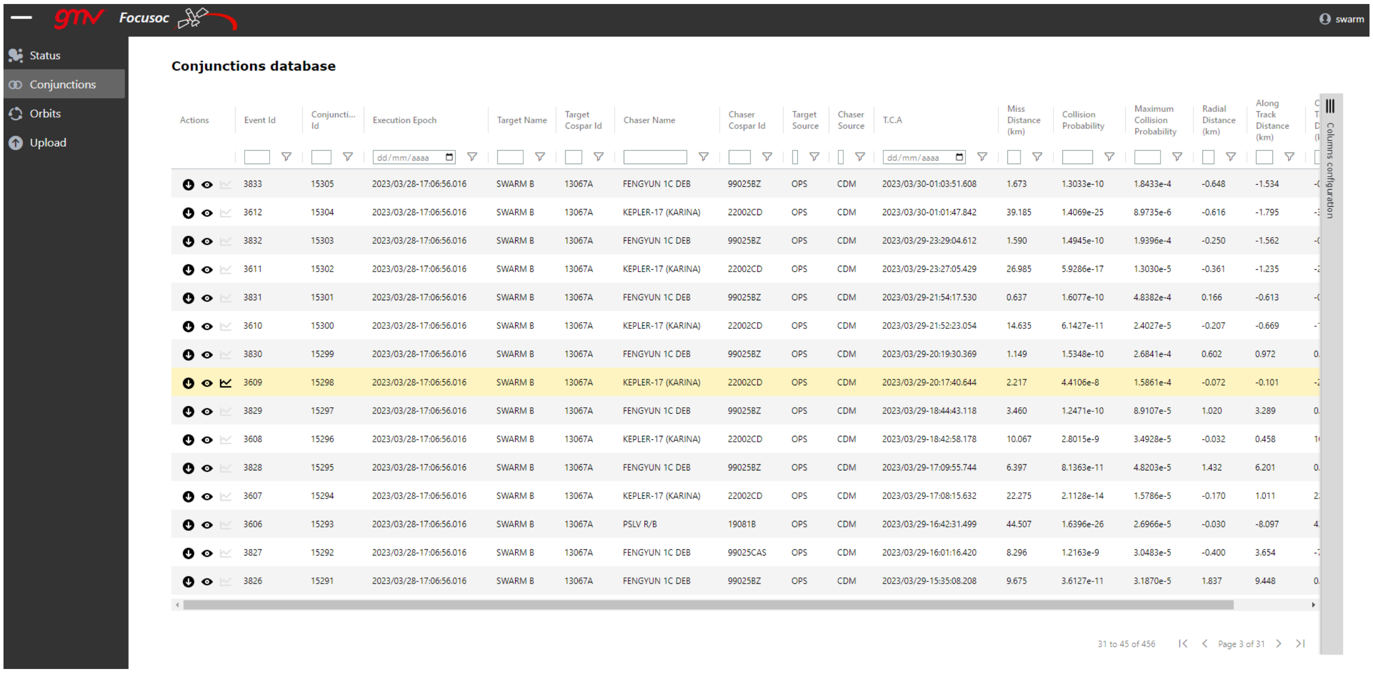
Figure 27: Example of CAM parametric analysis.

7.3. *FOCUSOC* WEB BASED HMI

All the relevant information provided by the system will be presented through am HMI based on web technologies. It is deployed in GMV's facilities, and it is accessible through typical web browsers (such as Chrome, Firefox or MS Edge). The back-end is based on Java and it uses **Spring Boot** framework, providing an efficient and fast navigation through the data. A dedicated user and password for each operator is defined; the authentication process and user management is based on **KeyCloak**, and data security, accesses and permissions are managed with Spring Security.

Front-end has been developed in **JavaScript**, making use of **React, Redux and Rxjs** libraries. When interacting with the front-end, apart from being able to visualize all the relevant information, all output products (such as CDMs generated for high risk conjunctions) are available for downloading too.

All historic conjunction information are provided in the conjunction database. It allows the user to query the database and sort data according to different filters, providing a user-friendly interaction for data consulting. For each conjunction, it is possible to check the relevant data, additional analysis plots and, if the conjunction is high-risk, the user can download a CDM for the conjunction, the suggested CAM in OPM and check the results of the parametric CAM analysis. The figure below shows the aspect of the conjunction database.

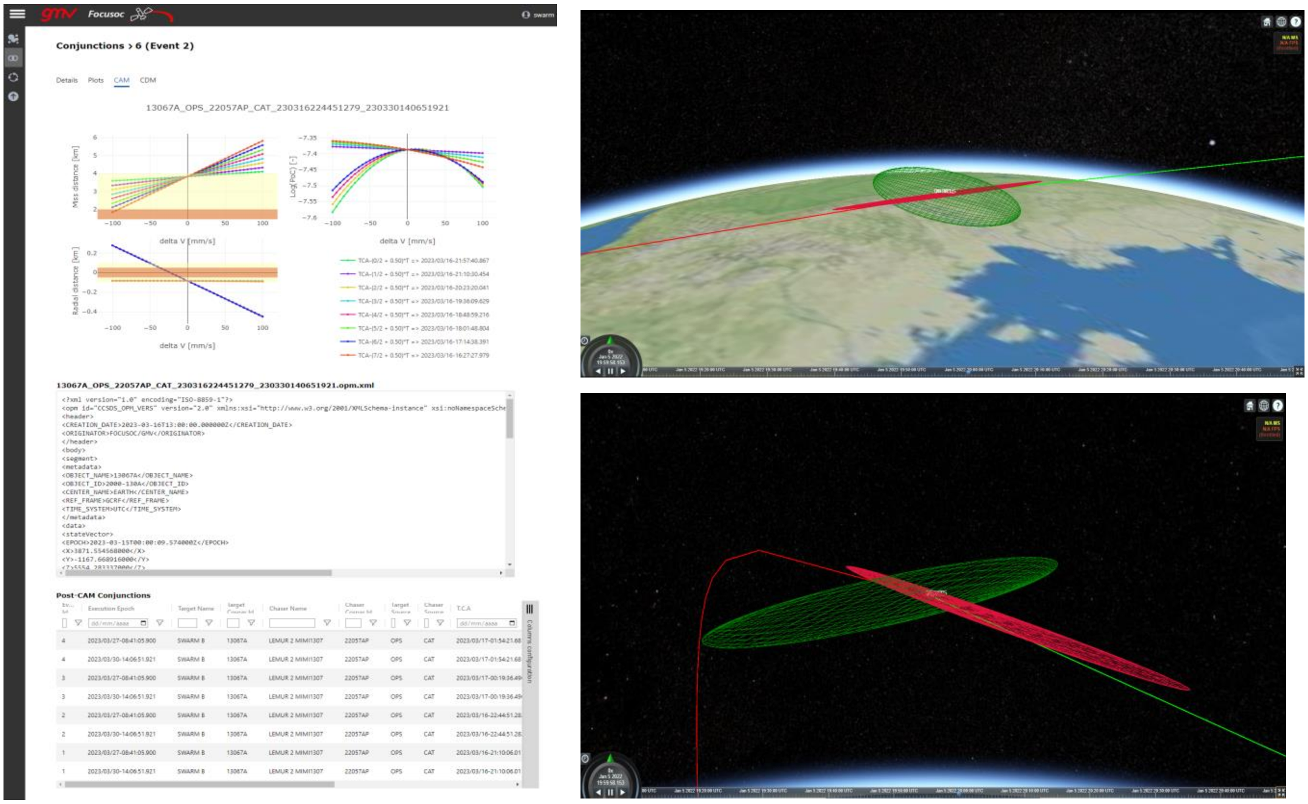


Conjunctions database

Actions	Event Id	Conjuncti... Id	Execution Epoch	Target Name	Target Cospar Id	Chaser Name	Chaser Cospar Id	Target Source	Chaser Source	T.C.A	Miss Distance (km)	Collision Probability	Maximum Collision Probability	Radial Distance (km)	Along Track Distance (km)
	3833	15305	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/30-01:03:51.608	1.673	1.3033e-10	1.8433e-4	-0.648	-1.534
	3612	15304	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/30-01:01:47.842	39.185	1.4069e-25	8.9735e-6	-0.616	-1.795
	3832	15303	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-23:29:04.612	1.590	1.4945e-10	1.9396e-4	-0.250	-1.562
	3611	15302	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/29-23:27:05.429	26.985	5.9286e-17	1.3030e-5	-0.361	-1.235
	3831	15301	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-21:54:17.530	0.637	1.6077e-10	4.8382e-4	0.166	-0.613
	3610	15300	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/29-21:52:23.054	14.635	6.1427e-11	2.4027e-5	-0.207	-0.669
	3830	15299	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-20:19:30.369	1.149	1.5348e-10	2.6841e-4	0.602	0.972
	3609	15298	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/29-20:17:40.644	2.217	4.4106e-8	1.5861e-4	-0.072	-0.101
	3829	15297	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-18:44:43.118	3.460	1.2471e-10	8.9107e-5	1.020	3.289
	3608	15296	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/29-18:42:58.178	10.067	2.8015e-9	3.4928e-5	-0.032	0.458
	3828	15295	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-17:09:55.744	6.397	8.1363e-11	4.8203e-5	1.432	6.201
	3607	15294	2023/03/28-17:06:56.016	SWARM B	13067A	KEPLER-17 (KARINA)	22002CD	OPS	CDM	2023/03/29-17:08:15.632	22.275	2.1128e-14	1.5786e-5	-0.170	1.011
	3606	15293	2023/03/28-17:06:56.016	SWARM B	13067A	PSLV R/B	19081B	OPS	CDM	2023/03/29-16:42:31.499	44.507	1.6396e-26	2.6966e-5	-0.030	-8.097
	3827	15292	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025CAS	OPS	CDM	2023/03/29-16:01:16.420	8.296	1.2163e-9	3.0483e-5	-0.400	3.654
	3826	15291	2023/03/28-17:06:56.016	SWARM B	13067A	FENGYUN 1C DEB	99025BZ	OPS	CDM	2023/03/29-15:35:08.208	9.675	3.6127e-11	3.1870e-5	1.837	9.448

Figure 28: Overview of the conjunction database.

For the suggested CAM, operator can access the information showing Collision Avoidance parametric analysis and a conjunction table showing post-CAM screening analysis. Operator can also check for each conjunction CDM a 3D visualization of it, including the covariance ellipsoid of targe and chaser.



Focusoc
swarm
Conjunctions > 6 (Event 2)
Details
Plots
CAM
CDM
13067A_OPS_22057AP_CAT_230316224451279_230330140651921
Miss distance [km]
Log(PoC) [-]
Radial distance [km]
delta V [mm/s]
TCA-(0/2 + 0.50)*T => 2023/03/16-21:57:40.867
TCA-(1/2 + 0.50)*T => 2023/03/16-21:10:30.454
TCA-(2/2 + 0.50)*T => 2023/03/16-20:23:20.041
TCA-(3/2 + 0.50)*T => 2023/03/16-19:36:09.629
TCA-(4/2 + 0.50)*T => 2023/03/16-18:48:59.216
TCA-(5/2 + 0.50)*T => 2023/03/16-18:01:48.804
TCA-(6/2 + 0.50)*T => 2023/03/16-17:14:38.391
TCA-(7/2 + 0.50)*T => 2023/03/16-16:27:27.979
Columns configuration

13067A_OPS_22057AP_CAT_230316224451279_230330140651921.opm.xml

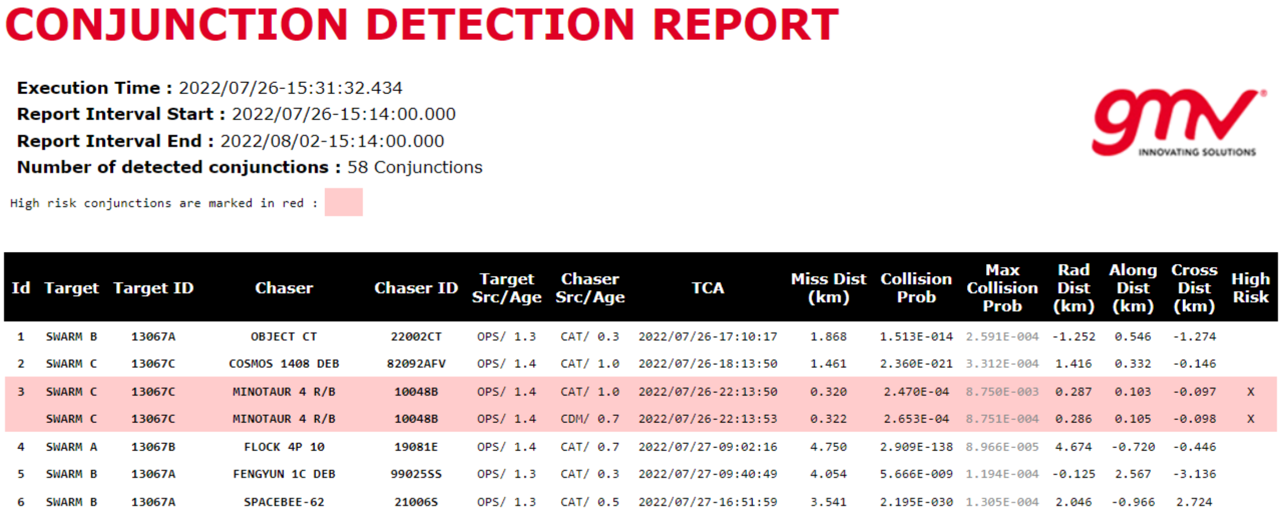
```
<?xml version="1.0" encoding="ISO-8859-1"?>
<opm id="CCSDS_OPM_VERS" version="2.0" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance" xsi:noNamespaceSche
<header>
<CREATION_DATE>2023-03-16T13:00:00.000000Z</CREATION_DATE>
<ORIGINATOR>FOCUSOC/GMV</ORIGINATOR>
</header>
<body>
<segment>
<metadata>
<OBJECT_NAME>13067A</OBJECT_NAME>
<OBJECT_ID>2000-130A</OBJECT_ID>
<CENTER_NAME>EARTH</CENTER_NAME>
<REF_FRAME>GCRF</REF_FRAME>
<TIME_SYSTEM>UTC</TIME_SYSTEM>
</metadata>
<data>
<stateVector>
<EPOCH>2023-03-15T00:00:09.574000Z</EPOCH>
<X>3871.554568000</X>
<Y>-1167.668916000</Y>
<Z>5554.283337000</Z>
```

Post-CAM Conjunctions

Ev... Id	Execution Epoch	Target Name	Target Conjun. Id	Chaser Name	Chaser Conjun. Id	Target Source	Chaser Source	T.C.A
4	2023/03/27-08:41:05.900	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/17-01:54:21.68
4	2023/03/30-14:06:51.921	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/17-01:54:21.68
3	2023/03/27-08:41:05.900	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/17-00:19:36.49
3	2023/03/30-14:06:51.921	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/17-00:19:36.49
2	2023/03/27-08:41:05.900	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/16-22:44:51.28
2	2023/03/30-14:06:51.921	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/16-22:44:51.28
1	2023/03/27-08:41:05.900	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/16-21:10:06.01
1	2023/03/30-14:06:51.921	SWARM B	13067A	LEMUR 2 MIMI1307	22057AP	OPS	CAT	2023/03/16-21:10:06.01

Figure 29: CAM parametric analysis and 3D CDM representation

The web HMI is not the only mechanism to provide information to the operators. In addition, every time ***Focusoc*** service performs a conjunction analysis, it can send an automatic email to a distribution list, including a conjunction report summarizing the conjunctions that were found. In case that high-risk conjunctions are found, some additional files (such as CDMs, plots or CAM OPMs) are generated and attached in the email:



CONJUNCTION DETECTION REPORT

Execution Time : 2022/07/26-15:31:32.434
Report Interval Start : 2022/07/26-15:14:00.000
Report Interval End : 2022/08/02-15:14:00.000
Number of detected conjunctions : 58 Conjunctions

High risk conjunctions are marked in red : 🟥

Id	Target	Target ID	Chaser	Chaser ID	Target Src/Age	Chaser Src/Age	TCA	Miss Dist (km)	Collision Prob	Max Collision Prob	Rad Dist (km)	Along Dist (km)	Cross Dist (km)	High Risk
1	SWARM B	13067A	OBJECT CT	22002CT	OPS/ 1.3	CAT/ 0.3	2022/07/26-17:10:17	1.868	1.513E-014	2.591E-004	-1.252	0.546	-1.274	
2	SWARM C	13067C	COSMOS 1408 DEB	82092AFV	OPS/ 1.4	CAT/ 1.0	2022/07/26-18:13:50	1.461	2.360E-021	3.312E-004	1.416	0.332	-0.146	
3	SWARM C	13067C	MINOTAUR 4 R/B	10048B	OPS/ 1.4	CAT/ 1.0	2022/07/26-22:13:50	0.320	2.470E-04	8.750E-003	0.287	0.103	-0.097	X
	SWARM C	13067C	MINOTAUR 4 R/B	10048B	OPS/ 1.4	CDM/ 0.7	2022/07/26-22:13:53	0.322	2.653E-04	8.751E-004	0.286	0.105	-0.098	X
4	SWARM A	13067B	FLOCK 4P 10	19081E	OPS/ 1.4	CAT/ 0.7	2022/07/27-09:02:16	4.750	2.909E-138	8.966E-005	4.674	-0.720	-0.446	
5	SWARM B	13067A	FENGYUN 1C DEB	99025SS	OPS/ 1.3	CAT/ 0.3	2022/07/27-09:40:49	4.054	5.666E-009	1.194E-004	-0.125	2.567	-3.136	
6	SWARM B	13067A	SPACEBEE-62	21006S	OPS/ 1.3	CAT/ 0.5	2022/07/27-16:51:59	3.541	2.195E-030	1.305E-004	2.046	-0.966	2.724	

Figure 30: Example of HTML conjunction report embedded on emails

8. AUTOMATION (*autofocus*)

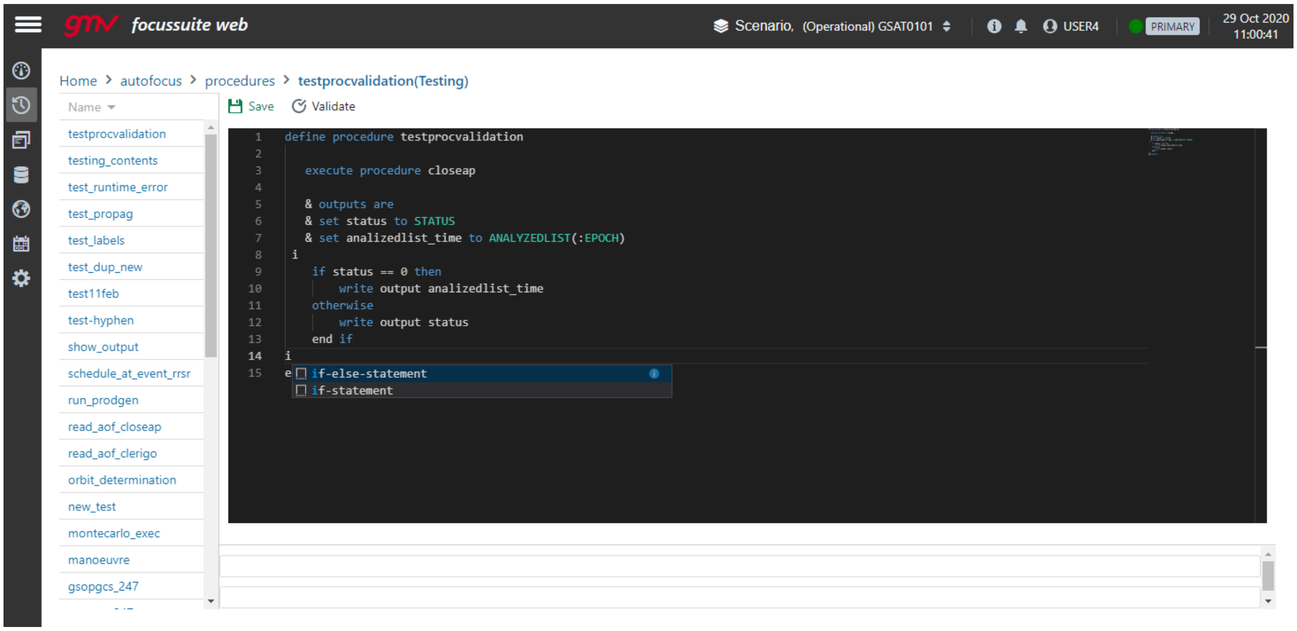
autofocus is an advanced component that delivers full automation support for hands-off operations to the entire ***focussuite***. The solution is based on an integrated set of tools for the definition, scheduling, execution, monitoring, and control of high-level user-defined operational procedures.

autofocus is fully compatible with today's operations based on procedures, but assists the human operator by means of an agent that handles procedures written in ***SOL***, the spacecraft operations language. ***autofocus*** provides two user environments,

- one for procedure definition (the ***SOL*** factory),
- another one for procedure execution (the procedure agenda).

8.1. SOL: SPACECRAFT OPERATIONS LANGUAGE

SOL is a GMV automation language specifically designed to support spacecraft operations. Oriented towards spacecraft operators (not programmers), ***SOL*** is a very high-level language with natural language-like syntax in which the number of language elements has been minimised.



```
define procedure testprocvalidation

  execute procedure closeap

  & outputs are
  & set status to STATUS
  & set analizedlist_time to ANALYZEDLIST(:EPOCH)
 i
   if status == 0 then
       write output analizedlist_time
   otherwise
       write output status
   end if
i
e ☐ if-else-statement
  ☐ if-statement
```

Figure 31: *autofocus* SOL Editor

SOL is a procedural language which features numeric, text, Boolean and date (relative and absolute) data as well as list handling.

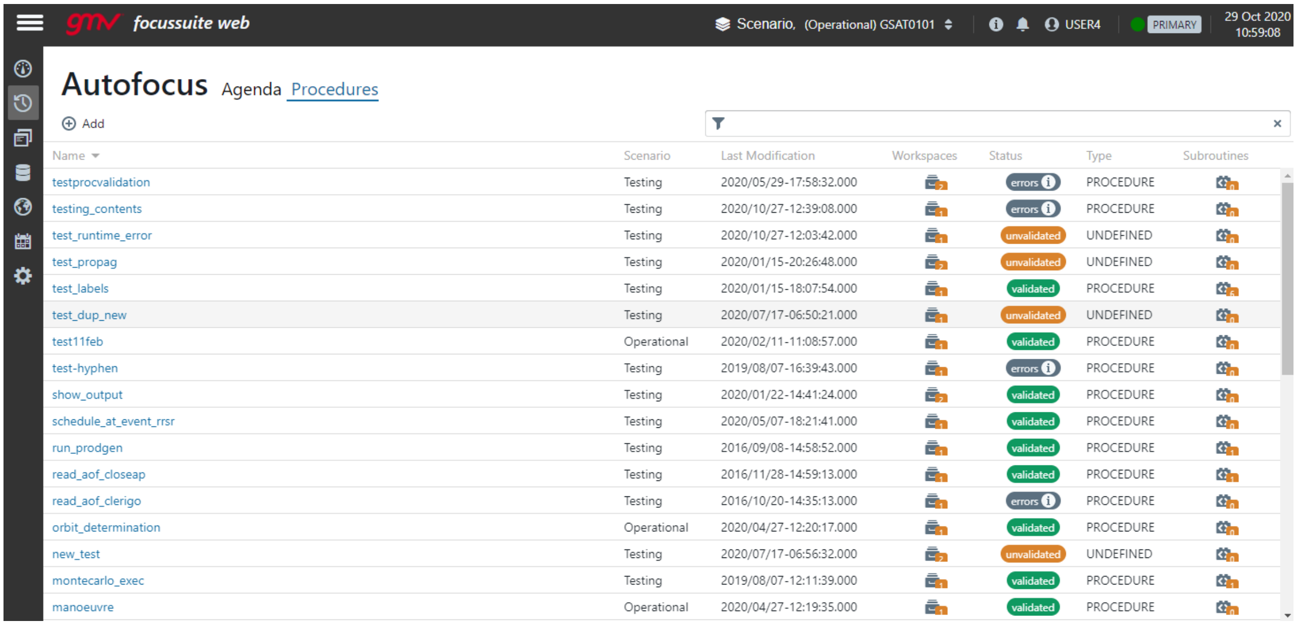
A rich set of mathematical (trigonometric and hyperbolic functions, logarithms, power, etc.) and logical expressions is available in ***SOL***. Date expressions and arithmetic operations are also supported, such as in

SOL features the ability to call procedures from within other procedures. Procedure call, via the execute construct, allows to explicitly enumerating the inputs and outputs of a procedure for improved legibility:

SOL control structures include branching via `if/otherwise/end` if and flexible looping: repeat a block of instructions a fixed number of times (`repeat for/end repeat`), repeat while a condition is true (`repeat while/end repeat`) and iterate over the elements of a list (`repeat for each/end repeat`). For example:

SOL supports the whole ***focussuite*** for full ***focussuite*** framework automation. It is possible, for example, to activate external ***focussuite*** components from a ***SOL*** procedure, collect its output and process it afterwards.

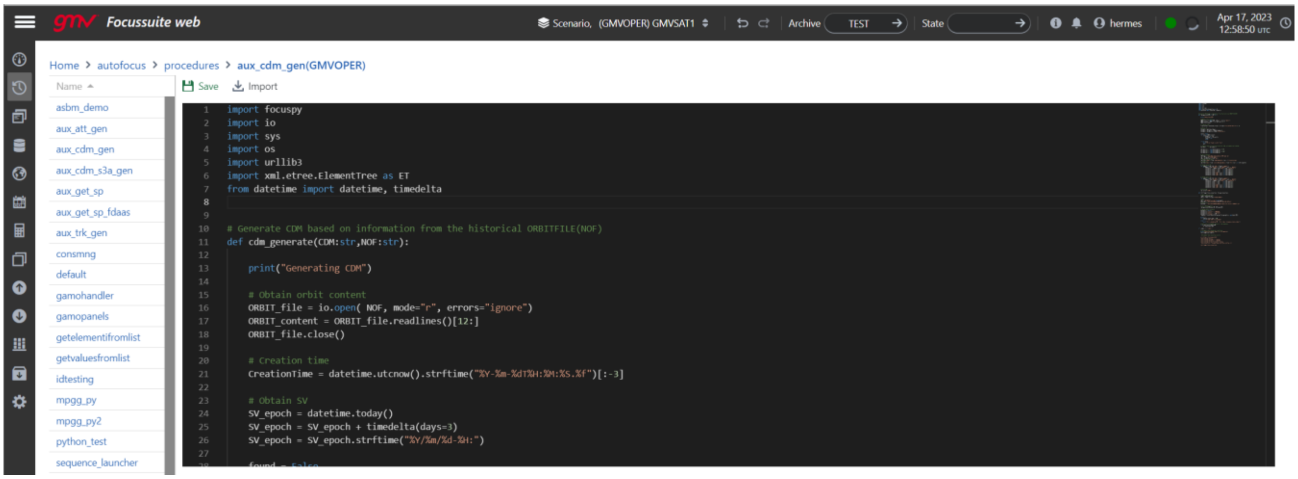
8.2. AUTOFOCUS PROCEDURE DEFINITIONS



Name	Scenario	Last Modification	Workspaces	Status	Type	Subroutines
testprocvalidation	Testing	2020/05/29-17:58:32.000		errors	PROCEDURE	
testing_contents	Testing	2020/10/27-12:39:08.000		errors	PROCEDURE	
test_runtime_error	Testing	2020/10/27-12:03:42.000		unvalidated	UNDEFINED	
test_propag	Testing	2020/01/15-20:26:48.000		unvalidated	UNDEFINED	
test_labels	Testing	2020/01/15-18:07:54.000		validated	PROCEDURE	
test_dup_new	Testing	2020/07/17-06:50:21.000		unvalidated	UNDEFINED	
test11feb	Operational	2020/02/11-11:08:57.000		validated	PROCEDURE	
test-hyphen	Testing	2019/08/07-16:39:43.000		errors	PROCEDURE	
show_output	Testing	2020/01/22-14:41:24.000		validated	PROCEDURE	
schedule_at_event_rrsr	Testing	2020/05/07-18:21:41.000		validated	PROCEDURE	
run_prodgen	Testing	2016/09/08-14:58:52.000		validated	PROCEDURE	
read_aof_closeap	Testing	2016/11/28-14:59:13.000		validated	PROCEDURE	
read_aof_clerigo	Testing	2016/10/20-14:35:13.000		errors	PROCEDURE	
orbit_determination	Operational	2020/04/27-12:20:17.000		validated	PROCEDURE	
new_test	Testing	2020/07/17-06:56:32.000		unvalidated	UNDEFINED	
montecarlo_exec	Testing	2019/08/07-12:11:39.000		validated	PROCEDURE	
manoeuvre	Operational	2020/04/27-12:19:35.000		validated	PROCEDURE	

Figure 32: *autofocus* procedures editor window

The ***autofocus*** integrated procedure definition environment allows the user to write and validate procedures at syntactic and semantic levels. Besides the definition of procedures using the dedicated domain language SOL. python scripts can also be defined to provide more extensive automation capabilities. The code editor in both cases provides code highlighting and code completion utilities.


Focussuite web
Scenario, (GMVOPER) GMVSAT1
Archive
TEST
State
hermes
Apr 17, 2023
12:58:50 UTC
Home > autofocus > procedures > aux_cdm_gen(GMVOPER)
Name
Save
Import

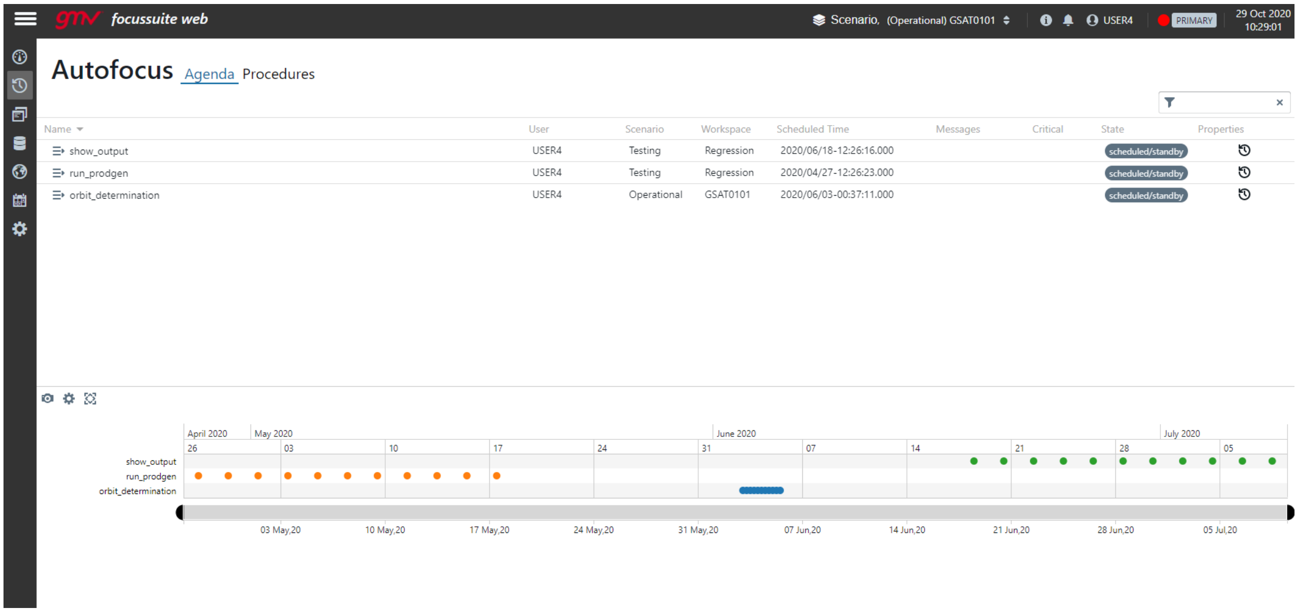
asbm_demo
aux_att_gen
aux_cdm_gen
aux_cdm_s3a_gen
aux_get_sp
aux_get_sp_fdaas
aux_trk_gen
consmng
default
gamohandler
gamopanels
getelementifromlist
getvaluesfromlist
idtesting
mpgg_py
mpgg_py2
python_test
sequence_launcher

```python
import focuspy
import io
import sys
import os
import urllib3
import xml.etree.ElementTree as ET
from datetime import datetime, timedelta


# Generate CDM based on information from the historical ORBITFILE(NOF)
def cdm_generate(CDM:str,NOF:str):

    print("Generating CDM")

    # Obtain orbit content
    ORBIT_file = io.open( NOF, mode="r", errors="ignore")
    ORBIT_content = ORBIT_file.readlines()[12:]
    ORBIT_file.close()

    # Creation time
    CreationTime = datetime.utcnow().strftime("%Y-%m-%dT%H:%M:%S.%f")[:-3]

    # Obtain SV
    SV_epoch = datetime.today()
    SV_epoch = SV_epoch + timedelta(days=3)
    SV_epoch = SV_epoch.strftime("%Y/%m/%d-%H:")

    found = False
```

Figure 33 *autofocus*: python procedure editor

8.3. AUTOFOCUS PROCEDURE EXECUTIONS

The ***autofocus*** agenda allows scheduling, monitoring and controlling ***SOL*** procedures.



Name	User	Scenario	Workspace	Scheduled Time	Messages	Critical	State	Properties
show_output	USER4	Testing	Regression	2020/06/18-12:26:16.000			scheduled/standby	
run_prodgen	USER4	Testing	Regression	2020/04/27-12:26:23.000			scheduled/standby	
orbit_determination	USER4	Operational	GSAT0101	2020/06/03-00:37:11.000			scheduled/standby	

Figure 34: *autofocus* procedures agenda window

Validated procedures can be scheduled immediately, at a given time (either absolute or relative) or by means of links to other procedures (soon before, late after, right before, etc.). The ***autofocus*** scheduler takes care of the execution of the procedures when their activation condition becomes true. The list of scheduled procedures can be viewed in both a full mode, where all scheduling details are available, or in a Gantt chart via an integrated ***ebro*** component.

9. COMPUTATION LAYER

The family of ***focussuite*** products is composed of:

- ***focusgeo*** for on-station phase of GEO satellites
- ***focusleop*** for GTO phase of GEO satellites
- ***focusleo*** for low Earth orbit satellites
- ***focuscn*** for satellite constellations

There exists an extension of the system, called ***autofocus*** that allows fully automating flight dynamics operations.

Each of the ***focussuite*** family members (***focusgeo***, ***focusleop***, ***focusleo***, and ***focuscn***) includes its own computational layer providing the required flight dynamics functions for the corresponding mission (GEO, LEOP, LEO or satellite constellations).

9.1. MISSION-INDEPENDENT MODULES

The following functionalities are shared between ***focusgeo***, ***focusleo***, ***focusleop*** and ***focuscn***:

- Tracking data pre-processing
- Orbit Determination
- Orbit Prediction
- Event Generation
- Orbit and attitude tools

PREPRO: Pre-processing function

PREPRO is the component centralising the management of most incoming interfaces, ingesting the data provided by other systems into the flight dynamics database and generating the files in a format understandable by other computational components.

The main data files being processed are:

- Tracking and ranging data from the ground stations (TDM)
- External orbit (OEM or OPM) and attitude (AEM)
- S/C telemetry
- EOP and leap seconds
- Solar magnetic information

BAHN: Orbit Determination function

The BAHN component is in charge of performing the orbit determination based on the measurements data from the stations.

BAHN uses a batch least squares method to perform the orbit determination, estimating the initial state vector at a reference epoch and the dynamic parameters of the orbital perturbation models. The estimation of parameter related to the observations (e.g. station time bias, clock drifts…) can be performed simultaneously with the orbit determination or analysing the observations assuming a fixed orbit.

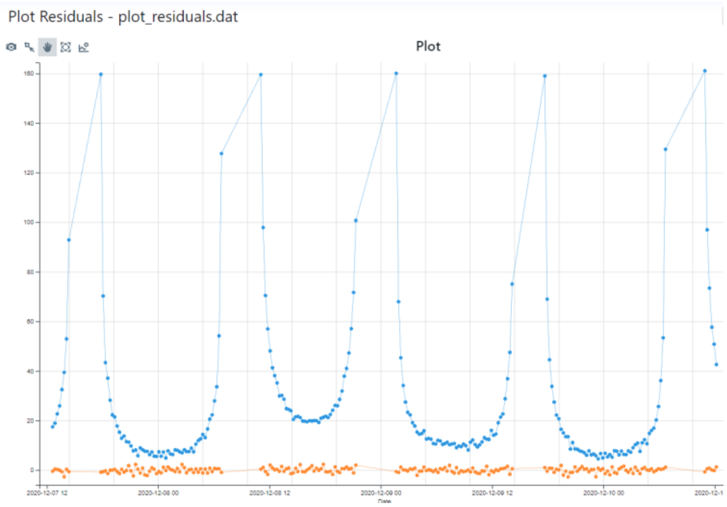


Figure 35: BAHN residuals plot example

PROPAG: Orbit Propagator function

The PROPAG component encapsulates all the orbit propagation capabilities available in the FDS libraries and allows performing some tasks (for products generation and for orbital manoeuvres computation) independently from the BAHN component.

The main purpose of this module is to perform a prediction of the S/C orbit based on the process of the following data:

- Updated orbit state vector, as computed by the Orbit Determination component, when the orbit prediction has to be performed for the satellite, or introduced manually by the operator.
- Additional parameters estimated by the Orbit Determination component that model the orbit environment (e.g. solar radiation pressure coefficients). These are of particular importance when dealing with long-term predictions.

Predicted manoeuvres (both impulsive and long ones) within the orbital propagation interval, which can be defined by the operator manually

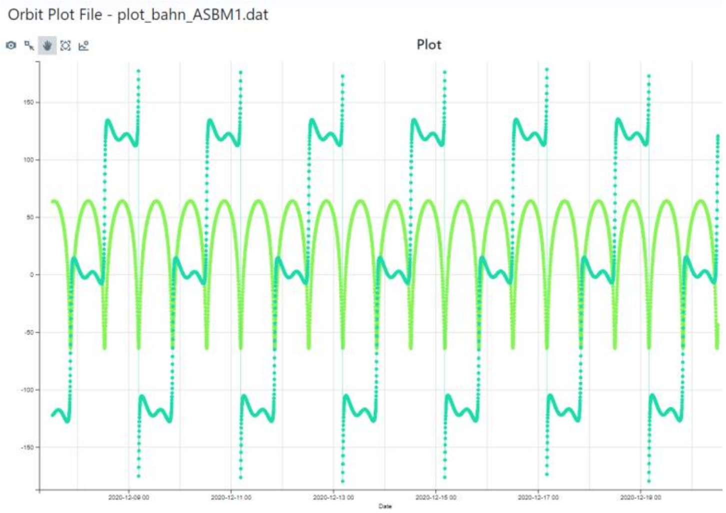


Figure 36: PROPAG orbit plot example

TLEORBIT: TLE to Orbit converser

TLEORBIT is the program implementing the analytical propagation based on SGP4 orbital theory. It receives a TLE (or a set of TLEs) from any source and generates an internal orbit file over a specified interval.

ATTSIM: Attitude simulator

This component generates an attitude file with the S/C nominal attitude based on a pre-defined law depending on the orbit position. Different laws can be defined for the specific guidance modes on each S/C:

- Sun Pointing.
- Nadir Pointing.
- Any other specific law

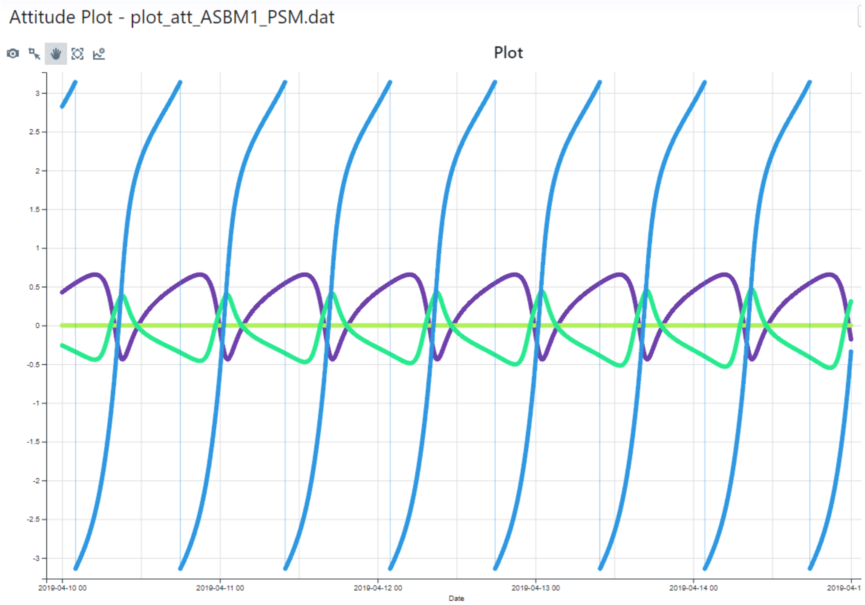


Figure 37: ATTSIM plot example

EVENTS: events generator

The main purpose of this component is to generate the orbital, station and sensor events needed by the mission taking into account the position of the sensors, the predicted orbits and attitudes, the stations, celestial ephemeris...

The following events may be computed by this module for each S/C in the mission:

- Apogee and Perigee crossing times
- Ascending and descending node crossing times
- Day night terminator crossing
- Earth Umbra and penumbra crossing times
- Moon Umbra and penumbra crossing times
- Sun-Satellite-Earth Colinearity
- Latitude and longitude crossing
- Satellite local time

- Earth zone crossing
- Meteor shower shading
- Manoeuvres
- Sun angles (zenith, elevation and azimuth)
- Dawn and dusk events (defined by Sun elevation)
- Phase angle
- AOS/LOS 0 and constant elevation
- AOS/LOS horizon mask
- Sun-Satellite-Station Colinearity
- Satellite-Station-Satellite Colinearity
- Antenna keyhole
- Switchover
- Satellites visibilities
- Station visibilities
- Transponder Activation and Visibilities
- Sun, Moon, Earth, planets, other satellites, stations and points on Earth AOS/LOS for sensors

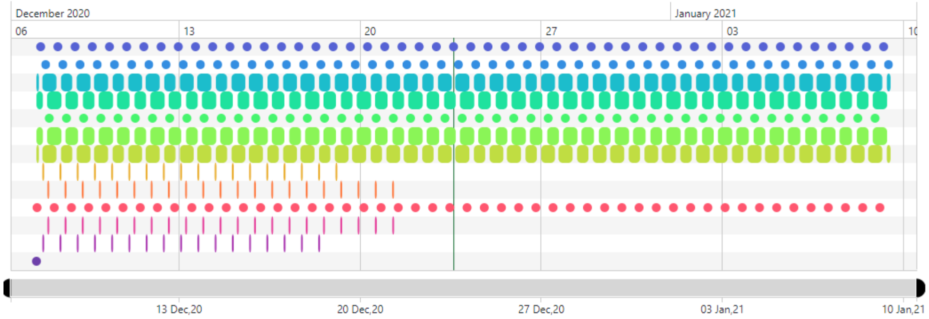


Figure 38: EVENTS ebro example

PRODGEN: Products generator

This package component is in charge of generating dedicated products required by the mission. The following generic products are available in PRODGEN:

- OEM
- AEM
- OPM
- TDM
- JSpOC
- INTELSAT-11 parameters

Any other product can be added to this module

9.1.1. METHODS AND MODELS

9.1.1.1. Force Models

The forces that affect the motion of a near-Earth satellite can be separated into gravitational forces and surface forces. In the following, the models implemented in ***Focussuite*** are briefly described. It is to be noted that the algorithms and models have been implemented to make the system compliant with the latest recommendations of the International Earth Rotation Service (IERS) standards.

Gravitational perturbations	
Gravitational Potential of the Earth	The potential function for the Earth is generally expressed in terms of a spherical harmonic expansion and is referred to as the geopotential. The harmonic coefficients are a function of the Earth's mass distribution and are commonly obtained from observing the motion of artificial satellites. In practice, the number of series expansion are taken to a finite number, N, where N may be chosen as a function of the individual satellite orbit, and the required orbit determination accuracy. A significant improvement has been achieved over the last years in the area of the gravity field. Several models have been developed, some of them are: GEM-T1, GEM-T2, GEM-T3, TEG-2, PGS-4591, PGS-4988, JGM, JGM-1, JGM-1S, JGM-2, JGM-3, EGM-96, TEG-3, etc. The latest models are high degree and order models (70x70, even 360x360 of EGM96), and they account for temporal variations in the low order coefficients and the effect of the permanent deformation of the Earth.
Solid Earth Tides	The Earth, which is not perfectly rigid, deforms under the solar and lunar gravitational attractions. These deformations, associated with the redistribution of mass, can be conveniently defined using the Love numbers introduced by A. Love in 1909. The deformation can be expressed as a change in the coefficients defining the external geopotential.
N-Body	The perturbing forces of the Sun, Moon and other planets, namely, Mercury, Venus, Mars, Jupiter, Saturn, Uranus, Neptune and Pluto, can be approximated with sufficient accuracy as point masses. The values of planet ephemeris are implemented in ***Focussuite*** from the Jet Propulsion Laboratory Development Ephemeris-200 (JPL DE-200 and DE-405).
Ocean Tides	The dynamic contribution of ocean tides due to the gravitational attraction of the Sun and Moon can be accurately formulated in terms of time-varying geopotential coefficient corrections. ***Focussuite*** implements the ocean tide model developed by the University of Texas, Centre for Space Research: CSR3.0.
General Relativity	The dynamic effect of general relativistic satellite perturbations on an Earth satellite is small but detectable. This effect is generated by the curvature in the space-time induced by the presence of a heavy body. For satellites closely orbiting the Earth, only the effect of the Earth needs to be considered
Indirect Moon-J2 Interaction	The effect of the Moon on the Earth bulge generates a deviation in the computation of the third body perturbation as considering Earth and Moon as point masses. ***Focussuite*** can take this effect into account for accurate data analysis.
Non gravitational Perturbations	
Atmospheric Drag	The dominant feature of atmospheric resistance for most satellites is a drag force in the direction opposite to the relative wind. The drag force is considerably larger than lift forces that, if they exist, would be perpendicular to relative wind velocity. ***Focussuite*** implements drag, lift and lateral forces. Atmospheric forces mainly depend on three factors: Air density. This can be computed using an accurate enough model. For precise data analysis these models are normally not accurate enough and temporal scale factors have to be estimated. ***Focussuite*** implements several atmospheric models: MSIS-E-00, JB2008 and DTM-2013. Solar activity: This influences the air density. Unexpected geomagnetic storms can induce rapid

	variations of air density that cannot be measured accurately enough. Measured and predicted data are retrieved from NOAA. This is the main source of inaccuracy in the computation of aerodynamic forces Satellite geometry: ***Focussuite*** can provide the effective cross and lateral areas, as function of the satellite attitude. This is just the spin-off from a sophisticated program to analyse the behaviour of a spacecraft under the aerodynamic influence of the free molecular flow.
Solar Radiation Pressure	Radiation from the Sun produces a small force by transferring momentum from particles streaming out from the Sun to the satellite. This force for a spherical symmetric satellite is a function of the momentum flux due to the Sun, the cross sectional area of the satellite normal to the Sun, its mass and the reflectivity coefficient. Reflectivity values vary between 0 and 1. Eclipse effects are also properly taken into account. As for the air drag forces modelling, ***Focussuite*** can produce cross section area tables to account for the time variations of this perturbation.
Earth Radiation Pressure	The Sun light reflected by the Earth (albedo) and the infrared radiation of the Earth produce the same effect as the Sun radiation pressure, only much smaller. ***Focussuite*** implements simplified models to account for these perturbations, which are accurate enough given the extremely small absolute value of these accelerations.

9.1.1.2. Observation Models

The system supports the processing of several tracking types, including pre-processing of raw observations and reconstitution of physical observable magnitudes. Without entering deeply in the details of the tracking processing, implementing the following algorithms in the processing of observables and the conversion between reference frames (considered as part of the observation reconstitution from an inertial orbit file):

- Precession/nutation (IERS)
- Detailed Earth orientation (polar motion and Earth rotation)
- Station tectonic plate motion
- Solid tide and ocean loading
- Ocean tide (altimetry only)
- Antenna phase correction
- Tropospheric/ionospheric delay
- Relativistic delay

The reconstitution of the following observation types is supported:

- Range
- Range Rate (Doppler)
- Azimuth/Elevation
- Right Ascension / Declination
- Phase and Pseudo-range (GNSS)
- Double differences in phase and pseudo-range
- Altimetry
- Inertial and Earth fixed positions
- TDoA

9.1.1.3. Databases

Underneath the processing and the algorithms implemented there is a set of databases holding the information required by the different components. This database consists of a set of tables that configure the properties of the Central Body, Physical Constants, Tracking Systems, Tracking Stations, Satellites, Transponders and Sensors. These databases are fully configurable from the user interface, and the system allows the simultaneous use of tables designated by mission and scenario.

9.2. MISSION-DEPENDANT MODULES

9.2.1. FOCUSGEO SPECIFIC FUNCIONALITIES

Mission dependent modules are platform specific modules, therefore they will be directly based on platform requirements. Nevertheless there are common functionalities that are share for all of them as are described below.

CALIB: Manoeuvre Implementation

CALIB is used to analytically predict the thrusters activity that the satellite on-board system will initiate for a given manoeuvre midpoint time and direction. CALIB models the performance and fuel flow rate of the thrusters based on telemetered measurements and mathematical expressions provided by the manufacturer.

CALIB is run following execution of one of the station keeping functions (INCLON, INCLEC, SOLONG or INICOL). It determines how the thrusters must be fired to reach a delta-v target set by the station keeping function. CALIB generates commanding information including required total impulse in jet seconds, starting epoch for the manoeuvre and the thrusters involved. At the end of a CALIB execution, the user will have all necessary commanding information to generate a manoeuvre sheet or to send commands directly to the Real Time System through the external interfaces.

ISKM: Ionic SK Manoeuvre Calibration and Preparation

This module is in charge of the computation of the continuous thrust durations and manoeuvre start times as a function of the Delta-V requirements and satellite/equipment configuration.

After having run INCLEC to plan the theoretical N/S manoeuvres (manoeuvre mid-point epoch and delta-V components), ISKM shall be run to compute the manoeuvre start times, durations and other relevant parameters to be commanded to the S/C.

Note that this module is only provided in case of satellite is using ionic propulsion.

MASSEVO: Mass Book-Keeping

MASSEVO is used to compute the propellant mass consumed by satellite on-board and to maintain the fuel book-keeping. MASSEVO will normally be run immediately following a manoeuvre to calculate the amount of fuel mass consumed so that a current estimate of the overall spacecraft mass and mass distribution may be maintained. Given a starting time and a finite interval, MASSEVO uses telemetered burn time totals for the thrusters in combination with the same fuel flow rate model used in CALIB to determine the total fuel consumption over the interval and updates the stored spacecraft mass estimate to reflect the loss of fuel mass. It also uses the telemetered burn times to generate an estimate of the actual delta-v achieved during the manoeuvre. It updates a mass evolution file, which is used by other functions in the system to get the current mass of the satellite.

DBUPDATE: Database Update

DBUPDATE is the function that updates the historical databases (which contain the information for the entire life of the satellite) using the information contained in the temporary files (which contain the information generated during the last few days of operations, such as the manoeuvres of the station-keeping cycle, the last initial state vector estimated, etc). The DBUPDATE program updates the Measurements File, the Initial State Vector, the Impulsive

Manoeuvre File and the Mass Evolution File, by taking the data from these file(s) and transferring it to their prospective database(s). Once the transfers are complete, and the database(s) are updated, the temporary files are emptied (except for the state vector file). DBUPDATE gives the option to select which file(s) to update. The consistency of the new data is checked to ensure temporal coherence in terms of date and duplication of records.

DBREPORTS: Database Reports

DBREPORTS is intended for the purpose of generating database reports. DBREPORTS generates plots using the historical information stored in the database, for all the selected satellites in a collocation group. The database reports generated are:

Orbit Plots

Mass Evolution Plots

Measurements Plots

Manoeuvre Plots

Collocation Plots

Latitude vs. Longitude Plots

Various Histograms

Other modules that are usually included as they are often required by satellite manufacturers could be:

MAPREP: Manoeuvre Sheet Preparation

This function generates reports in a flexible way using the information on manoeuvres existing on databases.

HPLP: Satellite Remaining Lifetime Estimation

HPLP is the function of ***focusgeo*** in charge of precisely predicting the lifetime of the satellites. This prediction is based on regular station-keeping cycles, specifying the execution of both inclination and drift manoeuvres. Additionally, this program provides the capability of introducing relocation and eccentricity manoeuvres. This program simulates the manoeuvres that a geostationary satellite should perform during its life, in order to calculate the propellant mass consumption and, hence, predict the spacecraft lifetime.

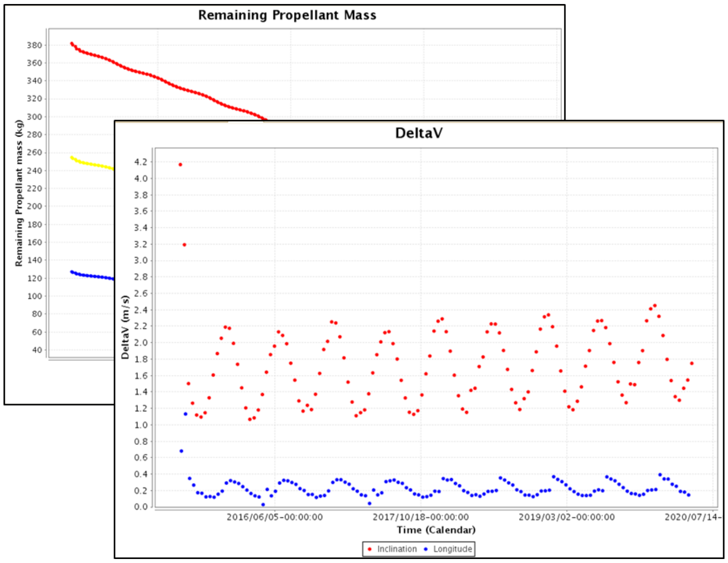


Figure 39: HPLP plots example

PVT: Remaining Fuel Computation

PVT is another function to estimate mass consumption. It is used as a checking tool for MASSEVO. While MASSEVO uses a mass-bookkeeping method of thruster data to calculate mass evolution, PVT uses pressure, density, and temperature to determine current volume and mass of the remaining fuel in the fuel tank.

OBPU: On Board Propagator Update

This module is in charge of computing the required information for updating the inputs used by the on board propagator.

9.2.2. FOCUSLEO SPECIFIC FUNCTIONALITIES

focusleo implement specific orbit control functionalities needed to fulfil the Low Earth Orbit satellites orbit control requirements.

CALIB: Manoeuvre Implementation

CALIB is used to analytically predict the thrusters activity that the satellite on-board system will initiate for a given manoeuvre midpoint time and direction. CALIB models the performance and fuel flow rate of the thrusters based on telemetered measurements and mathematical expressions provided by the manufacturer.

MASSEVO: Mass Book-Keeping

MASSEVO is used to compute the propellant mass consumed by satellite on-board and to maintain the fuel book-keeping. MASSEVO will normally be run immediately following a manoeuvre to calculate the amount of fuel mass consumed so that a current estimate of the overall spacecraft mass and mass distribution may be maintained. Given a starting time and a finite interval, MASSEVO uses telemetered burn time totals for the thrusters in combination with the same fuel flow rate model used in CALIB to determine the total fuel consumption over the interval, and updates the stored spacecraft mass estimate to reflect the loss of fuel mass. It also uses the telemetered burn times to generate an estimate of the actual delta-v achieved during the manoeuvre.

Ground track control: TARGETDEF, ORBANA, EOCONTROL

These modules allow the operator to keep a ground-track and local time orbit control. This control is mainly used for Sun-synchronous orbits, typically dedicated to Earth observation missions.

TARGETDEF: the purpose of this program is to generate the reference orbit, ground-track and Nodal Sequence file which will fulfil the user constraints on the definition of the orbit.

ORBANA: The main purpose of this program is to compute the ground-track and nodal separation of the satellite with respect to the reference.

EOCONTROL: The main purpose of this program is to compute the manoeuvres to maintain the current orbit within the limits defined by the user on the reference ground track, which will guarantee that the spacecraft does not leave the orbital tube define for the mission; the control strategy will then be based on a ground track control in all latitudes, with a configurable dead-band, and with the aim of minimizing the number of manoeuvres.

SVTARGET: target acquisition.

The Target Acquisition component computes manoeuvres to position the satellite.

MANCO: manoeuvre computation

MANCO is in charge of station keeping manoeuvres computation. It is responsible for computing the needed ΔV and epoch of the manoeuvres to keep the satellite inside several user-defined windows for all the relevant orbital parameters (SMA, eccentricity, inclination…). It is able to handle windows for different in-plane and out-of-plane parameters in the same execution, optimizing the computed manoeuvres to reach the desired targets.

ORBIN: orbit insertion

ORBIN is in charge of insert the satellite into its slot for starting the station keeping manoeuvres computation. It can be also used for de-orbiting. It is responsible for computing the needed ΔV and epoch of the manoeuvres to insert the satellite inside several user-defined windows for all the relevant orbital parameters (SMA, eccentricity, inclination…). It is able to handle windows for different in-plane and out-of-plane parameters in the same execution, optimizing the computed manoeuvres to reach the desired targets.

RELOC: relocation

RELOC is in charge of relocate the satellite from one slot to another one inside the same plane. It is responsible for computing the needed ΔV and epoch of the manoeuvres to perform an in-plane relocation.

9.2.3. FOCUSLEOP SPECIFIC FUNCTIONALITIES

focusleop addresses the flight dynamics needs for launch and early orbit phases of geostationary missions. It provides an engine firing optimization software supporting GTO and SSTO transfer strategies. Apart from that, the following functionalities are integrated:

- Automatic Ingestion of satellite parameter book data
- Tracking data pre-processing
- Orbit Determination
- Orbit Prediction
- Event Generation
- Antenna Pointing
- Manoeuvre optimisation (impulsive (chemical) manoeuvres and low thrust (electrical) manoeuvres) and calibration
- Mass evolution
- Graphical capabilities based on ***visualfocus***

The following platforms are already fully supported: Astrium Eurostar 3000 and Thales Alenia Space Spacebus 4000.

focusleop allows to define an **strategy tree** (set of nominal and backup strategies for performing a geostationary satellite transfer orbit) as shown in the following picture. In the following, **strategy profile** means each of the branches of a strategy tree, corresponding to the nominal or backup strategies.

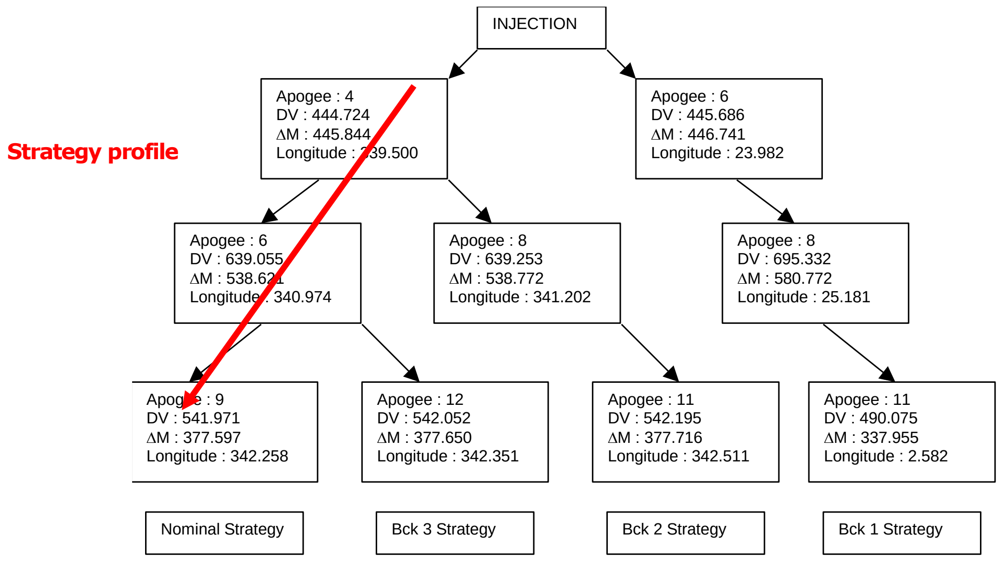


Figure 40: Strategy tree and strategy profile

9.2.4. *FOCUSLEOP* FOR MISSION ANALYSIS

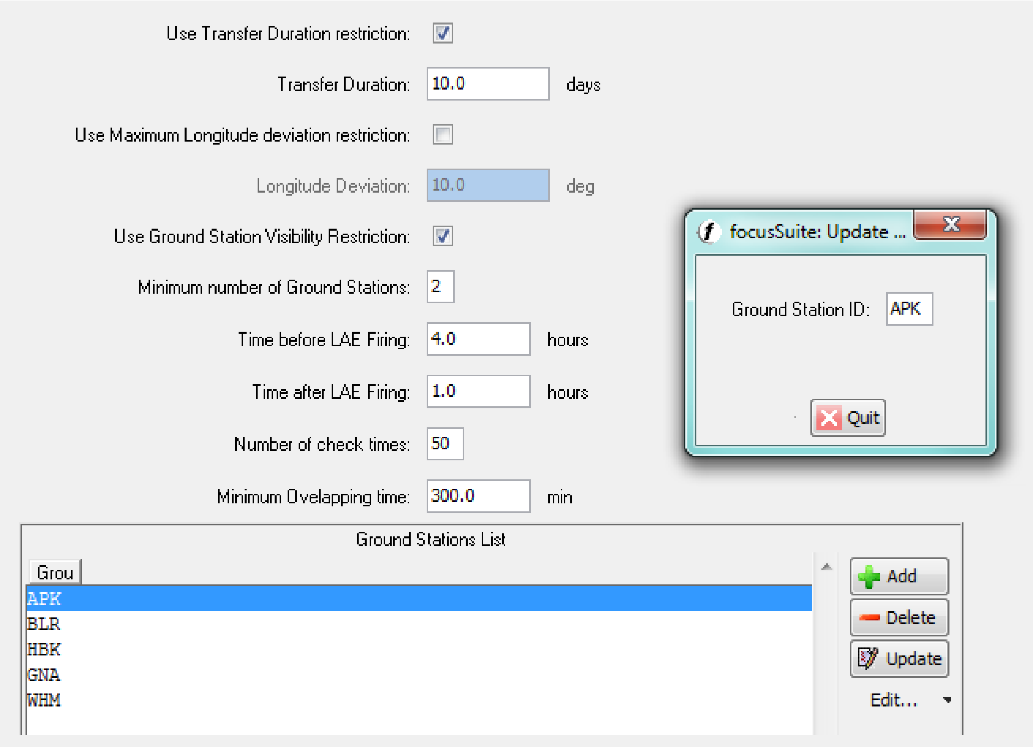
The following data have to be setup in ***focusleop*** for initialising a mission analysis:

- TT&C ground station network in the Stations Database
- State vector at separation
- On-station position in the station keeping Database
- Mission constraints and satellite constraints
- Satellite characteristics in the satellite Database, Main Engine database, Cross coupling database and Station Acquisition Thrusters database.
- Sensor characteristics in the Sensor Database
- Transponder characteristics in the Transponder Database

The sequence of modules to be executed for doing a mission analysis is the following:

- **PREPRO** ingests the files from the IERS with data about the Earth Orientation Parameters and Leap seconds and stores the data in an internal format used for reference frame changes and time conversions throughout ***focusleop***. The following two files have to be downloaded from the internet and stored in a specific directory in the ***focusleop*** workstation:
  - Earth Orientation parameters: ftp://maia.usno.navy.mil/ser7/finals.daily (it is updated on daily basis)
  - Leap seconds: ftp://maia.usno.navy.mil/ser7/leapsec.dat (it is updated on daily basis)
- **PREPRO** updates the local solar flux file and the solar flux history file if desired, by parsing the NOAA 3-day Solar and Geophysical Activity Report (Bulletin A), taking into account: the operational flux file, the new values from Bulletin A, and a prediction based on the combination of these two. The solar flux information is needed for the air density calculation used in the aerodynamic forces modelling. The following file has to be downloaded from the internet and stored in a specific directory in the ***focusleop*** workstation (it is updated on daily basis): http://www.swpc.noaa.gov/ftpdir/latest/RSGA.txt

- INITGUESS allows defining the separation state vector in several formats (covering the format provided by most of the commercial launchers) and the satellite properties and constraints to be taken into account for searching the possible transfer strategies.



Use Transfer Duration restriction: ☑

Transfer Duration: 10.0 days

Use Maximum Longitude deviation restriction: □

Longitude Deviation: 10.0 deg

Use Ground Station Visibility Restriction: ☑

Minimum number of Ground Stations: 2

Time before LAE Firing: 4.0 hours

Time after LAE Firing: 1.0 hours

Number of check times: 50

Minimum Ovelapping time: 300.0 min

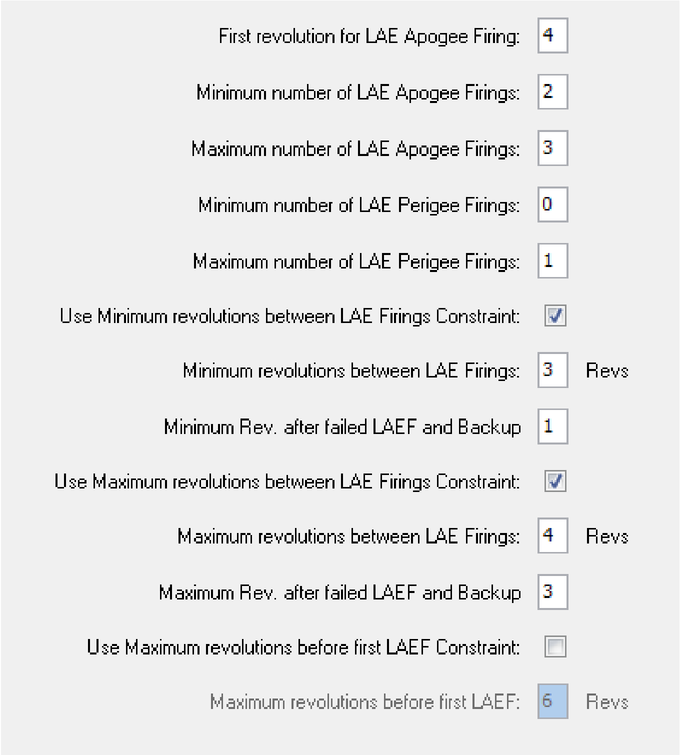
Ground Stations List

Grou
APK
BLR
HBK
GNA
WHM

focusSuite: Update ...

Ground Station ID: APK

Figure 41: Example of INITGUESS constraints options panel - Transfer Constrains Panel



First revolution for LAE Apogee Firing: 4

Minimum number of LAE Apogee Firings: 2

Maximum number of LAE Apogee Firings: 3

Minimum number of LAE Perigee Firings: 0

Maximum number of LAE Perigee Firings: 1

Use Minimum revolutions between LAE Firings Constraint: ☑

Minimum revolutions between LAE Firings: 3 Revs

Minimum Rev. after failed LAEF and Backup 1

Use Maximum revolutions between LAE Firings Constraint: ☑

Maximum revolutions between LAE Firings: 4 Revs

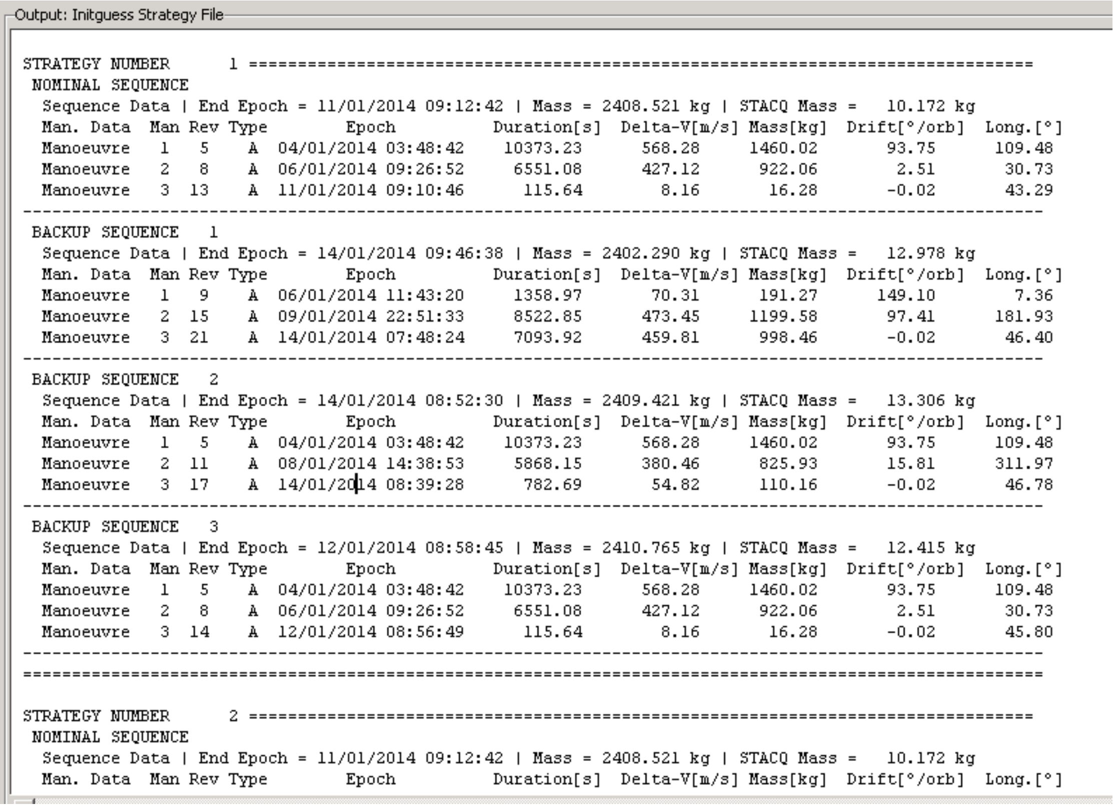
Maximum Rev. after failed LAEF and Backup 3

Use Maximum revolutions before first LAEF Constraint: ☐

Maximum revolutions before first LAEF: 6 Revs

Figure 42: Example of INITGUESS Constraints Options Panel - Sequencer Constrains

- First execution in sequencer mode to generate possible tree strategies, it means nominal and associated backup strategies. The following figure depicts an example of a strategy file containing several tree strategies.



```
STRATEGY NUMBER      1 =================================================================================
 NOMINAL SEQUENCE
  Sequence Data | End Epoch = 11/01/2014 09:12:42 | Mass = 2408.521 kg | STACQ Mass =   10.172 kg
  Man. Data  Man Rev Type        Epoch          Duration[s]  Delta-V[m/s] Mass[kg]  Drift[°/orb]  Long.[°]
  Manoeuvre   1   5    A  04/01/2014 03:48:42     10373.23      568.28     1460.02       93.75     109.48
  Manoeuvre   2   8    A  06/01/2014 09:26:52      6551.08      427.12      922.06        2.51      30.73
  Manoeuvre   3  13    A  11/01/2014 09:10:46       115.64        8.16       16.28       -0.02      43.29
---------------------------------------------------------------------------------------------------------
 BACKUP SEQUENCE   1
  Sequence Data | End Epoch = 14/01/2014 09:46:38 | Mass = 2402.290 kg | STACQ Mass =   12.978 kg
  Man. Data  Man Rev Type        Epoch          Duration[s]  Delta-V[m/s] Mass[kg]  Drift[°/orb]  Long.[°]
  Manoeuvre   1   9    A  06/01/2014 11:43:20      1358.97       70.31      191.27      149.10       7.36
  Manoeuvre   2  15    A  09/01/2014 22:51:33      8522.85      473.45     1199.58       97.41     181.93
  Manoeuvre   3  21    A  14/01/2014 07:48:24      7093.92      459.81      998.46       -0.02      46.40
---------------------------------------------------------------------------------------------------------
 BACKUP SEQUENCE   2
  Sequence Data | End Epoch = 14/01/2014 08:52:30 | Mass = 2409.421 kg | STACQ Mass =   13.306 kg
  Man. Data  Man Rev Type        Epoch          Duration[s]  Delta-V[m/s] Mass[kg]  Drift[°/orb]  Long.[°]
  Manoeuvre   1   5    A  04/01/2014 03:48:42     10373.23      568.28     1460.02       93.75     109.48
  Manoeuvre   2  11    A  08/01/2014 14:38:53      5868.15      380.46      825.93       15.81     311.97
  Manoeuvre   3  17    A  14/01/2014 08:39:28       782.69       54.82      110.16       -0.02      46.78
---------------------------------------------------------------------------------------------------------
 BACKUP SEQUENCE   3
  Sequence Data | End Epoch = 12/01/2014 08:58:45 | Mass = 2410.765 kg | STACQ Mass =   12.415 kg
  Man. Data  Man Rev Type        Epoch          Duration[s]  Delta-V[m/s] Mass[kg]  Drift[°/orb]  Long.[°]
  Manoeuvre   1   5    A  04/01/2014 03:48:42     10373.23      568.28     1460.02       93.75     109.48
  Manoeuvre   2   8    A  06/01/2014 09:26:52      6551.08      427.12      922.06        2.51      30.73
  Manoeuvre   3  14    A  12/01/2014 08:56:49       115.64        8.16       16.28       -0.02      45.80
---------------------------------------------------------------------------------------------------------
=========================================================================================================

STRATEGY NUMBER      2 =================================================================================
 NOMINAL SEQUENCE
  Sequence Data | End Epoch = 11/01/2014 09:12:42 | Mass = 2408.521 kg | STACQ Mass =   10.172 kg
  Man. Data  Man Rev Type        Epoch          Duration[s]  Delta-V[m/s] Mass[kg]  Drift[°/orb]  Long.[°]
```

Figure 43: INITGUESS output strategy file

– Second execution in analyser mode, selecting the desired strategy tree to be analysed, it generates a file (initial guess file) tree strategy data in a format suitable for ingesting them in STAN and AEFOS for further optimisation.

- **STAN** performs a first analysis of the strategy profile given as a set of apses and using a full numerical propagator for the nominal and backup profiles of the selected tree strategy (to be executed in separate workspaces)

- **AEFOS** performs a full optimization of the strategy profile for the nominal and backup profiles of the selected tree strategy (to be executed in separate workspaces).

  The problem solved by AEFOS is mathematically regarded as a constrained non-linear local optimization (non-linear programming), using a full dynamic model and implementing equality and inequality constraints. It takes in to account strategy constraints defined by the user such as eclipses duration, station visibilities, maximum duration of manoeuvres, minimum number of orbital revolutions between apogee/perigee manoeuvres, maximum duration of the transfer orbit, etc… It is stated as:

  Minimize $F(\mathbf{x})$

  Subject to $g_i(\mathbf{x}) > 0, \quad i = 1, \ldots, m_i$

  $h_i(\mathbf{x}) = 0, \quad i = 1, \ldots, m_e$

  Where $\mathbf{x} = (x_1, \ldots, x_n)$ is the vector formed by the *n* optimization variables, $F(\mathbf{x})$ is the non-linear objective function to be minimized (the propellant consumed by the manoeuvres), $g_i(\mathbf{x})$ are the non-linear inequality constraints that must be satisfied (the mission constraints), $h_i(\boldsymbol{x})$ are the non-linear equality constraints that must be satisfied (the target to be achieved), m_i is the number of inequality constraints and m_e is the number of equality constraints.

The optimisation variables are the following for each manoeuvre to be optimized:

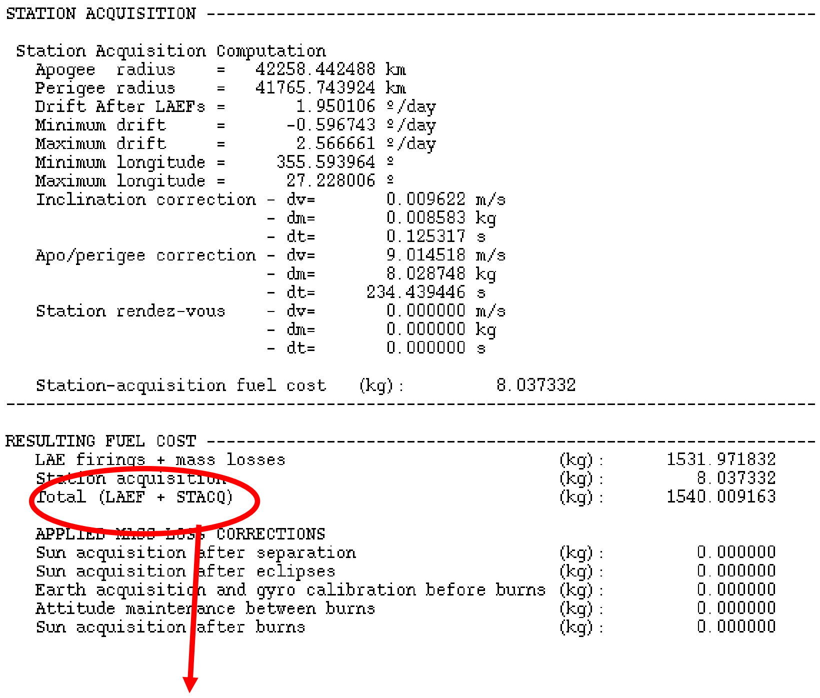
- Manoeuvre Midpoint
- Manoeuvre Duration
- Manoeuvre Right Ascension (inertial)
- Manoeuvre Declination (inertial)

Please note that the mass consumption to be minimised is defined as: $F(x) = \Delta m_{LAEFs} + \Phi$

Where Δm_{LAEFs} corresponds to the mass consumption corresponding to the transfer manoeuvres (apogee and perigee manoeuvres)

Φ is a function modelling the station acquisition mass consumption correction of residual inclination, residual eccentricity and rendezvous)

The following picture depicts a snapshot of part of the AEFOS output file.

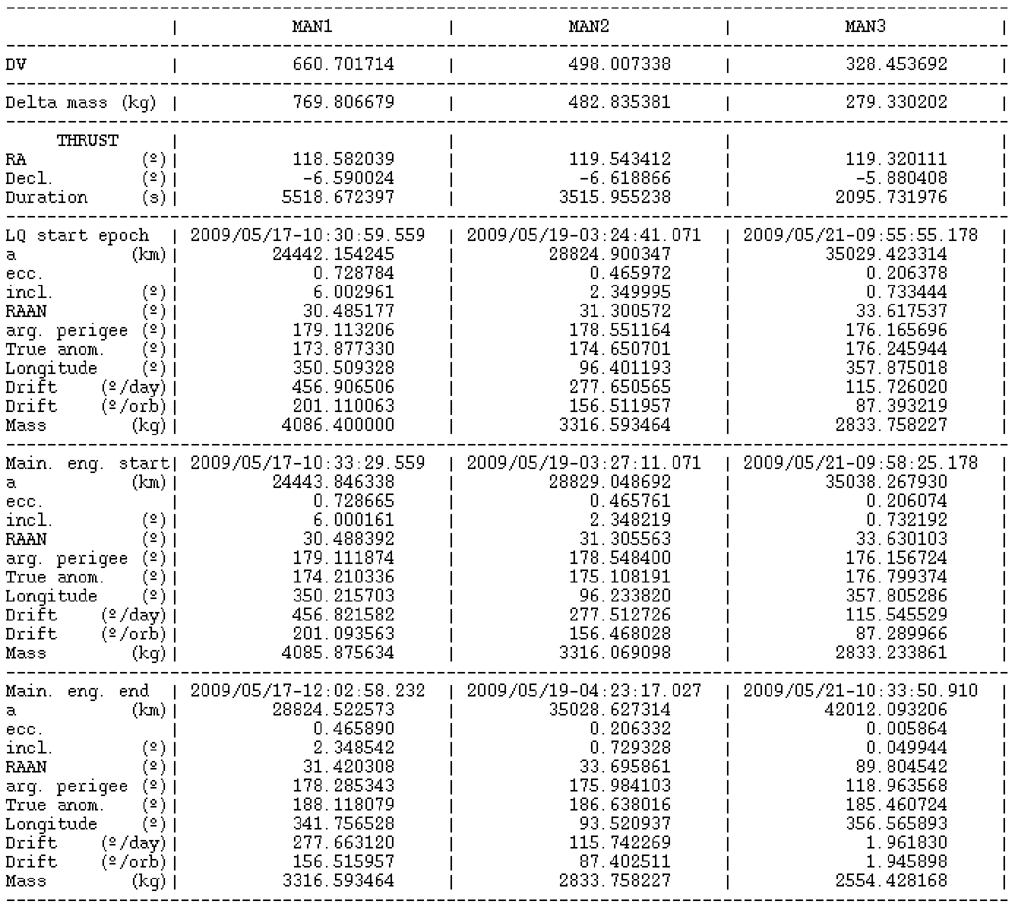


```
STATION ACQUISITION ------------------------------------------------------------

 Station Acquisition Computation
   Apogee  radius     =   42258.442488 km
   Perigee radius     =   41765.743924 km
   Drift After LAEFs =       1.950106 º/day
   Minimum drift      =      -0.596743 º/day
   Maximum drift      =       2.566661 º/day
   Minimum longitude =     355.593964 º
   Maximum longitude =      27.228006 º
   Inclination correction - dv=        0.009622 m/s
                          - dm=        0.008583 kg
                          - dt=        0.125317 s
   Apo/perigee correction - dv=        9.014518 m/s
                          - dm=        8.028748 kg
                          - dt=      234.439446 s
   Station rendez-vous    - dv=        0.000000 m/s
                          - dm=        0.000000 kg
                          - dt=        0.000000 s

   Station-acquisition fuel cost   (kg):          8.037332
--------------------------------------------------------------------------------

RESULTING FUEL COST ------------------------------------------------------------
   LAE firings + mass losses                             (kg):     1531.971832
   Station acquisition                                   (kg):        8.037332
   Total (LAEF + STACQ)                                  (kg):     1540.009163

   APPLIED MASS LOSS CORRECTIONS
   Sun acquisition after separation                      (kg):        0.000000
   Sun acquisition after eclipses                        (kg):        0.000000
   Earth acquisition and gyro calibration before burns (kg):        0.000000
   Attitude maintenance between burns                    (kg):        0.000000
   Sun acquisition after burns                           (kg):        0.000000
```

Final Cost

Figure 44: Example of part of the AEFOS output file

The following picture depicts an example of the report generated by AEFOS for an optimized strategy profile:



```
-----------------------------------------------------------------------------------------------------
                |           MAN1            |           MAN2            |           MAN3            |
-----------------------------------------------------------------------------------------------------
DV              |           660.701714      |           498.007338      |           328.453692      |
-----------------------------------------------------------------------------------------------------
Delta mass (kg) |           769.806679      |           482.835381      |           279.330202      |
-----------------------------------------------------------------------------------------------------
    THRUST      |                           |                           |                           |
RA           (º)|           118.582039      |           119.543412      |           119.320111      |
Decl.        (º)|            -6.590024      |            -6.618866      |            -5.880408      |
Duration     (s)|          5518.672397      |          3515.955238      |          2095.731976      |
-----------------------------------------------------------------------------------------------------
LQ start epoch  | 2009/05/17-10:30:59.559   | 2009/05/19-03:24:41.071   | 2009/05/21-09:55:55.178   |
a           (km)|         24442.154245      |         28824.900347      |         35029.423314      |
ecc.            |             0.728784      |             0.465972      |             0.206378      |
incl.        (º)|             6.002961      |             2.349995      |             0.733444      |
RAAN         (º)|            30.485177      |            31.300572      |            33.617537      |
arg. perigee (º)|           179.113206      |           178.551164      |           176.165696      |
True anom.   (º)|           173.877330      |           174.650701      |           176.245944      |
Longitude    (º)|           350.509328      |            96.401193      |           357.875018      |
Drift    (º/day)|           456.906506      |           277.650565      |           115.726020      |
Drift    (º/orb)|           201.110063      |           156.511957      |            87.393219      |
Mass        (kg)|          4086.400000      |          3316.593464      |          2833.758227      |
-----------------------------------------------------------------------------------------------------
Main. eng. start| 2009/05/17-10:33:29.559   | 2009/05/19-03:27:11.071   | 2009/05/21-09:58:25.178   |
a           (km)|         24443.846338      |         28829.048692      |         35038.267930      |
ecc.            |             0.728665      |             0.465761      |             0.206074      |
incl.        (º)|             6.000161      |             2.348219      |             0.732192      |
RAAN         (º)|            30.488392      |            31.305563      |            33.630103      |
arg. perigee (º)|           179.111874      |           178.548400      |           176.156724      |
True anom.   (º)|           174.210336      |           175.108191      |           176.799374      |
Longitude    (º)|           350.215703      |            96.233820      |           357.805286      |
Drift    (º/day)|           456.821582      |           277.512726      |           115.545529      |
Drift    (º/orb)|           201.093563      |           156.468028      |            87.289966      |
Mass        (kg)|          4085.875634      |          3316.069098      |          2833.233861      |
-----------------------------------------------------------------------------------------------------
Main. eng. end  | 2009/05/17-12:02:58.232   | 2009/05/19-04:23:17.027   | 2009/05/21-10:33:50.910   |
a           (km)|         28824.522573      |         35028.627314      |         42012.093206      |
ecc.            |             0.465890      |             0.206332      |             0.005864      |
incl.        (º)|             2.348542      |             0.729328      |             0.049944      |
RAAN         (º)|            31.420308      |            33.695861      |            89.804542      |
arg. perigee (º)|           178.285343      |           175.984103      |           118.963568      |
True anom.   (º)|           188.118079      |           186.638016      |           185.460724      |
Longitude    (º)|           341.756528      |            93.520937      |           356.565893      |
Drift    (º/day)|           277.663120      |           115.742269      |             1.961830      |
Drift    (º/orb)|           156.515957      |            87.402511      |             1.945898      |
Mass        (kg)|          3316.593464      |          2833.758227      |          2554.428168      |
-----------------------------------------------------------------------------------------------------
```

Figure 45: Example of report generated by AEFOS

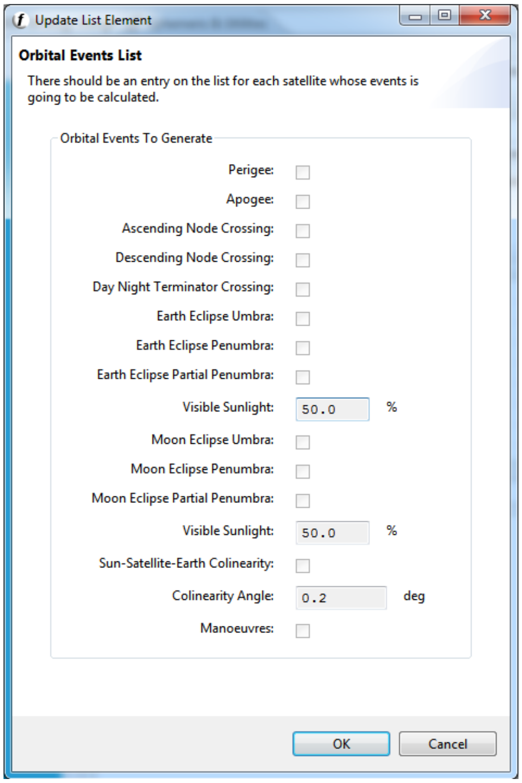
- **LAUNCH** computes the launch window for the transfer strategy profile optimised by AEFOS, it calculates the range of time in which it is possible to launch a satellite fulfilling all the platform and transfer strategy constraints. It allows the user to define sequence of satellite operations (timeline of operations) and the corresponding constraints to be fulfilled during the transfer phase. It supports some predefined satellite attitude operational modes (others can be added), these include: Earth pointing, Sun pointing, Inertial navigation with a defined attitude,... It provides as output the beginning and end epoch of the launch window per day.

- **GLOBLW** is in charge of merging the launch windows computed by the LAUNCH module for each transfer strategy (nominal and backups strategies), in order to compute the global launch window to be taken into account for the decision of the launch day and epoch.

- **ORBUPD** updates the operational orbit file from other orbit files generated in several modules in ***focusleop***, in this case, it will generate the operational orbit file from the orbit file generated by AEFOS.

- **EVENTS** computes geometrical events related to orbit, ground stations, sensors and transponders, the events to be generated can be selected by the operator.

The following figure depicts the EVENTS orbital events panels where the orbital events can be selected.



Orbital Events List

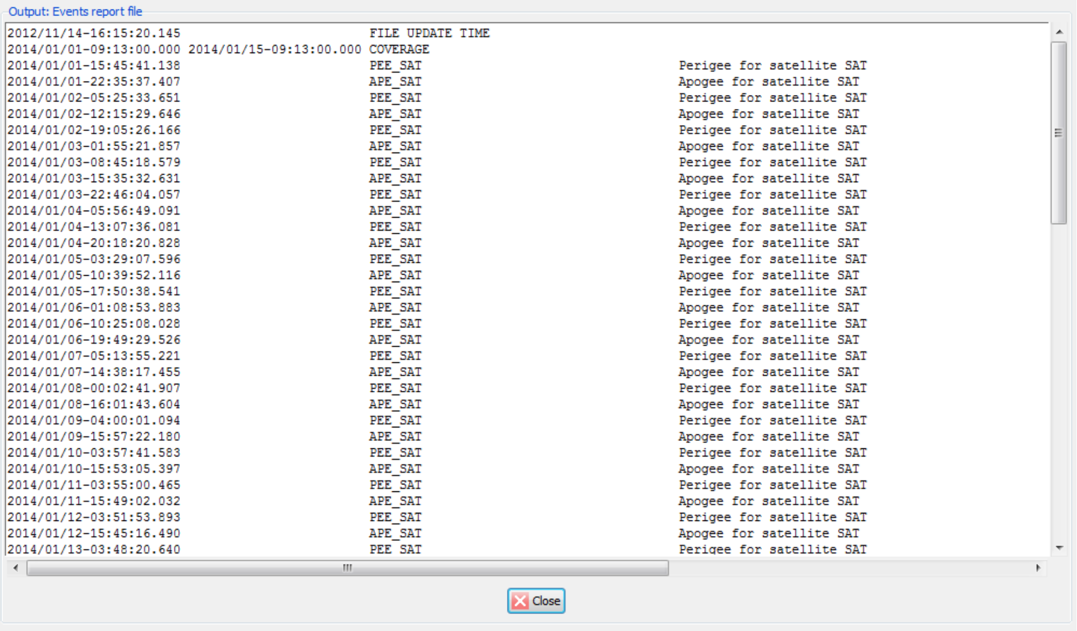
There should be an entry on the list for each satellite whose events is going to be calculated.

Orbital Events To Generate

Perigee: □
Apogee: □
Ascending Node Crossing: □
Descending Node Crossing: □
Day Night Terminator Crossing: □
Earth Eclipse Umbra: □
Earth Eclipse Penumbra: □
Earth Eclipse Partial Penumbra: □
Visible Sunlight: 50.0 %
Moon Eclipse Umbra: □
Moon Eclipse Penumbra: □
Moon Eclipse Partial Penumbra: □
Visible Sunlight: 50.0 %
Sun-Satellite-Earth Colinearity: □
Colinearity Angle: 0.2 deg
Manoeuvres: □

Figure 46: EVENTS Orbital Events panel

The following figure presents an example of a report generated by EVENTS.



```
2012/11/14-16:15:20.145                         FILE UPDATE TIME
2014/01/01-09:13:00.000 2014/01/15-09:13:00.000 COVERAGE
2014/01/01-15:45:41.138                         PEE_SAT                         Perigee for satellite SAT
2014/01/01-22:35:37.407                         APE_SAT                         Apogee for satellite SAT
2014/01/02-05:25:33.651                         PEE_SAT                         Perigee for satellite SAT
2014/01/02-12:15:29.646                         APE_SAT                         Apogee for satellite SAT
2014/01/02-19:05:26.166                         PEE_SAT                         Perigee for satellite SAT
2014/01/03-01:55:21.857                         APE_SAT                         Apogee for satellite SAT
2014/01/03-08:45:18.579                         PEE_SAT                         Perigee for satellite SAT
2014/01/03-15:35:32.631                         APE_SAT                         Apogee for satellite SAT
2014/01/03-22:46:04.057                         PEE_SAT                         Perigee for satellite SAT
2014/01/04-05:56:49.091                         APE_SAT                         Apogee for satellite SAT
2014/01/04-13:07:36.081                         PEE_SAT                         Perigee for satellite SAT
2014/01/04-20:18:20.828                         APE_SAT                         Apogee for satellite SAT
2014/01/05-03:29:07.596                         PEE_SAT                         Perigee for satellite SAT
2014/01/05-10:39:52.116                         APE_SAT                         Apogee for satellite SAT
2014/01/05-17:50:38.541                         PEE_SAT                         Perigee for satellite SAT
2014/01/06-01:08:53.883                         APE_SAT                         Apogee for satellite SAT
2014/01/06-10:25:08.028                         PEE_SAT                         Perigee for satellite SAT
2014/01/06-19:49:29.526                         APE_SAT                         Apogee for satellite SAT
2014/01/07-05:13:55.221                         PEE_SAT                         Perigee for satellite SAT
2014/01/07-14:38:17.455                         APE_SAT                         Apogee for satellite SAT
2014/01/08-00:02:41.907                         PEE_SAT                         Perigee for satellite SAT
2014/01/08-16:01:43.604                         APE_SAT                         Apogee for satellite SAT
2014/01/09-04:00:01.094                         PEE_SAT                         Perigee for satellite SAT
2014/01/09-15:57:22.180                         APE_SAT                         Apogee for satellite SAT
2014/01/10-03:57:41.583                         PEE_SAT                         Perigee for satellite SAT
2014/01/10-15:53:05.397                         APE_SAT                         Apogee for satellite SAT
2014/01/11-03:55:00.465                         PEE_SAT                         Perigee for satellite SAT
2014/01/11-15:49:02.032                         APE_SAT                         Apogee for satellite SAT
2014/01/12-03:51:53.893                         PEE_SAT                         Perigee for satellite SAT
2014/01/12-15:45:16.490                         APE_SAT                         Apogee for satellite SAT
2014/01/13-03:48:20.640                         PEE_SAT                         Perigee for satellite SAT
```

Figure 47: EVENTS Events Report File

The EVENTS report can be browse using a ***focusleop*** application (EBRO), the following figure depitcs an example.

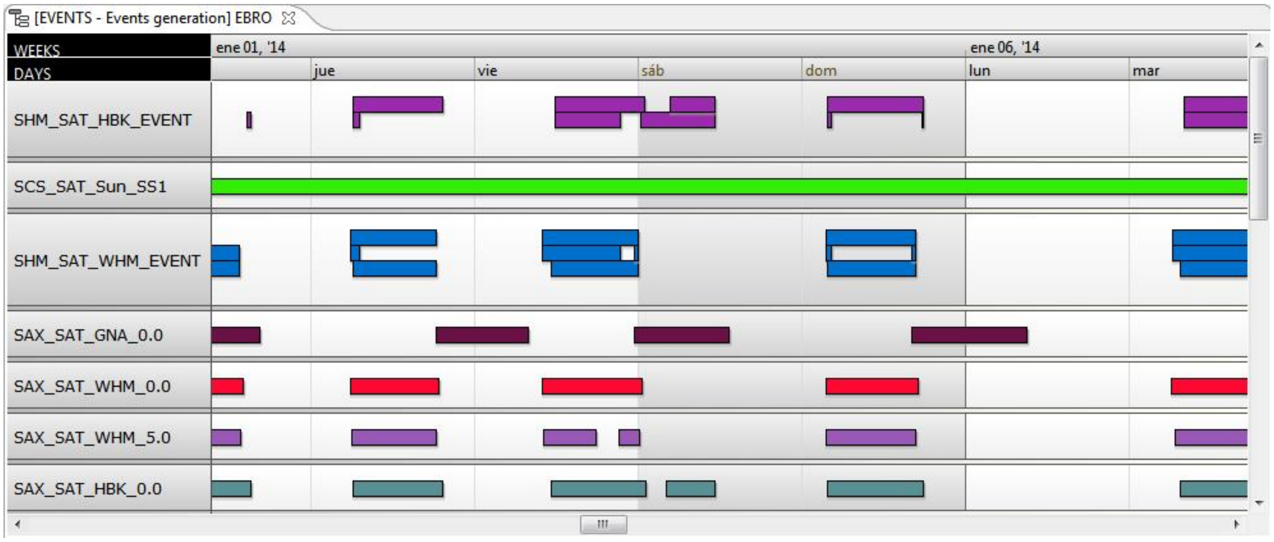
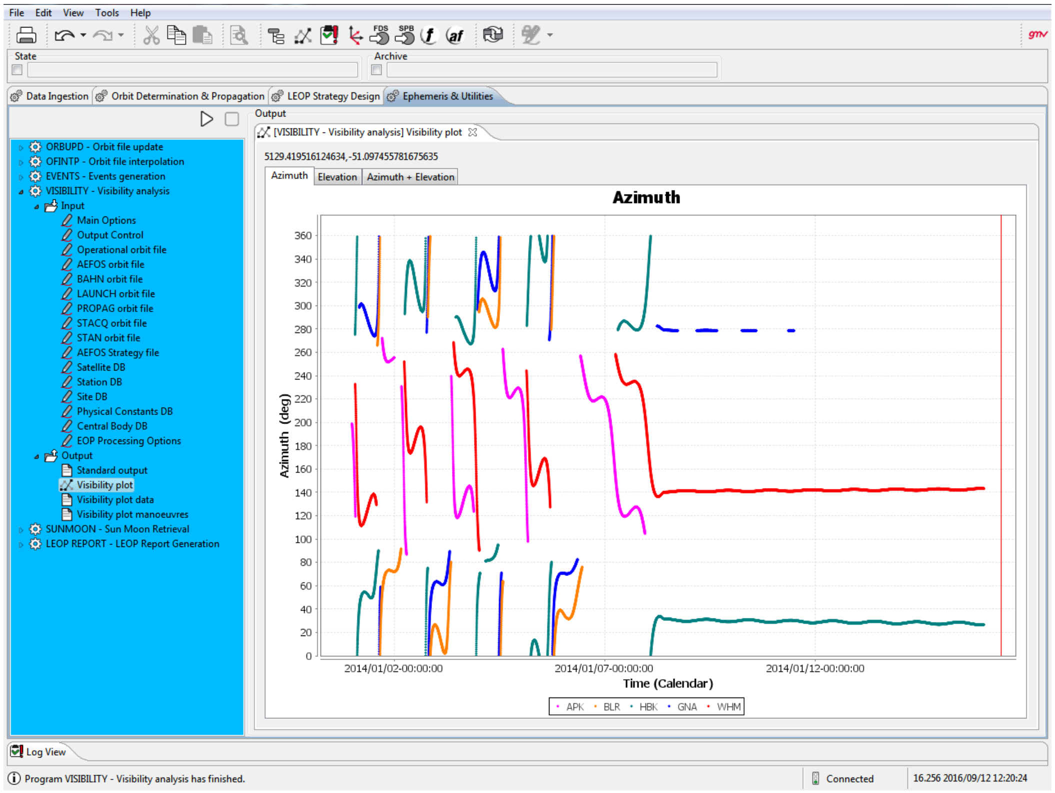


Figure 48: EVENTS EBRO Gantt chart

- **VISIBILITY** computes the visibility between a satellite and a set of ground stations, and plots the azimuth and the elevation of the satellite.



5129.419516124634,-51.097455781675635

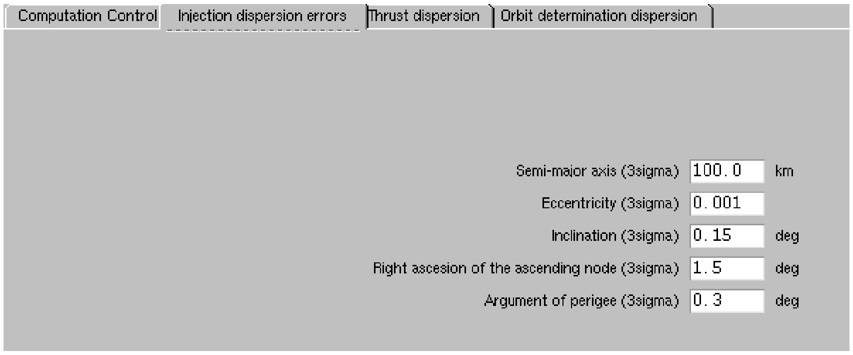
Program VISIBILITY - Visibility analysis has finished.

16.256 2016/09/12 12:20:24

Figure 49: Example of plot generated by VISIBILITY

- **MONTECARLO** simulates errors in the injection orbit, in orbit determination and in the manoeuvre attitude and thrust performance in order to evaluate the robustness of the transfer strategy.

  The following figure depicts the injection dispersion errors that can be simulated in this module:



Semi-major axis (3sigma) 100.0 km
Eccentricity (3sigma) 0.001
Inclination (3sigma) 0.15 deg
Right ascesion of the ascending node (3sigma) 1.5 deg
Argument of perigee (3sigma) 0.3 deg

Figure 50: MONTECARLO injection dispersion errors

- **STACQ** computes the in-plane and out-of-plane manoeuvres required during the station acquisition phase to initialise the station keeping cycles. It takes also into account the collocation parameters in case the satellite will be included in a collocation cluster
- **OFINTP** is a tool used to interpolate state vectors from various possible orbit files created by other modules in ***focusleop***. This component is in charge of providing output with one or more state vectors read from the orbit file, in any reference frame and vector type that the user specifies. It is proposed as an auxiliary tool

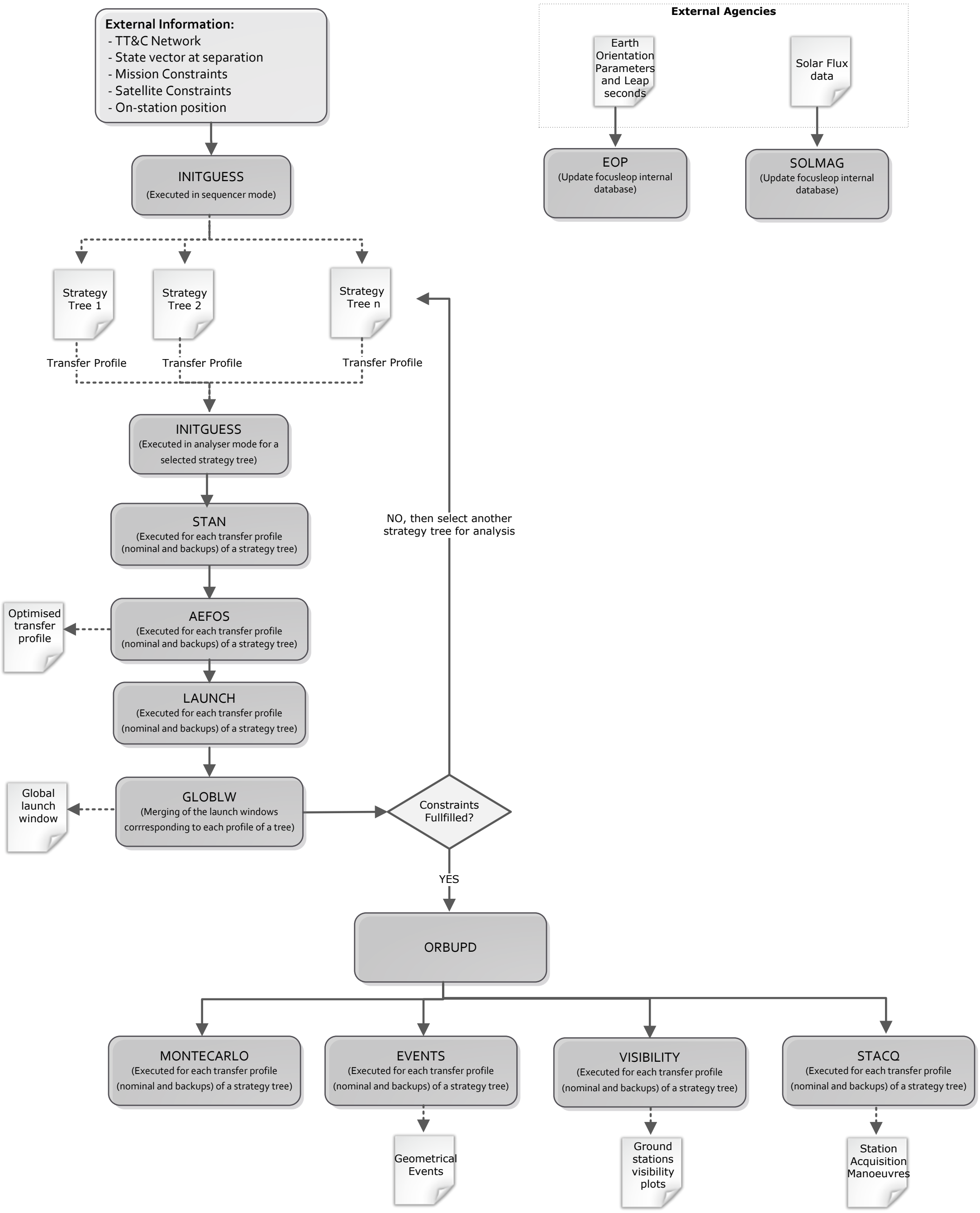

External Information:
- TT&C Network
- State vector at separation
- Mission Constraints
- Satellite Constraints
- On-station position
External Agencies
Earth Orientation Parameters and Leap seconds
Solar Flux data
EOP
(Update focusleop internal database)
SOLMAG
(Update focusleop internal database)
INITGUESS
(Executed in sequencer mode)
Strategy Tree 1
Strategy Tree 2
Strategy Tree n
Transfer Profile
Transfer Profile
Transfer Profile
INITGUESS
(Executed in analyser mode for a selected strategy tree)
STAN
(Executed for each transfer profile (nominal and backups) of a strategy tree)
NO, then select another strategy tree for analysis
Optimised transfer profile
AEFOS
(Executed for each transfer profile (nominal and backups) of a strategy tree)
LAUNCH
(Executed for each transfer profile (nominal and backups) of a strategy tree)
Global launch window
GLOBLW
(Merging of the launch windows corresponding to each profile of a tree)
Constraints Fullfilled?
YES
ORBUPD
MONTECARLO
(Executed for each transfer profile (nominal and backups) of a strategy tree)
EVENTS
(Executed for each transfer profile (nominal and backups) of a strategy tree)
VISIBILITY
(Executed for each transfer profile (nominal and backups) of a strategy tree)
STACQ
(Executed for each transfer profile (nominal and backups) of a strategy tree)
Geometrical Events
Ground stations visibility plots
Station Acquisition Manoeuvres

Figure 51: focusleop for mission analysis

9.2.5. ***FOCUSLEOP*** FOR GENERIC OPERATIONS

The sequence of modules to be executed for doing a mission analysis is the following:

- **PREPRO**: see previous section.

- **PROPAG**: propagates satellite orbits accounting for multiple dynamical parameters (including manoeuvres) with either a fixed or variable step size in the integration of the equations of motion.
- **BAHN**: Estimates satellite orbit, multiple dynamical parameters (including manoeuvres), ground station, and geophysical parameters by processing a batch of measurements. It is based on an iterative Bayesian least-squares estimation algorithm. It is executed several times after the separation from the launcher and before the manoeuvre optimization.
- **ORBUPD**: see previous section.
- **STAN**: see previous section.
- **AEFOS**: see previous section.
- **BAHN**: it is executed after the manoeuvres execution to estimate them and to compute their performance.
- **ORBUPD**: see previous section.
- **EVENTS**: see previous section.
- **VISIBILITY**: see previous section.
- **STACQ**: see previous section.
- **OFINTP**: It is proposed as an auxiliary tool, see previous section.

Apart from that, additional modules have to be implemented for supporting specific functionalities of each satellite bus.

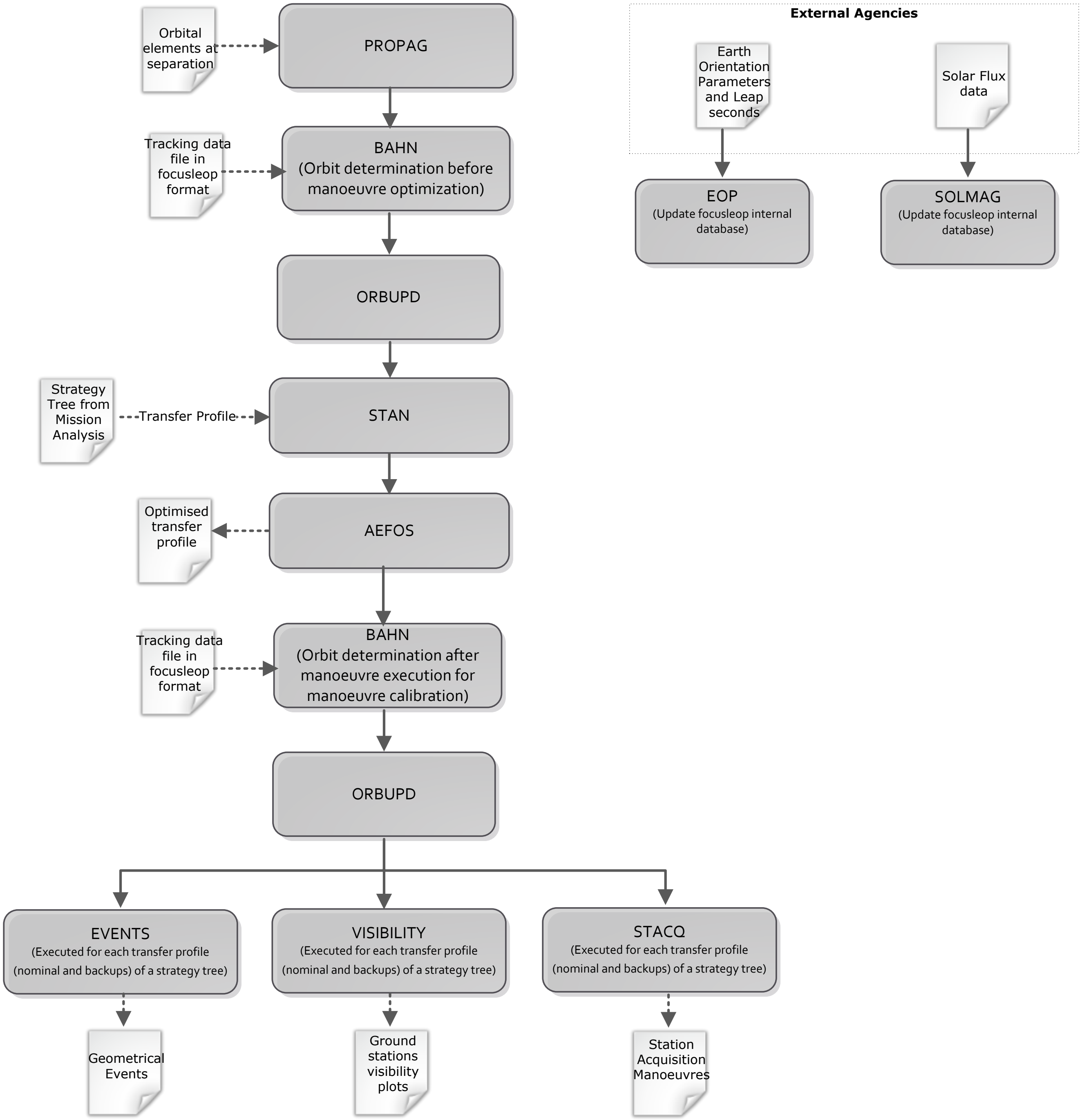

Orbital elements at separation
PROPAG
Tracking data file in focusleop format
BAHN (Orbit determination before manoeuvre optimization)
ORBUPD
Strategy Tree from Mission Analysis
Transfer Profile
STAN
Optimised transfer profile
AEFOS
Tracking data file in focusleop format
BAHN (Orbit determination after manoeuvre execution for manoeuvre calibration)
ORBUPD
EVENTS (Executed for each transfer profile (nominal and backups) of a strategy tree)
VISIBILITY (Executed for each transfer profile (nominal and backups) of a strategy tree)
STACQ (Executed for each transfer profile (nominal and backups) of a strategy tree)
Geometrical Events
Ground stations visibility plots
Station Acquisition Manoeuvres
External Agencies
Earth Orientation Parameters and Leap seconds
Solar Flux data
EOP (Update focusleop internal database)
SOLMAG (Update focusleop internal database)

Figure 52: focusleop for real operations

Apart from the modules described above there are dedicated mission-specific modules that depend directly on the satellite platform.

Please note that currently ***focusleop*** supports two platforms: EUROSTAR-3000 and SPACEBUS-4000 and it would be required to perform dedicated development to support new platforms.

In general terms the following functions are considered Mission-specific:

- **Manoeuvre Command generation**: using the theoretical delta-V, simulates the manoeuvre on-board according to manufacturer specifications and generates the command.
- **Manoeuvre calibration**: using the estimated delta-V and the predicted one, computes calibration factors for next manoeuvres.
- **Mass computation**: compute mass consumption from TM data according to manufacturer specifications
- **Manoeuvre attitude computation**: generates the command to be sent to the S/C to acquire the attitude during manoeuvre.

Additionally, the station keeping acquisition would include some common functionality with ***focusgeo***, as they are: INCLON/SOLONG/INICOL in case of chemical propulsion or INCLEC/ISKM in case of ionic propulsion.

9.2.6. FOCUSCN SPECIFIC FUNCTIONALITIES

The following constellations are currently supported: Galileo, Globalstar and O3b.

Manoeuvre Planning software for constellations has been developed covering the following functionalities: Insertion, relocation, station acquisition and deorbiting.

The following operational set-up is used in these systems:

- A Constellation workspace to execute all the multisatellite tasks.
- A Satellite workspace per satellite of the constellation, they are devoted to execute nominally all the satellite dependent modules (monosatellite tasks, such that Attitude Determination, Mass Computation and TC data Generation). The non-dependent satellite tasks will be also available allowing to operate a satellite autonomously in its own workspace without any interference with the rest of the constellation. This can be needed in case of contingency in one of the satellites of the constellation.
- Databases are shared between Constellation and satellite workspaces.
- Orbit and attitude data are exchanged between Constellation and satellite workspaces.

The following picture depicts the share of operations and data between the constellation workspace and the satellite workspaces:

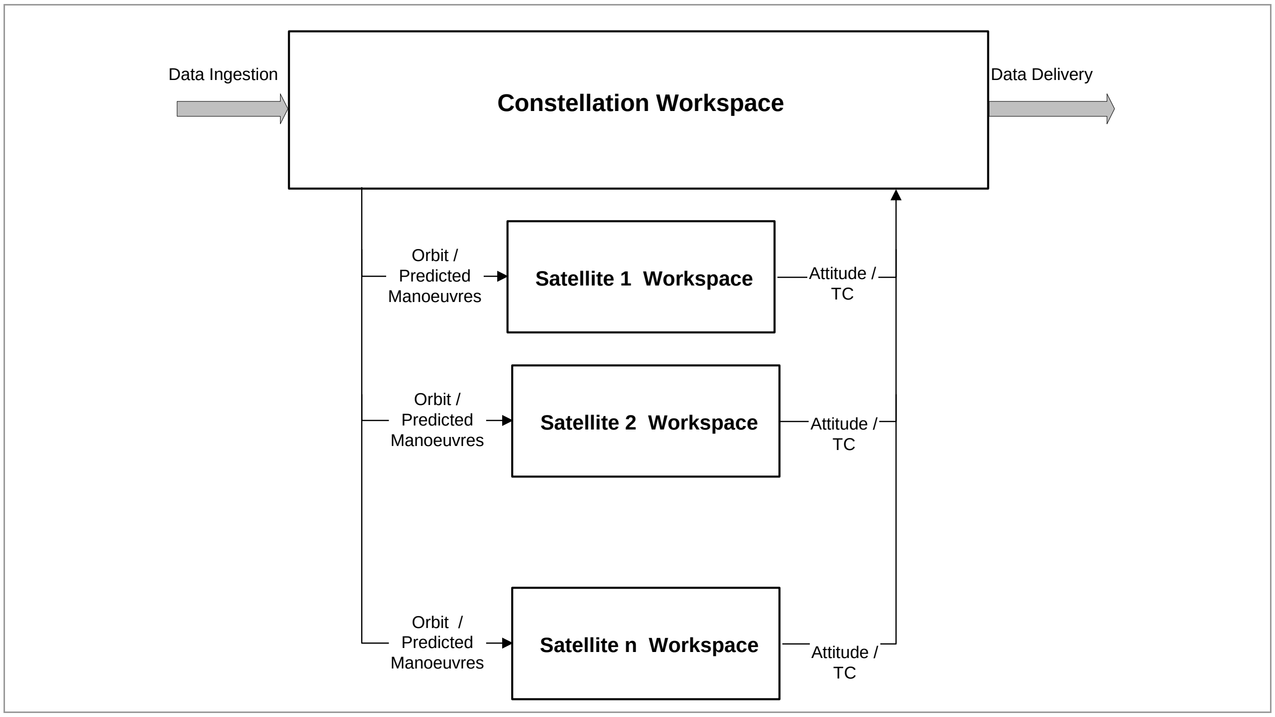
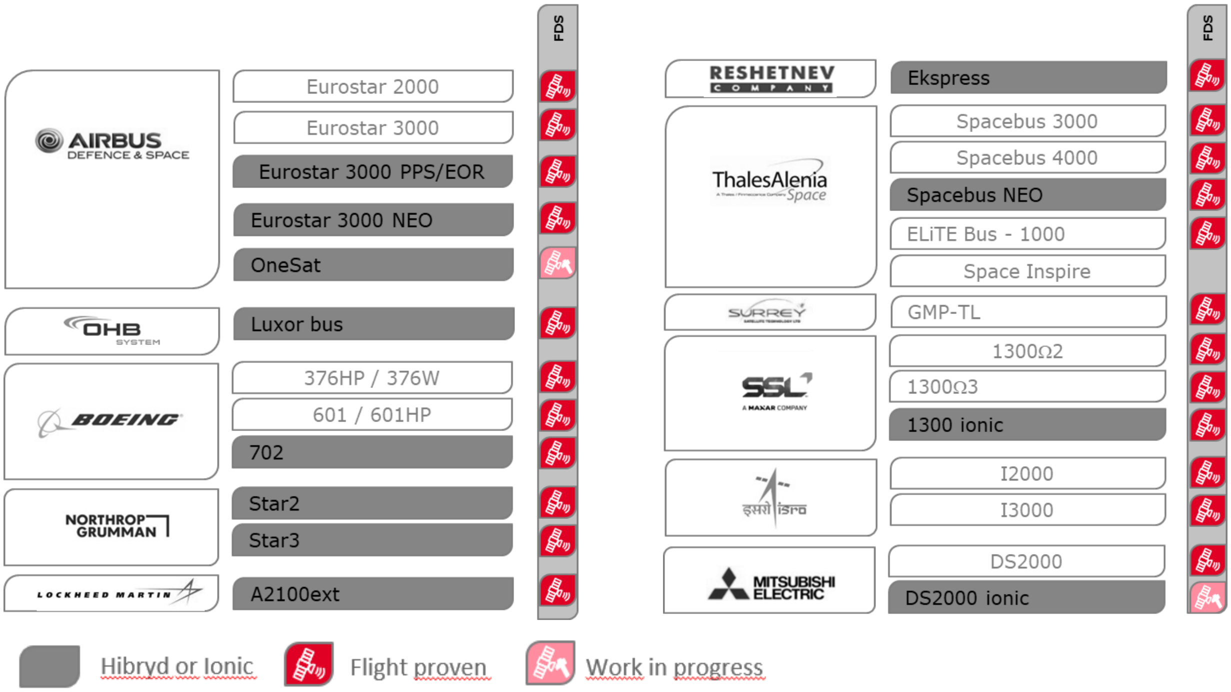


Figure 53: *FocusCn* Scenario and workspace structure

The constellation workspace will perform nominally the following tasks:

- Data Ingestion
- Orbit Determination & Propagation
- Manoeuvre Planning
- Geometrical Events Generation
- Products Generation (TLE, daily plan,…)
- Data Delivery

9.3. FOCUSSUITE SUPPORTED PLATFORMS



		FDS
AIRBUS DEFENCE & SPACE	Eurostar 2000	✓
	Eurostar 3000	✓
	▨ Eurostar 3000 PPS/EOR	✓
	▨ Eurostar 3000 NEO	✓
	▨ OneSat	◔
OHB SYSTEM	▨ Luxor bus	✓
BOEING	376HP / 376W	✓
	601 / 601HP	✓
	▨ 702	✓
NORTHROP GRUMMAN	▨ Star2	✓
	▨ Star3	✓
LOCKHEED MARTIN	▨ A2100ext	✓
RESHETNEV COMPANY	▨ Ekspress	✓
ThalesAlenia Space	Spacebus 3000	✓
	Spacebus 4000	✓
	▨ Spacebus NEO	✓
	ELiTE Bus - 1000	✓
	Space Inspire	
SURREY	GMP-TL	✓
SSL A MAXAR COMPANY	1300Ω2	✓
	1300Ω3	✓
	▨ 1300 ionic	✓
इसरो isro	I2000	✓
	I3000	✓
MITSUBISHI ELECTRIC	DS2000	✓
	▨ DS2000 ionic	◔

▨ Hibryd or Ionic ✓ Flight proven ◔ Work in progress

Table 9–1: *focussuite* supported platforms (April 2023)

END OF DOCUMENT