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AGILE SPACE

ExoOPS™ – *Mission Design*

Mission design made easy

Document reference	EXO_DCM_PRE_200514_1MKF
Version number (date)	V1 (14 may 2020)
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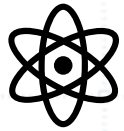
WE GUIDE YOU THROUGH ALL THE STEPS OF YOUR MISSION

ALL THE TOOLS YOU NEED TO DESIGN, DEPLOY AND OPERATE YOUR SPACE MISSION IN ONE SINGLE SOFTWARE



Constellation design for optimized performances

Optimisation of launch scenario

Optimisation of propulsion system, target orbit, available power, mass of the satellite, etc.

Advanced mission design of the manoeuvres, intricacies with the spacecraft systems, operations simulation

ExoOPS™ – *Mission Design*

INTRODUCTION

ExoOPS™ – *Mission Design* is our custom designed and built operational software for mission simulations – with an emphasis on propulsion. It is cloud-based, user friendly and gives users unique insights into mission & propulsion planning.

Mission Optimization & Insights

- Compare the impact of different propulsion solutions on your system, your mission, your business case
- Generate reports with ΔV, duration, power consumption, duty cycle, propellant use, thrust & attitude sequence, you can also create your own metrics
- Compute your manoeuvres with optimized thrust strategies
- Analyse the precise impact of propulsion on attitude, power system, etc.

Optimized Launch Strategies

- Analyse the impact of different missions, such as RAAN* Phasing or altitude transfers, on your operation
- Compute thousands of different scenarios in seconds
- Analyse orbital deployment timings and costs
- Perform trade-off analysis between rideshare followed by propulsion manoeuvre and dedicated launch scenarios

Access Anywhere & Easy to use

- Intuitive software and user-friendly interface make the platform easy to use, even for non experts
- Cloud based software, with local data storage options
- Time-based licenses, frequent updates automatically included

Modules

CONSTELLATION

DEPLOYMENT STRATEGIES

ANALYTICAL MISSION

NUMERICAL MISSION

*RAAN = Right Ascension of the Ascending Node

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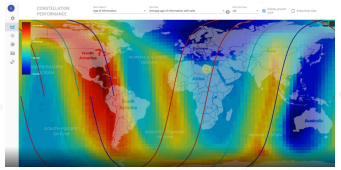
FOUR DIFFERENT MODULES FOR DIFFERENT APPLICATIONS

CONSTELLATION

With the Constellation Module, one can easily prototype the deployment of a constellation of satellites. This module facilitates the analysis of the performances of the constellation and its ability to deliver a given level of service, in terms of coverage, revisit rates and communication with a ground station network.

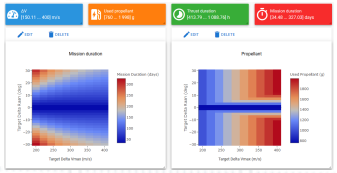


DEPLOYMENT STRATEGIES

The Deployment Strategies Module allows to analyze hundreds of different launch scenarios involving different launchers and propulsion systems automatically. The optimization of the scenario can be chosen depending on the user's KPI.

ANALYTICAL MISSION

The Analytical Mission Module allows almost instantaneously to simulate mission performances (ΔV, duration, power consumption, duty cycle, propellant use, number of burns...) for thousands of different scenarios with different parameters: propulsion system, target orbit, available power, mass of the satellite, etc.



NUMERICAL MISSION

The Numerical Mission Module allows to precisely simulate the satellite's trajectory thanks to state-of-the-art integration algorithms. A detailed system description is provided in this module (define satellite geometry, solar panels and battery). Time histories of all orbital and system parameters are provided with a customizable step.

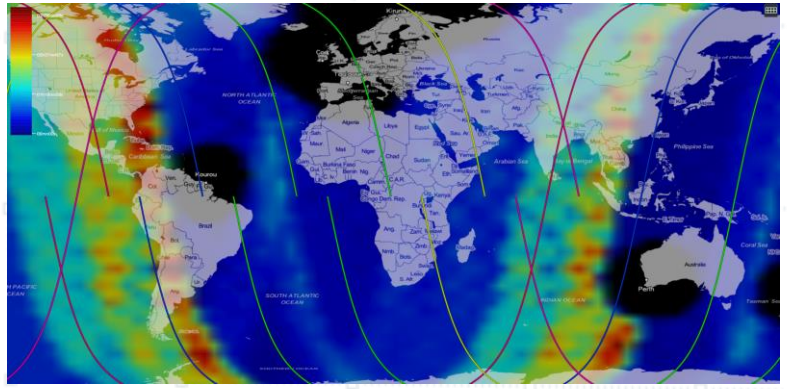
Modules presentation

CONSTELLATION

The Constellation Module helps Systems or Sales Engineers to size a constellation of satellites identifying the orbit and geometry that best fit a given mission.

The Constellation Module can be used to perform two types of studies:

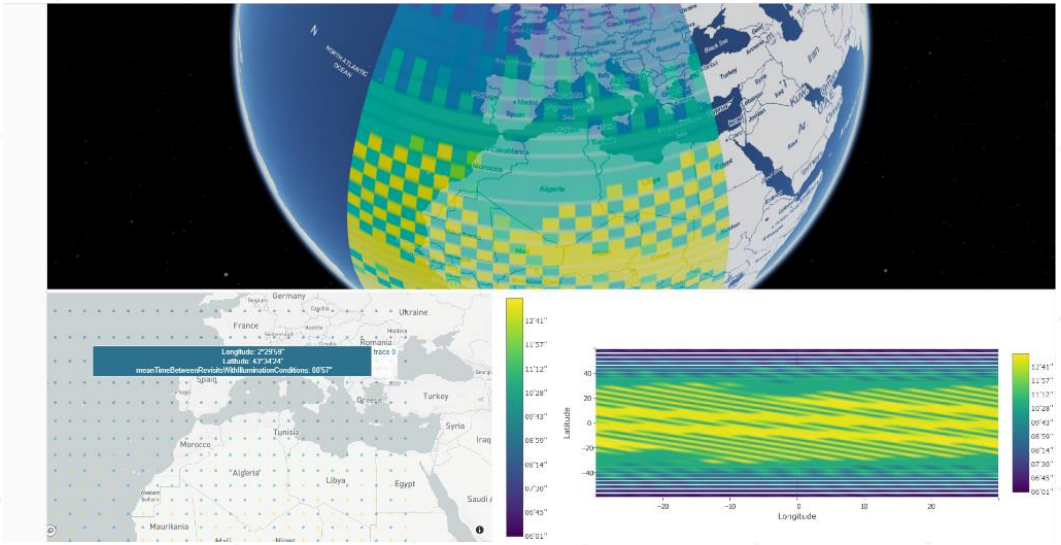
- Revisit statistics over a user-defined Earth mesh;
- Age of information and data transmission latency analysis over a user-defined ground station network.



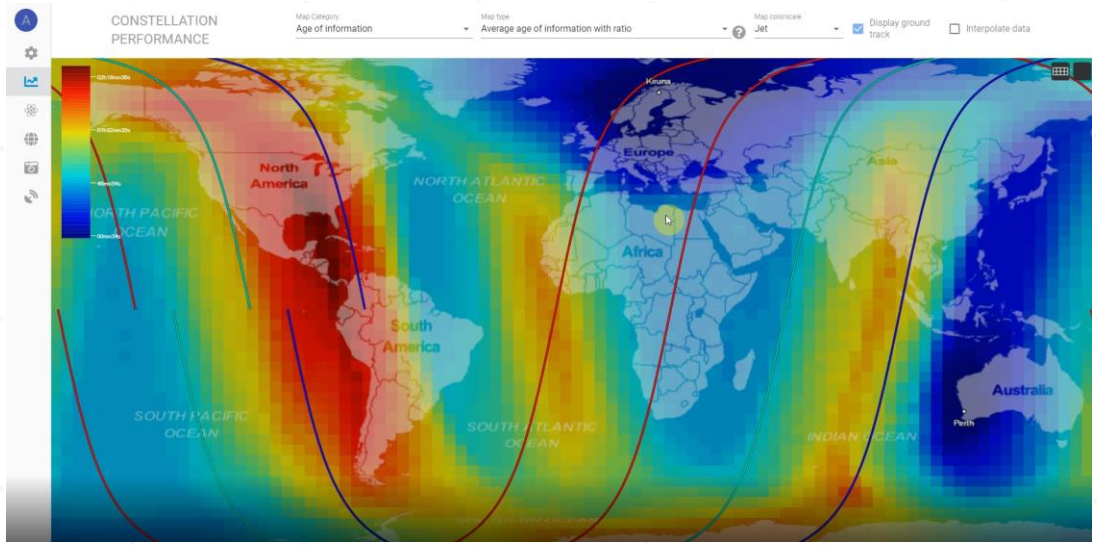
The analytical algorithms we developed at Exotrail to simulate constellations of satellites are very fast and can handle hundreds of satellites over a simulation duration of several days or weeks. This enables the user to rapidly iterate on his design choices and to perform trade-offs between different coverage patterns.

Results examples

CONSTELLATION



Mean duration between revisits



Age of information statistics, ground stations and ground tracks

Detailed workflow

CONSTELLATION

Nominal altitude
Operating altitude
Ground range
Max incidence
Min elevation
Semi-view angle
Swath

Payload

Payload

Payload
Orbits (altitude, inclination, phased orbit…)
Number of planes
Number of satellites per plane
Orbital planes repartition

Constellation Geometry

Min and max latitudes
Number of latitudes
Min and max longitudes
Number of longitudes

Earth Mesh

Latitude
Longitude
Altitude
Min elevation

Ground Stations

Constellation Geometry
Earth Mesh
Ground Stations
Simulation date
Simulation duration
Sun zenith angle

Constellation Performance Analysis

COMPUTATION

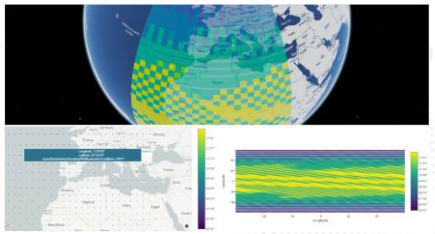
Proprietary simulator for fast and accurate analytical simulations

Revisit and coverage maps
Data latency
Age of information

Results

Dashboard

PLOT MODULE / RESULTS TABLE



Import functions

Export functions

Other software / customer databases

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Modules presentation

DEPLOYMENT STRATEGIES

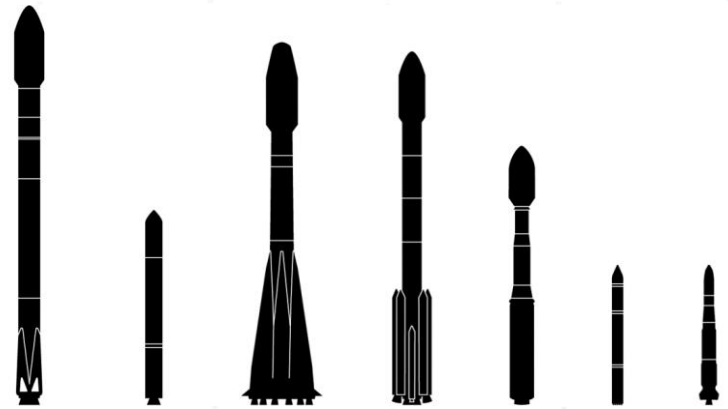
The Deployment Strategies Module allows engineers to perform a preliminary analysis of a constellation deployment scenario, in order to evaluate its cost and the time before the full operational capability.

A deployment scenario is modelled as a succession of launches, with several spacecrafts in each launch. A plane change maneuver is computed for each spacecraft so that it reaches its operational plane within the constellation's geometry.

The Deployment Strategies Module can be used to perform two types of studies:

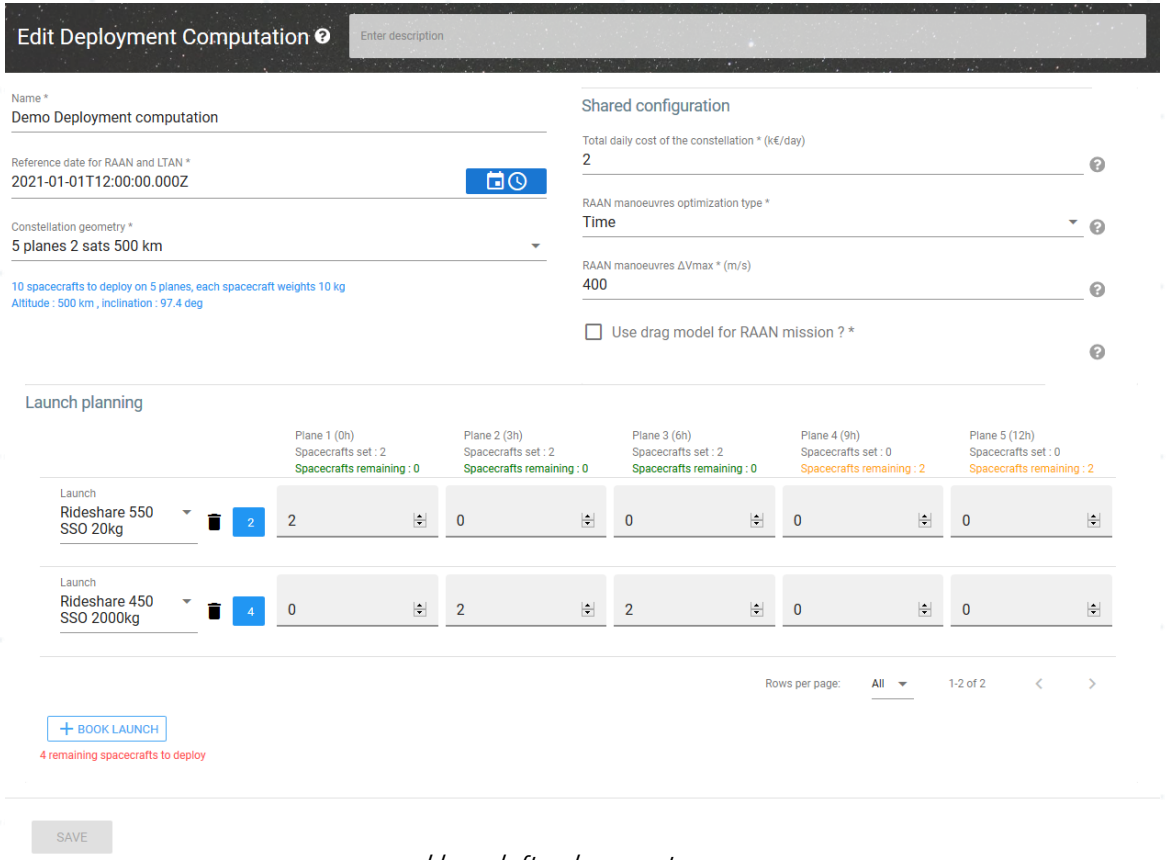
- Evaluate the cost and the duration of a user-defined scenario: launches, satellites per launches, maneuver for each satellite.

- Find the optimal strategy taking all available launches into account with user defined constraints. All possible and realistic deployment configurations will be computed and sorted.

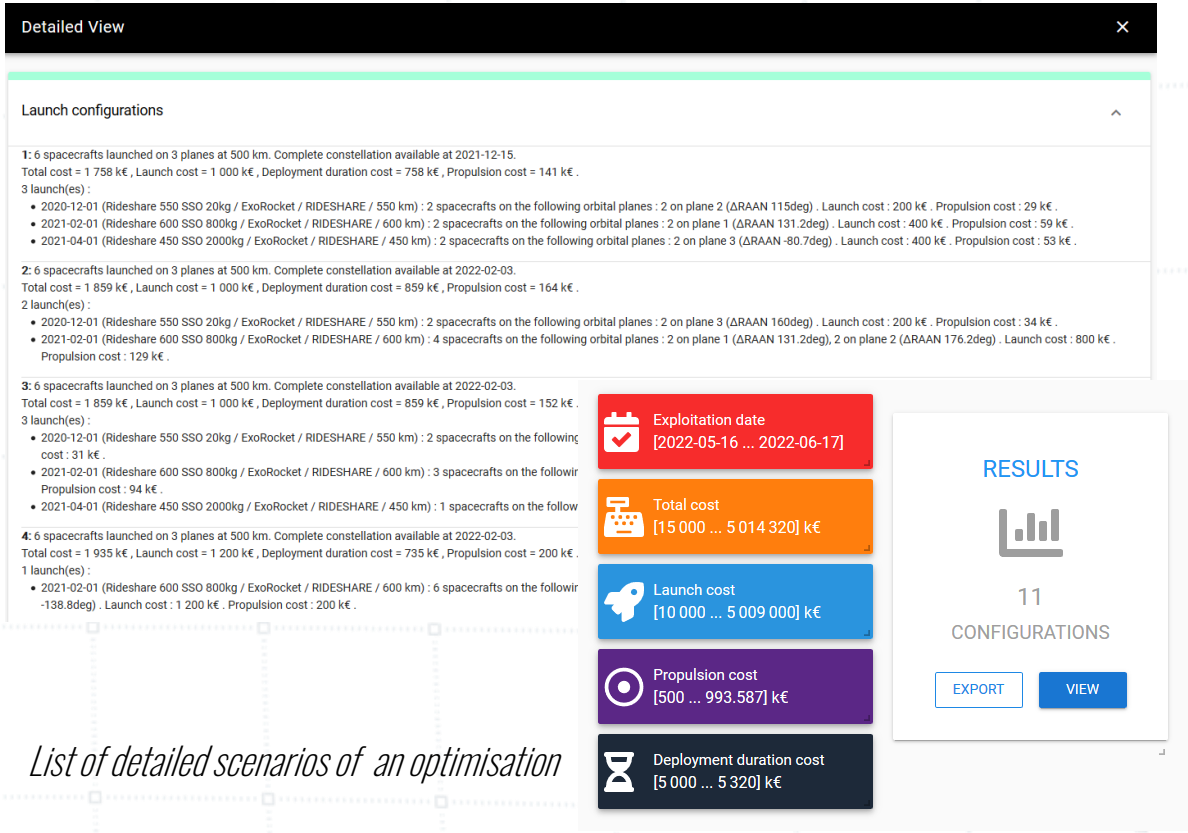


Configuration and results examples

DEPLOYMENT STRATEGIES



User defined scenario



List of detailed scenarios of an optimisation

Detailed workflow

DEPLOYMENT STRATEGIES

Thruster
Mass
Volume
Drag model
Power for propulsion

Satellite

Spacecraft
Orbits (altitude, inclination, phased orbit...)
Number of planes
Number of satellites per plane
Orbital planes repartition

Constellation Geometry

Electric/Chemical
Thrust
Power
Specific impulse
Mass
Volume
Cost

Thruster

Altitude
Inclination

Orbit

Orbit
Rocket
Date
Rideshare/Dedicated
Cost
Maximum load

Launch

Mission choice

Mission

Constellation Geometry
Launches
Duration cost
RAAN manoeuvres configuration
Launches settings

COMPUTATION

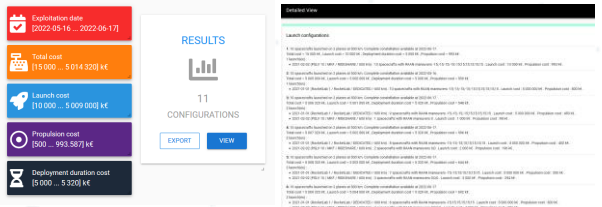
Custom launch configuration
or analyse all possibilities

Exploitation date
Total cost
Launch cost
Propulsion cost
Deployment duration cost
Details on each launch : number of spacecrafts and manoeuvres

Results

Dashboard

SUMMARY / DETAIL VIEW



Import functions

Export functions

Other software / customer databases

Modules presentation

ANALYTICAL MODULE

The Analytical Module allows to perform rapid analysis of multiple scenarios involving propulsion. It is based on fast analytical models which accurately approximate the real manoeuvres.

The Analytical Module allows to compute mission performances (ΔV, duration, power consumption, duty cycle, propellant, number of firings...) for thousands of different scenarios with different parameters: propulsion system, target orbit, available power, mass of the satellite, etc.

Specifically, this module can be used to:

- Evaluate how different types of propulsion performance (thrust-to-power ratio, specific impulse, ...) impact the mission financials in order to choose the right propulsion system;
- Simulate and assess the key design principles of many propulsion missions including orbital transfer, plane change, station-keeping, etc.

Optimize the profile of your mission through **parametric analysis**

Most of parameters can be selected within a range of values, either for the spacecraft (e.g. mass, propulsion system, power generated,...) or for the mission (orbital parameters, optimization constraints, ...).
This enables a systems engineer to rapidly design and optimize a satellite and a mission profile using propulsion.

Available missions


ORBITAL TRANSFER


RAAN PHASING

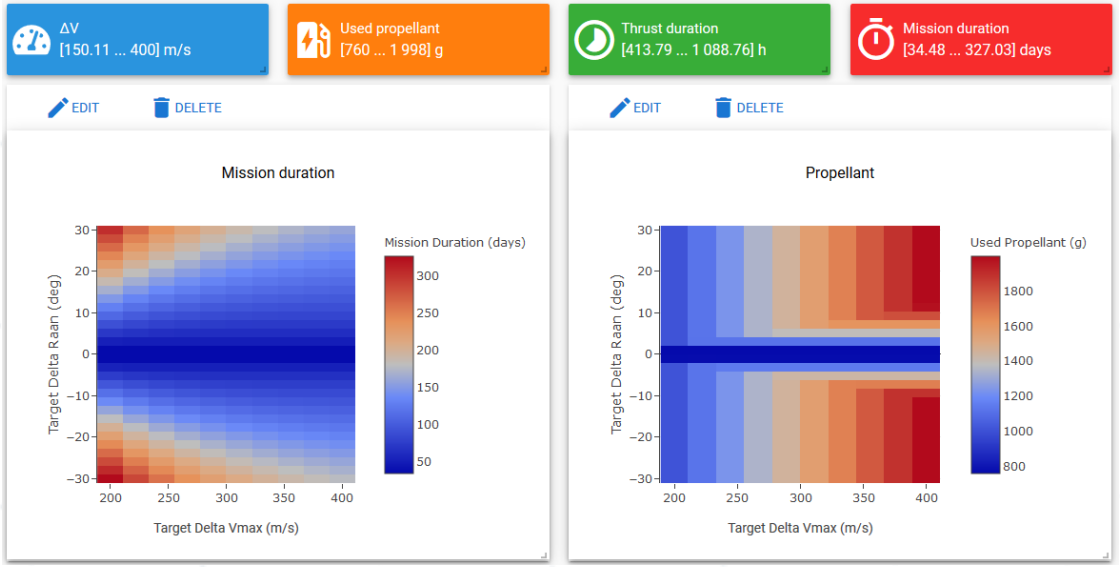

ORBIT PHASING


STATION KEEPING

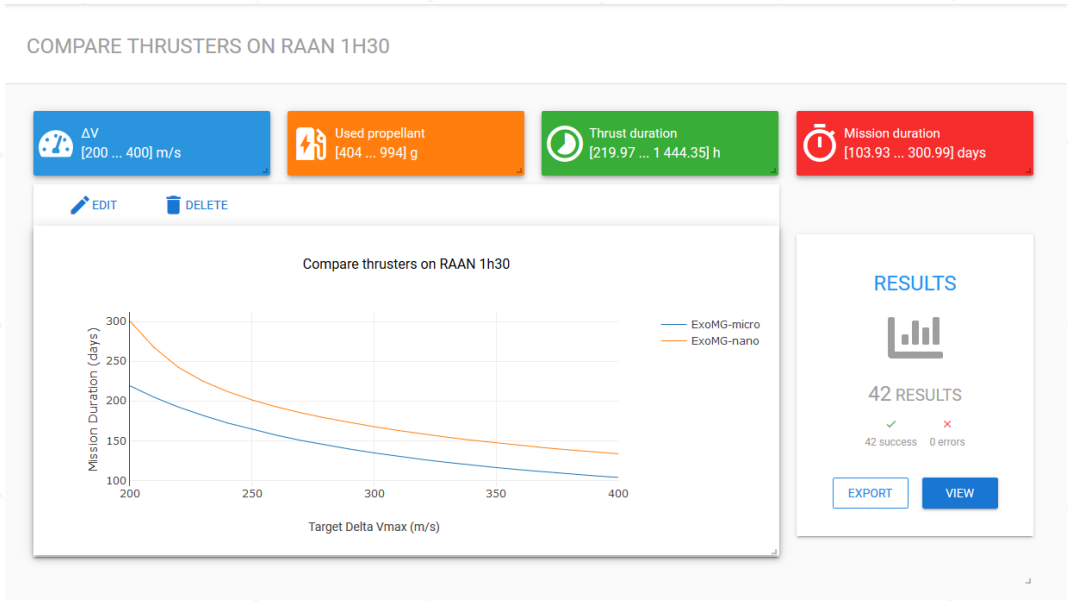

DEORBITATION

Results examples

ANALYTICAL MODULE



Example of a dashboard for parametric RAAN studies



Compare propulsion systems

Detailed workflow

ANALYTICAL MODULE

Electric/Chemical
Thrust
Power
Specific impulse
Mass
Volume
Cost

Thruster

Thruster
Mass
Volume
Drag area & drag coefficient
Power for propulsion

Satellite

Altitude
Inclination

Orbit

Mission choice

Satellite
Initial Orbit
Final Orbit
Duration cost
Mass cost
Mission-specific parameters

Mission

COMPUTATION

Results compared to those given by well-known GMAT space mechanics library.

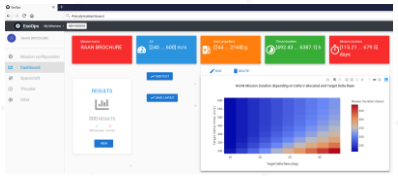
Mission duration
ΔV
Propellant consumption
Number of firings
Drifting orbit & duration
Cost of the mission including duration & mass
... many more results!

The scripting interface allows one to add custom results for his specific needs.

Results

Dashboard

PLOT MODULE / RESULTS TABLE



Import functions

Export functions

Other software / customer databases

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Modules presentation

NUMERICAL MODULE

The **Numerical Module** provides precise insights on the early operations and the deployment of a satellite constellation.
The two main differences compared with the Analytical Module are:

- Results vary over time (the entire manoeuvre is simulated);
- The satellite definition is more detailed and accurate, including solar panels, satellite's geometry, attitude...

Using the Numerical Module you can:

- Define the satellite's geometry and its power system (including battery and solar panels)
- Simulate manoeuvres (including non-coplanar transfers, RAAN phasing etc..) taking attitude changes into account
- Consider the influence of perturbations (Earth potential, atmospheric drag, solar radiation pressure and third body) and eclipses on your manoeuvre strategy
- Perform optimized manoeuvres by tuning the parameters of your propulsion system
- Compute the time history of your results (orbital parameters, attitude angles, battery state...)

Available missions

ORBITAL TRANSFER

RAAN PHASING

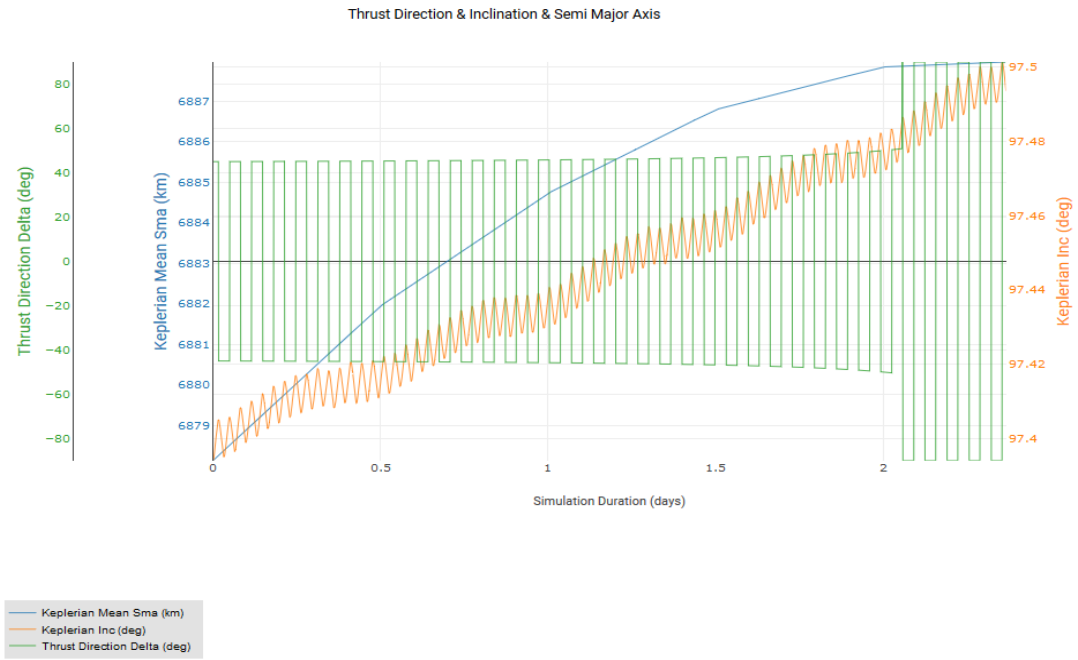
ORBIT PHASING

ORBIT EXTRAPOLATION

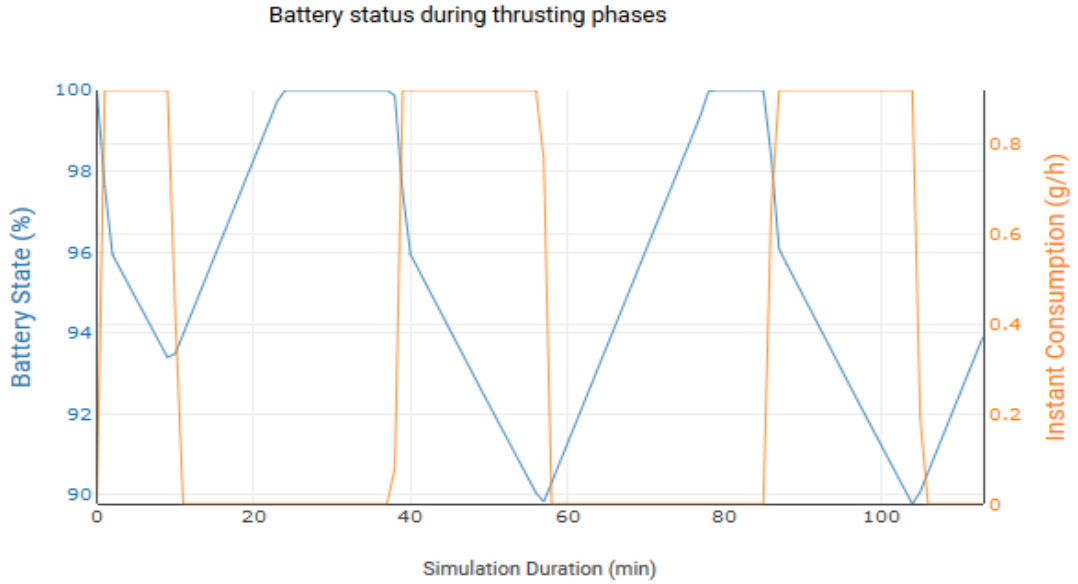
SPACECRAFT DESIGN ANALYSIS

Results examples

NUMERICAL MODULE



Time history for semi-major axis, inclination and thrust direction



Time history for battery state and consumption

Detailed workflow

NUMERICAL MODULE

Thrust
Specific impulse
Power
Warm-up duration
Warm-up power
Thruster axis

Thruster

Type (deployable, body mounted,...)
Axis
Efficiency
Maximum Power

Solar Panels

Nominal capacity
Depth of discharge
Minimum charge for firing

Battery

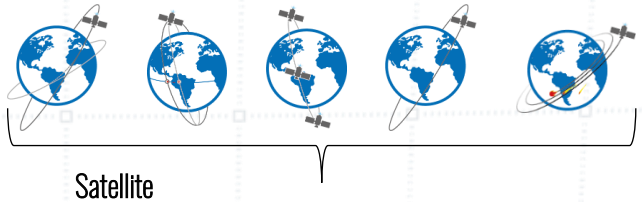
Altitude
Eccentricity
Inclination
RAAN
Argument of perigee
Anomaly
Orbit Date

Orbit

Thruster
Solar Panels
Battery
Mass
Shape
Duty cycle
Drag & radiative parameters

Satellite

Mission choice



Satellite
Initial Orbit
Mission date
Simulation duration
Perturbations
Mission-specific parameters
Ephemerides type
Number of ephemerides

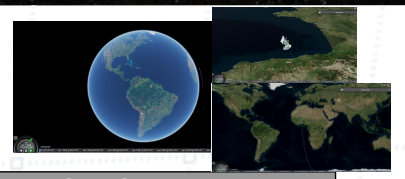
Mission

COMPUTATION

Exploits OREKIT: an open-source, state of the art space mechanics library developed by CS and used by many agencies (NASA, ESA, CNES) and companies (TAS, Airbus, SSC).

Choose between precise numerical integration and fast propagation of mean elements using semi-analytical propagation.

Results



3D Simulator

Dashboard

PLOT MODULE / RESULTS TABLE

Import functions

Export functions

Other software / customer databases

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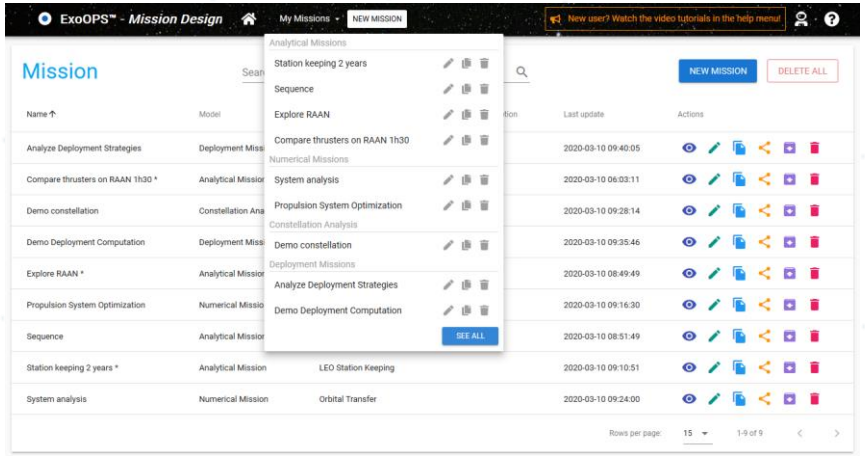
VALIDATION AND RELIABILITY

- ✓ Developed using continuous integration and covered by non regression tests
- ✓ The numerical simulation is based on the space mechanics library Orekit[1], the well-known open source library used by Airbus, ESA, Thales Aliena Space, Eumetsat, ...
- ✓ The results and algorithms have been validated against the literature and external reliable software (GMAT, CelestLab)
- ✓ Used and verified by internal and external users

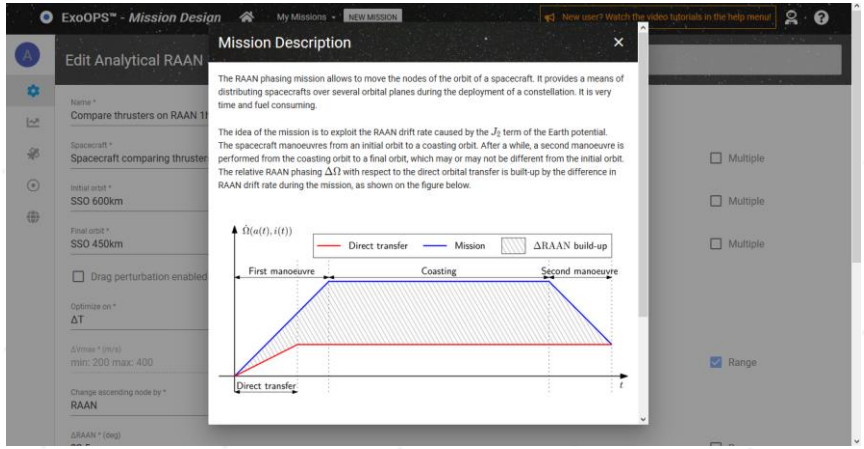
[1] Orekit website: https://orekit.org/

User interface

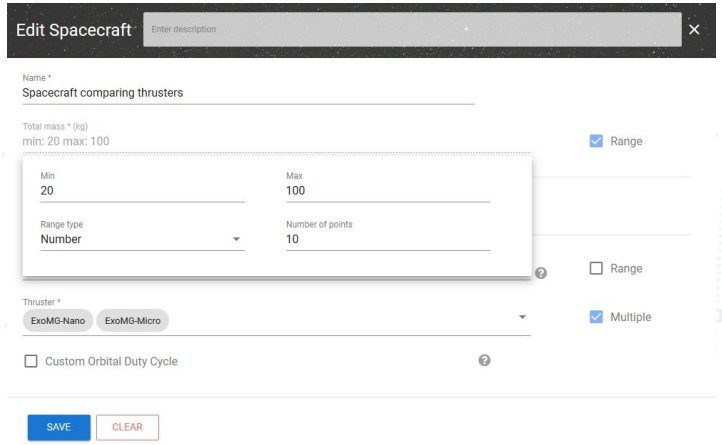
INTUITIVE USER EXPERIENCE



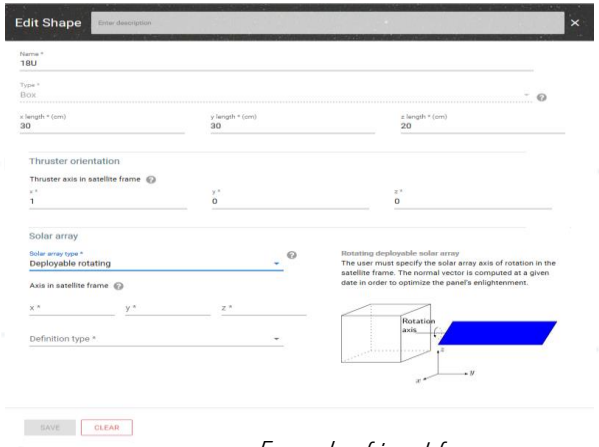
Quick access to missions and objects



Contextual help items



Define ranges of values to compare multiple scenarios



Example of input form

User interface

COMPREHENSIVE DOCUMENTATION

Complete technical documentation and nomenclature

Documentation

Technical documentation

Follow this link to view the full technical documentation.

Fields bounds

Most of the fields do not accept any value in forms. An error message will be displayed when the inputs do not respect the requirements. Below is a summary of all limits on fields grouped by forms. Note that only the fields with bounds are listed.

Notation:

;
separator between lower and upper bounds

]
lower bound excluded / upper bound included

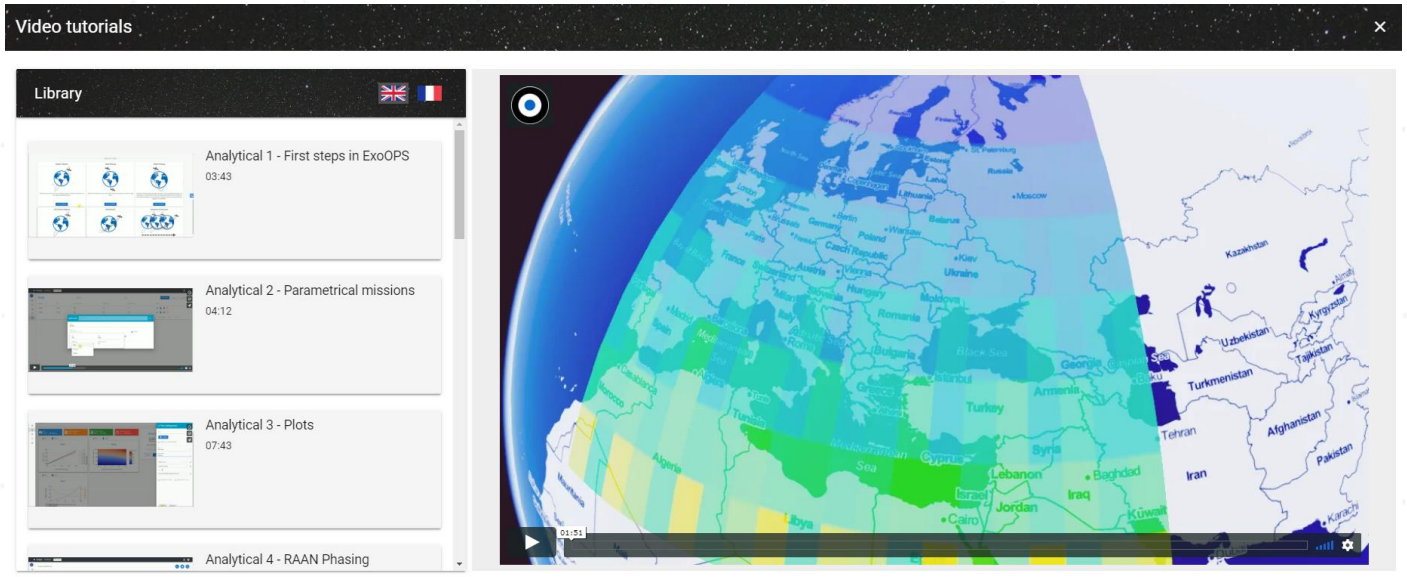
[
lower bound included / upper bound excluded

+∞[
no maximum value

]-∞
no minimum value

]0; +∞[
any positive value bigger than 0

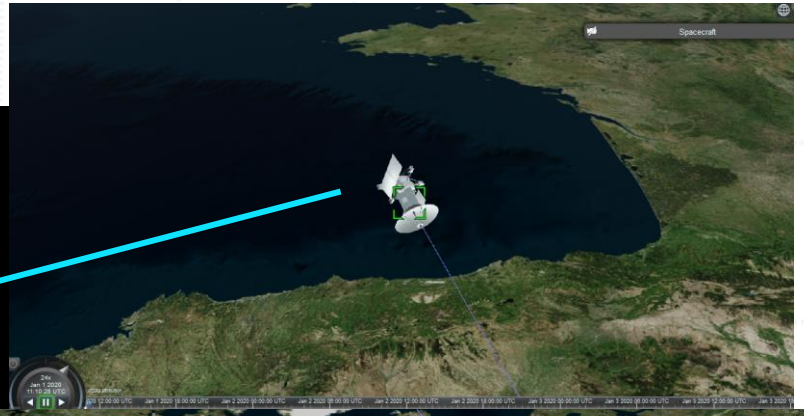
Constellation deployment mission	Unit	Range
RAAN manoeuvres ΔVmax	m/s	]0; +∞[
RAAN manoeuvres target duration	days	]0.01; +∞[
Duration cost	k€/day	[0; +∞[
Maximum number of spacecrafts per launch		[1; 500]

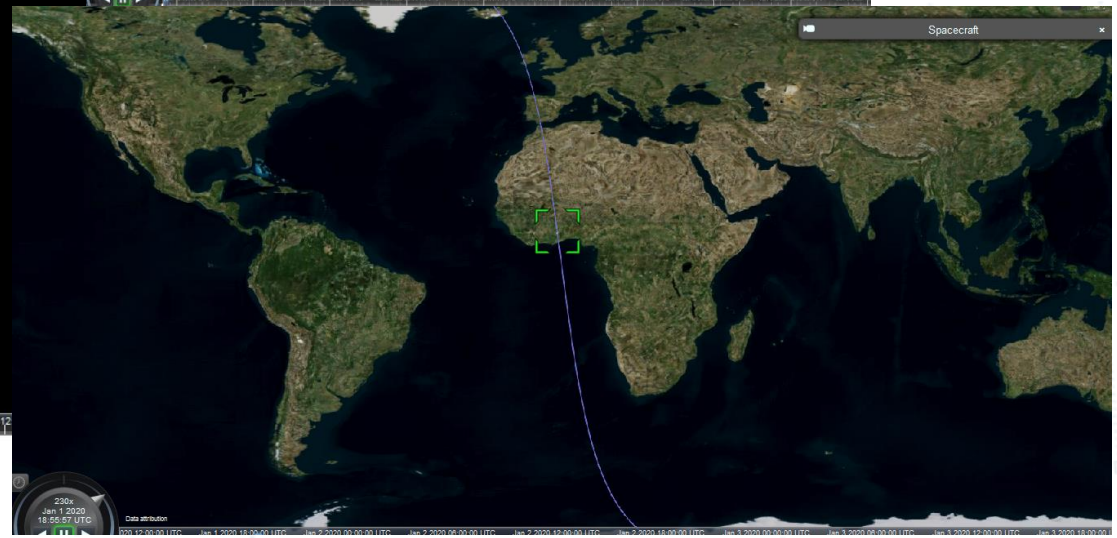


Video tutorials which covers all the features of ExoOPS™ - Mission Design

User interface

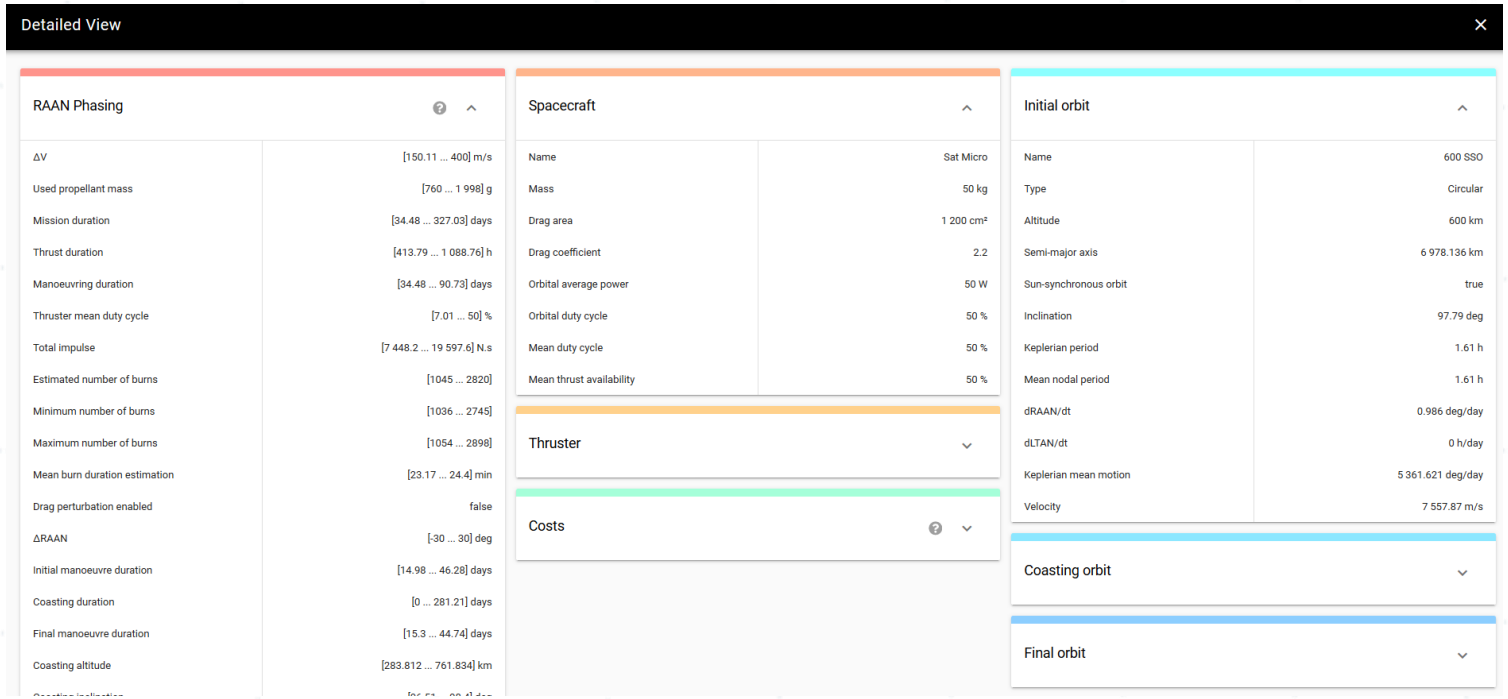
3D VISUALIZATION



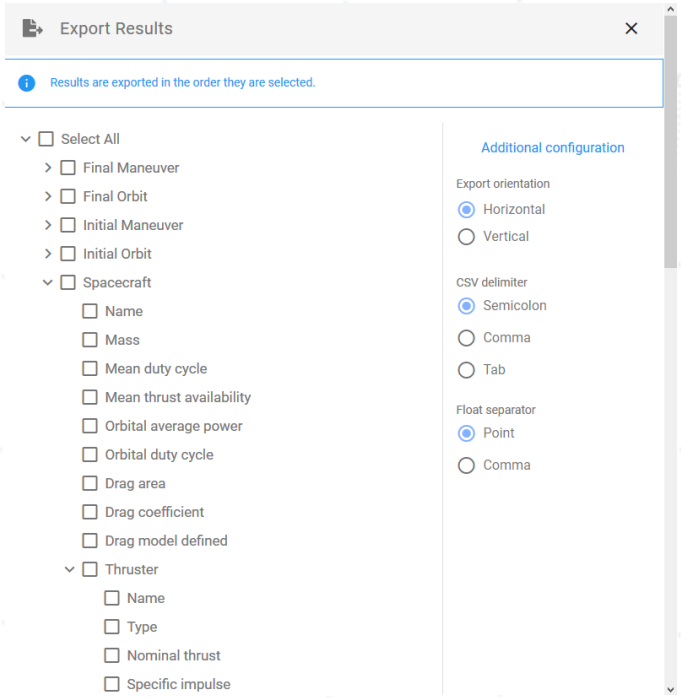


User interface

DETAILED RESULTS



Detailed results view



Custom results export in CSV files

ROADMAP

2020

Telecom simulation: define your ground segment network and add telecommunication requirements during the simulation.

Payload simulation: configure your payload and indicate your area of interest.

Standard data format support: integrate ExoOPS™ - *Mission Design* with your other software tools

More constellations analysis results: global timeline and detailed events per mesh

Improved launch strategies: group, filter and navigate inside launch scenarios

2021

AOCS simulation: take into account your spacecraft agility and constraints on attitude

Constellation simulation: visualize all the spacecrafts of your constellation in a single simulation

Optimized trajectories: change all the orbital elements with the minimum ΔV budget or the minimum duration

Optimal launch strategies: minimize your launch costs by taking custom criteria into account

2022

Optimal constellation configuration: minimize the number of spacecrafts needed and improve the performances of your constellation

Spacecrafts replacement strategies: long term vision of your spacecraft fleet

How you can get ExoOPS™ - *Mission Design*

REQUEST A DEMO

It will be a pleasure for our software development team to setup a demonstration of all the features included in ExoOPS™ for you to understand how our software can meet your needs.

GET A FREE TRIAL VERSION

Once you are convinced by the demonstration, you can request a two-week trial period for a demonstration version of the software. This version contains all features and will allow you to play around with ExoOPS™ and see what it is capable of.

PURCHASE YEARLY LICENSES

ExoOPS™ uses a per-year / per-user licencing model. It is a Software-As-A-Service model: all the new functionalities developed by our Software Development team will automatically be included in the package you purchased.
ExoOPS™ is natively cloud-based, but hosting on-premises is possible.

CONTACT US FOR MORE INFORMATION:

www.exotrail.com
exoops@exotrail.com

ExoOPS™ – *Operations*

Operation software to make propulsion easy

ExoOPS™ – *Operations*
Key Points

ExoOPS™ - *Operations* is a software linked with your Mission Control Centre. It manages the propulsion systems as well as all the flight dynamics features. It will help you to minimize your launches and operations costs, and to improve the performances of your constellation.

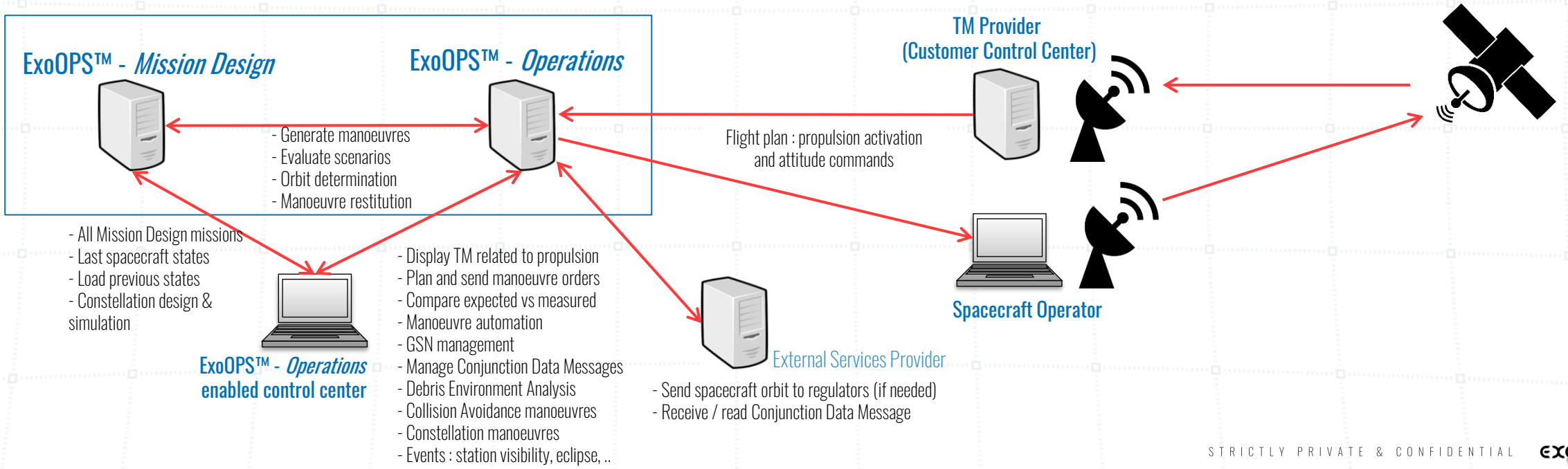
Orbit & maneuver restitution	Unforeseen events detection and tracking
Thruster performance analysis	Thruster in-flight thrust calibration
Low duty cycle planning	Efficient and representative mission planning
Automated thrust plan creation	Intuitive and not requiring a lot of operator's time
Maneuver planning at the constellation level	Handle complex maneuvers with simple mission requirements
Collision avoidance management	Notification mechanism with correction maneuver suggestion
Based on ExoOPS™ – *Mission Design* interface and algorithms	Same intuitive interface, smooth transition from design to operations
Simulation environment from current state as input	Fast iteration & understanding spacecraft/propulsion interactions

ExoOPS™ – *Operations*

OVERVIEW

ExoOPS™ - *Operations* is a software which is the interface between your mission control centre and ExoOPS™ - *Mission Design*. , our custom designed and built operational software for mission simulations – with an emphasis on propulsion. It gathers useful data from the spacecraft telemetry – position, batteries state of charge, propulsion system status, etc. When manoeuvres are specified, ExoOPS™ - *Operations* will call ExoOPS™ - *Mission Design* to compute the associated manoeuvre sequence. All the commands and associated manoeuvres computations are tracked, can be easily accessed and, if you are using an ExoMG™ thruster, the telecommands are automatically created in the right format for the propulsion unit.

Several modules can be acquired separately – ExoOPS™ can also serve as the complete flight dynamics system for your mission, not only for propulsion purposes.



Modular Architecture

Modules	Features	
TM / TC	Data visualization (TM)	AVAILABLE NOW
	Telecommand generation (TC)	AVAILABLE NOW
Orbit management	Orbit restitution (TLE / GPS data must be supplied)	2020
	Orbit propagation (with perturbations: earth potential, third body, drag, sun radiation pressure)	AVAILABLE NOW
Propulsion	Simulate and compute maneuvers (station keeping, constellation geometry, end-of-life ...)	AVAILABLE NOW
	Conversion of maneuvers into flight plan (thrust direction and amplitude)	2020
	Maneuver performance estimation (comparison between predicted and determined performance)	2020
	Schedule of periodic maneuvers (e.g.: weekly station keeping instruction)	2020
Constellation	Adapt constellation geometry to increase performances	AVAILABLE NOW
	Ground station network (data up/down link capacity, spacecraft pointing, minimum pass duration ...)	2020
	Satellite propagation to detect events (point of interest, ground station communication ...)	2020
	Constellation maneuvers (e.g.: station keeping, geometry change)	2021
Debris & Collision	Collision avoidance	2021

ROADMAP

2021

Constellation maneuver: lower the operations cost by controlling all the spacecraft together.

Automated maneuver correction: compare the predictions to measure and adapt the next flight plans.

Collision avoidance: be notified in case of alert. Accept or edit the proposed maneuver.

2022

Plan, launch and maneuver for a spacecraft deployment: all the steps from the ground to the operational orbit.

Constellation deployment: deploy a whole constellation

Optimized station keeping for spacecrafts: set your operational constraints and lower the propellant consumption

2023

Automated constellation operation: either to maintain or to change your constellation

Constellation station keeping: maintain the initial quality of service

Constellation collision avoidance: analyze the risks inside your constellation and adapt the repartition of the spacecrafts

Validation and Reliability

- ✓ Developed using continuous integration and covered by non regression tests
- ✓ Developed in close relation with the thrusters' development team
- ✓ Used internally for our demonstration mission
- ✓ All space mechanics computations are made through ExoOPS™ – *Mission Design*. This software is already used by prime customers such as Eutelsat. It is based on the space mechanics library Orekit[1], the famous open source library used by Airbus, ESA, Thales Aliena Space, Eumetsat, …
- ✓ The results and algorithms have been validated against the literature and well-known reliable software (GMAT, Celeslab)

[1] Orekit website: https://orekit.org/

INTERFACES

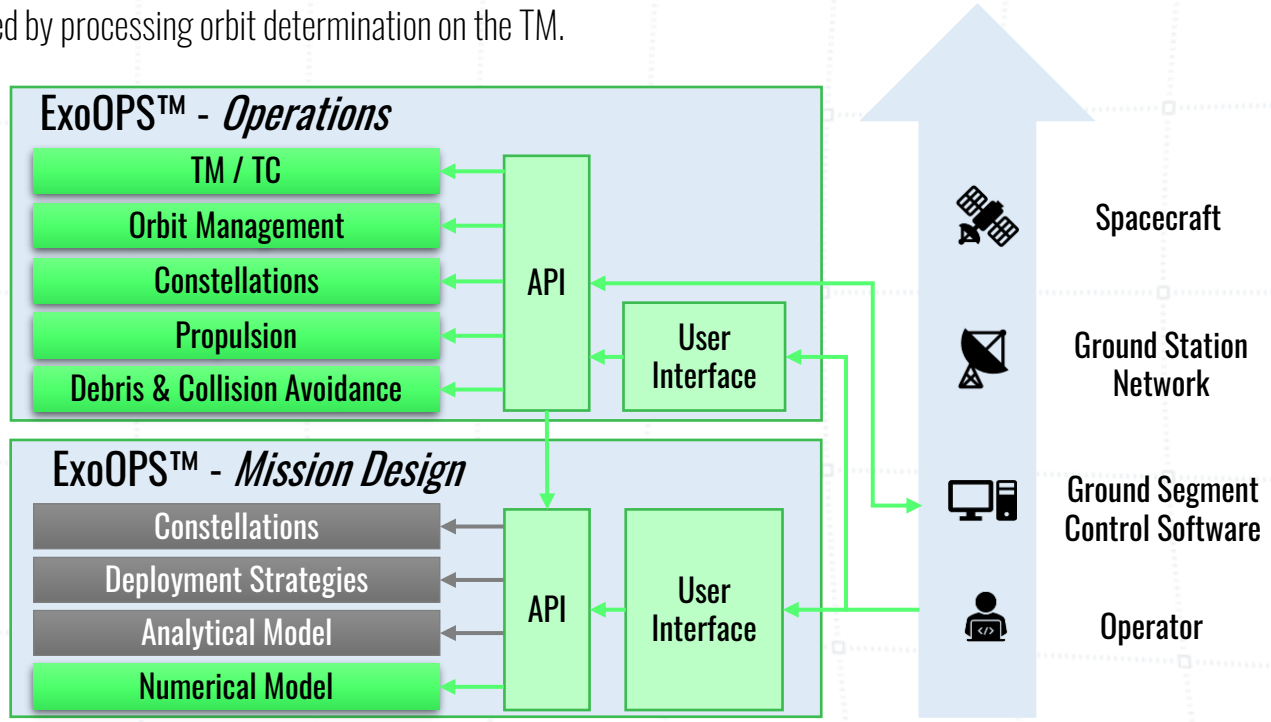
ExoOPS™ – *Operations* is a cloud-based software linked to ExoOPS™ – *Mission Design.* It can be used with our user interface or with a REST API. The required inputs are :

- the spacecraft model (thruster, power management, shape, AOCS),
- for each manoeuvre:
  - spacecraft state: battery level, remaining propellant. It can be provided by the user, read from TM, or evaluated from the last manoeuvre.
  - spacecraft position (orbit + date): it can be provided by the user, or evaluated by processing orbit determination on the TM.
  - manoeuvre configuration: e.g. target orbit.

The manoeuvres processing will generate flight plans : sequence of thrust & required attitude at the time of thrust.

If the TC library of the propulsion system is available (which is the case with our ExoMG™ propulsion systems), the flight plan can be translated into TC directly in ExoOPS™ – *Operations.*

The flight plan can be automatically sent to the Mission Control Center or retrieved from the API.



Deployment Options

ExoOPS™ – *Operations* is a SaaS application with a dedicated instance for each customer. Additional options can be chosen to increase the safety level and protect your data.

Baseline package

- Dedicated server
- Dedicated database
- HTTPS encryption
- Hosted on our private cloud provided by OVH[1]

OVH.com

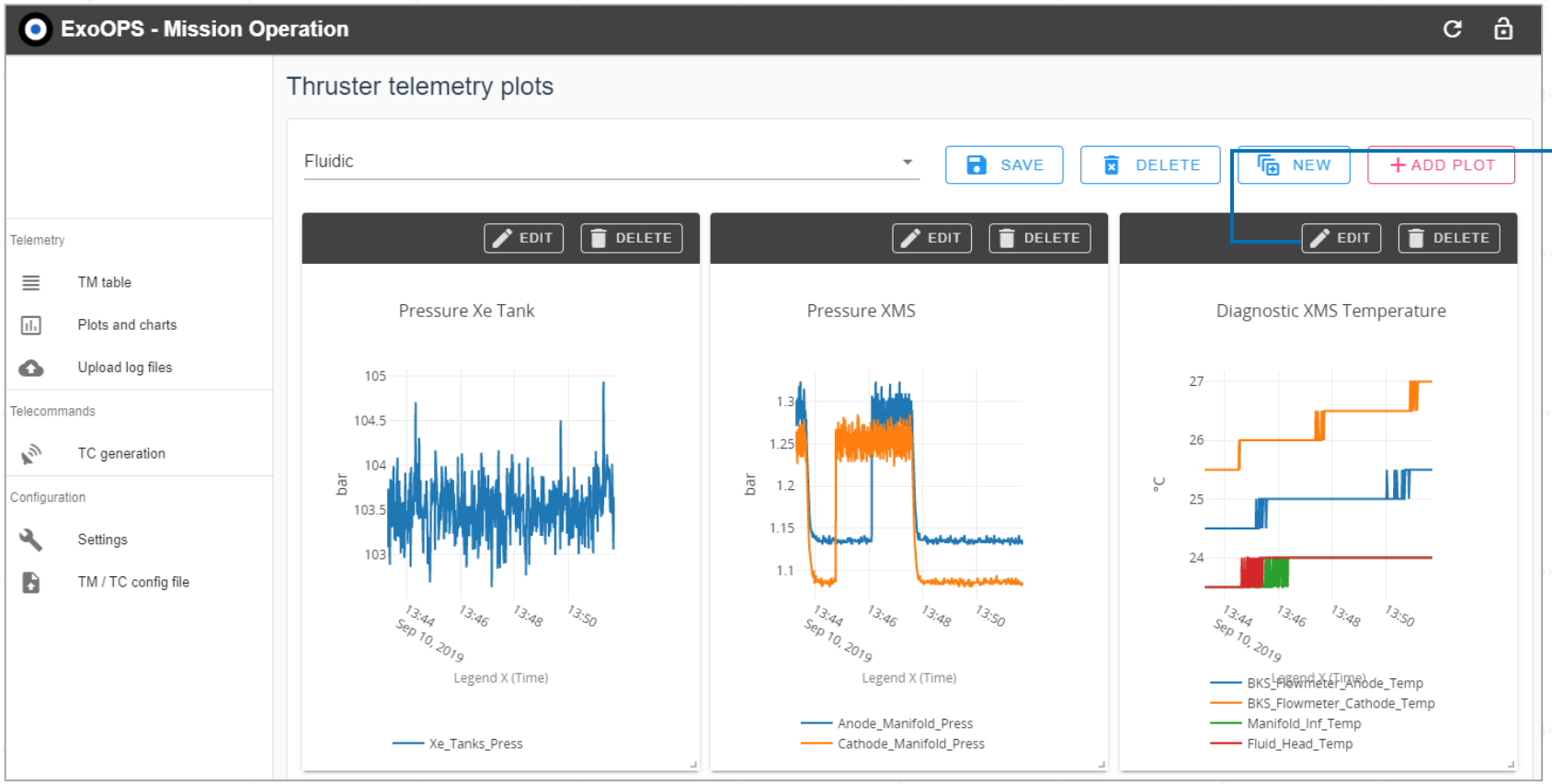
Additional options

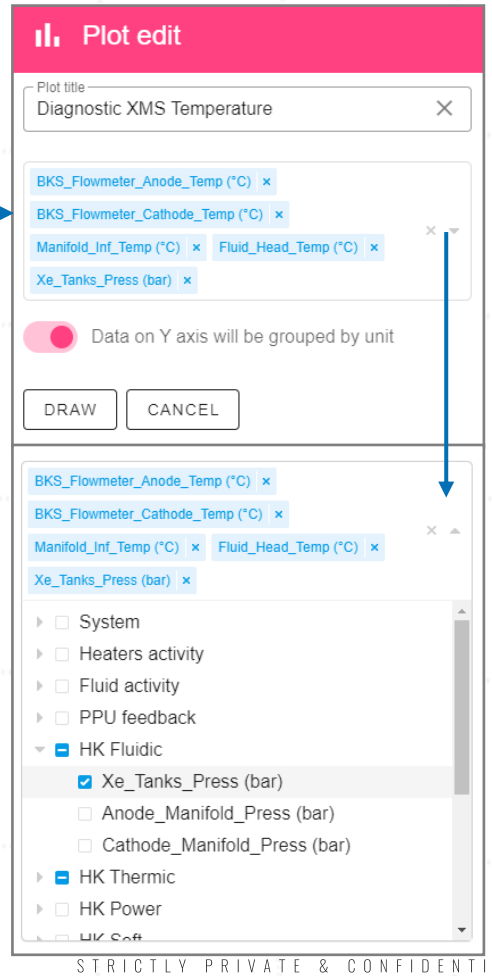
- VPN access
- Database hosted by user
- On-premises deployment

[1] Cloud Service Provider

Telemetries dashboard

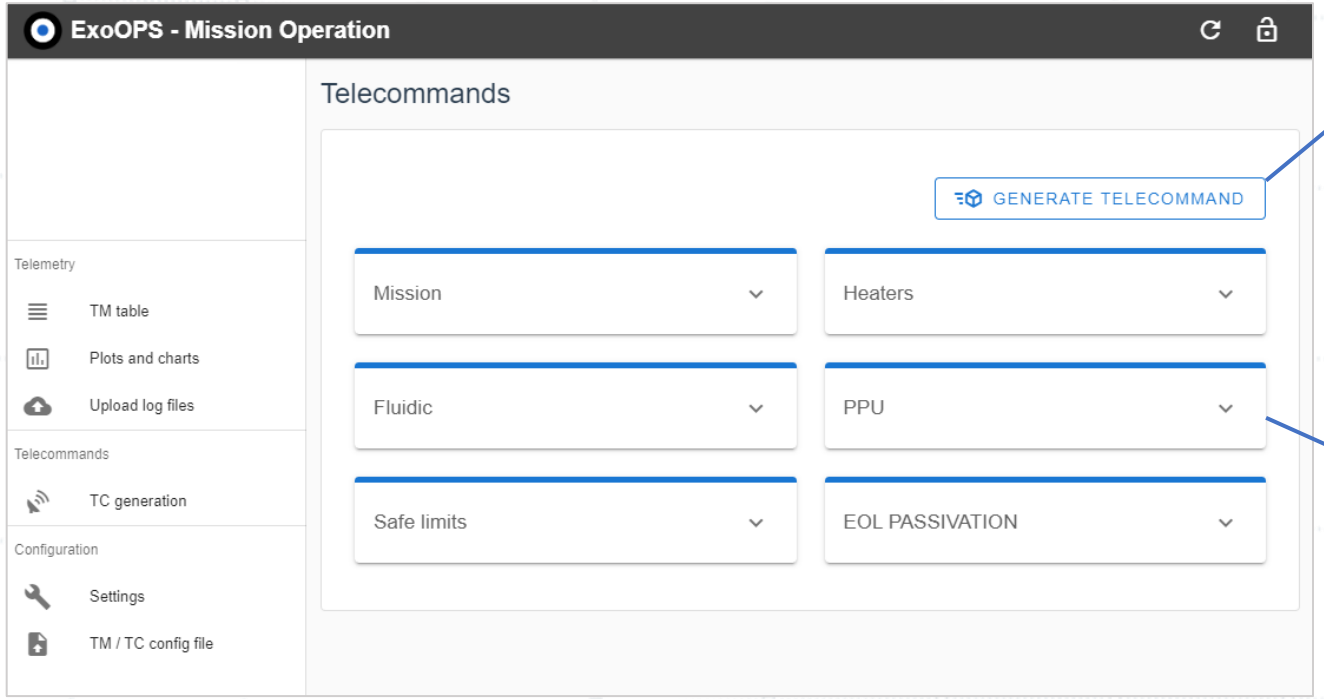
USER INTERFACE

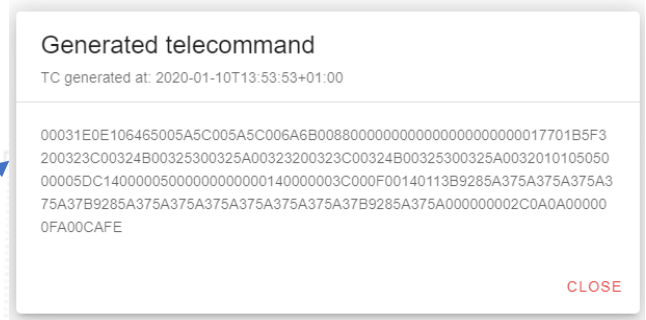


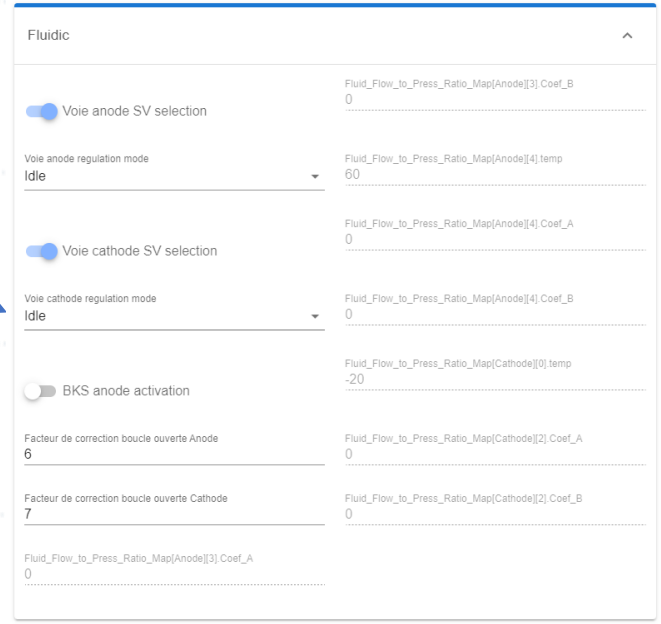


Telecommands creation

USER INTERFACE







Flight plan management

USER INTERFACE