MBSE 2022 – ESA Conference
Early validation of operational concept

24 Nov 2022

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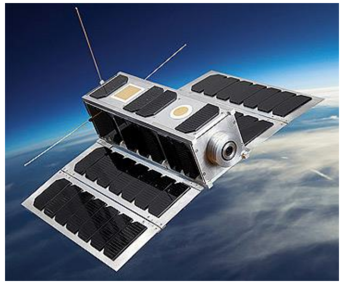
Co author: **Petros Pisias, ESA**

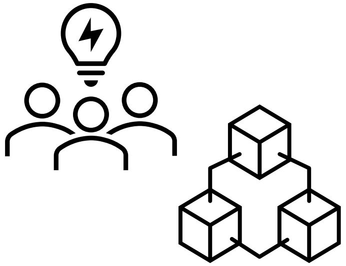
Complements of initial study also provided by **Luis Garcia Mozos**, ***MSc Aerospace Engineering*** – *Space Systems as part of his End of study internship project and* **Mirna Ojeda, Samares Engineering**

ESA study on reverse engineering with MBSE

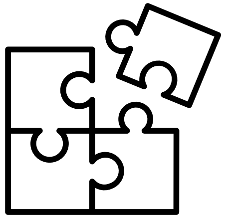


- In April 2021, ESA has started a study on Reverse engineering with MBSE of OPS-SAT mission and system
  - First CubeSat mission designed and operated by ESA since 2019
  - Low-cost, open, and flexible flying ‘laboratory’ powerful platform for in-orbit demonstration (IOD)
  - Large and diverse team mixing academic and industrial stakeholders

  ➔ some challenges and pain points…



- 1st goal was to investigate whether an MBSE approach and tool could help in addressing those pain points and to which extent

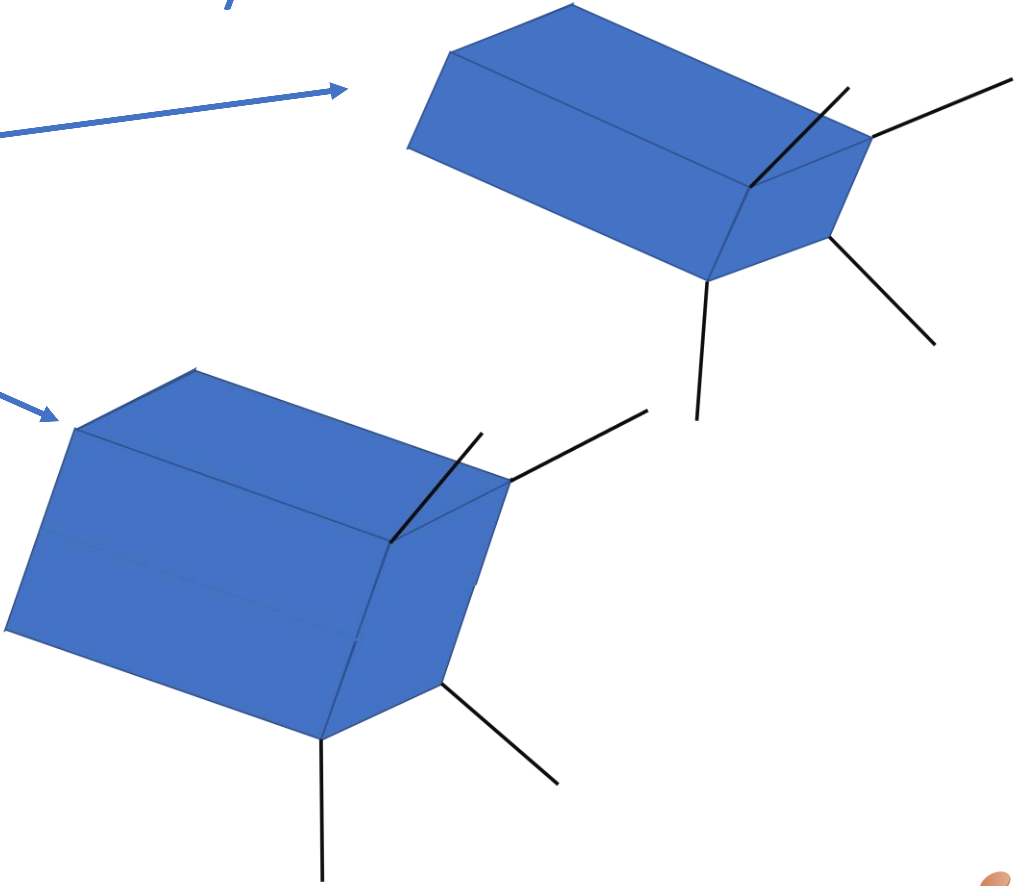


- **2nd goal was to build a model as a reference for use by future missions including OPS-SAT 2 (planned for 2024)**

Samares Engineering was awarded as Prime on that study with the support of Airbus DS and some consulting from TU Graz (OPS-SAT development)

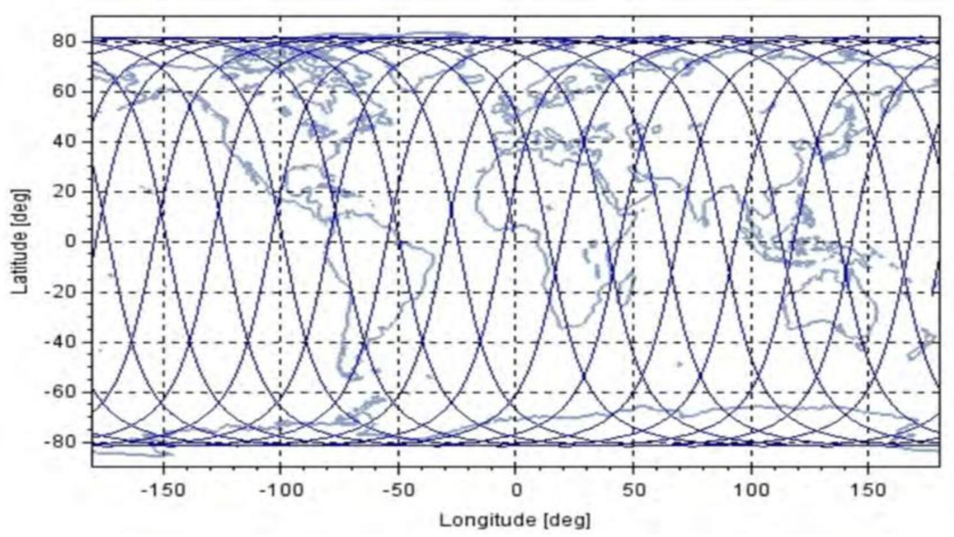
OPS-SAT2 fundamentals

- Mission duration: 2 years + 2 optional years
- Sun Synchronous Orbit (SSO) compatible with any LTAN
- Altitude between 500 km and 600 km
- Baseline design: 6U CubeSat
  - Possible alternative design: 12U CubeSat
- 5 operational modes:
  - SAFE
  - STBY (Stand-by)
  - OCOM (Optical communication)
  - RFCOM (Radiofrequency communication)
  - EXP (Secondary experiments mode)

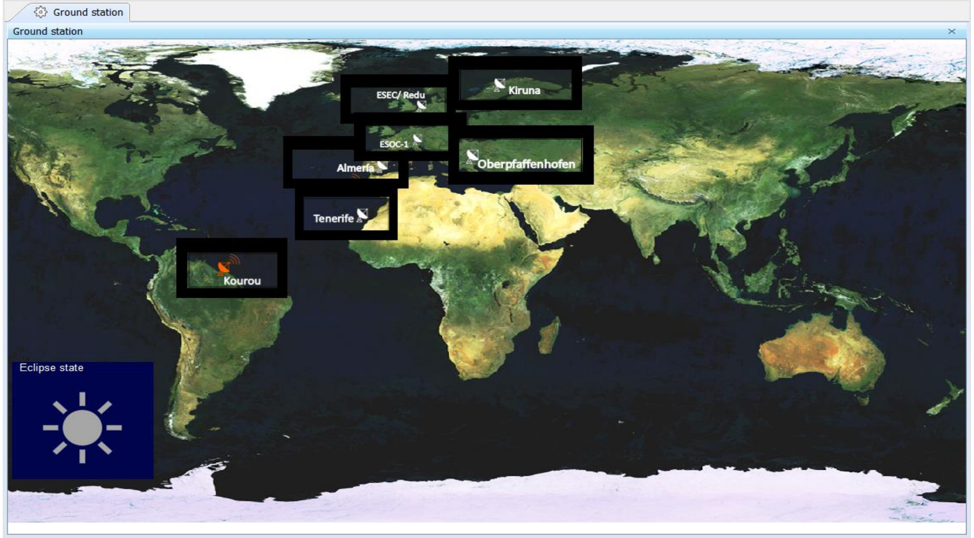


OPS-SAT2 orbit details and communication

- Orbit period: Approx. 1h30min
- Eclipse duration: Approx. 30min every orbit
  - It is the fraction of the orbit in which the Earth blocks the sunlight to the satellite



- Communication only possible when the satellite overflies a ground station
  - Location of ground antennas important for TC transmission, monitoring, OCOM...
  - 7 ground stations identified for this mission, with different capabilities



An operational concept described in various formats

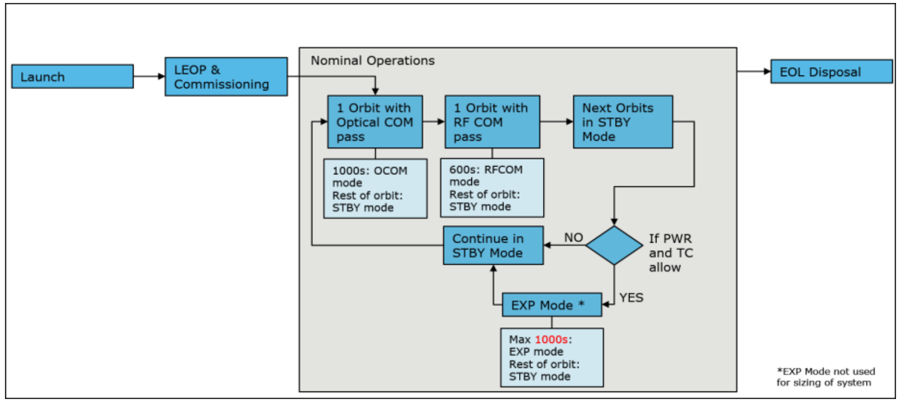


Figure 7-7: Concept of Operations – Mission Level

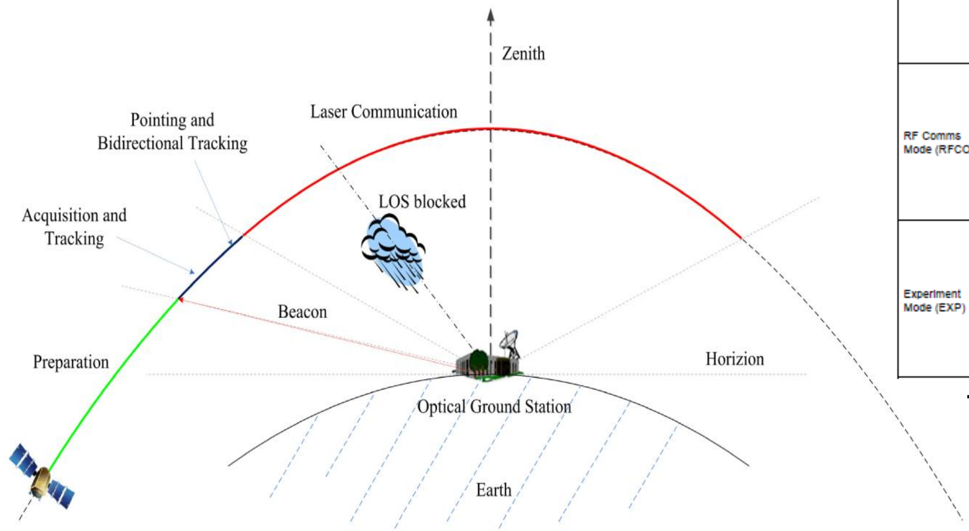


Figure 4-1: Sequence of Optical Communications LEO-OGS RD[7].

OPS-SAT-2 - System Modes		
Mode	**Description**	**Duration**
Safe Mode (SAFE)	• Attitude: Tumbling (assuming 1 – 60°/s) • Payload: completely switched off • Platform: o SBand and UHF RX always on o TX with 10% duty cycle (assuming regular transmission of spacecraft monitoring data)	Continuous up to 3 days
Standby Mode (STBY)	• Attitude: o Nadir pointing and solar yaw steering o Possibly including attitude changes for drag minimization in eclipse • Payload: GNSS and Payload OBC in standby (see section 7.5 – Power reduction) • Platform: o SBand and UHF RX always on o SBand and UHF TX off (Communications are assumed to only happen during OCOM and RFCOM modes) o AOCS equipment always on (RW assumed 20% duty cycle) except star tracker remaining always off	Continuous
Optical Comms Mode (OCOM)	• Attitude: Slewing or ground station pointing and solar yaw steering • Payload: o GNSS, Camera on o Laser Communication Terminal (50% duty cycle) o Payload OBC on at medium duty cycle (60%) • Platform: o SBand and UHF RX always on o SBand TX at 10% duty cycle, UHF TX off o AOCS equipment always on including star trackers and highest power consumption on the reaction wheels (RW assumed 30% duty cycle)	1000s (500s of actual optical link)
RF Comms Mode (RFCOM)	• Attitude: Nadir pointing and solar yaw steering • Payload: o GNSS, Camera on o Payload OBC on at medium duty cycle (40%) • Platform: o SBand and UHF RX always on o SBand TX and XBand TX on, UHF TX off o AOCS equipment always on including star trackers and reaction wheels (RW assumed 20% duty cycle)	600s
Experiment Mode (EXP)	• Attitude: Nadir pointing and solar yaw steering • Payload: o GNSS on at max. power, Camera on o Payload OBC on at max. power • Platform: o SBand and UHF RX always on o SBand TX at 10% duty cycle, UHF TX off • AOCS equipment always on including star trackers and reaction wheels (RW assumed 20% duty cycle)	Maximum of 1000s cumulative over 1 orbit

Table 7-2: System Modes

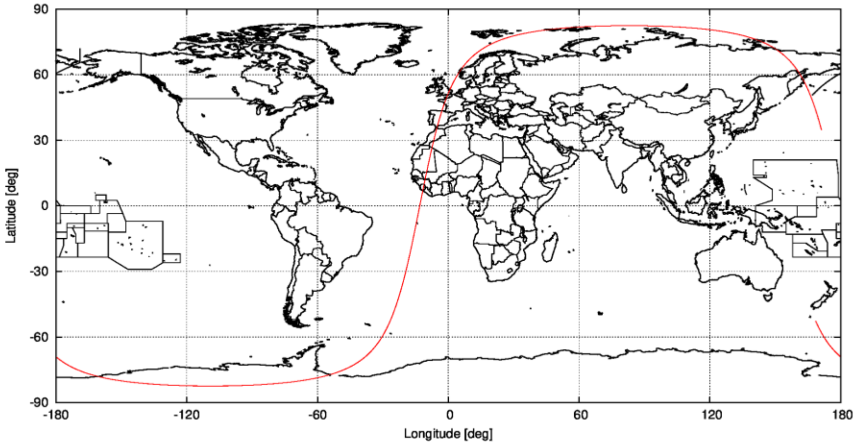


Figure 6-8: Ground Track of Sample Orbit Arc

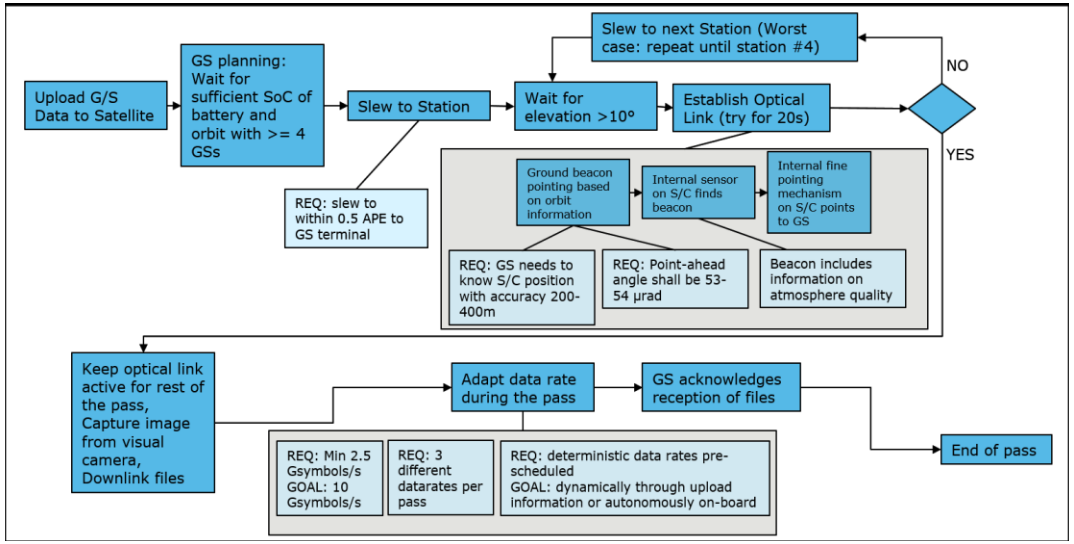


Figure 7-8: Concept of Operations – Optical Communication pass

The global MBSE approach – a set of models with layers

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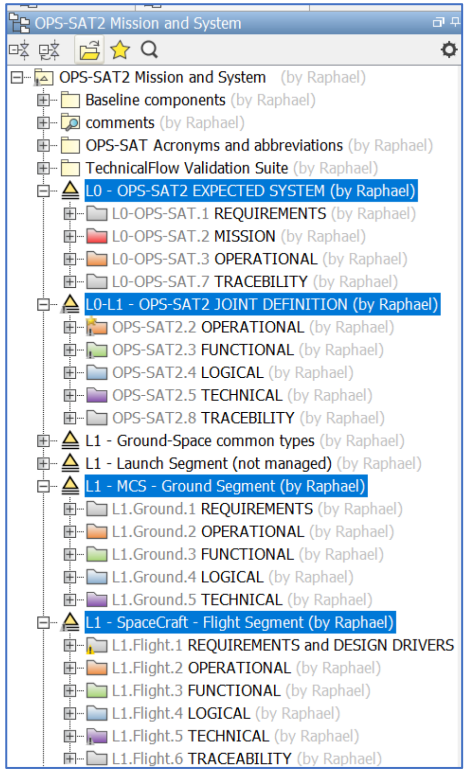
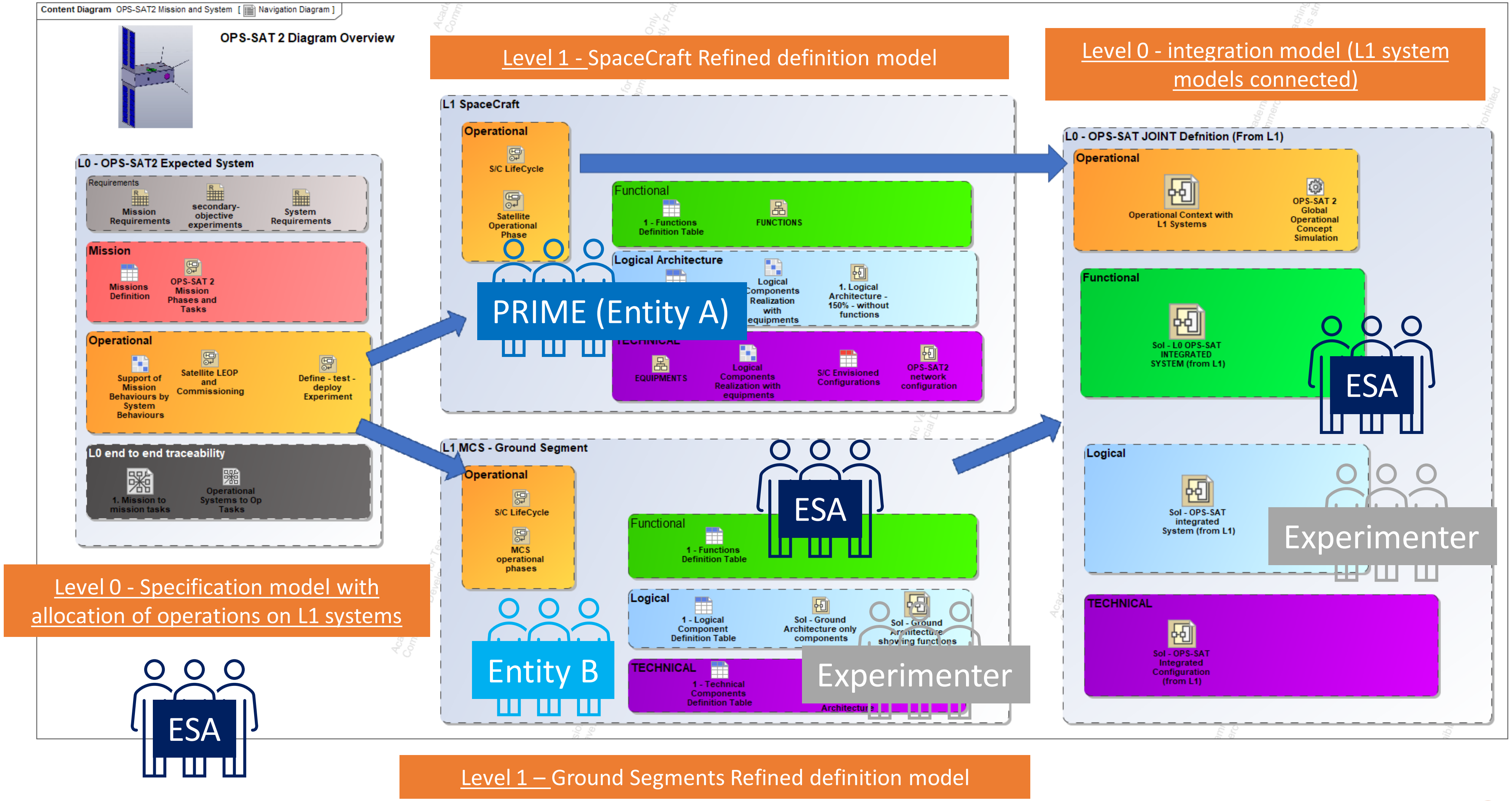




Airbus RMOFLT framework

requirements

- Mission
- Operations
- Functional
- Logical
- Technical

Mission, Operations: Problem

Functional, Logical, Technical: Solution

Focus on the formalization of the operational concept

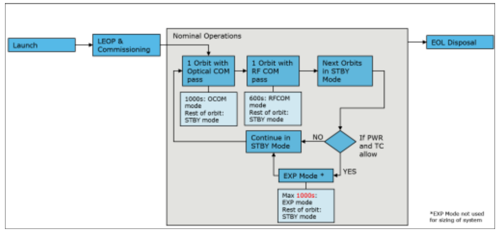
- Operational model objectives:
  - Define the **operational systems (Flight, Ground, Launcher) and their key properties**
  - Define system evolution depending on its **life cycle phases and modes**
  - Refine the operational states by a detailed **behavior with execution logics**
  - Define the **interaction between the operational systems** as **signals** exchanged through **ports**

- SysML translation:
  - Structure → Block definition diagram the architecture
    Internal block definition diagram for communication
  - Behavior → State machine diagrams
    Activity diagrams
  - Parametrics → diagram to bind the key parameters including time
  - Requirements → Requirements table for traceability

OpsTypeID	Type of command
10	OCOM activity
20	RFCOM activity
30	Secondary experiment (EXP)
40	Complete nominal sequence
50	Custom operations
100	Enter in SAFE mode
200	Enter in STBY mode
300	Leave SAFE mode and restore nominal

- Trajectory state block:
  - Position
  - Eclipse state
  - GS data
- OpsCommand block:
  - Unique ID, Priority
  - Operations type ID
  - Start time
  - Operation details
    - OCOM and RFCOM ground stations
    - Sub-activities starting times

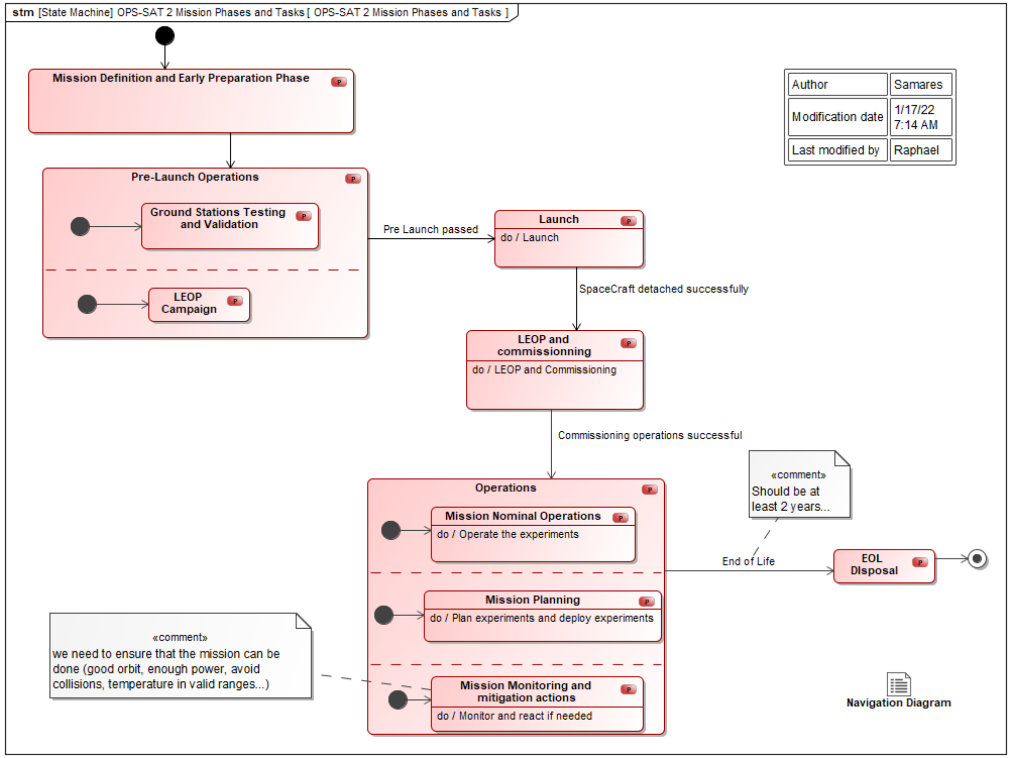
The SysML model – Level 0 for the mission and operations

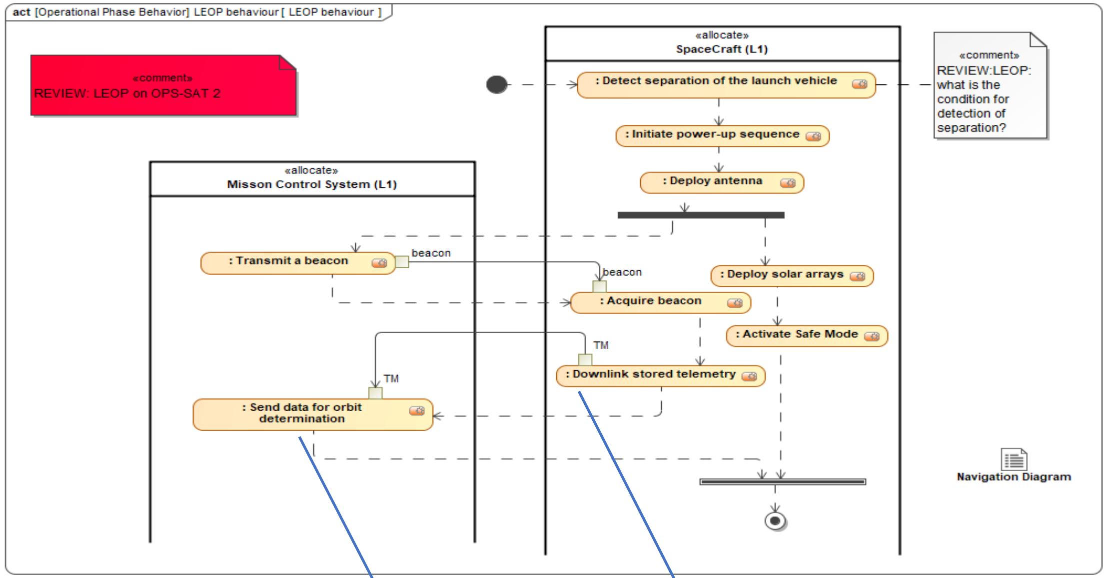


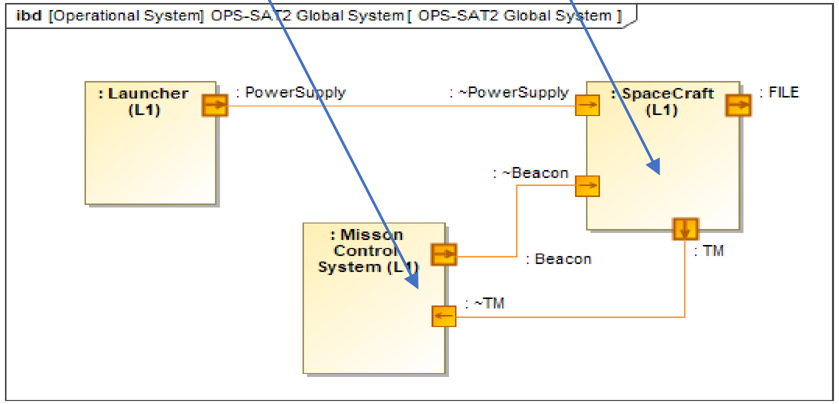
3.3.1 *LEOP*

Once released from inside the rocket, the spacecraft will automatically switch on all its essential loads and if spacecraft state is nominal, the deployment sequence will start automatically.
Due to the agreed launch configuration, the OPS-SAT separation sequence and the autosequence will most likely start and complete outside the ESOC-1 A ground station visibility.
The automatic sequence shall execute the following steps ([RD-5]):

- automatically detect the separation from the launch vehicle
- initiate power-up sequence
- 30 minutes after the (first) boot, the UHF antenna deployment will automatically start; confirm UHF antenna deployment status is Deployed (antennas 1, 2 and 3)
- 5 minutes after successful UHF antenna deployment continue with:
  - Solar panel 1 wing 1 and 2 automatically deployment
  - Solar panel 2 wing 1 and 2 automatically deployment
  - Confirm solar arrays deployment status is Deployed
- bring the satellite into Safe Mode





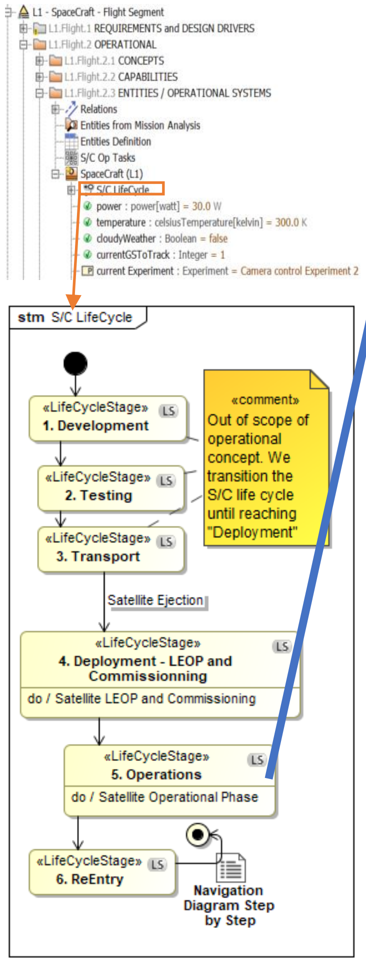


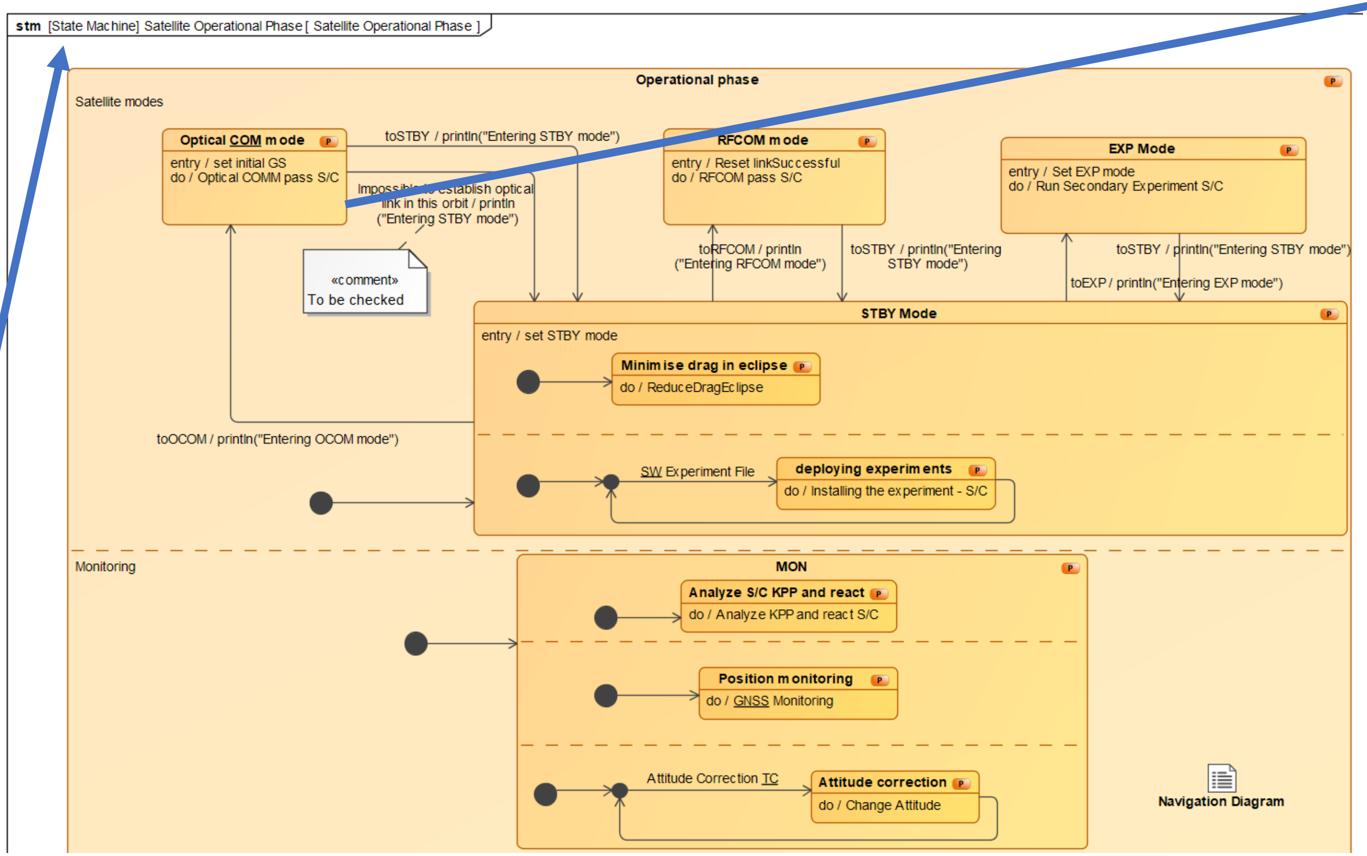
From mission to op tasks allocated to L1 Systems

We show here a first decomposition of the mission into phases, operational behaviours and op tasks allocated to Systems

Note: this is a simplified view of the operational concept that is next refined at L1 level by both S/C and MCS teams

L1 - Refinement of S/C behavior – from lifecycle to modes and to tasks





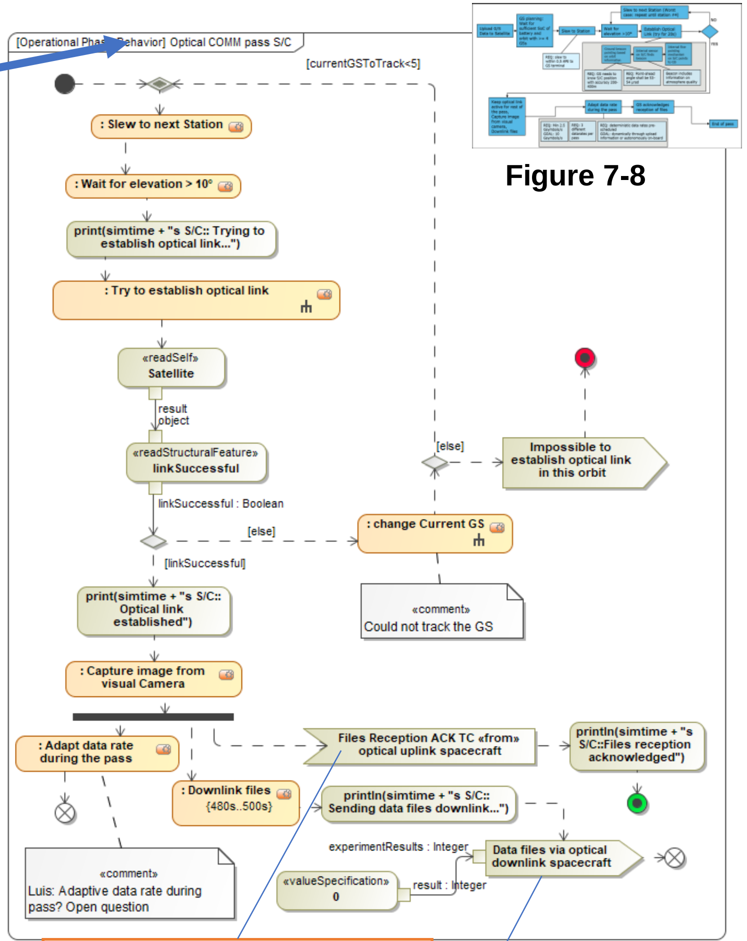


Figure 7-8

Waiting for a given signal…

Sending a given signal…

Monitoring and TC Handling is common for most satellite missions
Some tailoring for the operational states

S/C behavior is complete and consistent by construction – simulation will show if it is also correct (as expected)

L1 - Refinement of MCS behavior – from lifecycle to modes and tasks

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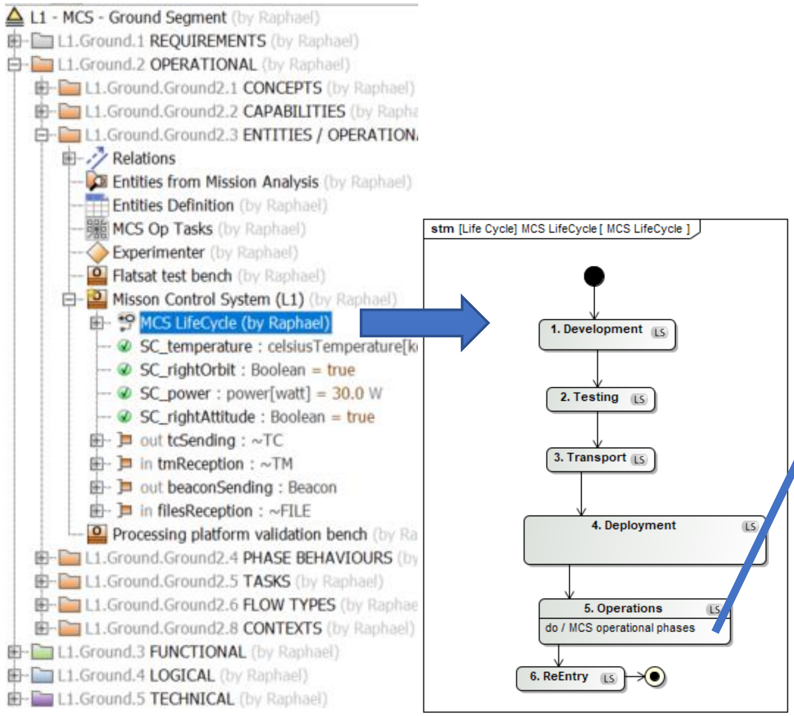
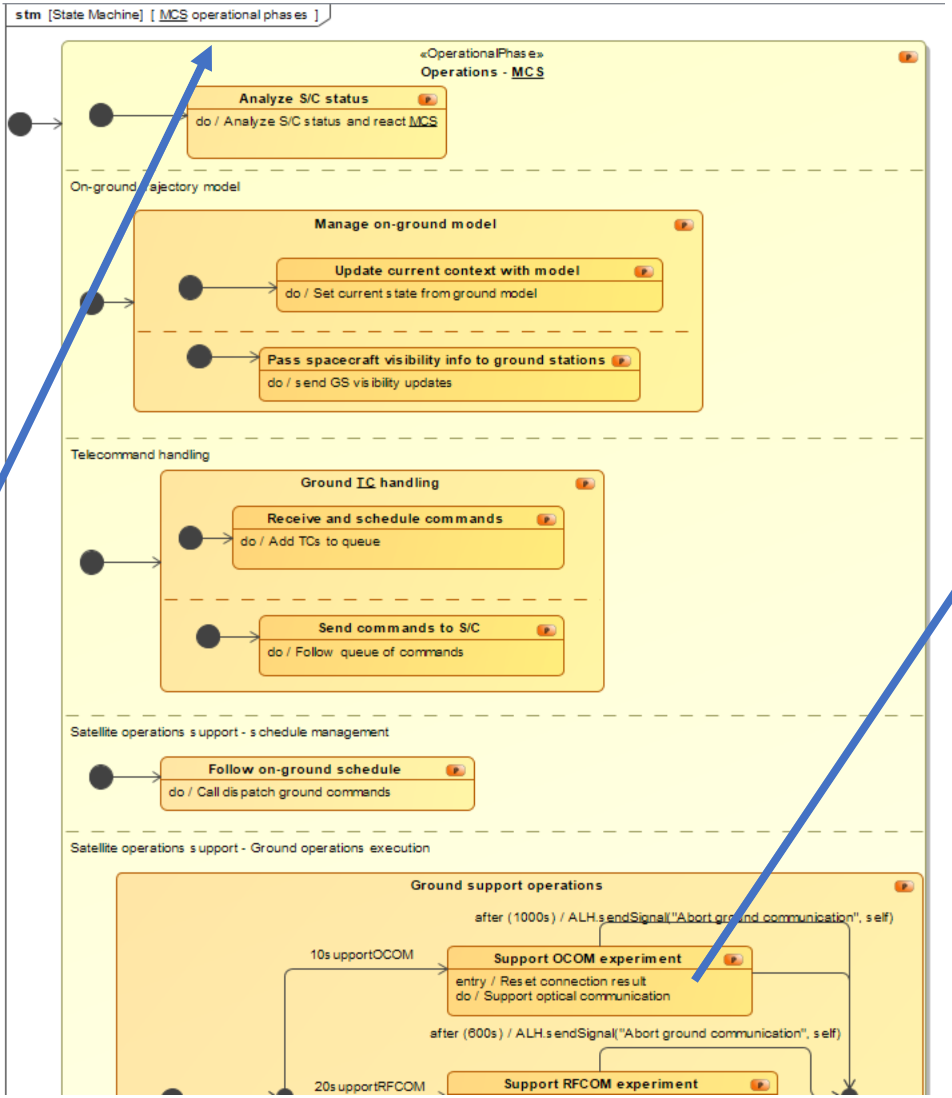
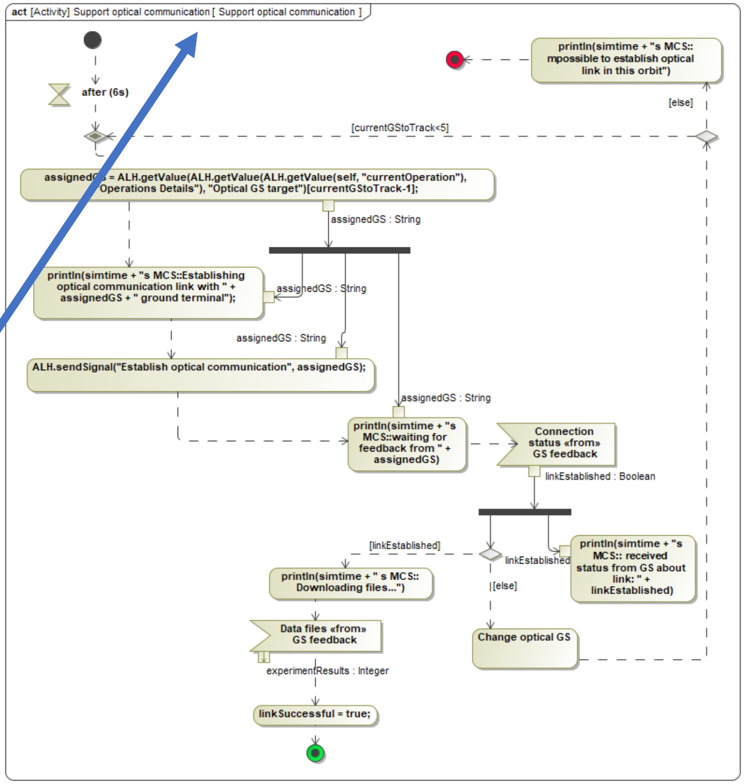


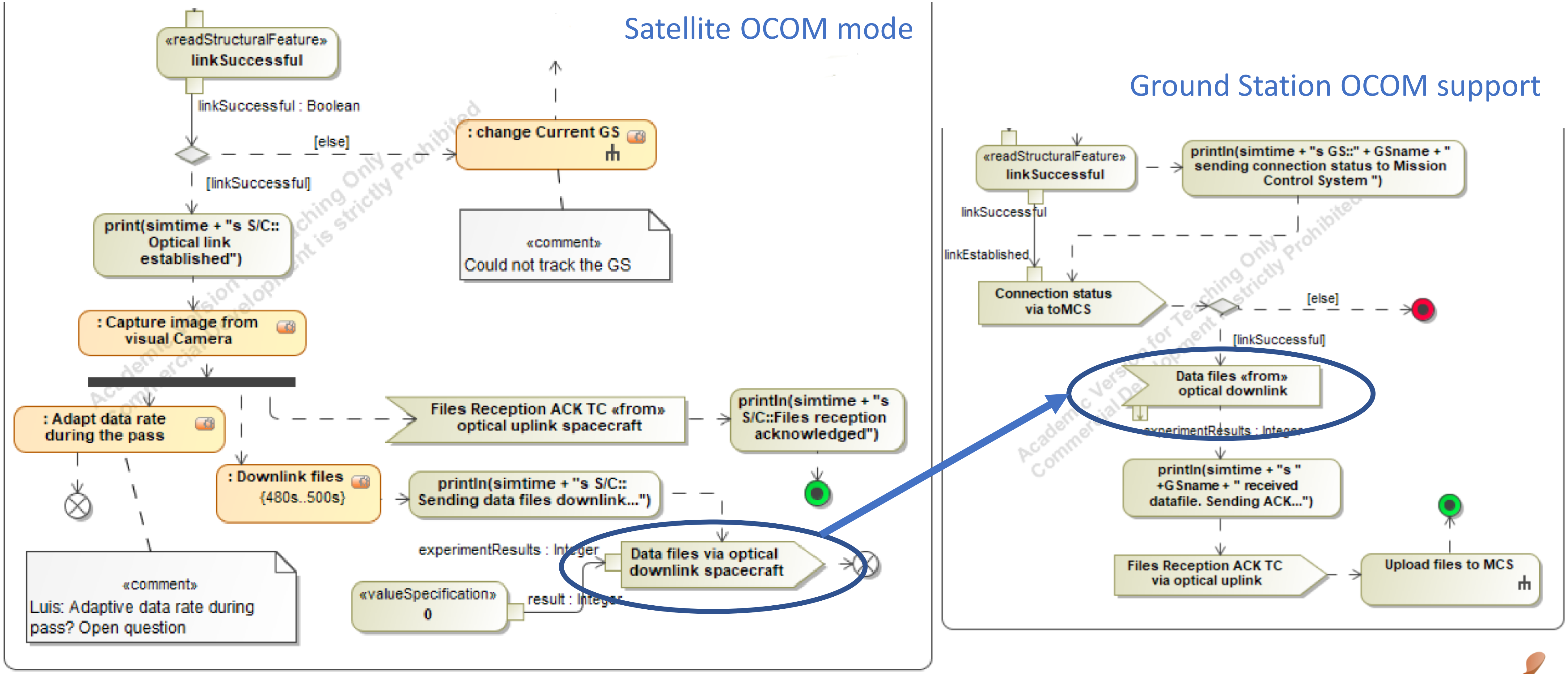




Common for most satellite missions

Some tailoring for the support of operational states

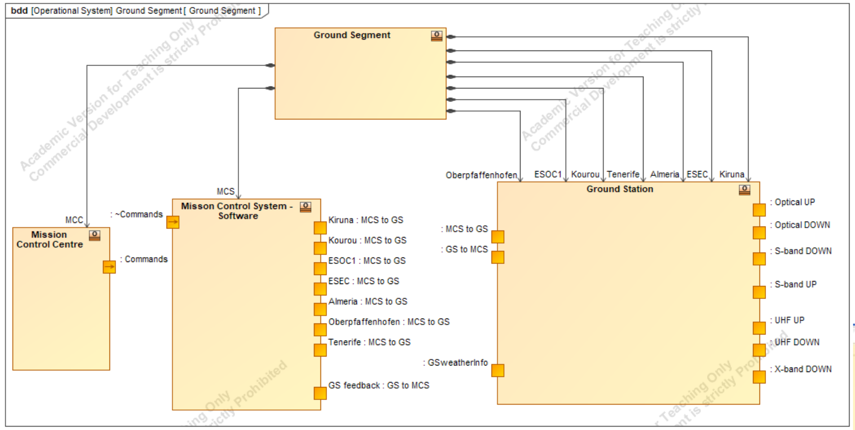
Ground-Space interactions

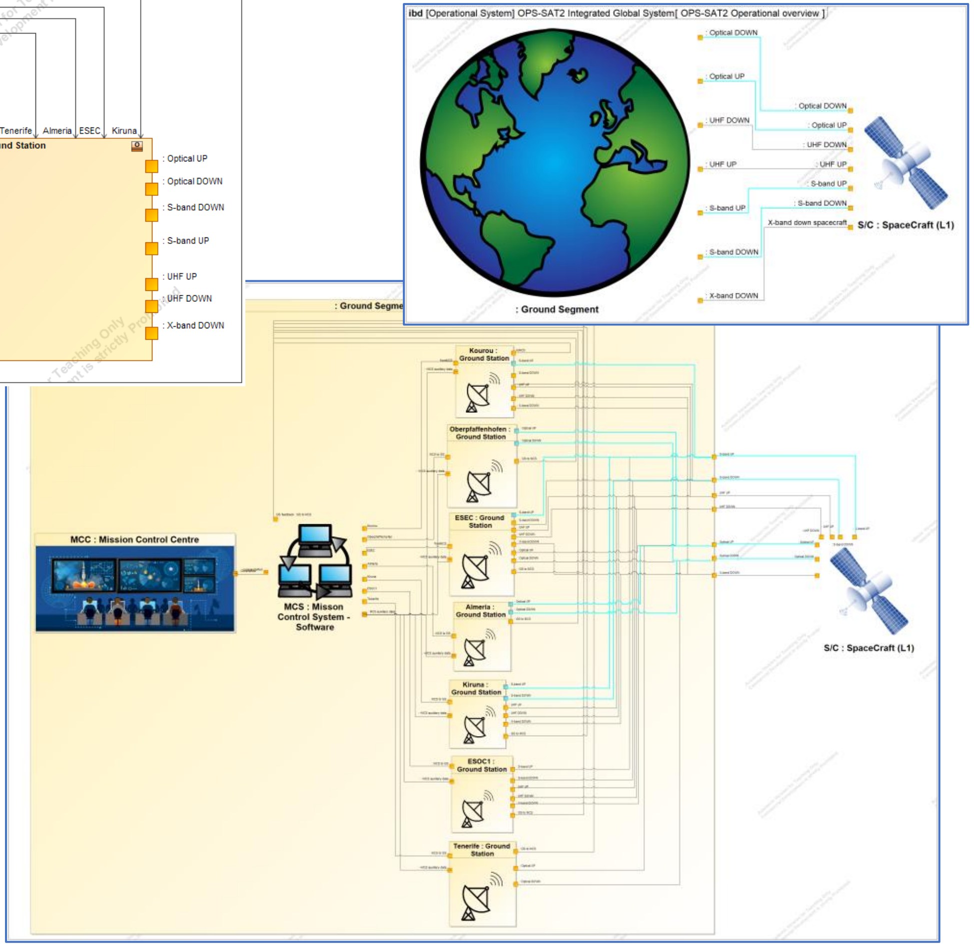


Internship to enhance OPS-SAT2 operational model

Luis Garcia Mozos, *MSc Aerospace Engineering – Space Systems - End of study internship project – Apr to Oct 2022*

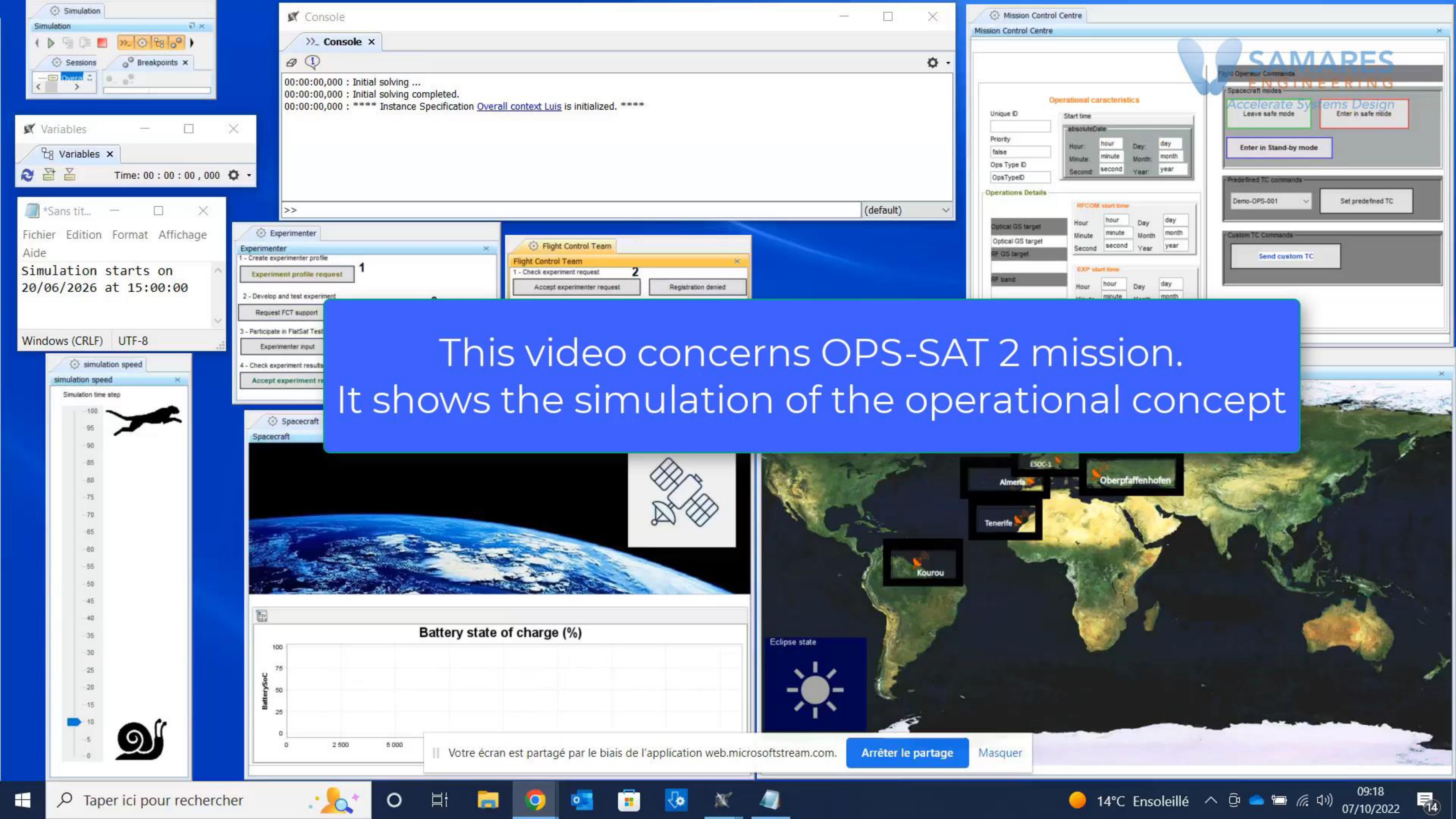
- Ground segment architecture
- Time data using UTC times
- Spacecraft operations
- Ground segment operations
- Power monitoring
- Trade offs between 6U and 12U (not presented here)





Mirna Ojeda, Samares Engineering has also contributed with the development of simulation widgets and support on simulation tuning

Experimenter and Flight Control Team (FCT), User interface with widgets (Mission Control Centre perspective), Time speed management


This video concerns OPS-SAT 2 mission.
It shows the simulation of the operational concept
Console
00:00:00,000 : Initial solving ...
00:00:00,000 : Initial solving completed.
00:00:00,000 : **** Instance Specification Overall context Luis is initialized. ****
Variables
Time: 00 : 00 : 00 , 000
Simulation starts on 20/06/2026 at 15:00:00
Experimenter
1 - Create experimenter profile
Experiment profile request
2 - Develop and test experiment
Request FCT support
Experimenter input
4 - Check experiment results
Flight Control Team
1 - Check experiment request
Accept experimenter request
Registration denied
Mission Control Centre
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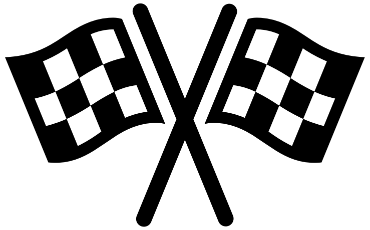
Operational caracteristics
Leave safe mode
Enter in safe mode
Enter in Stand-by mode
Set predefined TC
Send custom TC
simulation speed
Simulation time step
Spacecraft
Battery state of charge (%)
BatterySoC
ESOC-1
Almeria
Oberpfaffenhofen
Tenerife
Kourou
Eclipse state
Votre écran est partagé par le biais de l'application web.microsoftstream.com.
Arrêter le partage
Masquer
Taper ici pour rechercher
14°C Ensoleillé
09:18
07/10/2022

Conclusion

This MBSE model developed to support early validation of OPS-SAT 2 operational concept through simulation can certainly be reused with little tailoring for many future missions !

What about setting a community to share this model as a "mission early analysis framework"?

Thanks for your attention !



Note: I can do the demo or give more precisions on the model and simulation today… or later…

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