Covered Objectives: O-1, O-4, T-3

Short Paper – MBSE2022

# Simulation of Operational Concept – Illustration on OPS-SAT 2

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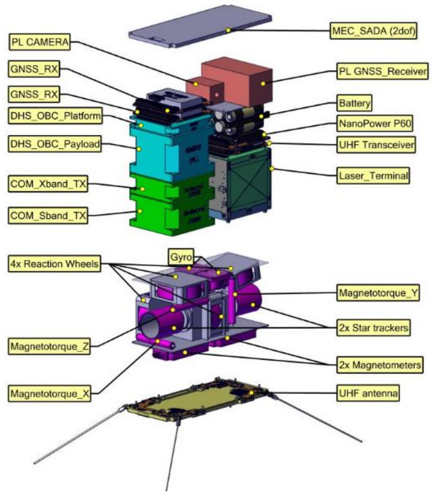
A few years ago, ESA has launched OPS-SAT mission, the first CubeSat mission designed and operated by ESA with the goal to provide a low-cost, open, and flexible flying 'laboratory' – a powerful platform for in- orbit demonstration of new, innovative control systems and software.

Mid 2021, ESA has decided to launch OPS-SAT 2 mission, that will extend OPS-SAT mission and system with more emphasis on optical communication (optical terminal, autonomous optical link scheduling) and that will provide an improved architecture with regards to the lessons learned on OPS-SAT. A CDF Study Report has been defined with assessment of CubeSat In-Orbit Demonstration experiments. This report details the operational concept and the various trades analyzed to define the technical baseline.




In this paper, we explain how it is possible to formalize this operational concept into a model that contains both the architecture and the operational behavior and how this model can be simulated to ease the early validation of the operational concept.

## Formalization of operational behavior at L0 – systems of systems

The first step consists in considering the set of all operational systems as one global system. With this approach, we introduce the OPS-SAT 2 global system as a set of 3 cooperating operational systems: Launcher, spacecraft and Ground Segment. The interactions are not defined directly but are rather derived from the main behavior of the mission.

The behavior of the mission is described in 2 steps]:

1. First, we have the mission phases that formalize the key stages of the mission; One phase can have sub-phases.
2. Then, for each phase, we get the phase behavior that define an arrangement of operational tasks to perform to drive and monitor the mission.

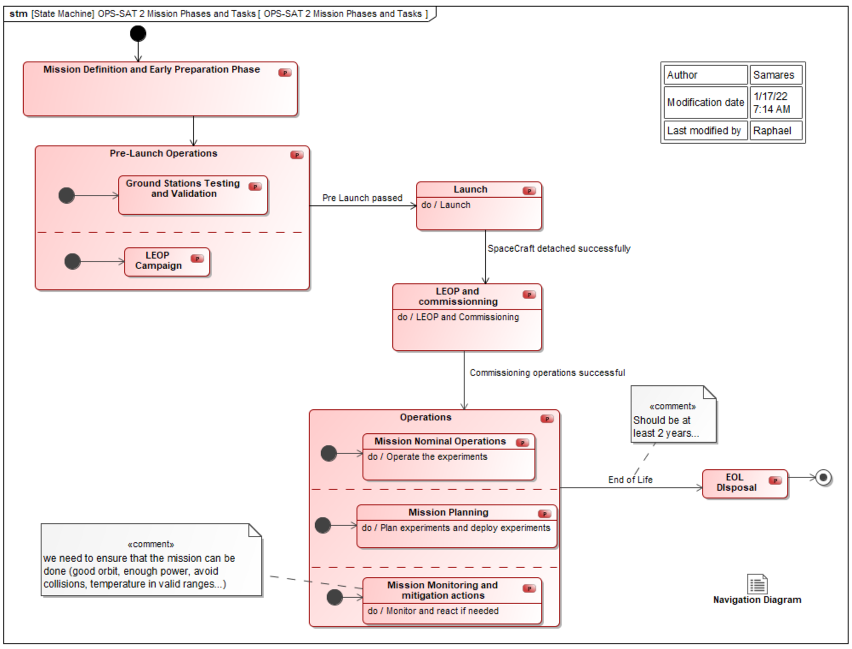



Figure 1: mission phases

Each operational behaviour is detailed in terms of operational tasks organized with an execution logic and allocated to L1 Operational Systems (Launcher, Satellite, MCS) ➔ we can deduce a first set of operational exchanges between L1 systems

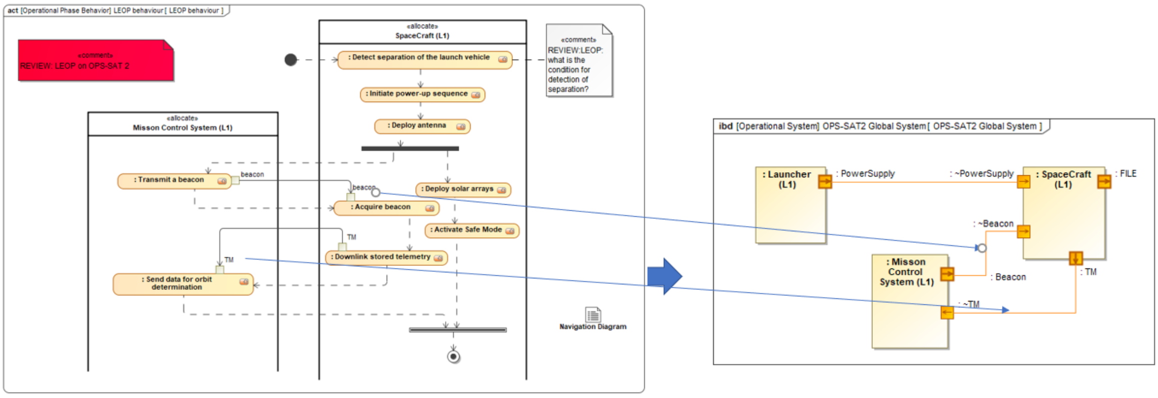



Figure 2: refinement of behavior (SysML Activity) into an architecture (SysML IBD)

## Refinement of operational behavior for each operational system

The refinement of an operational system consists in defining its full behaviour starting from its life cycle (high level view), and with refinements for "operations" phase down to the exchanges with the other systems.

Concerning the spacecraft (S/C), we have built the following execution logic refinements:

- Execution of the S/C Life cycle (as a state machine) with several phases including "operations"
- During "operations", execution of "Satellite Operational Phases" (state machine), with the different system modes (including the "Optical COM pass") and their transitions
- During "Optical COM pass" phase, execution of the associated behavior as a SysML activity showing the protocol to acquire the beacon sent by a ground station within 20 s and then downlink images captured by the camera.

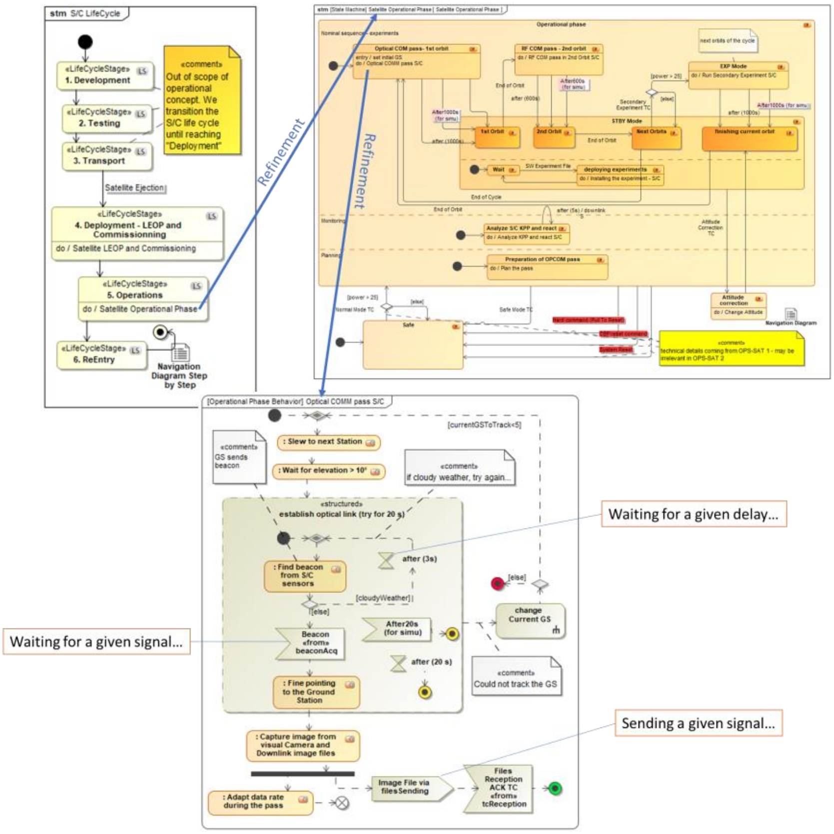



Figure 3: refinement of spacecraft behavior over time

With the same systematic approach, we have refined the Mission Control System to show the detailed behavior during operations, as illustrated below:

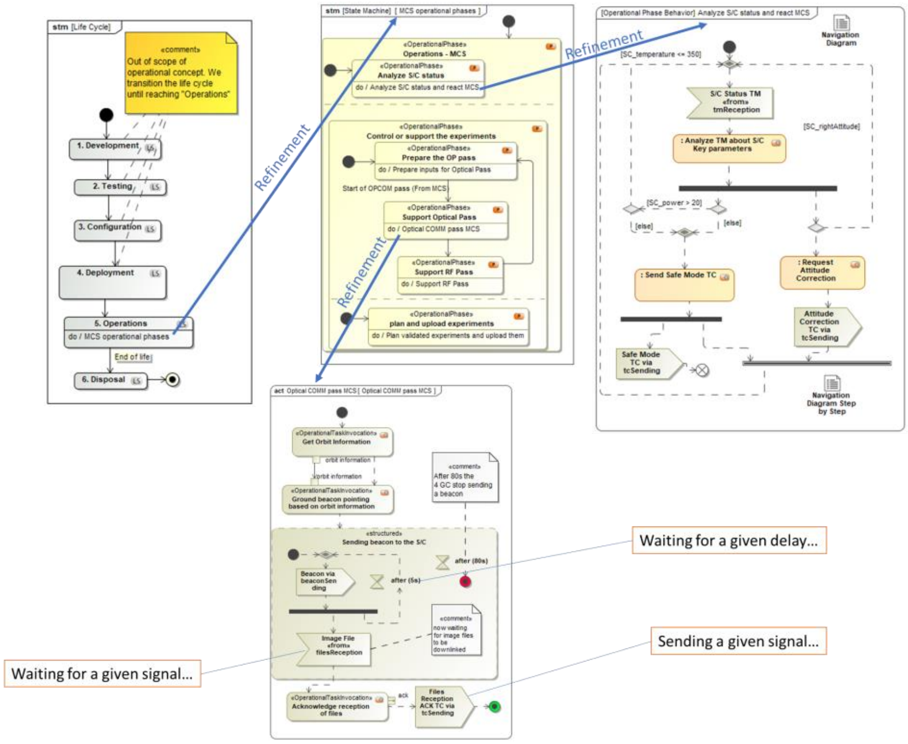
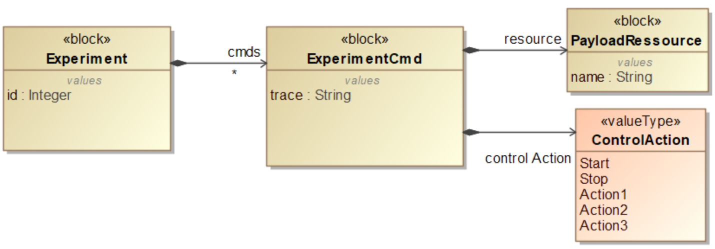


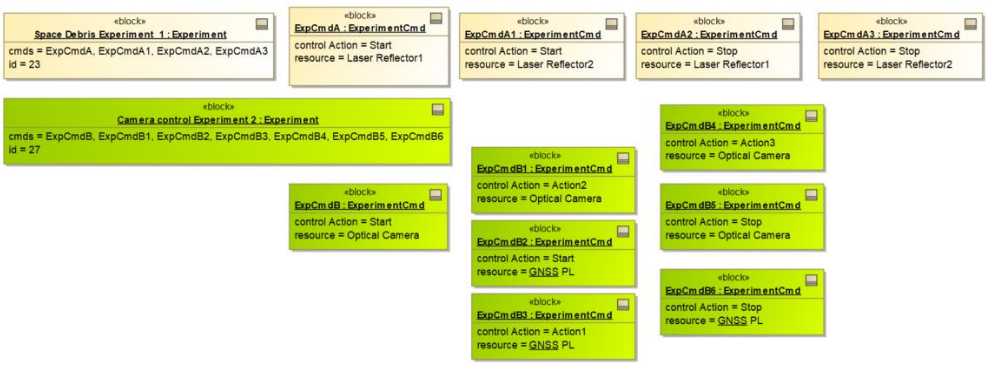
Figure 4: refinement of mission control system behavior over time

## Upload, installation and run of experiments during the mission

We have developed a small modelling framework to describe an experiment in terms of commands that act on payload resources.




Then we have shown that it was possible to define different experiments by instantiating this framework on several elements as illustrated below with 2 experiments (Id 23 and Id 27):



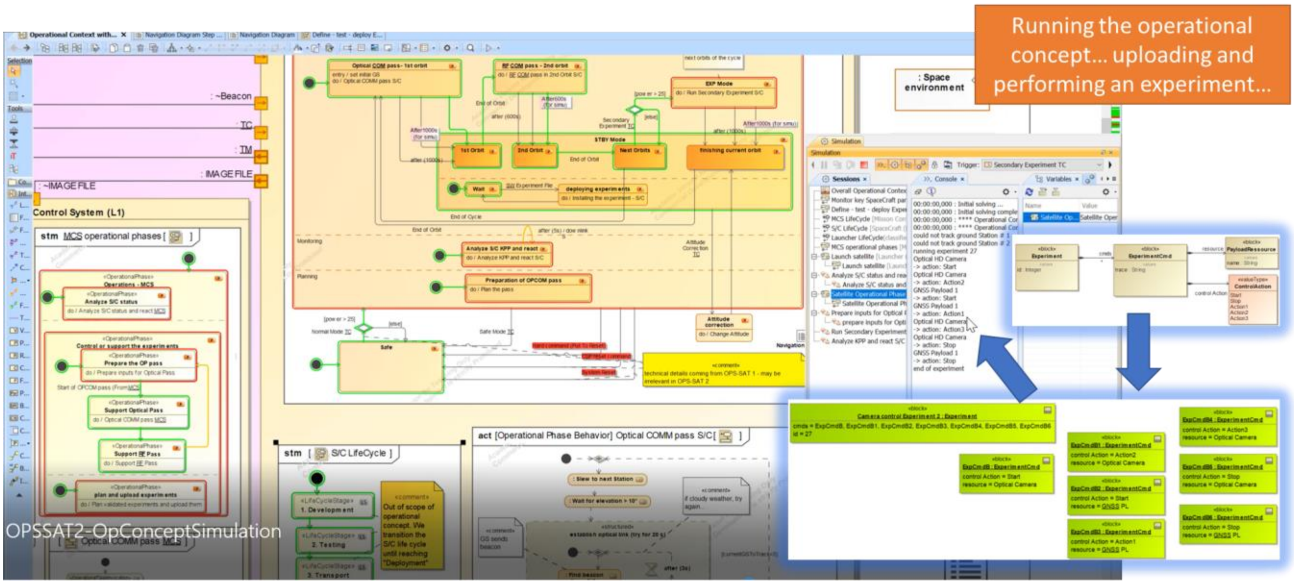
## Simulation of the operational concept

With the approach described previously, it is possible to define the operational behaviour of each operational system: each system has their lifecycle refined into phases and modes using SysML state machines, that are then refined with activity diagrams to formalize the set of steps performed by a system and the operational exchanges with the other operational systems (sending, reception).

If we ensure that each exchanged data is really transmitted between the systems through their ports as illustrated below (SysML internal Block Diagram), we ensure consistency and completeness by construction: each behaviour is refined and simulated which means that there is no missing step and all exchanged data are connected to the interfaces of the various systems and are transmitted to the other systems.

But we cannot ensure that the behaviour is correct (as expected by end users). This last step is performed through sessions of simulation with end users/customers. It is then possible to play a wide set of operational scenarios by injecting different external events/stimuli to reflect the sending of a TC from MCS, to simulate the end of an orbit or to simulate the upload of a new experiment to install and run. The simulation tool uses the injected events to transition to another mode or phase if it makes sense in the context, or to continue a behaviour blocked waiting some specific data or signal.

The following diagram shows a snapshot taken during the simulation of the operational concept, with an experiment uploaded on the spacecraft and run (the experiment progress is displayed in the console).




## Conclusion

We have demonstrated the interest of reaching an operational architecture model with operational behavior that can be simulated to support early validation of the operational concept. End users and customers can use this model as a toolbox to run a various range of operational scenarios: they can introduce events or experiments that can be uploaded onto the spacecraft during the mission, installed and finally run when the spacecraft has reached the "experiment" mode. This greatly facilitates early validation of mission operational concepts, ensuring a common understanding among key mission stakeholders and we believe that future missions can have significant benefits by using MBSE to perform such early simulation and validation of operational concepts.

## References

[1] ESA OPS-SAT mission, https://www.esa.int/Enabling_Support/Operations/OPS-SAT_your_flying_laboratory