Better Commissioning through Simulation: How to Trust your Satellite Pointing Faster

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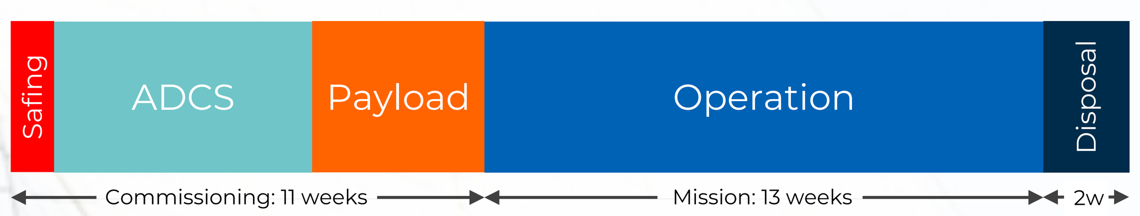
The Need

The on-orbit satellite commissioning period serves to incrementally build trust in the orbital asset, from first contact to calibration of specialized payloads.

Often, the Attitude Determination and Control Subsystem (ADCS) dominates the commissioning timeline, as engineers work to:

- Characterize / calibrate sensors & actuators
- Tune filters & controllers
- Upload new parameters settings / software

A reduction in ADCS commissioning time yields a day-for-day increase in operational time, which is especially critical for low-altitude small satellite missions (see 6 month example below).



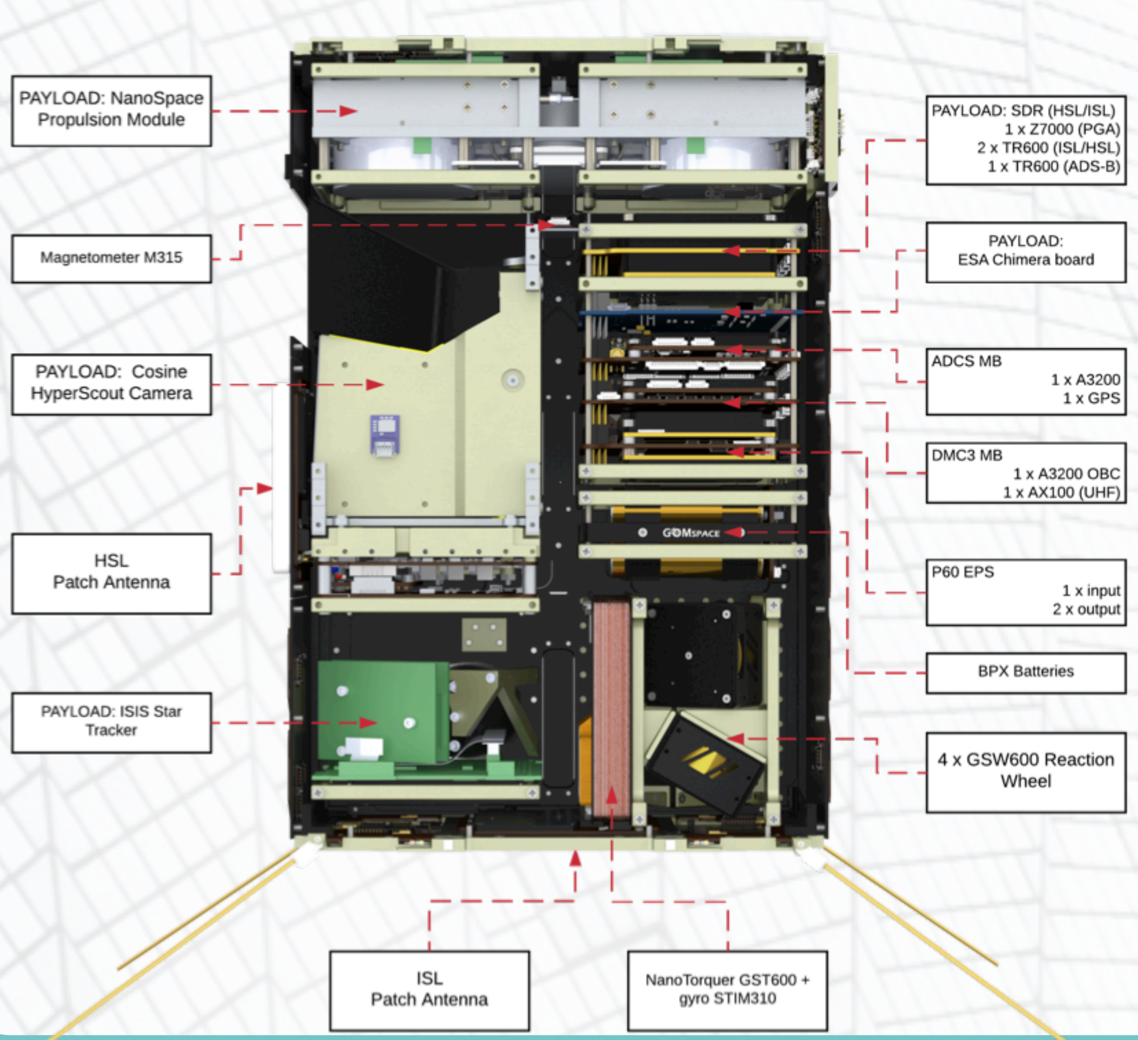
Without a realistic simulation sandbox, ADCS commissioning is a slow march of trial-and-error limited by available satellite communication periods. In order to be useful for ADCS performance prediction, a simulation must be able to account for the following:

1. Environmental attitude disturbances
2. Internal attitude disturbances
3. Non-ideal sensors and actuators
4. Mission flight software

Fulfilling this need is helpful for both commissioning and development – it allows developers to predict the impact of orbital scenarios, physical configurations, and operational choices.

The Example: GOMX-4B

- GOMX-4A/B is a dual 6U CubeSat mission launched to a 500 km SSO on 2nd Feb 2018.
- GOMX-4A developed for Danish Defense Acquisition and Logistics Organization to monitor Greenland & the artic region
- GOMX-4B developed for ESA as an In-Orbit Demonstration (IOD) mission. Carries a propulsion module to test ISL over a range of distances. Hyperspectral camera and S-band patch antenna benefit from ground-point tracking.



The Method: ADCSSIM

ADCSSIM is a Software-in-the-Loop attitude dynamics simulation that generates real-world inputs to flight software and receives actuator commands. It has been in continuous development / validation since 2003, and is based on the Matlab Simulink environment of drag & drop functional blocks.

Features

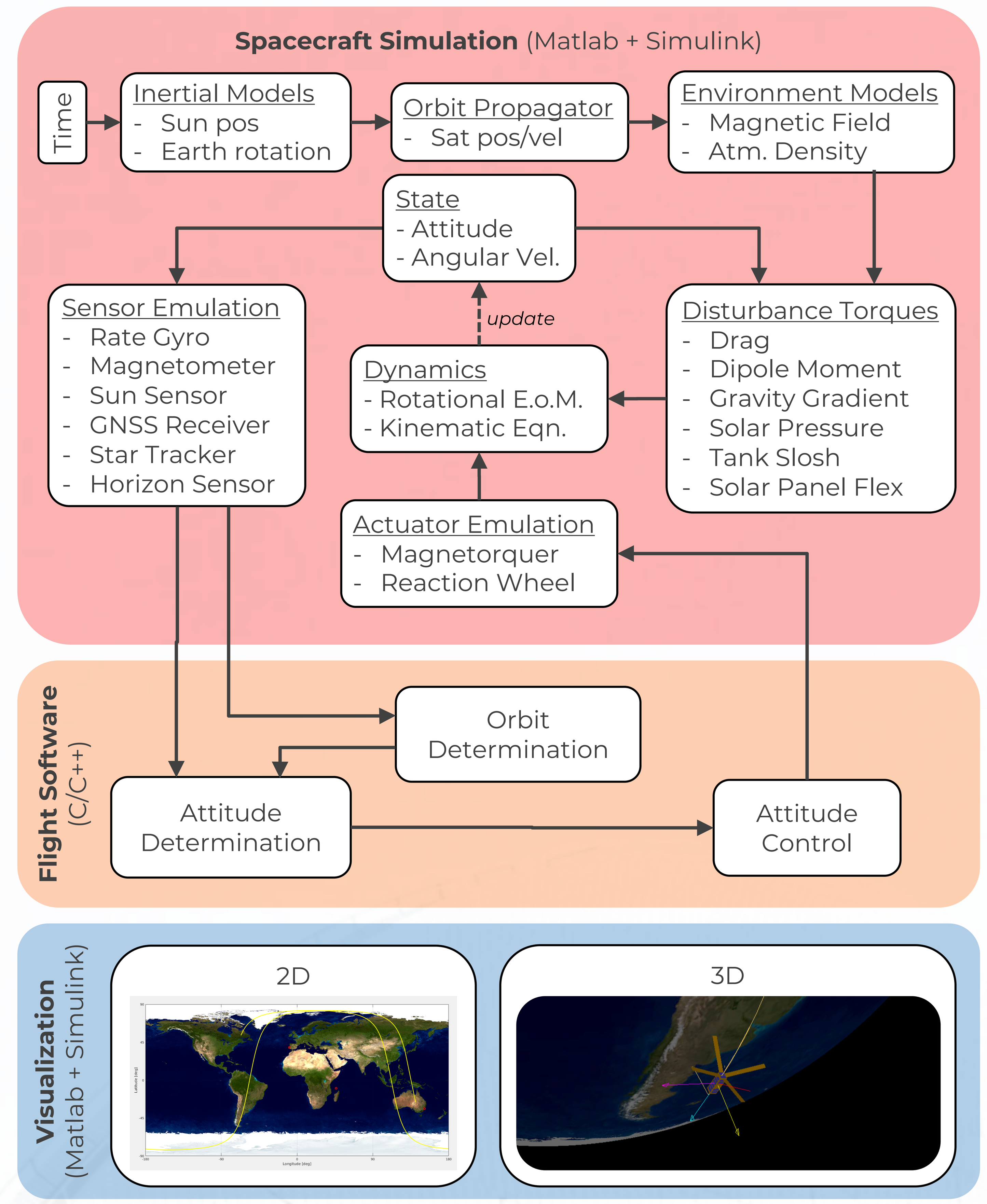
- Closed-loop environmental simulation & flight software response
- Open loop orbit propagation using TLE + SGP4 (attitude does not affect orbit)
- Configure simulation, environment, and satellite parameters via mission-specific JSON file
- On-the-fly changes to ADCS parameters via real-time commanding interface
- Output post-processing plots and statistics

Use

- Perform trade studies vs. orbit, sensor / payload configurations, operations, etc.
- Verify software images against nominal, new, or off-nominal operational scenarios without risk to satellite hardware
- Tune Kalman Filters by comparing on-orbit data to a simulation of the same scenario.

Benefits

- Agile – decrease software update turnaround time
- Safe – try new scenarios / software in a no-risk simulation environment before exposing to orbital hardware
- Transparent – visualizations & post-processing help developers debug and understand performance
- Adaptable – functional blocks & configuration files allow for analysis of many different scenarios



The Results: GOMX-4B UKF Tuning

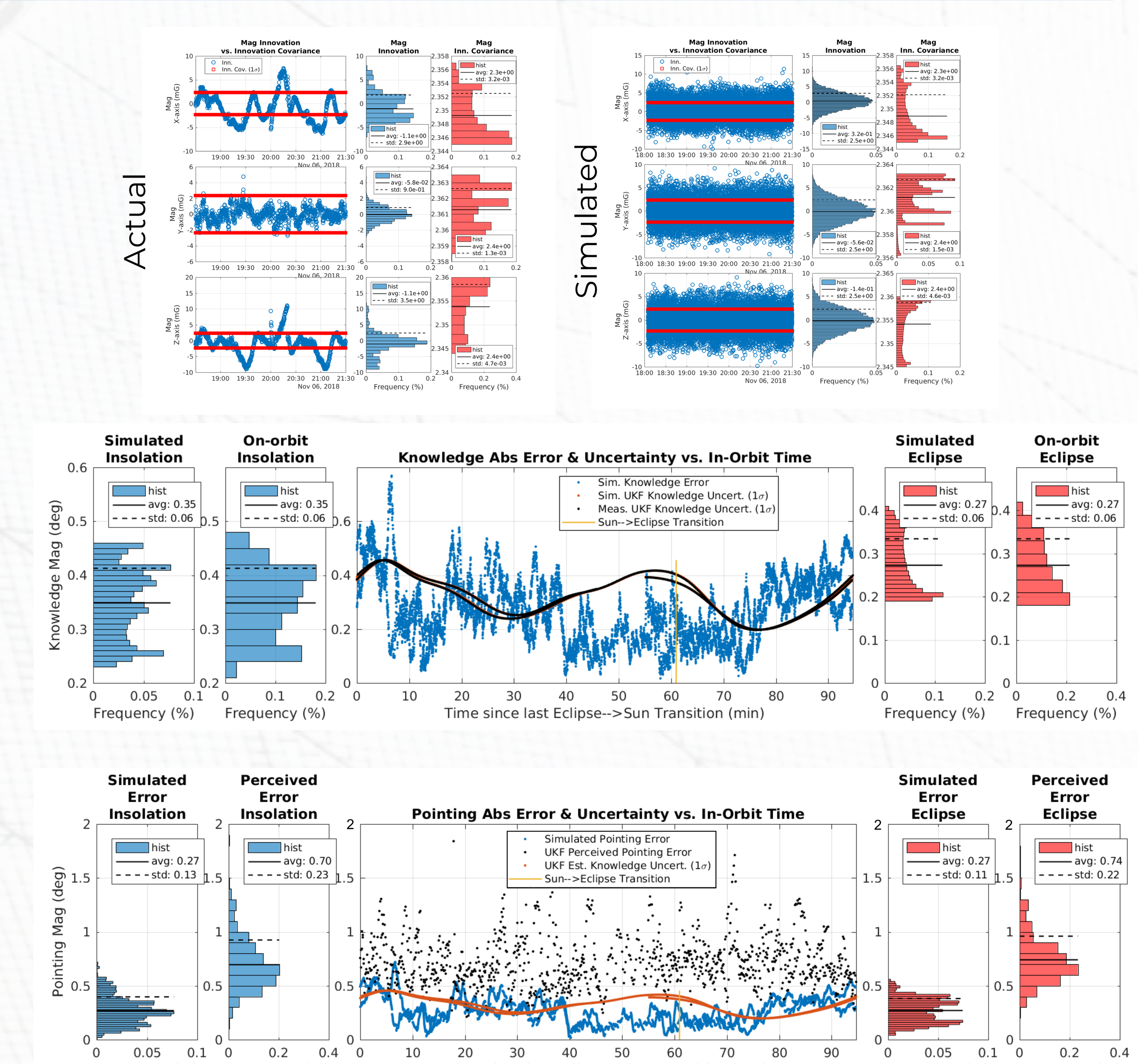
ADCSSIM was used time and again throughout GOMX-4B commissioning to incrementally establish trust in the orbital asset.

One example is the use of ADCSSIM to update the satellite's own estimate of its pointing performance. The onboard Unscented Kalman Filter provides an estimate of the knowledge uncertainty with each attitude estimate. Without proper tuning, this uncertainty estimate is baseless and should not be trusted.

The UKF tuning was performed using ADCSSIM as follows:

1. Perform on-orbit calibration and/or characterization of attitude sensors
2. Update satellite estimate of Measurement Covariance
3. Downlink satellite UKF innovation vector and compare to ADCSSIM innovation (order of magnitude should be equivalent)
4. Use ADCSSIM to vary Process Covariance until 1-sigma knowledge uncertainty bounds 68% of simulated true knowledge error
5. Update satellite estimate of Process Covariance
6. Downlink new satellite UKF dataset of state estimate + innovation
7. Compare new satellite UKF dataset to simulation of same time period & note differences
8. Repeat as necessary

The steps above were able to tune the GOMX-4B UKF sufficiently to produce the simulation vs. actual plots shown to the right. As shown, the measured UKF knowledge error is in good agreement with the simulated true knowledge error. The same goes for the simulated true pointing error + knowledge uncertainty vs. the perceived pointing error.



The Conclusion

ADCS simulation is a critical part of any small satellite mission with significant pointing requirements. ADCSSIM is one solution developed incrementally with each mission it was used to support.

Without ADCSSIM, critical commissioning events would take significantly longer to execute and would be higher risk to the orbital asset. In the case of GOMX-4B, the UKF tuning was able to be performed using just 3 rounds of ADCS data downlink + parameter uplink thanks to multiple ADCSSIM runs.

The example of GOMX-4B UKF tuning is but one among many. The first satellite GomSpace designed for 3-axis pointing was GOMX-3 (launched in 2015). Its ADCS was able to perform this complex task nearly out-of-the-box thanks to the myriad ADCSSIM runs which verified critical functionality before launch.

The Future

ADCSSIM will continue to develop in the following ways as it supports additional and more complex missions:

- Automatic testing – nightly or weekly tests of ADCS development software to ensure continued compatibility and performance.
- Automatic reporting – generate PDF output with information on sensor layout, parameters used (both Flight Software parameters and ADCSSIM parameters) and performance results.
- Scripting – a layer on top of ADCSSIM would allow for Monte Carlo simulations of parameter variations. For example, different injection spin rates, different slosh properties or orbital parameters (inclination, Beta angle variation, etc.).
- Ease of use – additional documentation, education tools and streamlining.

The References

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