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A new way to perform GNC closed loop testing in the hardware for the ESA PROBA3 mission*

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***Abstract*— This short paper describes a new way to perform GNC closed loop testing in the FM hardware for the ESA PROBA3 mission. Unfortunately, a full featured GNC-SCOE is not available. It has been found a way to close the loop with some logic being executed inside the flight computer. We call this product "miniDKE'. The validation of the miniDKE is in course and we expect to perform the testing of the critical modes in the PROBA3 satellites soon.**

I. INTRODUCTION

Proba-3 is an ESA mission devoted to the demonstration of technologies and techniques for highly precise satellite formation flying. It consists of two small satellites (Coronagraph Spacecraft or CSC and Occulter Spacecraft or OSC) launched in stacked a configuration that will separate apart to fly in tandem, to demonstrate precise formation flying in highly elliptical orbits in a completely autonomous way to achieve large virtually rigid structures in space. The launch is foreseen in second half of 2024.

The ESA GNC Handbook remarks as a recommended step the testing of the AOCS/GNC algorithms in closed loop with the flight HW. Usually a GNC-SCOE is procured that: 1) get data from the actuators, 2) implements the "Real world" model and 3) from the torques and forces exerted by the actuators calculates and transmit the stimuli to the spacecraft sensors. This "closes the loop". See Figure 1.

In small projects ("New Space", CubeSats, etc.,) the relative cost of procurement of a GNC-SCOE can be high. (The cost can range from ~500KEuros to several millions of Euros depending on the complexity). In PROBA3 the procurement of a GNC-SCOE was not possible due to varied reasons.

It is proposed a new concept for mitigating the absence of a GNC-SCOE. A similar functionality is implemented as an additional SW function running in the PROBA3 OBC. We name this new concept "miniDKE".

II. ARCHITECTURE AND IMPLEMENTATION

The OBSW executed inside the OBC reads by default the telemetry from the actuators and acquires data from the sensors. The "miniDKE" intercepts the data read from the actuators, calculates the spacecraft dynamics based on these commanded actuations, and replaces/complements the data coming from the sensors so closing the GNC loop inside the OBC without need of a separated GNC-SCOE. See Figure 1. We restrict the miniDKE to the safe critical SAM mode (Sun Acquisition Mode).

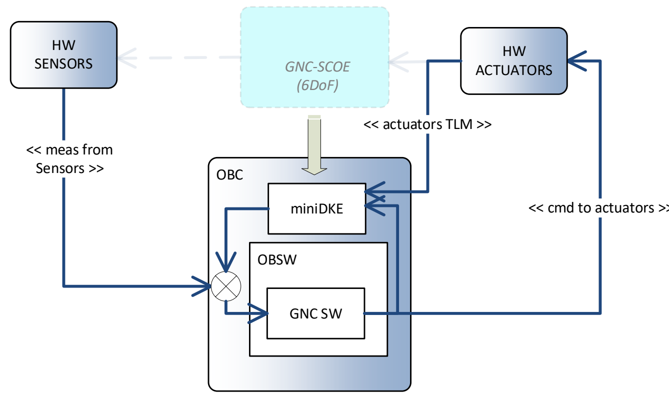

Figure 1. The miniDKE concept with the external GNC-SCOE removed

In the SAM mode, depending on the flight condition, the angular rates are estimated by means of 3 IMUs (named MIRU, allocated inside the optical heads of the star tracker) or by 3 angular rate sensors (named QRS) present inside the RWs. The actuators are thrusters and reaction wheels. The OBC sends the commands to the wheels directly via a serial line and to the thrusters through a RTU (named IEU in PROBA3).

In the PROBA3 SW, an existing task processes all the input data to GNC SW, before executing the GNC SW itself. A call to the entry-point of the miniDKE is inserted just before calling the GNC processing.

The miniDKE logic is as follows:

- Acquire the "thrusters commands" of the previous cycle. These are the "GNC output commands" and not the "applied commands at the RTU end" due to low frequency of the related telemetry. This limitation is accepted.
- Acquire the "applied torque" by the wheels. This is the real TLM provided by the wheels at 16 Hz.
- Compute the effect on the attitude dynamics of the satellite of these actuations. A simple "rotational dynamics" model is used that does not include gravity effects, the solar pressure induced torques, etc.
- Once the new state of the satellite has been computed (i.e., attitude and angular rates) the next step is to compute "what the sensors will see", i.e. the projection on the sensors axis of the body dynamics.
- Finally, the miniDKE calculates and provides the sensor outputs that are the inputs to the GNC.

* This work is under review for patent protection (ESA patent 832).
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The Sun sensors model is quite elaborated as includes a look up table: however, it does not model albedo and occultation by the companion spacecraft or by the Earth). The QRS and MIRU models are simple ones. A special case are the MIRUs. The STR used in PROBA3 has a simulation mode that accept TCs containing a quaternion expressing the rotations from the inertial frame to the unit frame and their time variation. The unit will consult its internal stellar map to identify stars visible from that orientation and will provide measurements for the MIRUs angular rates (note that the SAM mode does not utilize attitude quaternions). The miniDKE calculates the contents of these TCs from the inertial spacecraft attitude and send them to the STR.

All the previous calculus shall be performed in a time compatible with the OBC CPU free load. In PROBA3 the calculus is performed by the miniDKE in a few milliseconds.

The miniDKE is developed following MBSE techniques The Simulink™ and SimulinkCoder™ products of MathWorks are used. Use of MBSE allows a very fast development cycle. The C code generated is fast and allows to fulfill the requirement on CPU load.

III. Validation

The miniDKE is validated in the official PROBA3 simulator named SBTB. The simulator can be considered a twin-digital of the PROBA3 computer (including a simulator of the LEON2 processor that executes the SW flight image). The SBTB includes also high-fidelity functional models of the Avionics sensors and actuators.

Several test cases are defined in different spacecraft configurations (stacked, CSC and OSC) and dynamic conditions (high angular rates, unfavorable orientation to the Sun, etc.). In addition, are also tested the two different SAM modes one using the QRS (named SAM-B) and one using the MIRUs (named SAM-A). The different combinations are tested by around 20 test cases.

Validation in the SBTB is almost finished at the date of submission of this paper. In figure-2 it can be seen an example of a test with the correct progression of the “Sun and Pointing sub-modes” (wheels speed reduction, detumbling, sun pointing, spin around sun, keeping of sun pointing station with reaction wheels). Figure-3 shows the reduction of the angular rates. The test cases executed so far have been successful. A risk identified is the noise level in the RWs measures torque telemetry that is used to close the loop: if too high it could create problems.

IV. Testing in Flight Model

Several tests will be executed in the PROBA3 Flight model. The most critical one is the test case in stacked configuration. In this test case, the SC separates from the launcher with relatively high angular rates and a failure during this phase could compromise the mission. At the date of completion of this paper the foreseen date of execution in the HW is still to be decided. We expect to provide further data about the testing during the conference.

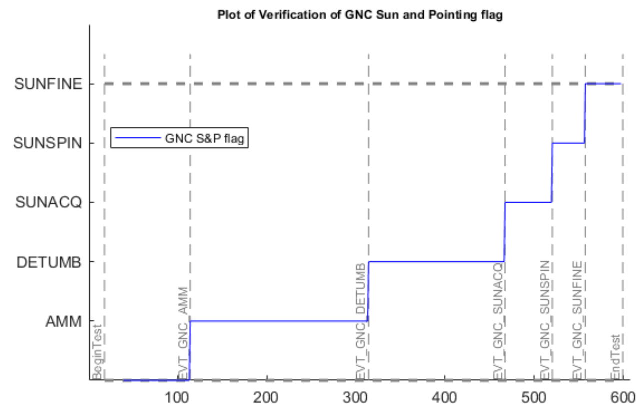

Figure 2. Progression of GNC SAM modes

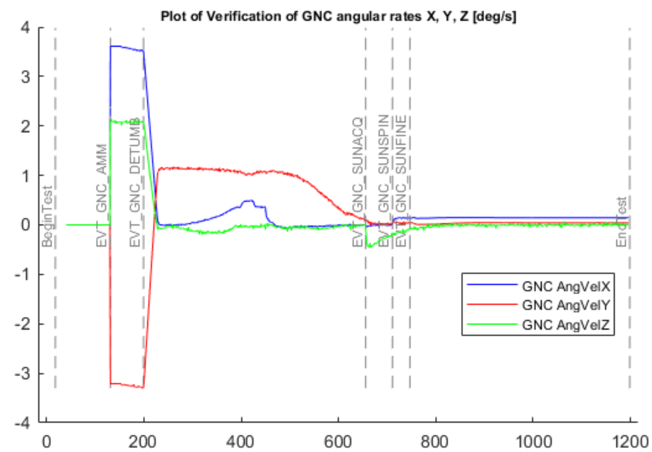

Figure 3. Reduction of angular rates

V. Conclusion

The use of a miniDKE allows to run GNC closed-loop tests in the case of a classical GNC-SCOE is not available. A second use case could be to complete the GNC closed loop tests when connection of a classical GNC-SCOE is problematic (e.g. satellite integrated in the launch vehicle, providing proper safety barriers are in place). A third use case could be the ESA HERA mission. HERA has two “satellite-drones” that are activated only when arriving to the target asteroids that could be further tested during commissioning using this technique.

Acknowledgment

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References

[1] PROBA3 mission homepage. https://www.eoportal.org/satellite-missions/proba-3