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Space Rider Re-Entry Module GNC

J. Cardín[1], F. Cacciatore[1], R. Sánchez[1], J. Veenman[1], G. Blanco[1], M. Lucrezia[1]
C. Recupero[2], F. Tache[3], D. Bottero[4]

Abstract

Space Rider programme is devoted to providing Europe with and affordable, independent, reusable end-to-end integrated space transportation system for routine access and return from low orbit, operating in-orbit, de-orbiting, re-entering, landing on ground, being re-launched after limited refurbishment. The Space Rider Re-Entry Module will be deorbited at the end of its operational mission, it will separate from the AOM and carry out an orbital coasting and an atmospheric re-entry to decelerate from hypersonic to supersonic speed. After that, the transonic regime is crossed during the TAEM phase, followed by subsonic parachute deployment at Mach 0.73. At 5.5 km altitude the parafoil is opened and the vehicle is steered towards the target landing site to execute a precision soft landing within 150m accuracy. This paper describes the status of SR Re-Entry Module Guidance Navigation and Control subsystem design, currently undergoing the overall System CDR.

Keywords: **Space Rider, GNC, Re-entry, Precision Landing**

Nomenclature

APA - Airspeed Path Angle
CL - Confidence Level
DES - Descent
DRS - Descent & Recovery System
FM - Flight Manager
HDR - Airspeed Heading Rate
IXV - Intermediate Experimental Vehicle
MVM - Mission Vehicle Manager
ORB - Orbital Coasting
PF - Parafoil
PGNC - Parafoil GNC
REE - Re-Entry
RM - Re-Entry Module
SR – Space Rider

1. Introduction

The Space Rider (SR) programme aims to provide Europe with an affordable and reusable space platform suitable for in-orbit operations, experimentation and demonstration of orbit applications and technologies. Space Rider vehicle is composed by an AVUM Orbital Module (AOM) and a Re-entry Module (RM). The RM is based on the Intermediate eXperimental Vehicle (IXV), which was successfully flow in February 2015 [1][2].

Funded by the European Space Agency and lead by Thales Alenia Space Italia (TASI) and AVIO as prime contractors, the project is currently in the middle of the system's Critical Design Review (CDR). The GNC of the RM is designed by a consortium of companies in which SENER Aeroespacial acts as the GNC subsystem Design Authority. The GNC design is a shared between TASI (Coasting G&C), DEIMOS Space (Entry and TAEM G&C; and DRS trigger algorithms, in core team with SENER) and SENER (Navigation, Initialization, Flight Manager and PGNC).

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[1] *SENER Aeroespacial, C/Severo Ochoa 4, Tres Cantos, 28760, Spain, jorge.cardín@aeroespacial.sener*
[2] *DEIMOS Space S.L.U., Ronda de Poniente 19, Tres Cantos, 28760, Spain, cristina.recupero@deimos-space.com*
[3] *DEIMOS Space S.R.L., 75-77 Buzești Street, 8th floor, office 18, District 1, 011013, Bucharest, Romania, florin.tache@deimos-space.com*
[4] *Thales Alenia Space, Str. Antica di Collegno 253, 10146 Torino TO, Italy, davide.bottero@thalesaleniaspace.com*

The Re-entry Module is a lifting platform characterized by a aerodynamic efficiency of 0.7 in hypersonic regime controlled by two flaps and four thrusters, all mounted on the rear panel. The wet mass of the system at launch lays between 2350 and 2950kg depending on the installed payload. The reusability of the system is linked to the controlled landing allowed by the Descent & Recovery System (DRS) that includes a drogue parachute and a ram air parafoil.

Space Rider mission will be placed into orbit by a VEGA C launcher. After over 2 months of in-orbit operations the re-entry phase will start. The mission profile of the re-entry is depicted in Fig 1.

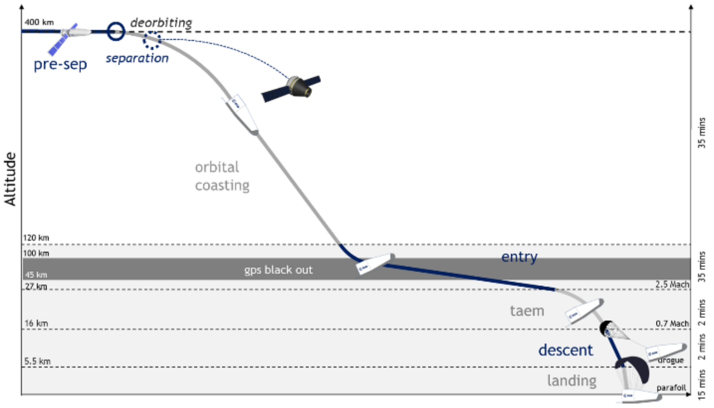

Fig 1. Space Rider mission profile

- **Initialization**: Calibrate/initialize navigation unit using AOM data transfer and initialize navigation. Once the navigations units are ready the RM detaches from the AOM.
- **Orbital Coasting**: Control the vehicle in orbital regime to reach the Entry Interface Point with the desired conditions. Coasting ends at an altitude of 175km.
- **Entry**: Control the vehicle in hypersonic and supersonic regime to reach beginning of TAEM with the desired conditions. Entry phase ends when the estimated drag is below 0.153g
- **TAEM**: Control the vehicle in transonic regime to reach beginning of Descent with the desired conditions. TAEM ends when the system reaches Mach 0.73.
- **Descent**: Deploy DRS system to slow down system to reach conditions compatible with parafoil flight. The end of this phase is based on a timer, triggered at the parafoil deployment event (5500m)
- **Landing**: Control the vehicle in flight under parafoil to reach ground with proper touchdown conditions and landing accuracy. This phase ends at touchdown.

The RM GNC is the application software in charge of the Guidance, Navigation and Control of the Space Rider Re-entry module. This paper gives a broad overview of the GNC logic associated to each mission phase, focusing on the algorithms and performances of the Landing phase. Previous iterations of this work are described in [3][4].

2. System architecture

The Re-entry Module is composed by the following elements:

- The main vehicle and DRS
- The set of sensors and actuators listed in Table 1.
- The onboard computer, including the Mission Vehicle Manager (MVM), GNC and FDIR.

Based on the diverse flight regimes associated to the different mission phases, the GNC is divided into a set of modes and submodes. Nomenclature wise, a mode involves a system reconfiguration (e.g: change of actuator) while the submode only introduces a software change (e.g: update control config). Submode changes are issued internally at GNC level, while the mode changes require a command from the Mission Vehicle Manager (MVM). The list of modes and submodes is presented in Table 2.

Table 1 SR RM Sensors and Actuators

Sensor	Measurement	Phase	Actuator	Action	Phase
NavUnit SIGI	PVT Angular Rates Inertial Acc. Attitude	Initialization, Coasting, Re-entry, TAEM, Descent, Landing	RCS	Torque (roll, pitch, yaw)	Coasting, Re-entry, TAEM
Star tracker	Inertial Attitude	Initialization	ASCS	Torque (roll, pitch)	Re-entry, TAEM
Radar altimeter	Height to ground	Landing	Winches	Parafoil deflection	Landing

Table 2 GNC Modes and Submodes

Mode	Submode	Description	Trigger
Idle (IDL)	IDL	RM Power ON	RM Power On
Initialization (INIT)	PSM_INIT	NavUnit Initialization	System Mode = Preparation for Deorbit
	PSM_NAV	Nav Algorithms Initialization	Both Navigation units initialized
Orbital Coasting (ORB)	ORB_LP	Attitude Control – Low Precision	Separation + TBC Time (RCS Ready)
	ORB_HP	Attitude Control – High Precision	Alt $\leq$ 175km (WGS84)
Re-Entry (REE)	REE_LPOL	Low Precision – Open Loop	Alt < 120km (WGS84)
	REE_HPOL	High Precision – Open Loop	Drag $\geq$ 0.065g
	REE_HPCL	High Precision – Closed Loop	Drag $\geq$ 0.153g or Specific energy threshold
	TAE_FULL	TAEM – Full Control	Mach $\leq$ 2.5
	TAE_LINH	TAEM – Longitudinal Trim Control Inhibited	Mach $\leq$ 1.2
Descent (DES)	DES_DRS	Descent under drogue	Mach $\leq$ 0.73
	DES_PF	Descent under parafoil	Alt $\leq$ 5.5km (WGS84)
Landing (PGNC)	STNDBY	Standby	RM Power On
	WP1ACQ	Homing towards WP1	PGNC activation
	HOMING	Homing towards WP2	Distance to WP1 axis $\leq$ 150m
	ENEMNG	Energy management around WP2	Distance to WP2 axis $\leq$ 1000m
	TERGUID	Quasi-optimal terminal guidance	PGUI flag = FULLQOPT (or backup logic triggered)
	FINALTGT	Final targeting towards LP	PGUI flag = EXITQOPT
	LVELCOR	Lateral velocity correction	Time based logic
	PREFLARE	System tranquilization prior FLARE	Remaining time to reach preflare trigger is zero
	FLARE	Flare	Height (terrain) < Onboard LUT

From an architectural point of view the GNC is split into the modules listed in Table 3. These functions are called sequentially at either 25Hz (Navigation, Flight and Control Managers) or 2.5Hz (Guidance Manager). The complete navigation and flight manager are executed from initialization down to descent while the guidance and control algorithms run at any given time are governed by the current GNC mode and submode.

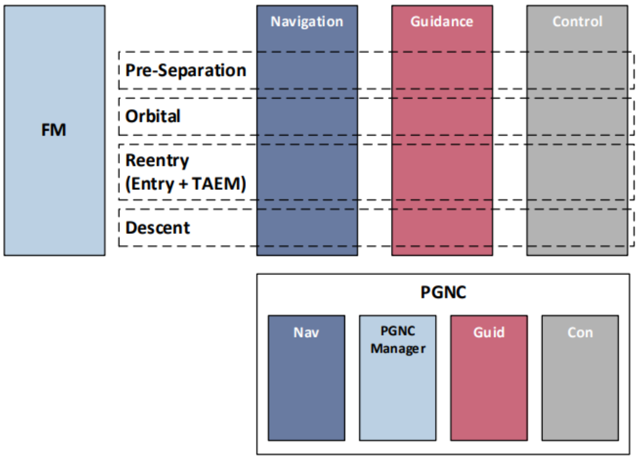

Fig 2. GNC Top Level Architecture

The Parafoil GNC (PGNC) contains the whole GNC logic to be used during the flight under parafoil phase, including a dedicated navigation, flight manager, guidance and control (run at the same frequency as their no-parafoil counterpart). The isolation of this module serves the purpose of avoid introducing modifications when the algorithms are extracted for the system characterization flight tests.

Table 3 GNC Top Level Architecture

Functions	**Description**
Navigation Manager	Main navigation function for the Initialization, Orbital Coasting, Re-entry, Descent phases
Flight Manager	Function in charge of selecting the Control and Guidance modes based on the flight conditions, and of calling the Triggering functions
Guidance Manager	This function receives the guidance mode from the Flight Manager (FM), and calls the appropriate guidance function
Control Manager	This function receives the control mode from the Flight Manager (FM), and calls the appropriate control function
Parafoil GNC	This function is the complete PGNC, including a submode manager, and navigation, guidance and control functions

3. Navigation

Space Rider navigation is composed of a set of modular functions that are used to estimate the system state. The navigation manager calls the same set of functions from Initialization to Descent. Once the PGNC is triggered, the PGNC navigation manager takes control over the navigation but reuses several of the SW functions of the main navigation.

One of the most relevant aspects of the navigation is the height management, which is based on the hybrid INS/GNSS provided by the Honeywell SIGI, until the radar altimeter becomes available. Due to the ionization of the air around the vehicle in the upper part of the atmosphere during re-entry, GNSS signals are temporarily unavailable in a range that can span from 100 km to 50 km altitude. In such phase the SIGI unit will rely on inertial propagation (notice that the management of the hybrid navigation is totally internal to the navigation unit). To ensure acceptable altitude estimation during GNSS outage, a Drag Derived Altitude (DDA) estimation is included in the navigation architecture. The DDA consists of estimating the drag based on accelerometer measurements after which the atmospheric density is estimated via an onboard model of the aerodynamic coefficients as function of flap deviation and angle of attack, which in turn is then used to compute the altitude via a look-up table of atmospheric density vs altitude.

As opposed to the IXV mission where the Navigation module included a switch to select between the DDA method and GPS/IMU for the altitude estimation, here a more robust and simpler approach is chosen where both the SIGI and DDA outputs are fused via a schedule gains filter. The SIGI unit outputs a figure of merit used to weight the estimated altitude error, while for DDA a look-up table of the expected estimation error vs altitude is implemented, considering the expected uncertainties.

The figure below shows the expected DDA errors driven by its main contributors, for a worst-case analysis from which a simplified look-up table for onboard implementation is constructed.

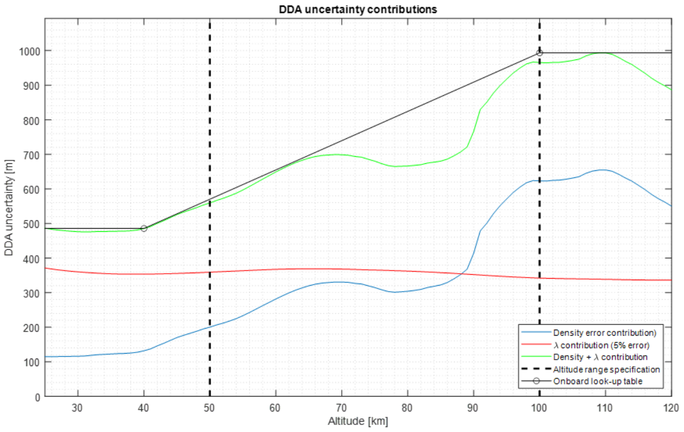

Fig 3. Expected DDA error vs altitude

4. Coasting

The goal of the orbital coasting phase is to bring the vehicle from the Separation Point to the Entry Interface Point (EIP), controlling the spacecraft attitude while following a ballistic trajectory. Two different flight regimes are defined: The low precision submode follows a NADIR pointing from AOM separation to 175km, maintaining the pointing errors within ±10deg for roll and ±20deg for pitch and yaw. Between 175 and 120km, the guidance switches to high precision and performs a +45deg pitch up manoeuvre with respect Local Vertical frame. During high precision submode the pointing errors must be under ±5deg, ensuring a smooth transition between coasting and entry modes. Guidance is quaternion-based for both submodes.

Due to the low atmospheric density at the coasting altitudes (>120km), only the RCS has enough control authority to steer the vehicle during this phase. The commands are generated by a PID-deadband controller. The control torque is then split in the 3 principal components and allocated sequentially to the thrusters. The allocation is performed by a PWM logic inherited from IXV that assigns 120ms intervals to each torque component. This logic is subject to additional constraints aimed to prevent residual torques and cross couplings, imposing minimum on and off command times of 50ms.

5. Entry

Once the vehicle reaches an altitude of 120km the GNC switches to Entry mode and steers towards the DRS Entry Point (DEP). The Re-entry phase spans both hypersonic and supersonic regimes, with different authorities of the ASCS and RCS due to the atmospheric environment. For this reason, the Re-entry mode is divided in to 5 submodes. As previously introduced, the each submode has an associated guidance and control algorithm:

- Low performance, open loop: Due to the low atmospheric pressure the control authority is limited. The attitude is controlled in open loop following a predefined profile and controlled only by the RCS.

- Low performance, closed loop: As the air density increases, so does the steerability of the system, allowing to track an angle of attack profile in closed loop. The control is still exerted solely by the RCS.
- High performance, closed loop: Once the dynamic pressure is high enough, the ASCS becomes effective in controlling the system attitude. After reaching this condition the control for roll and pitch is performed by the ASCS, leaving the RCS only to control the yaw motion and to desaturate the ASCS in case of need.
- TAEM Full control: The GNC keeps controlling the vehicle in closed loop using the ASCS and RCS using a different tunning.
- TAEM Longitudinal Trim Control Inhibited: Below Mach 1.2 the integral action of the elevator controlled is inhibited to prevent the saturation of the actuator due to increased vehicle stiffness in the subsonic regime.

For a more in-depth discussion on Entry and TAEM Guidance and Control, refer to [5].

6. Descent

Descent phase corresponds to the transition from the trajectory regime in which the vehicle behaves as a lifting body to the flight under parafoil. During this phase the system deploys a drogue chute to slow down the vehicle to the conditions compatible with ram parachute flight. The navigation and flight managers remain active, monitoring the states involved in the mode transitions but no actuation is generated by the guidance and control, which are deactivated. The nominal drogue deployment is triggered at Mach 0.73 whereas the parafoil is deployed at 5500m.

7. Landing

As previously introduced, the Landing phase has a dedicated GNC module (PGNC) that is triggered after parafoil deployment and substitutes the algorithms that steer the vehicle when it behaves as a lifting body. The PGNC takes as input the raw data provided by the NavUnit and the radar altimeter and generates the symmetric and asymmetric stroke commands that control the longitudinal and lateral responses of the parafoil system.

Based on the system dynamics, it is possible to generate two independent control loops: the longitudinal motion is governed by the airspeed flight path angle (APA) controlled by the symmetric stroke of the parafoil lines; the lateral motion is governed by the airspeed heading rate (HDR) controlled by the asymmetric stroke. Although the dynamic responses of both channels are decoupled, the definition of the symmetric and asymmetric strokes impose some limitations on the command envelope that need to be taken into account in the design (it is not possible to command an arbitrary APA_HDR pair). The overall PGNC interconnection is depicted in Fig 4.

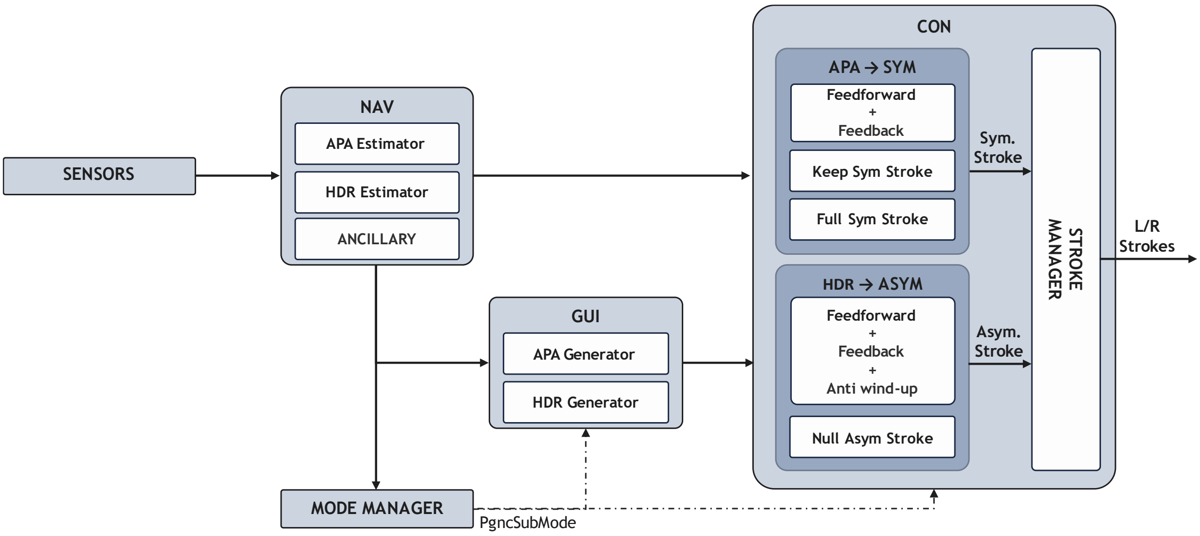

Fig 4. PGNC interconnection

7.1. PGNC Navigation

The PGNC Navigation estimates the states involved in the control loop (i.e. APA/HDR) but also all the ancillary data required to evaluate the internal PGNC submode and generate the reference trajectory. To do so, it combines the sensor measurements with the onboard wind tables. These tables are needed to compute the states referred to the airmiles position and airspeed as the system does not include an air data system to measure these magnitudes. Therefore, the main functionalities of the navigation are:

- Estimation of ground-based position and velocity from SIGI readouts
- Estimation of air-based position and velocity combining the SIGI readouts with the onboard wind knowledge.
- Height and altitude estimation. The height wrt terrain is extracted from the SIGI until the radar altimeter is available. After this point the radar altimeter is prioritized as it provides a better accuracy.
- Estimation of airspeed flight path angle and heading rate required by the control loops.
- Estimation of time to ground, time to reach landing point position, time to correct remaining lateral velocity, time to trigger Lateral Velocity Correction and Preflare (more on Section 7.3).
- Computation of derived quantities referred to the landing point and waypoints

The complete navigation module is executed every GNC step independently of the current submode.

7.2. PGNC Manager

The Landing submode is internally controlled by the PGNC manager. It takes as input a set of ancillary signals generated by the navigation (e.g: position relative to the Waypoints) and, based on the submode issued on the previous GNC cycle, checks the conditions required to trigger the transition to the following submode (see Table 2).

The submodes are sequential and only go in one direction. However, in order to protect the system integrity, the Preflare and Flare submodes have priority and can be accessed from any other submode.

7.3. PGNC Guidance

The guidance manager generates a reference APA and HDR to be tracked by the control. Depending on the submode a different logic is used to generate these magnitudes.

7.3.1. Waypoint Acquisition

Waypoint Acquisition's goal is to steer the vehicle towards the Waypoint 1 (WP1). To do so, it tracks the heading error between the current groundspeed vector and the WP1. The heading error is converted into an airspeed heading rate command by a PID controller tuned using the H_∞ framework. The longitudinal channel tracks a reference airpath angle, selected to maximize the flight range while remaining enough lateral control margin (see Section 7.4).

7.3.2. Homing

The guidance for Homing submode is equivalent to the one used during Waypoint Acquisition. The only difference is that the target point is the Waypoint 2.

7.3.3. Energy Management

Once the vehicle reaches Waypoint 2, it flies around it describing a spiralling motion. To generate this trajectory, a target point is placed at a fixed distance to the WP2, leading the vehicle by an angle. The target point is recomputed every GNC steps, ensuring that the vehicle is always turning around the WP2 independently of the wind conditions (as long as they are compatible with the flight capabilities of the system). Once the target point is generated, the same heading tracking logic implemented in the previous phases is used to generate the heading rate command. During this phase the airpath angle followed by the longitudinal control is updated to expand the achievable heading rates (see Section 7.4).

During this mode, the quasi-optimal algorithm (described in Section 7.3.4) is activated. Once it finds a valid solution, it raises a flag and the PGNC manager transits to Terminal Guidance. This transition can only be triggered below 1500m to avoid following long trajectories during Terminal Guidance, reducing the risk of crossing any no-flight zone. In addition, a logic based on the horizontal vs vertical times to reach the landing point is introduced as ultimate condition to exit Energy Management with enough energy to reach the landing site.

7.3.4. Terminal Guidance

During Terminal Guidance the GNC steers the system to bring it from its current position and velocity to the landing point, aligned to the wind, in the time available before reaching the ground. This problem is subject to optimization but due to the limited computational resources, it was decided to solve it analytically by imposing a straight-turn at constant rate-straight profile. This approach, referred as quasi-optimal trajectory generation, ensures that a trajectory (i.e. HDR profile) will be generated every Guidance cycle.

However, the solution of this algorithm will be purely mathematical and might be physically unfeasible. For this reason, once a trajectory is generated it must pass a series of checks to be deemed valid and sent to the control. Depending on the outcome of the checks, several trajectories might be generated.

- Full Solution: All criteria passed. Follow the generated solution.
- Relaxed Solution: One criterion failed. Relax the final heading constraint and rerun the algorithm. If the new solution passes all criteria, follow the relaxed solution.
- Null Solution: All criteria failed at this step and previous ones (only accessible during Energy Management)
- Lost Solution: All criteria failed at this step, but a solution was found previously and the manoeuvre time is shorter than the time to ground. Recover the heading for which the last solution was found.
- Final Targeting: All criteria failed at this step, but a solution was found previously and the manoeuvre time is larger than the time to ground. Point towards the landing point.
- Exit Solution: The heading to be corrected is smaller than a defined threshold.

7.3.5. Final Targeting

The goal of the Final Targeting mode is to compensate any remaining heading error in the landing point tracking after completing the Terminal Guidance manoeuvre. In addition, during this phase the GNC actively computes the airpath angle required to reach the landing point and generates the associated longitudinal commands.

7.3.6. Lateral Velocity Correction

The Lateral Velocity Correction manoeuvre aligns the vehicle with the known wind at ground trying to minimize the lateral velocity at touchdown (i.e. aligning the system with the incoming wind). Knowing the current groundspeed heading and the ground wind, the algorithm computes the heading error to be compensated and generates a heading rate command using the same PID used in the guidance point tracking algorithms (e.g. Homing). The longitudinal channel uses the same logic defined for Final Targeting.

7.3.7. Flare & Preflare

The Flare is a manoeuvre executed in open loop that consist in a fast pull both lines of the parafoil up to the maximum stroke. This generates a dynamic response of the system that allows to reach vertical velocities outside range achievable in steady state conditions. By tuning the trigger time, it is possible to minimize the impact velocity, improving the reusability of the system.

The tuning of the flare time is highly dependent on the plant (i.e. MCI and aerodynamics) but also on the environment (i.e. wind).

7.4. PGNC Control

The PGNC control generates the left and right winch deflections required to track the APA and HDR requested by the guidance module. To do so, it includes two independent controllers that generate the required symmetric and asymmetric strokes. Both controllers include a feedforward and feedback action synthesized using the H_∞ framework. In the case of the lateral controller, the feedback action is expanded with an anti wind-up logic to prevent command saturation.

Once the symmetric and asymmetric strokes are computed they need to be converted into left and right winch deflections. As both commands have been generated independently but are executed using the same actuators, they need to pass a compatibility check. This check confirms whether the stroke pair is within the feasible envelope (see Fig 5). If the pair is outside the envelope, one of the commands is prioritized and the other reduced within limits. The asymmetric stroke is prioritized from Waypoint Acquisition to Terminal Guidance while the symmetric is prioritized in Final Targeting and Lateral Velocity Correction.

The stroke envelope also affects the feasible APA-HDR pairs. However, in this case the achievable range also depends on the local air density and the system MCI. By characterizing the system response to different command pairs, it is possible to generate plots as the one shown in Fig 6. This information is then used to select the APA to be commanded by the guidance in the submodes with a constant glide slope (i.e from Waypoint Acquisition to Terminal Guidance).

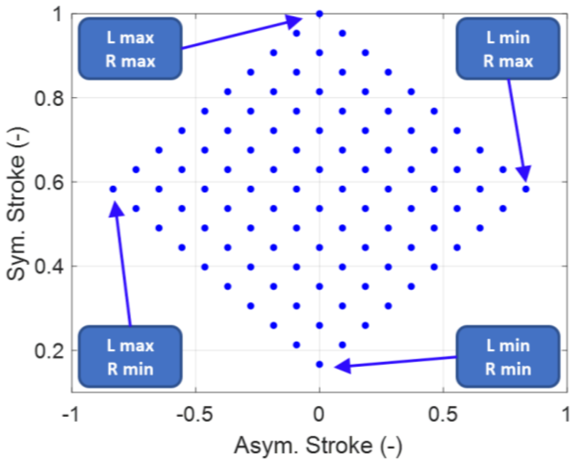

Fig 5. Stroke command envelope

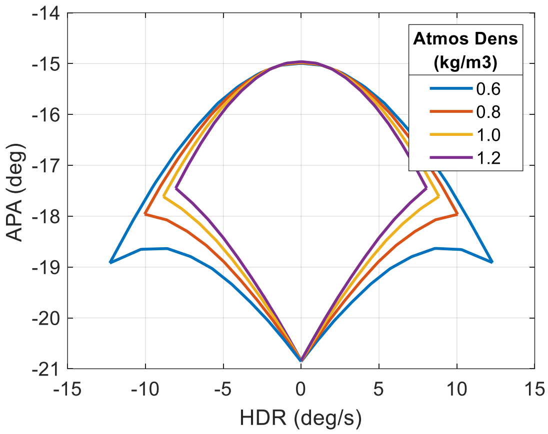

Fig 6. System under parafoil dynamic envelope

8. Performance assessment

To evaluate the effectiveness and robustness of the GNC algorithms, a 6DoF Functional Engineering Simulator (FES) has been developed. This tool includes all the effects impacting the system dynamics, including gravity, aerodynamics (lifting body and DRS), atmospheric environment; as well as the modelling of the vehicle MCI, sensors, actuators and the onboard computer. These models are currently undergoing validation as part of the Model In the Loop (MIL) campaign execution, which has just been started.

The FES includes the whole GNC and can simulate the complete Re-entry mission from Separation to touchdown. A preliminary assessment of the current performances is presented in the following sections.

8.1. Separation to Descent

To evaluate the behaviour of the vehicle during the regime from Coasting to Descent a Monte Carlo campaign with a sample size of 350 shots (to be expanded for the formal MIL campaign) has been carried out. For each shot, the initial conditions, system and unit's properties and the environment are perturbed according to specifications to verify the robustness of the algorithms.

Fig 7-Fig 8 show the evolution of the altitude and Mach number over the End-to-End (E2E) simulations, where the Coasting corresponds to the first ~2000s in orbital regime, followed by ~1500s of Entry & TAEM that bring the vehicle from the hypersonic to the subsonic regime. The remaining time is devoted to the DRS opening and flight under parafoil.

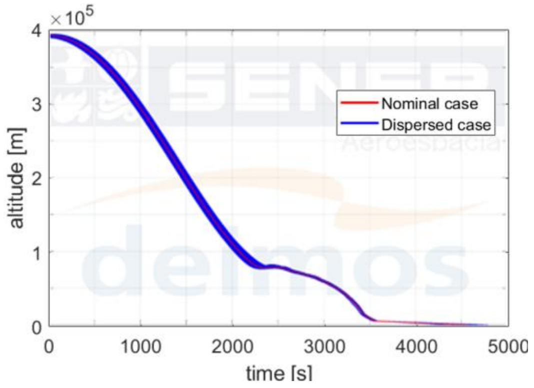

Fig 7. E2E altitude evolution

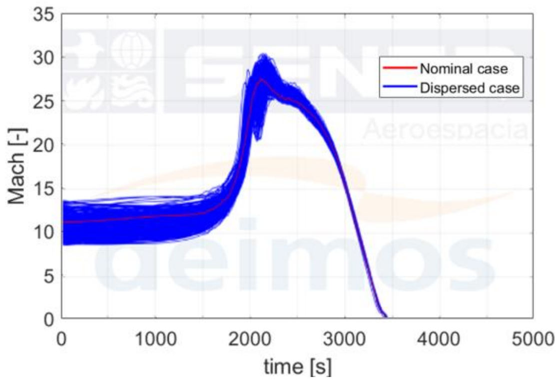

Fig 8. E2E Mach evolution

The evolution of the Euler angles during Coasting phase is shown in Fig 9, where the dashed red lines represent the system requirements, that are met for both the low and high precision submodes.

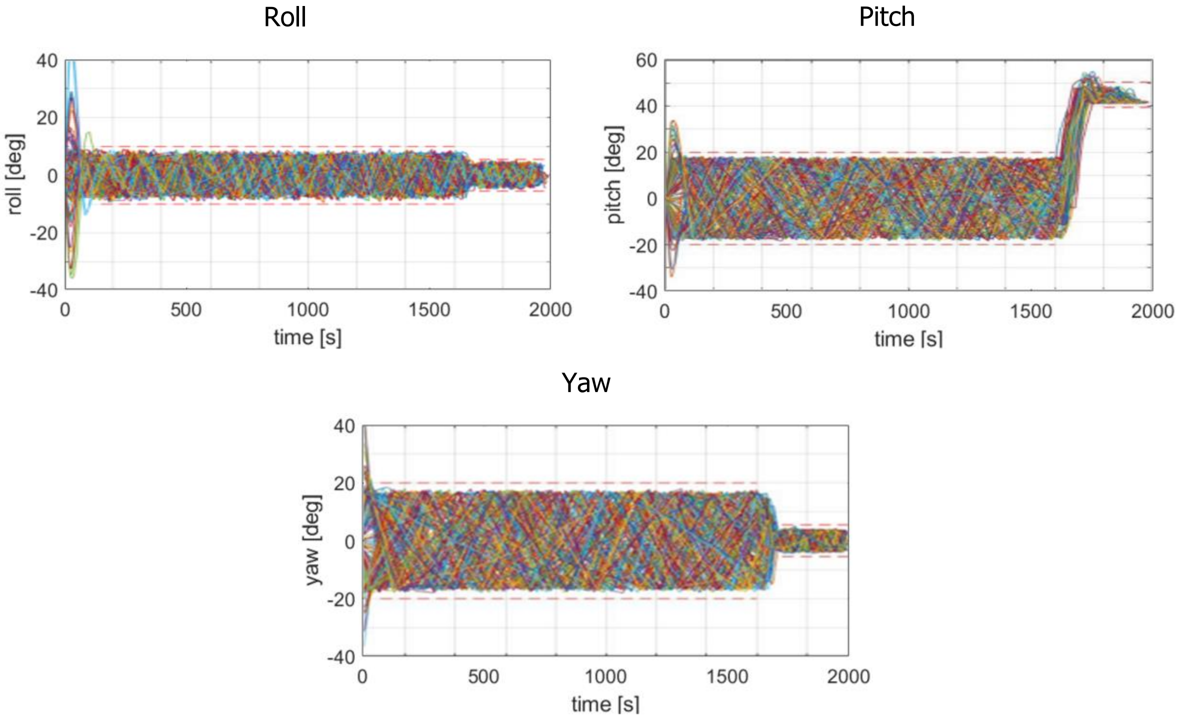

Fig 9 Coasting attitude evolution wrt Local Vertical

For a more detailed discussion of Guidance and Control performances during Entry and TAEM refer to [5].

8.2. Flight under parafoil & touchdown

Due to the low speeds at which the vehicle under parafoil operates, its behaviour and performances are largely affected by the wind environment and plant characteristics. For this reason, 3 different Monte Carlo campaigns with 1000 simulations are evaluated with varying levels of uncertainty.

- Ideal case: Perfectly known aerodynamic coefficients and perfect onboard wind knowledge

- Baseline case: Perfectly known aerodynamic coefficients and onboard wind knowledge of up to 5m/s below 2500m
- Stress case: 10% dispersion (3σ, uncorrelated) on aerodynamic coefficients and onboard wind knowledge of up to 5m/s below 2500m

Besides aerodynamics and wind knowledge, system MCI, initial conditions and sensor & actuator noises are dispersed for each shot.

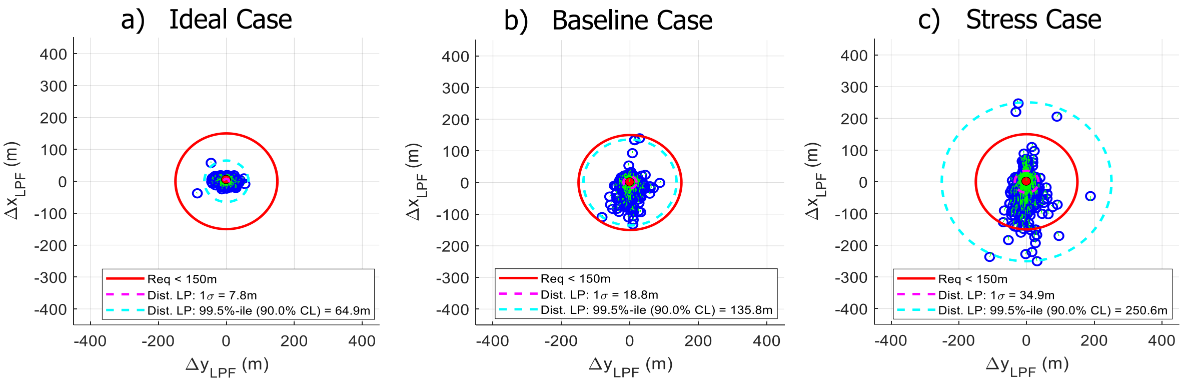

Fig 10 Miss distance to LP

Fig 10 shows how by increasing the aerodynamic and onboard wind uncertainty, the touchdown performance is degraded from a miss distance of 64.9m in the ideal case to up to 250.6m in the stress case (99.5%-ile, CL 90%). By further analysing the stress case, it is possible to see that, although due to the system complexity there is no a 1:1 correlation between each effect and the miss distance, the higher the knowledge error, the higher the chance to miss the target. Fig 11 graphically shows this relation, together with the proposed maximum knowledge error the Space Rider programme should aim to achieve.

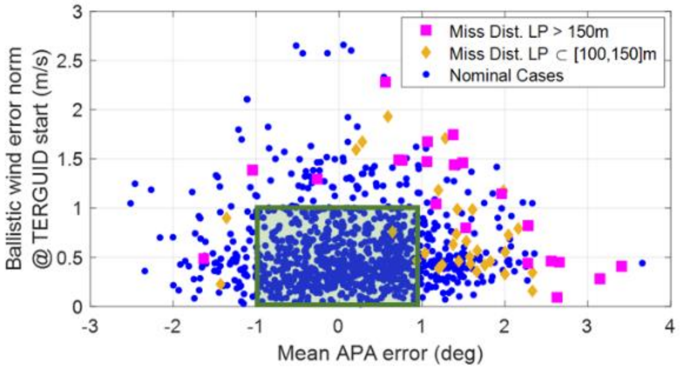

Fig 11. Miss distance correlation with wind knowledge error and aerodynamic uncertainty

Focusing on the impact velocity, Fig 12 shows the touchdown velocity for the baseline case, decomposed in the horizontal, vertical and lateral components as well as their requirements. While the horizontal velocity meets the requirement, some cases are outside bounds for lateral and vertical components. The outliers of the lateral velocity are the result of the wind knowledge error while the ones for the vertical component are caused both by the combination of wind uncertainty, MCI knowledge and the error on the height estimation caused by the radar altimeter noise. Although the Lateral Velocity Correction tries to align the system with the wind on ground, minimizing the lateral velocity, its reference is the onboard wind. Any discrepancy between the encountered and onboard wind won't be observed and cannot be compensated, resulting in larger lateral velocities at touchdown. In the case of the vertical velocity, the Flare trigger height is characterized for a nominal plant in steady conditions with null wind, so any deviation from this configuration will result in a degradation of the trigger height estimation that in turn will reduce the effectiveness of the flare manoeuvre as shown in Fig 13. Solutions to both issues are currently being under investigation, focusing mainly on a better characterization of the wind environment and system aerodynamics to reduce their associated uncertainties. In addition, more advanced algorithms such as an MPC-based flare are being tested with promising results.

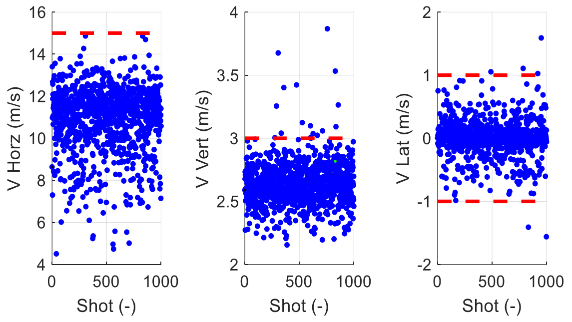

Fig 12. Touchdown velocities

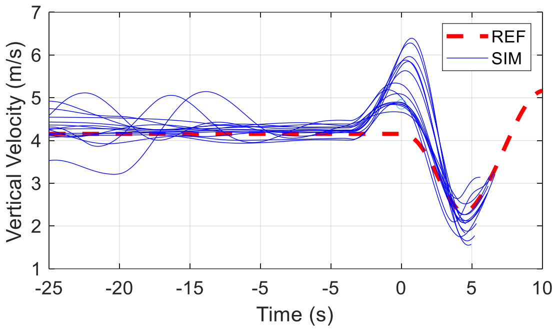

Fig 13. Flare vertical velocity evolution

9. Conclusions

This paper has presented the current state of the SR RM GNC subsystem and its preliminary performances. The complete GNC for the different mission phases has been integrated allowing to simulate the complete re-entry mission from separation to touchdown.

The phases associated to the orbital and lifting body regime of the vehicle meet their requirements showing a good degree of robustness. The flight under parafoil complies with the requirements in its nominal conditions and is highly sensitive to dispersions on plant and environment. The risks associated with such sensitivity and their impacts have been identified, and mitigations have been defined and are currently being implemented, both at System and GNC subsystem level.

The GNC subsystem is currently in its Bridging Phase and ongoing CDR, starting to carry out the formal MIL campaign and approaching phase D by October 22.

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