GNC Solutions for Safe and Sustainable Space Operations

José Vasconcelos
GNC/AOCS Unit Lead
Indra Space

06/May/2026

doi: 10.82124/CEAS-GNC-2026-K02

01

GNC as enabler of space sustainability

Motivation

Why sustainability matters in space operations?

GNC as a Key Enabler for
Safety & Sustainability – Full Cycle

Enabling a safer, more sustainable space ecosystem through advanced Guidance, Navigation & Control

1 Reusable and Smart Launcher with Optimal Control

Autonomous control for precise ascent, stage recovery, and reusability

- High-precision guidance, navigation & control
- Optimal control for fuel efficiency and reusability
- Autonomous control for stage recovery and landing
- Reduced cost and environmental impact

OUTCOME: Lower cost, lower emissions, higher reusability

2 Servicing & Life Extension

Refueling, repair, and upgrade in orbit

- Precision GNC for rendezvous and docking
- Stable control for servicing operations
- Extended asset life through in-orbit upgrades

OUTCOME: Maximize asset value, minimize lifecycle cost

3 GNC for Recovery

with On-board Optimal Guidance

Precision landing and recovery of fairing or launcher stage / platform

FAIRING RECOVERY

STAGE / PLATFORM RECOVERY

On-board Optimal Guidance

- Precision tracking
- Controlled splashdown / landing
- High recovery reliability
- Robust navigation & control through reentry and descent

OUTCOME: Reusability, reduced waste, and lower environmental impact

Lifecycle Optimization
Minimizing waste and maximizing asset utilization → Minimize Waste | Maximize Utilization | Sustainable Future

02

Indra Space Flight Segment

Indra Space : End to End Space Solution

A European space company with a global footprint, combining system integration and satellite operations to deliver end-to-end civil and defence solutions. A national and European leader at the forefront of the space ecosystem, covering the design, deployment and operation of satellite constellations.

INDRA

1. GROUND SEGMENT
Mission brain

- Mission Planning & Scheduling
- Command & Control (TT&C)
- Data Processing & Exploitation
- Mission Monitoring & Operations
- Data Distribution & User Services

2. LAUNCH SEGMENT
Access to space

Launch Vehicles
Deliver payloads to orbit

GNC FOR LAUNCHERS

- **Guidance** – Trajectory optimization
- **Navigation** – State estimation
- **Control** – Stability, thrust vectoring, stage separation

3. ORBITAL SEGMENT
Space infrastructure & applications

EARTH OBSERVATION
Imagery, radar, hyperspectral data

SATELLITE COMMUNICATIONS
Connectivity & data relay

POSITIONING, NAVIGATION & TIMING
Precise PNT services
Global timing & navigation

GNC FOR ORBITAL APPLICATIONS

- Orbit Determination & Control
- Collision Avoidance Maneuvers
- Rendezvous & Proximity Operations (RPO)
- Formation Flying & Constellation Management
- End-of-Life Deorbiting & Disposal
- Attitude Control & Pointing

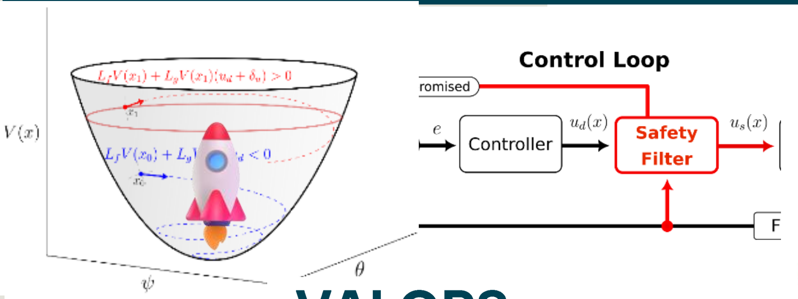
4. SPACE SITUATIONAL AWARENESS (SSA)
Safety & sustainability in orbit

- **Detect** – Space objects
- **Track** – Precise tracking & cataloging
- **Analyze** – Conjunction & collision risk assessment
- **Alert** – Mitigation & avoidance recommendations
- **Monitor** – Orbital environment & debris evolution

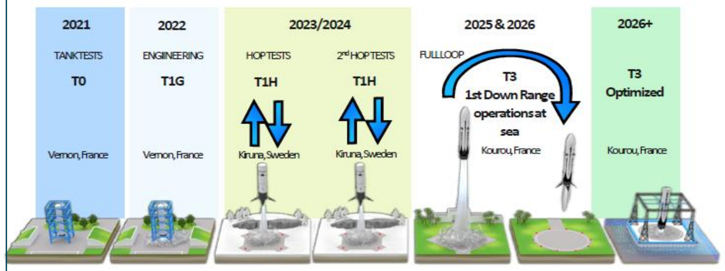
Multiple space applications | All steps in the development cycle | End-to-end satellite systems

GNC/AOCS Projects

Launchers & Re-usable solutions



VALORS



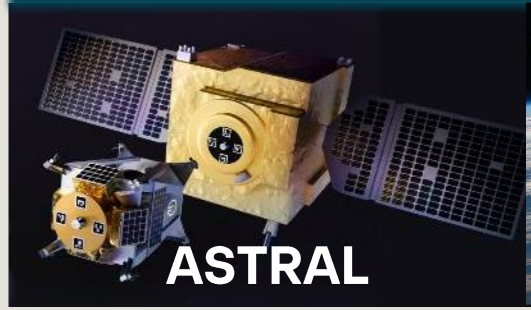
SALTO

MIURA5

PLD SPACE

SURE

In-orbit servicing



ASTRAL

ClearSpace-1

PROBA-3

GEORYDER

Reentry

Space Rider

EARS

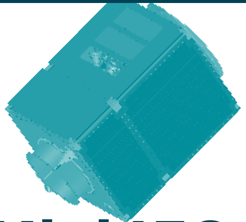
ICARUS

REFAIR

GNC/AOCS Projects

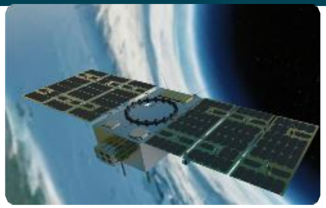
Missions and Platforms

DRACO

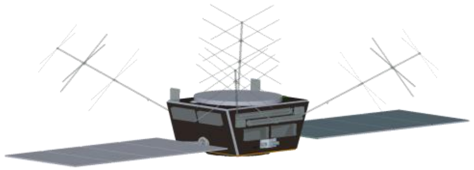


Mini4EO

CASSINI

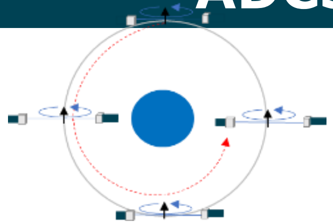


CELESTE/VORAX

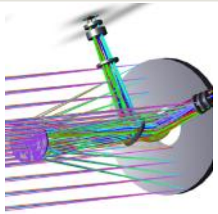


LINCE

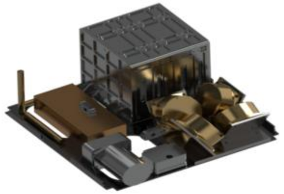
ADCS & GNC Technologies



E.T. COMPACT



OPTIFLEX



READY

AOCS H/W (STR, MTR)

Digital Twins

03

In-orbit Servicing GNC

ClearSpace-1

Context: ESA ADRIOS program

Rendezvous, capture and de-orbit PROBA-1

Objective

Demonstrate removal of PROBA-1 from LEO with tentacles capture system

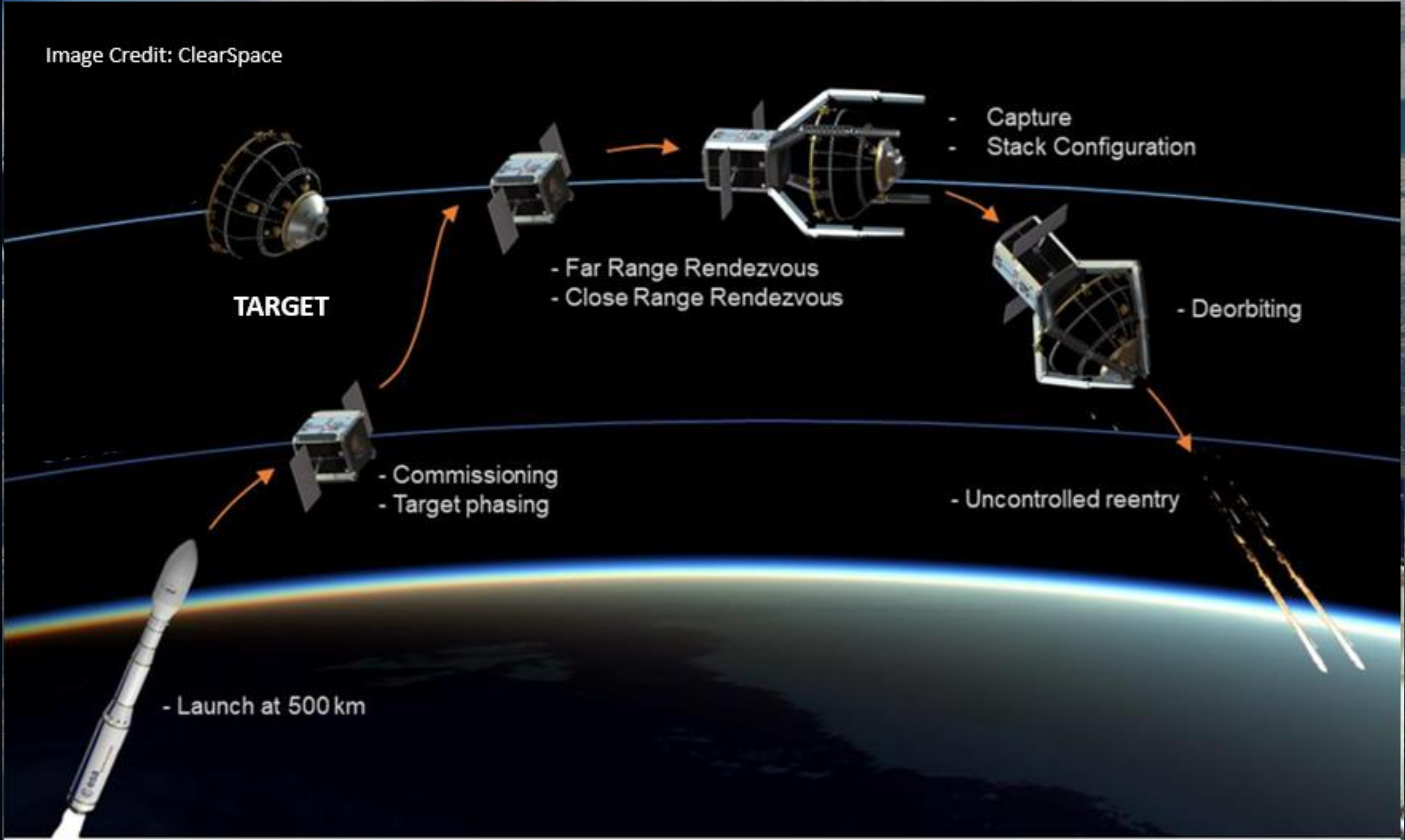
Develop building blocks for active debris removal (ADR) commercial missions.

Phases involved

- LEOP;
- Orbit Phasing;
- Closing;
- Fly-around;
- Proximity Operations.
- De-orbiting

Building blocks of ADR service

- uncooperative rendezvous (RV),
- motion synchronization,
- stack stabilization+ deorbiting,
- target release.



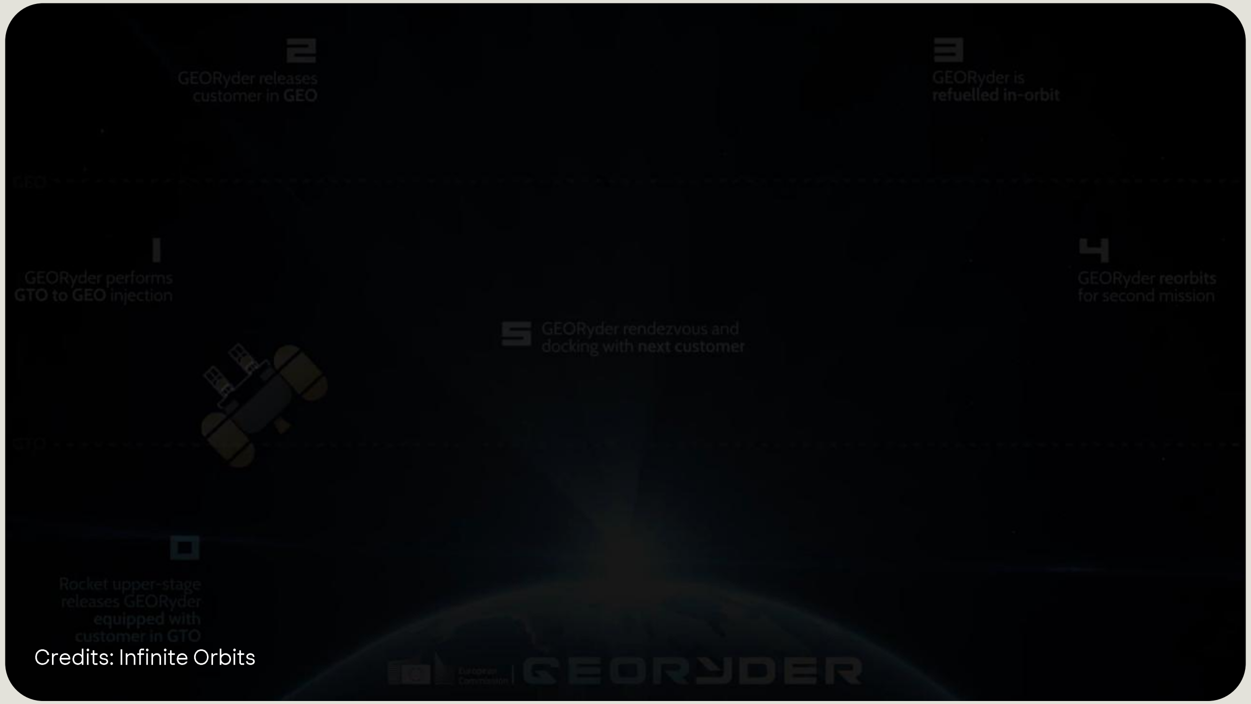
GEORYDER: Goals

Project Goals

Design a reusable platform capable of deploying two small satellites into GEO orbit (~400 kg payload) .

- first reusable European kick-stage by performing in-orbit refueling .
- reusable concept together with rendezvous and docking capabilities with small satellites
- aims to enable in-orbit logistics.

Validation of technologies up to TRL 5/6.



Credits: Infinite Orbits

The baseline ConOps is:

1. GTO -> GEO -> payload deployment (covered by normal AOCS functions)
2. Rendezvous in GTO with new target payload (covered by relative G&N + AOCS)

GEORYDER: Key Activities

📦 **Product missionization:** Adapt the existing ADCS-READY baseline to GEORyder

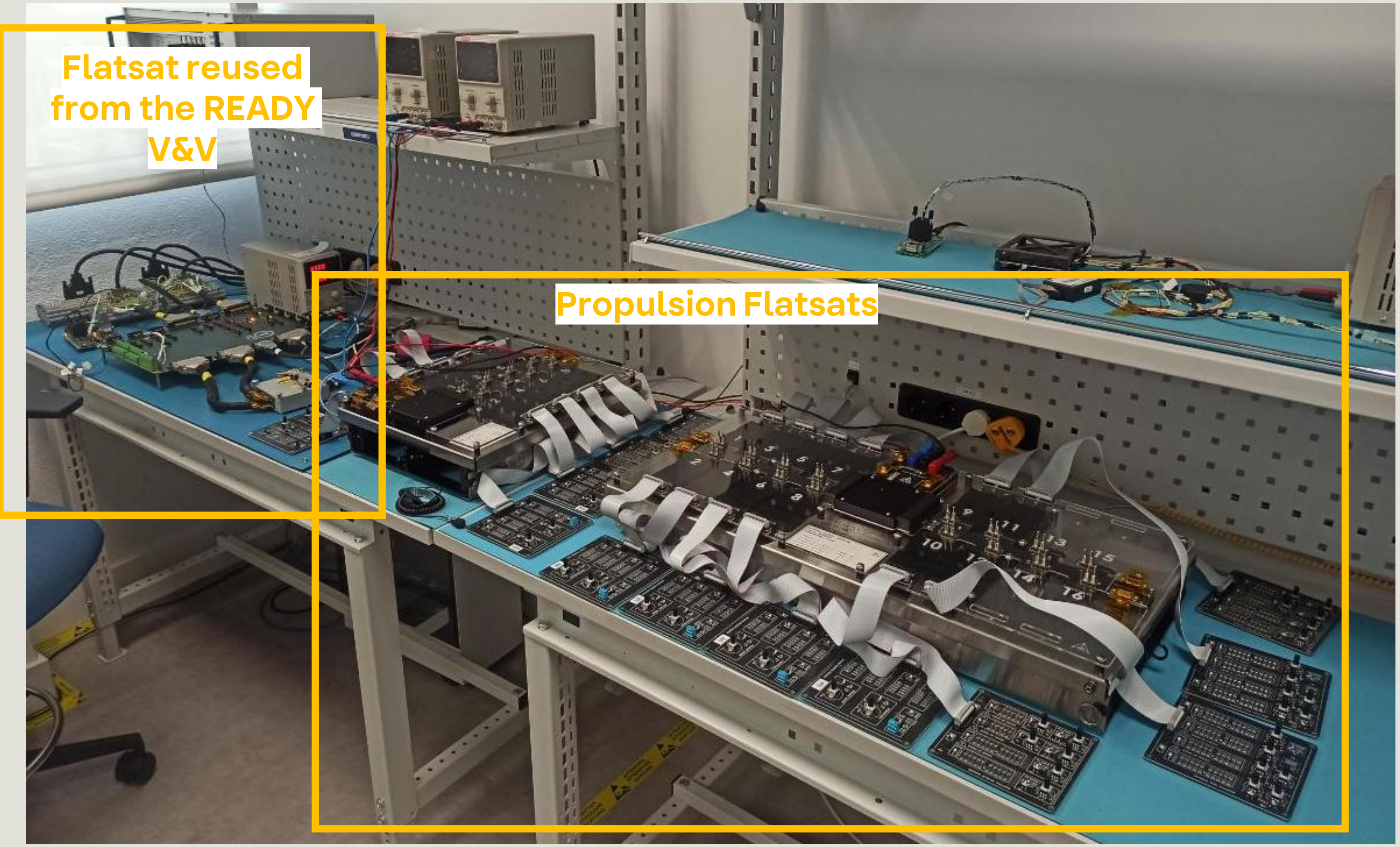
- Develop new GNC solutions covering orbital control, thruster management and relative 6DoF control.
- Adapt READY product avionics for the GEO environment.
- Realize an Avionics Test Bench to support the V&V Campaign up to the HIL included.

↔️ **Perform/support end-to-end system integration tests**:

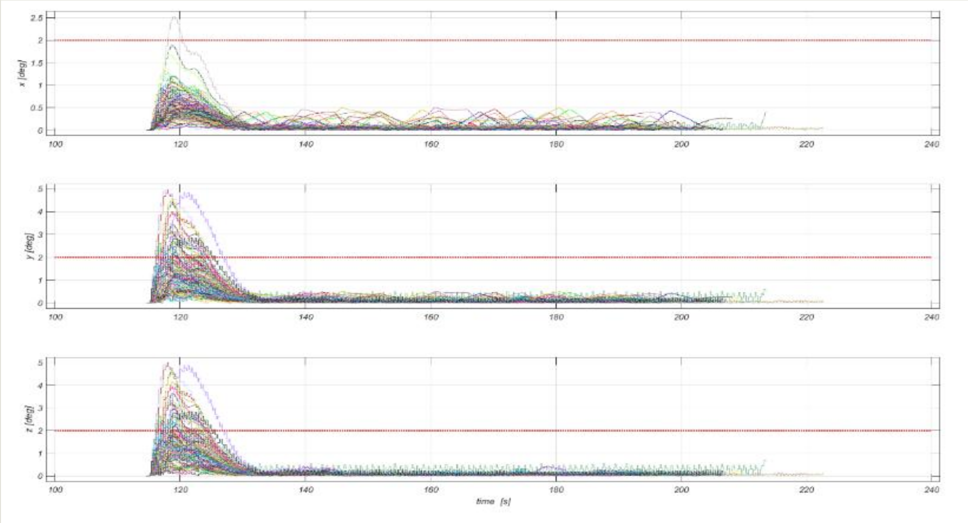
- HW E2E tests between AOCS-OBC and Propulsion controller to validate SW I/F and propulsion commands.
- MIL closed-loop to test
  - integration of relative G&N with AOCS-SW
  - HW E2E tests between AOCS-OBC and RdV camera to validate SW I/F.
- Integration test between PF-OBC - AOCS-OBC – Propulsion controller to validate CDH communication between OBCs.

GEORYDER: AOCS Flatsat

AOCS flatsat of GEORyder – ready to run the HW E2E tests with propulsion



MIL closed-loop results: APE during main-engine firing



- MIL test campaign during an orbit raising manoeuvre. Attitude control with the main engines and the RCS
- Keep the attitude error below 2 deg requirement

ASTRAL: Overview

🔍 What is ASTRAL?

- Advanced Satcoms Technology for Refueling & Logistics (ASTRAL)
- Definition Phase of GNC for in-orbit refueling demonstration (launch in 2028)

🏃 Challenges

- Precise rendezvous capture requirements
- High fidelity simulations of multibody interactions (plume impingements)
- Tight approach geometry to ensure safety and no debris is created

🌿 Sustainability

- Prolong the lifespan of satellites
- Reducing space debris at source
- Lower launch demand

04

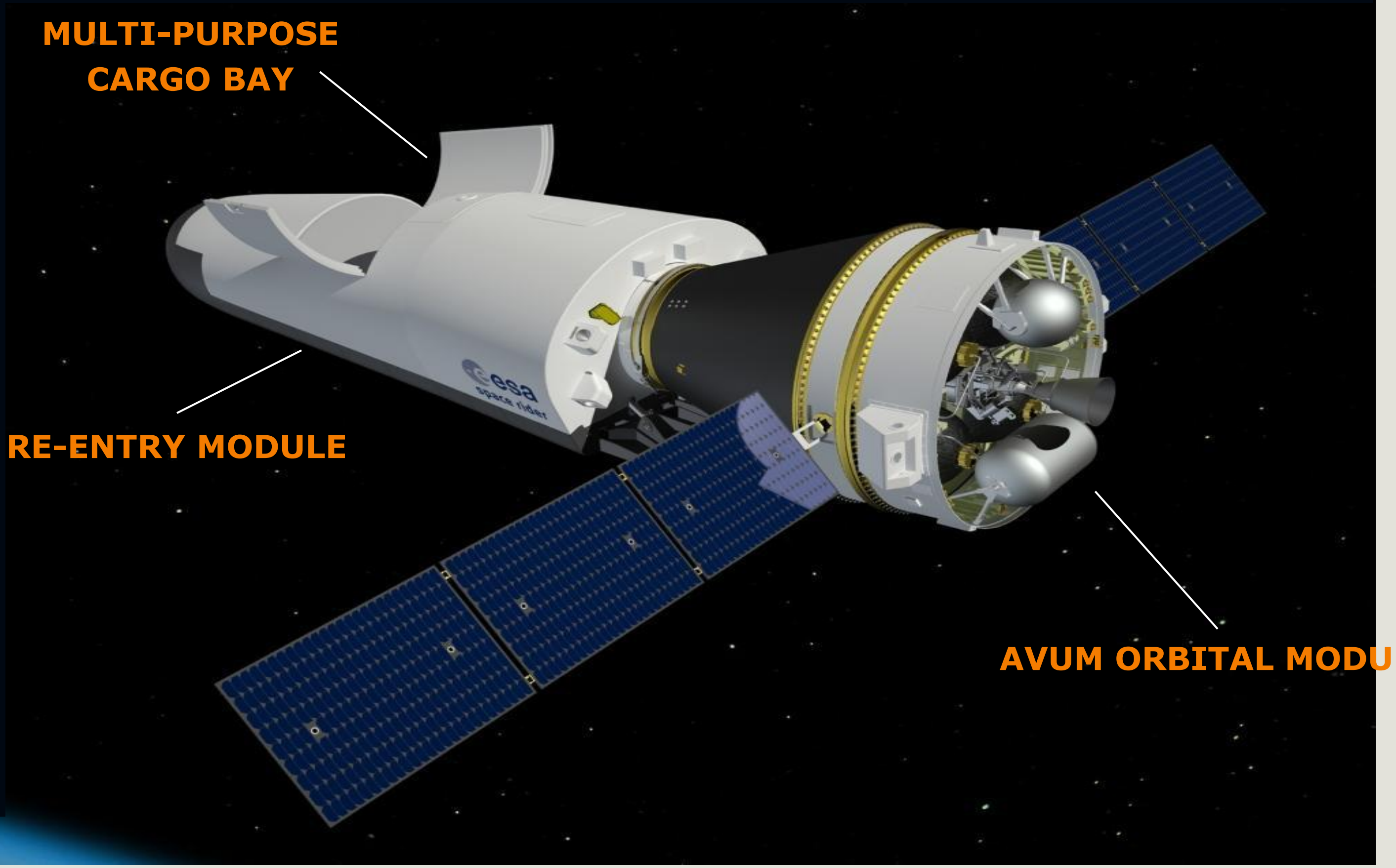
GNC for Recovery & Reusability

SRGNC: Overview

Follows the **successful development, qualification and flight** of the Intermediate eXperimental Vehicle (**IXV**),
Develop a **sustainable reusable European space transportation system** integrated with VEGA C launcher
Enables **routine launch and return** space missions

Integrates modular payloads to fulfill **multiple mission objectives** and **space applications**:

- Space Transportation System fully operated in Europe, from launch to landing
- Operational demonstrator (up to 6 missions with minimum maintenance)
- Orbital operations in multiple scenarios
- High maneuverability
- Safe and precise soft-landing on ground
- Fault tolerant and with stringent safety constraints
- Low overall mission costs

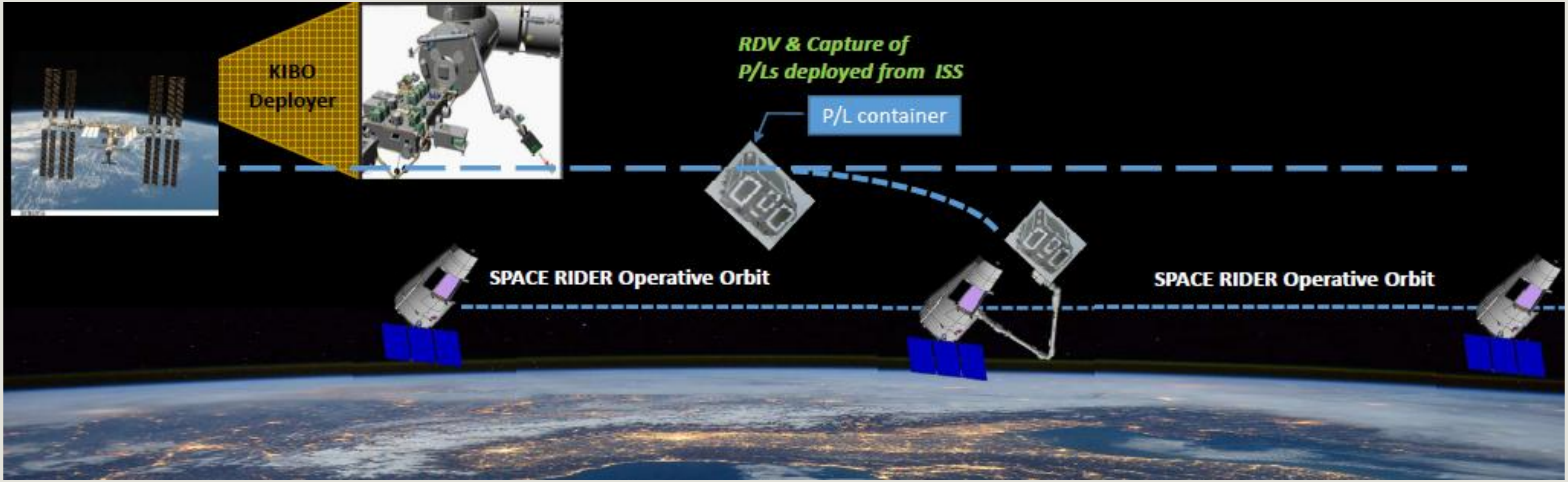


SpaceRider Vehicle: baseline aeroshape of IXV-like lifting body (no wings, L/D of ~0.7), max mass of **~3 tons (160% of IXV)** when loaded. IXV video

SRGNC: Rendezvous

Rendezvous capabilities - ISS Cargo return

- **RDV, capture and soft re-entry** of P/Ls experimented inside the ISS.
- The SPACE RIDER vehicle allows to achieve the ISS orbits, perform **RDV & Capture operations** through the manipulator arm located inside the **Multi Purpose Cargo Bay (MPCB)** and store the P/Ls inside the MPCB for **return to Earth**.



REFAIR

Design and test a GNC subsystem for a 5.4-meter class fairing to enable its **safe and reliable recovery for reuse.**

GNC subsystem architecture designed for a fully recoverable launcher fairing

- Leverages **COTS-based avionics** to minimize cost, complexity, and environmental impact.

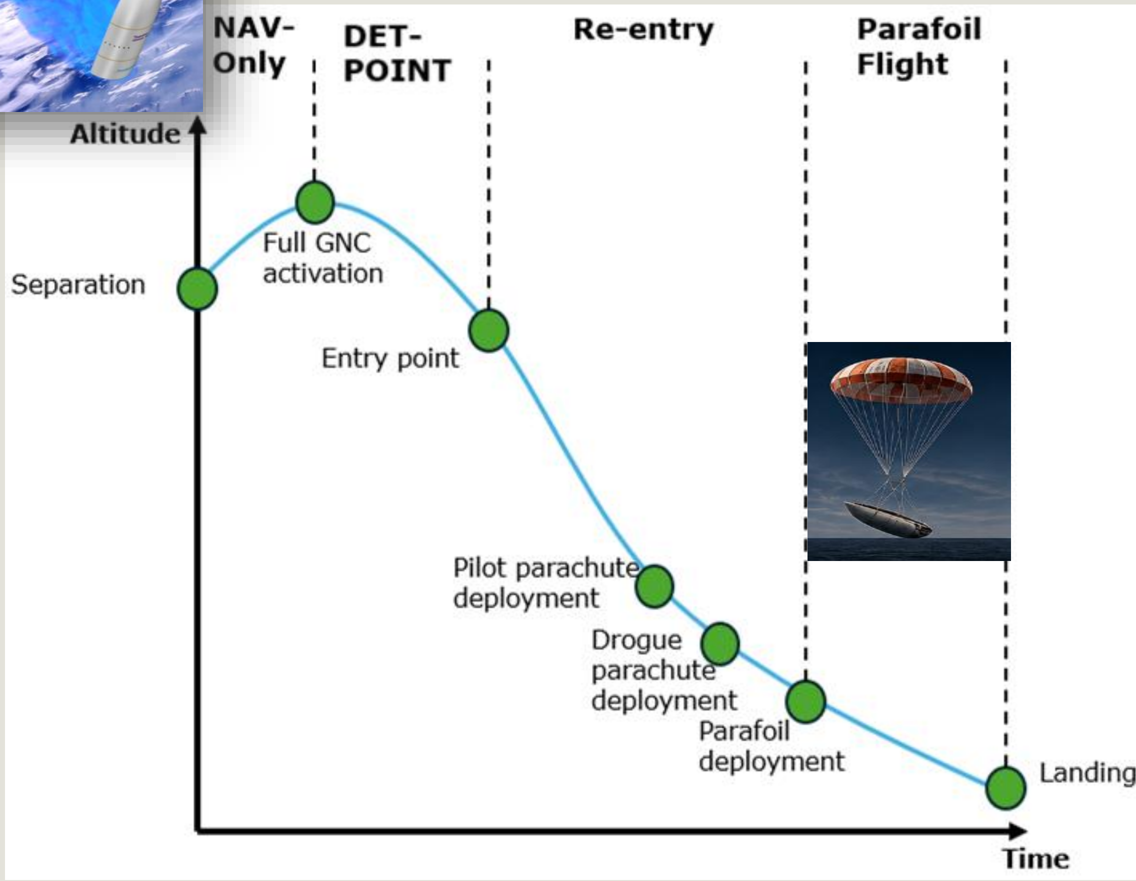
GNC development for the free-flight atmospheric re-entry phase,

- accounts for **fairing flexibility**,
- ensure safe recovery, including **structural integrity, fuel efficiency, and controlled trajectory targeting**

GNC design for the parafoil descent and recovery phase,

- enables **high-precision autonomous landing** on a **moving sea-based platform**,
- supports rapid and reusable recovery operations.

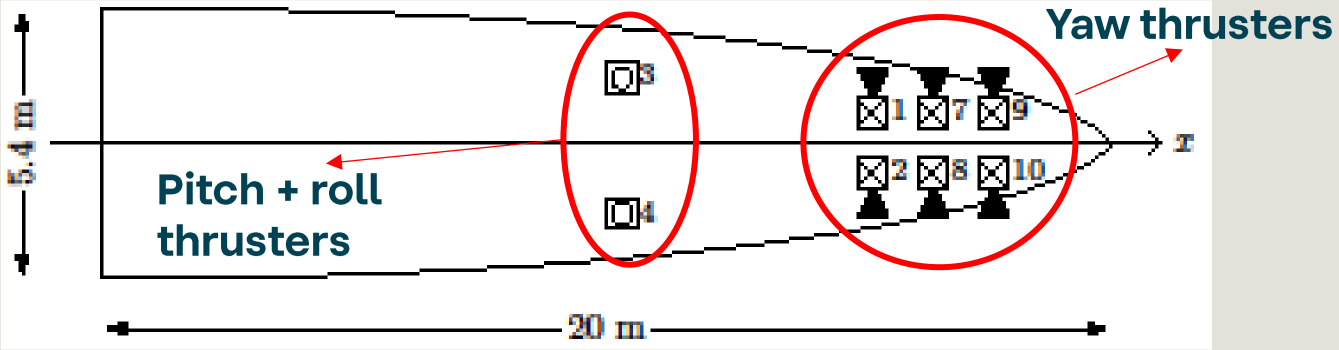
.



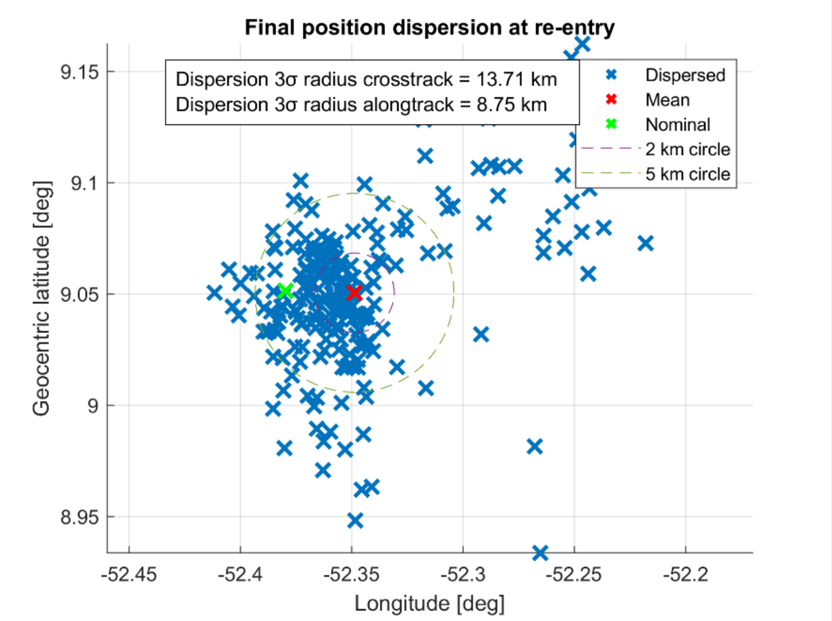
REFAIR: Challenges

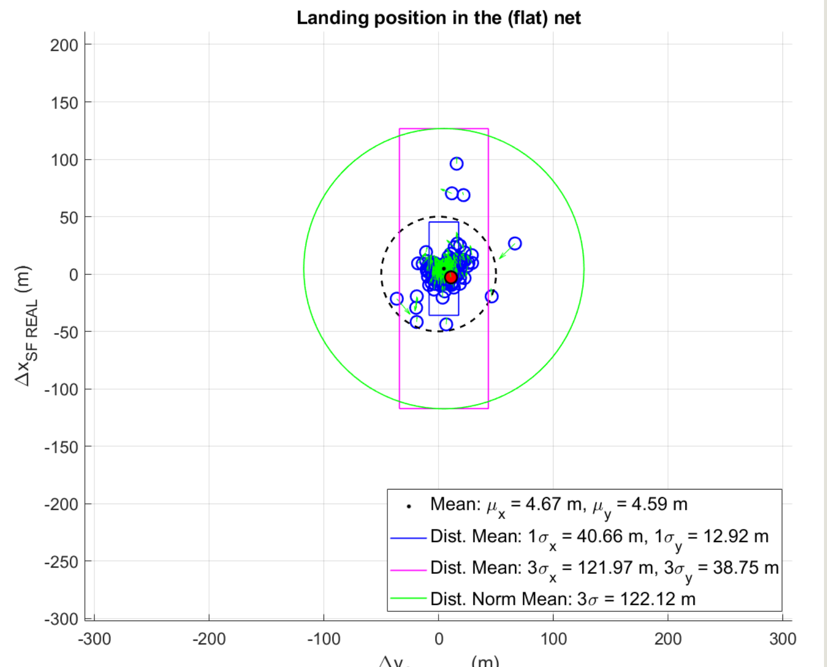
Technical challenges and achievements:

- **Limited modifications and mass budget allowed for the fairing.**
  - impacted mostly control strategy for atmospheric flight phase prior to parachute deployment.
  - selected actuation was **RCS** with a combination of **phase plane control** for detumbling and **H_∞-based control** for trajectory tracking.
  - Control architecture fuses simplicity and reduced fuel consumption from phase plane with robustness and stability guarantees from **H_∞-based control.**
- **The coordinated landing on top of a movable sea-platform** meant that the GNC for parafoil flight had to consider **coordinated guidance and control functions** and communications with the barge.



Fairing sketch with RCS placement





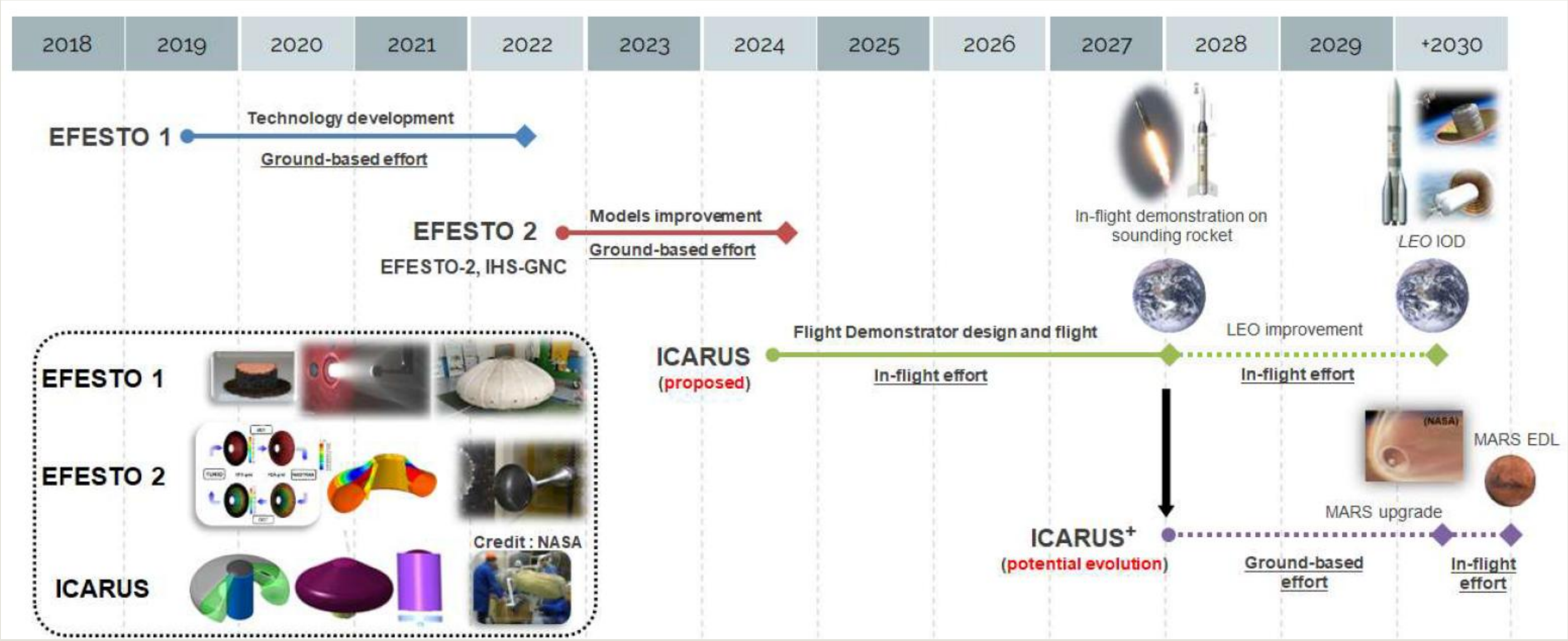
EFESTO/ICARUS: Overview

Goals

Mature **Inflatable Heat Shield (IHS)** technologies, which ensure a **smooth deceleration** during **reentry** without being constrained by the diameter of the launcher during ascent.

Great **potential** for:

- **Launch systems reusability**.
- Inflatable structures for **de-orbiting technologies** (as Inflatable Drag Device) and for **space applications**
- Potential advanced technologies for **Mars Exploration**

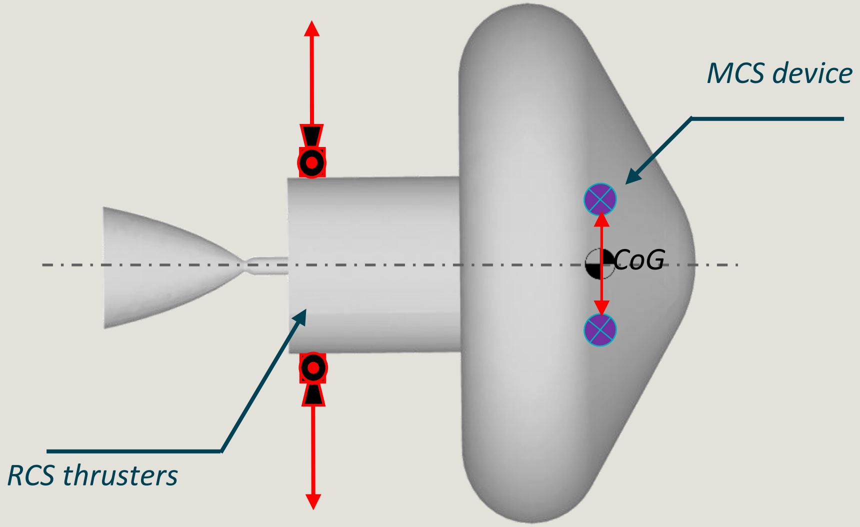


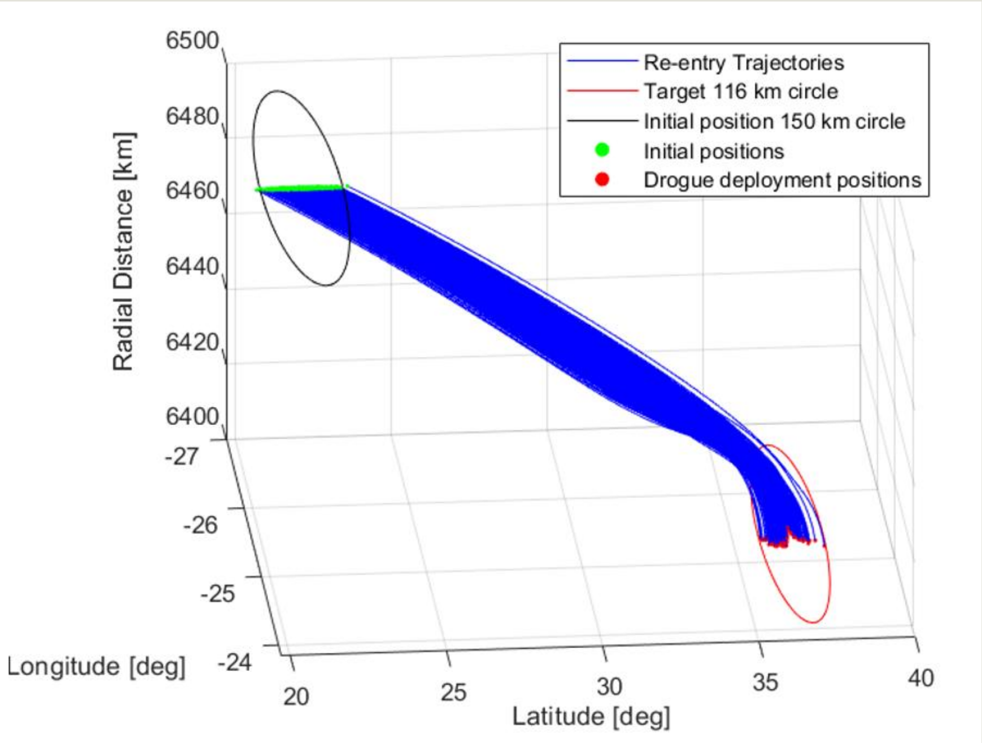
Legacy of European Commission funded projects

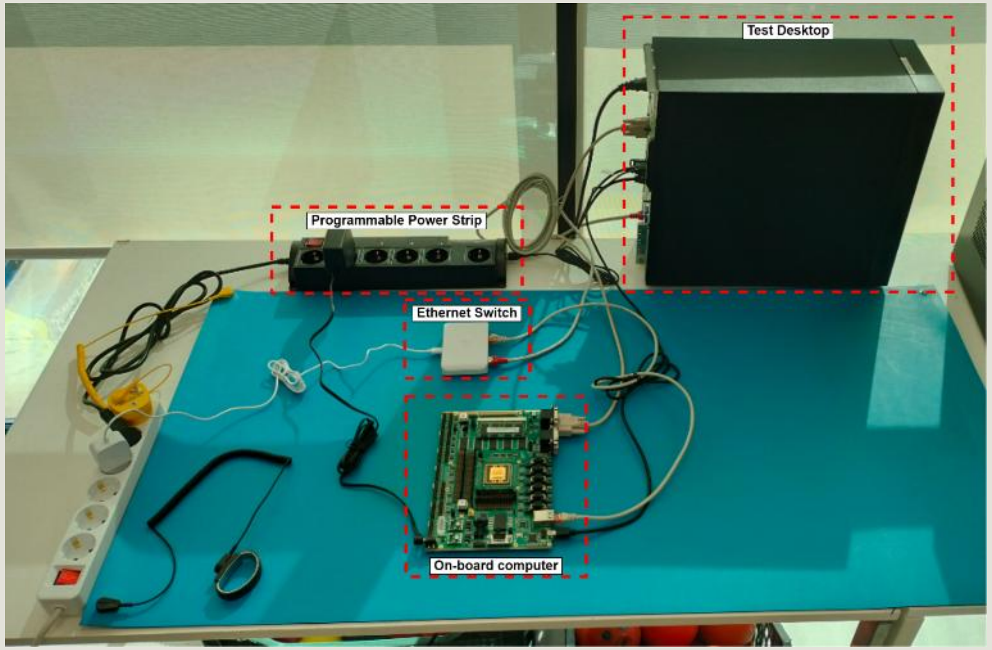
EFESTO

GNC Work Package achievements

- Conceptual definition: **RCS** + **Mass Control System** (MCS)
- Mission and range capability analyses
- **Guidance, Navigation and Control** algorithms design and development, from de-orbit, hypersonic reentry to parachute deployment.
- Validation of the algorithms up to **processor-in-the-loop**.



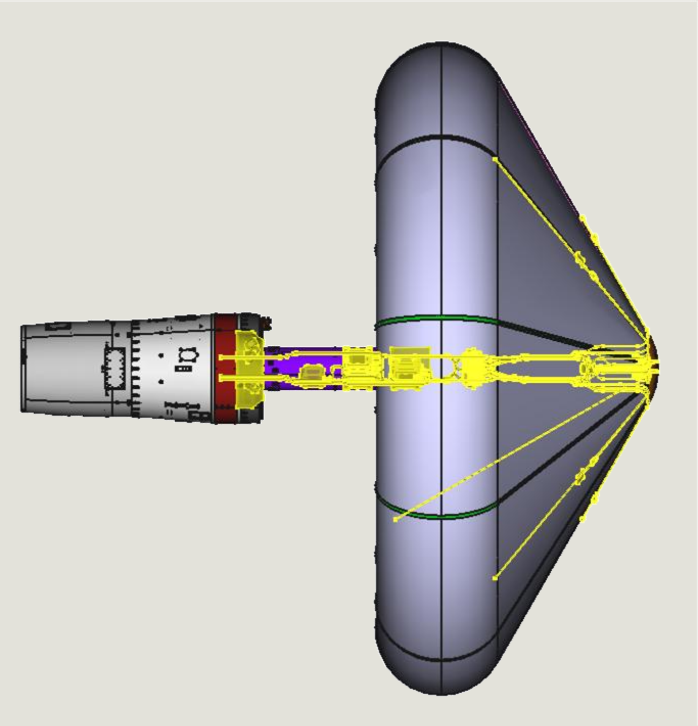


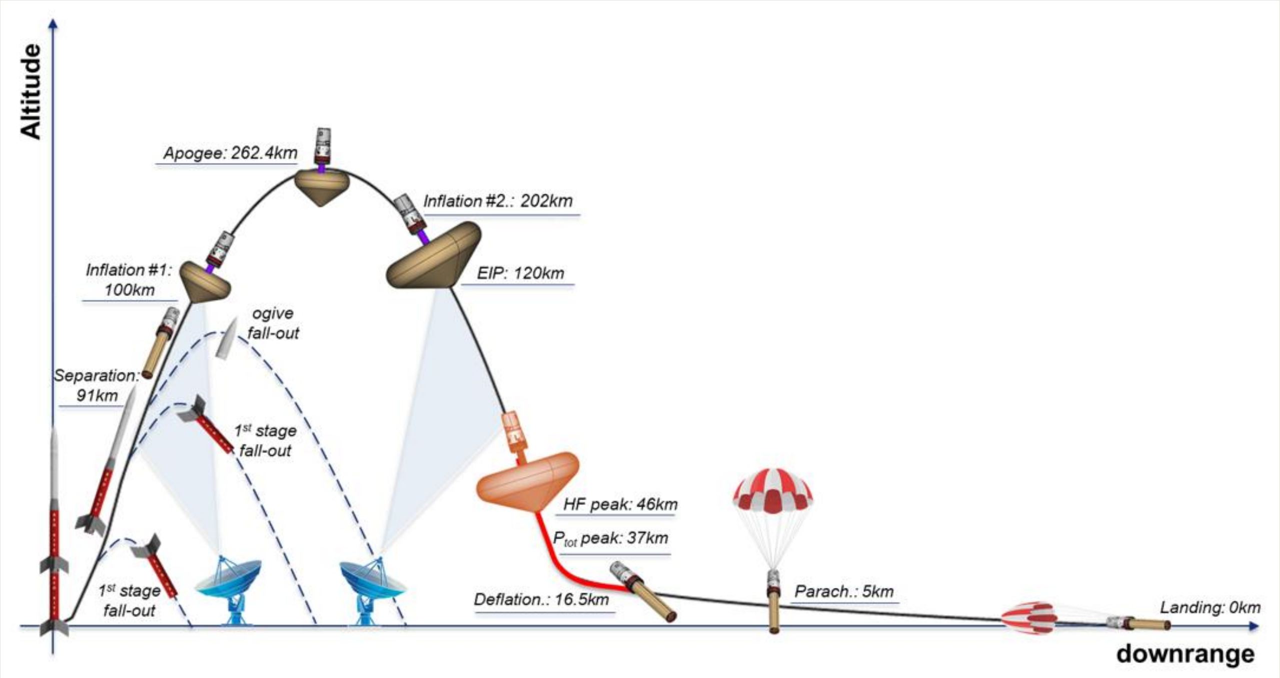


ICARUS

Goals

Flight demonstration of an IHS based re-entry system will be designed, manufactured and flown on board a **sounding rocket** (from DLR-MORABA) for a **ballistic re-entry flight** in 2028





Indra Space responsibilities

- **Project Coordinator** and **System level Integration**
- **Mission/System design** – mission analysis, systems engineering, structure and mechanisms design
- **Flight Management System** (Avionics, SW, EGSE) responsible

Navigation function from EFESTO2 will be included in the on-board SW, validated in **hardware-in-the-loop** and tested **in flight**.

MIURA: Overview

PLD MIURA 5 is a **two-stage partially reusable rocket,** a next-generation European small launch vehicle designed to place small satellites into orbit.

First stage is designed to be recovered—using a combination of propulsion and parachutes.

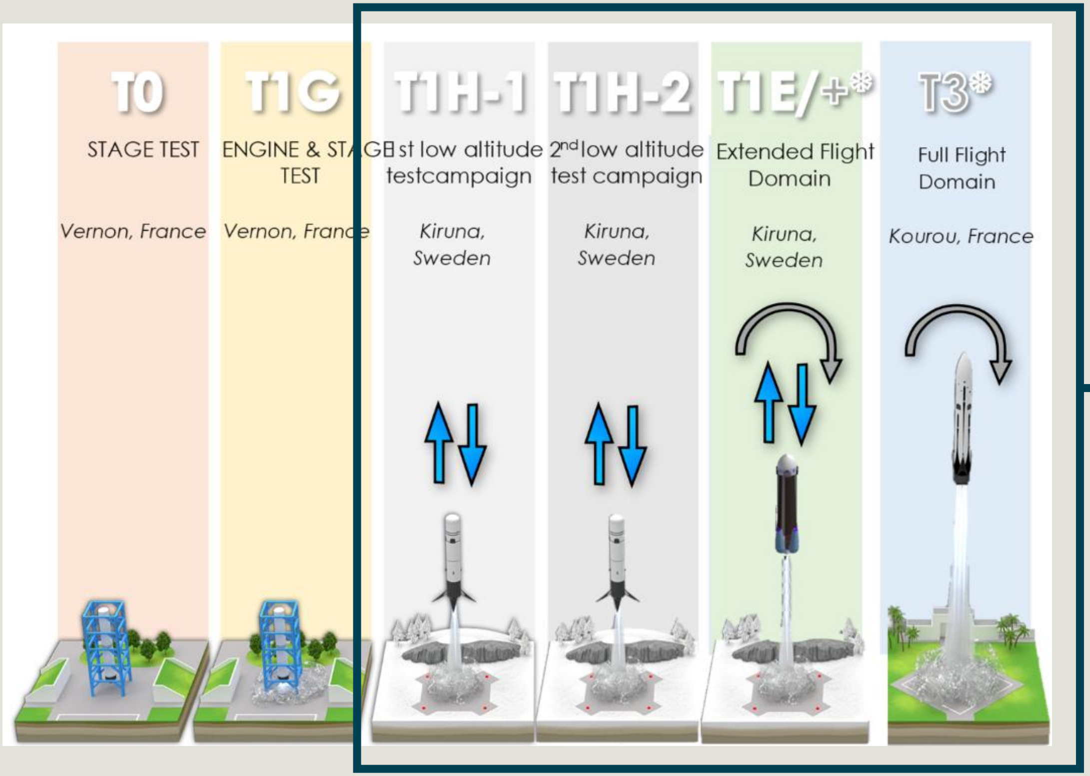
Can be **reused multiple times**, aiming to reduce launch costs and increase launch frequency.

Indra GNC activities

1. GNC subsystem co-engineering and FM definition
2. Navigation development
3. Atmospheric and Orbital phase G-C development
4. GNC SW development for STG1 and STG2
5. GNC Verification & Validation: test facilities (FES and RTTB), system tests (MIL,SIL,PIL) and support AIT

SALTO: Overview

- SALTO project develops technologies and building blocks to enable first stage launcher reusability
- Main goal: reduction of cost for accessing space and grant European space industry independence
- Indra forms part of consortium of more than 30 top notch European industries led by Ariane Group

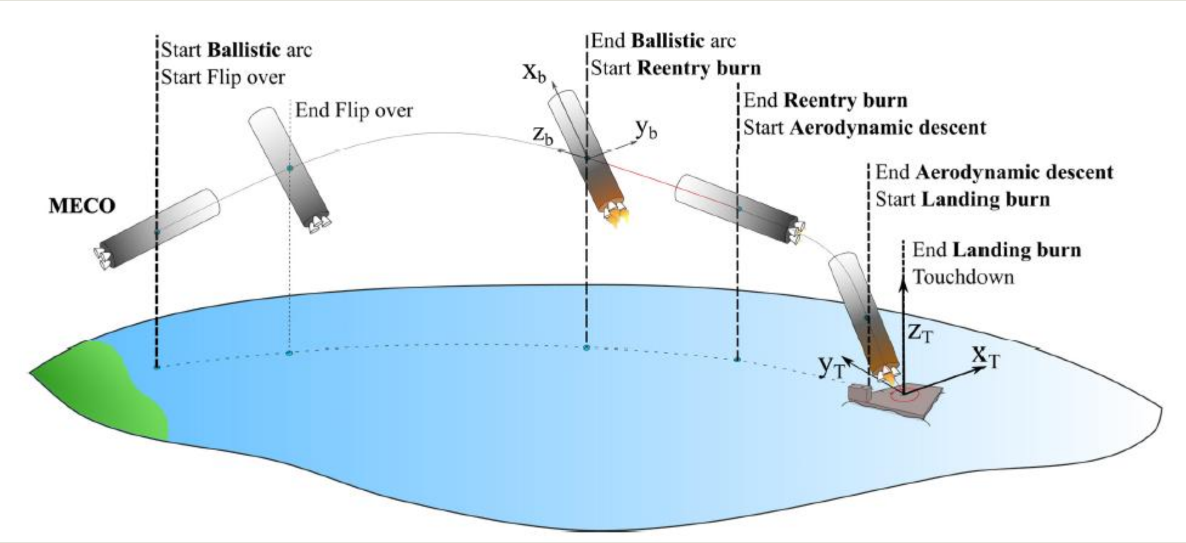


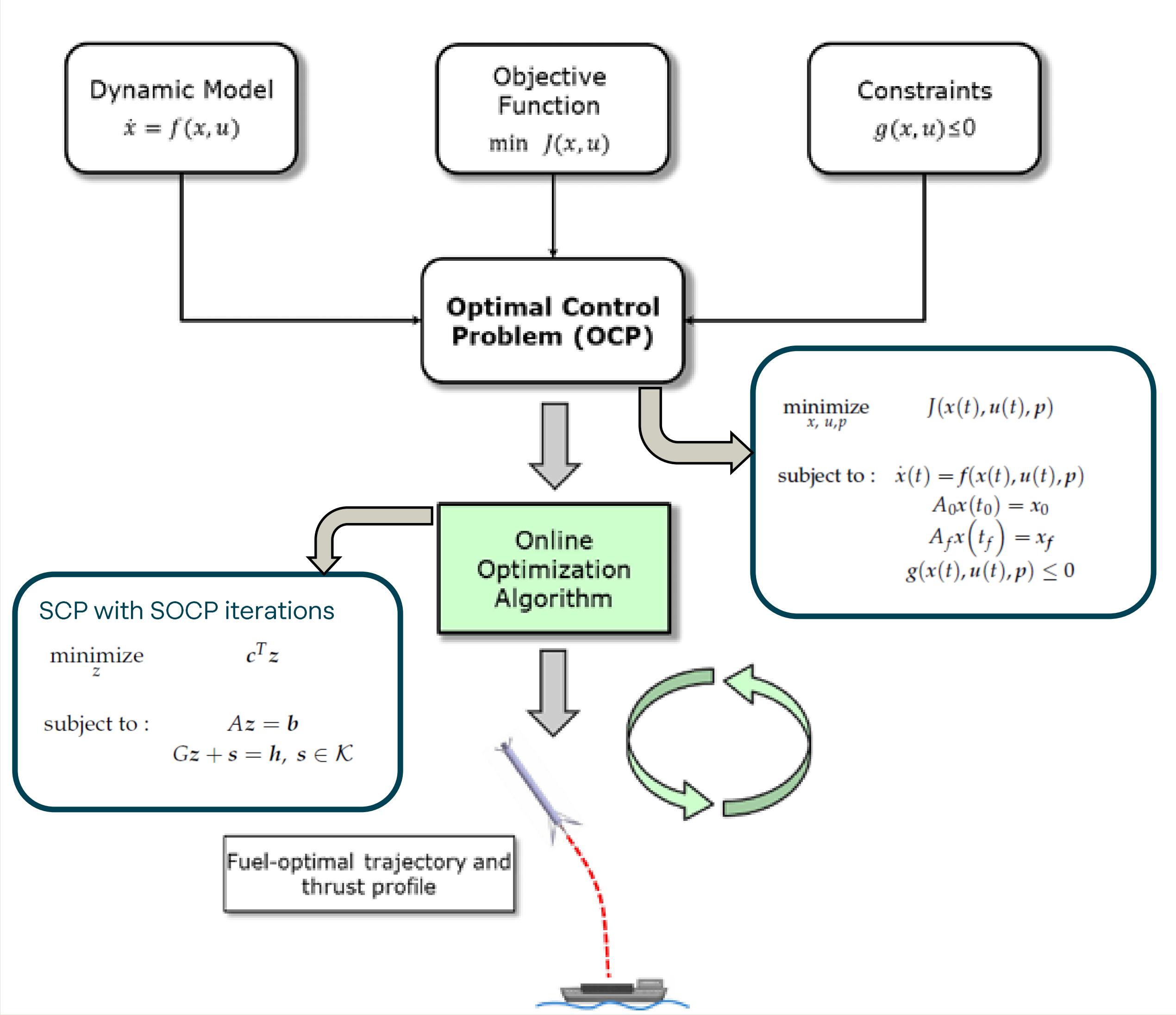
Original Themis roadmap, [Credits: ESA]

Key Indra role

1. Consolidation of *innovative GNC concepts* (onboard optimization, robust methods) adapted to *flight demonstrators* of the Themis programme (*MIL/SIL/PIL*)
2. Assessment of recovery GNC solutions to the *next generations of reusable launchers*
3. Development of methods for *real-time monitoring of flight corridor* and alert generation

SALTO: GNC solution

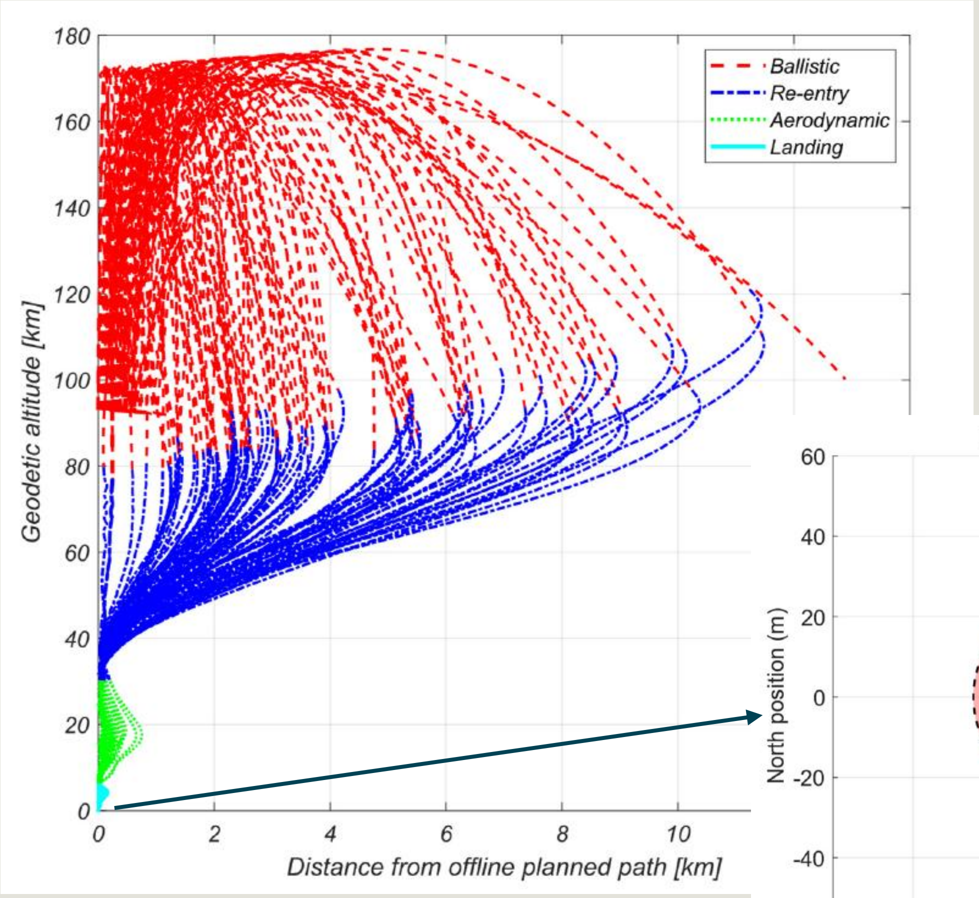


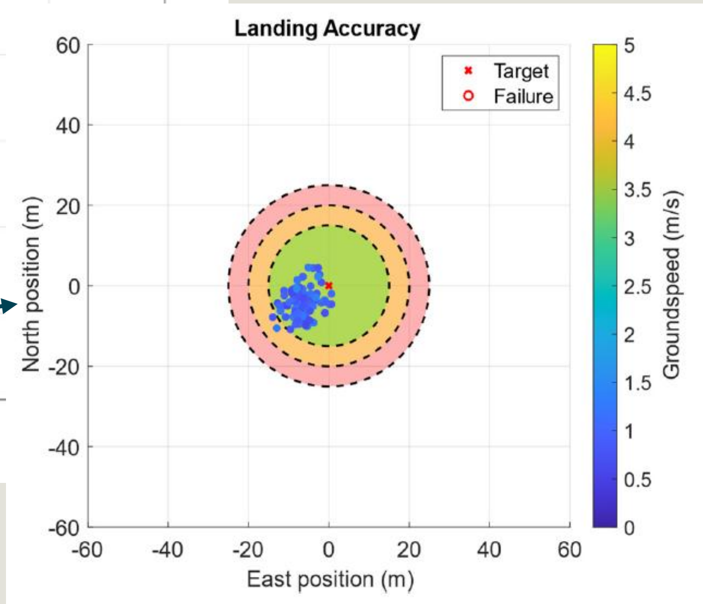


Proposed GNC solution:

- Robust control of multi-actuated vehicle to tackle multivariable problem nature
- Hybrid navigation to ensure precise localization of stage
- Onboard optimization to cope with strict landing requirements

SALTO: Results





Very promising MIL results of the proposed GNC solution

Leon 3	Zedboard	SIL
Not compliant	Almost compliant	Compliant (<10ms)

Ongoing analysis of current boards and code optimization to meet PIL runtime requirements

05

GNC Solutions for Safety

SALTO: Flight Dynamics Health Monitoring

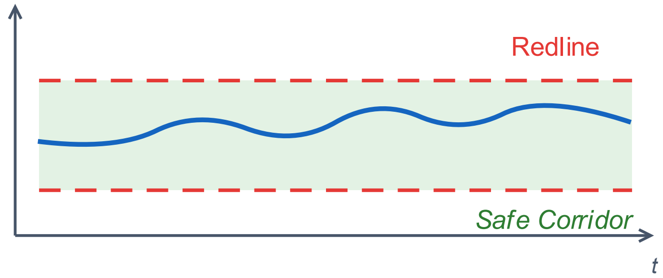
Technology Overview

Reachability analysis and envelope monitoring allow for warning generation for off-nominal flight parameters (Mach-AoA Corridor, angular rates, dynamic pressure).

Instantaneous Impact Point (**IIP**) and Adjusted IIP (**AIIP**) **allow online monitoring and prediction of impact point**.

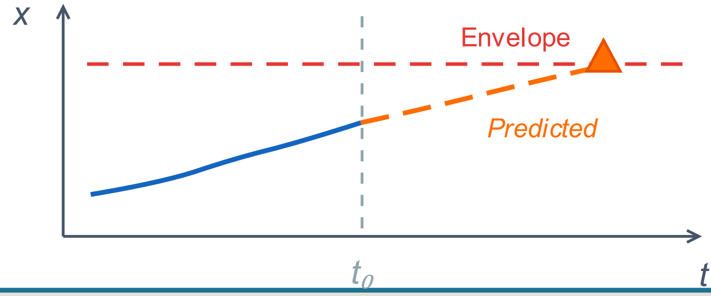
Flight Envelope Monitoring

Real-time tracking of flight parameters against safe corridors per mission phase



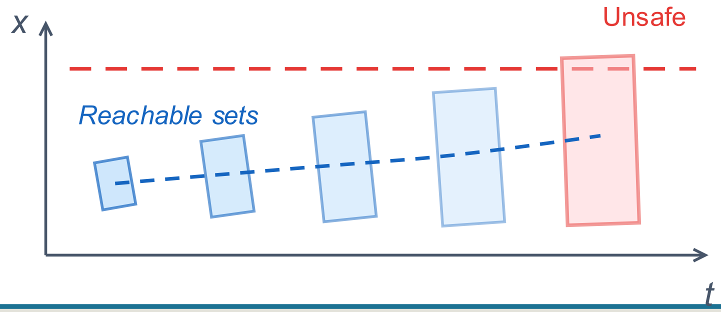
State Prediction

Short-horizon propagation of vehicle state for early breach detection



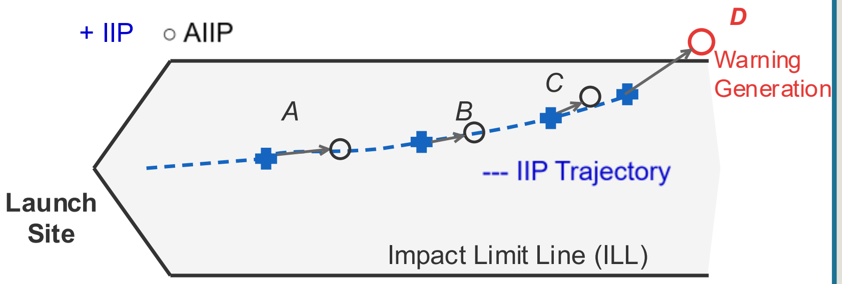
Reachability Analysis

Zonotope-based overapproximation of forward reachable sets



Flight Safety & IIP / AIIP

Impact point estimation and tiered warning decision rules

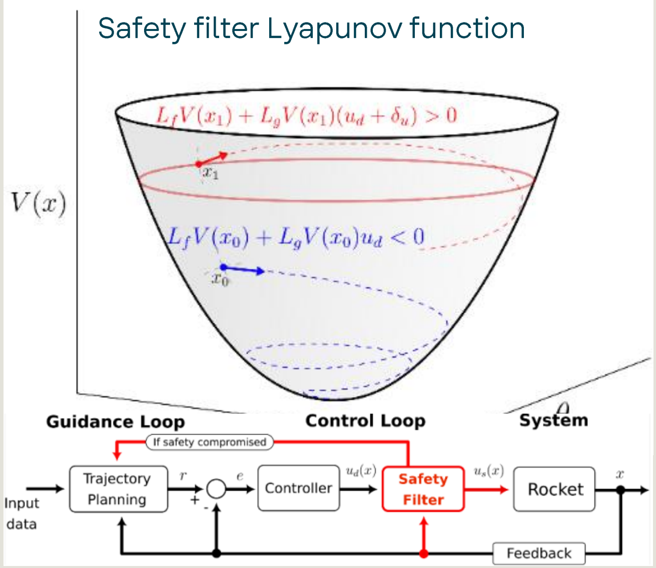


Original IIP / AIIP Image Concept from: "Adjusted Instantaneous Impact Point and New Flight Safety Decision Rule" Young-Woo Nam, et al. Journal of Spacecraft and Rockets 2016 53:4, 766-773

VALORS: Smart Launcher V&V

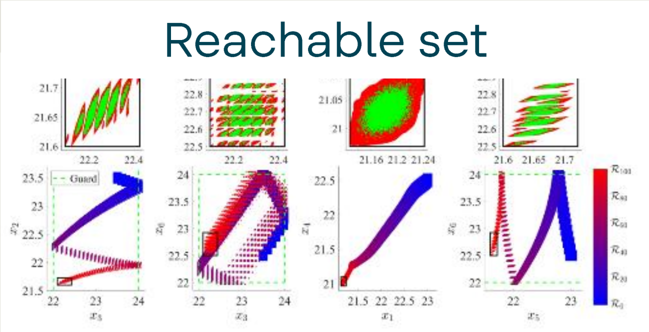
SLV-1: Obtaining stability and safety certificates using neural networks and deep learning

- **Problem:** How to get stability and safety certificates for complex systems?
- **Possible techniques:** baseline techniques contain Lyapunov Functions (LF), Barrier Functions (BF), Integral Quadratic Constraints (IQCs). For complex systems, the use of Neural Networks can offer great potential: DFNNs, PINNs
- **Preliminary selected techniques:** LF/BF+PINNs



SLV-2: Improving worst-case search using reachability analysis and Bayesian inference

- **Problem:** How to identify combinations of parameters that lead to the most critical degradation of stability or performance?
- **Possible techniques:** Reachability Analysis (Contrained Convex Generatorsor Hybrid Zonotopes), Bayesian inference
- **Preliminary selected techniques:** Reachability Analysis using CCGs and using Hybrid Zonotopes



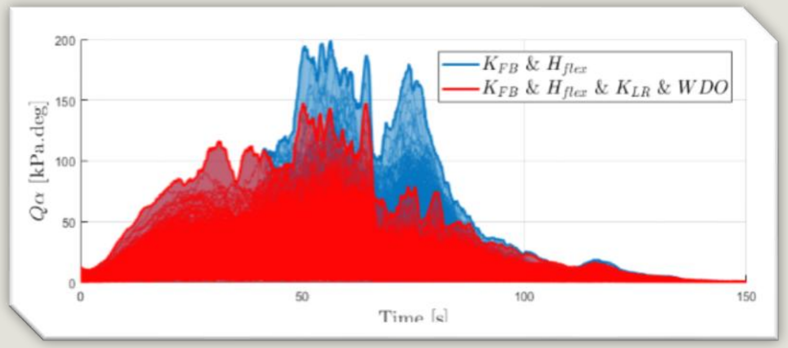
Applied to SURE solutions (Enabling techniques for a Smart Launchers)

Complements BRAVE (INDI based control solutions applicable to several launcher models)

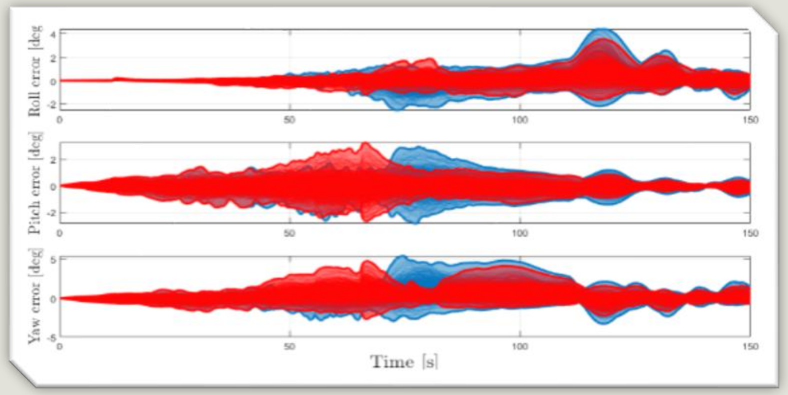
SURE
Enabling techniques for Smart Launchers

Control using Wind Information

Improve Load Relief capability through the design and Implementation of robust Wind Disturbance observer (rWDO) for a Flexible Launch Vehicle



Significant Load reduction

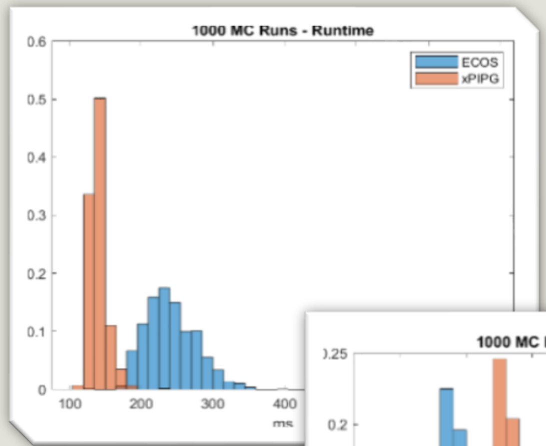


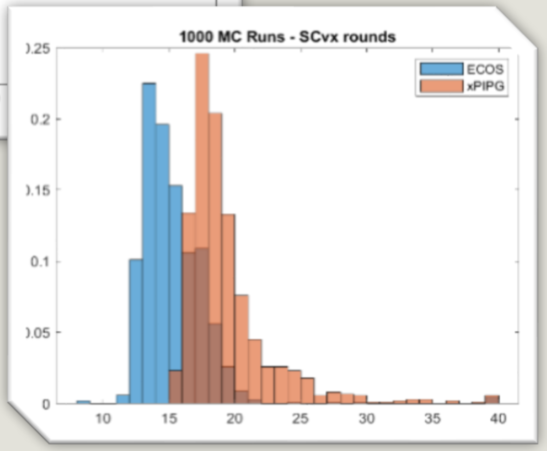
Larger attitude error

Real-Time Optimized Guidance

Improve performance and simplicity of Successive Convexification (Scvx) convex solver xPIPG through:

- Custom solver
- xPIPG warm-start
- Initial guess for SCvx
- And others…



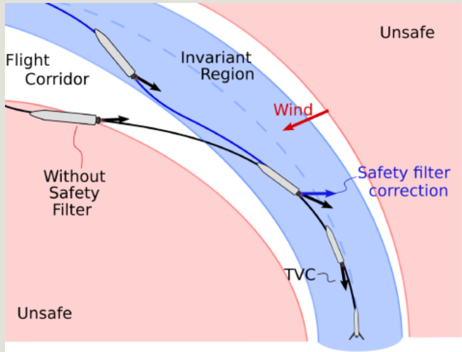


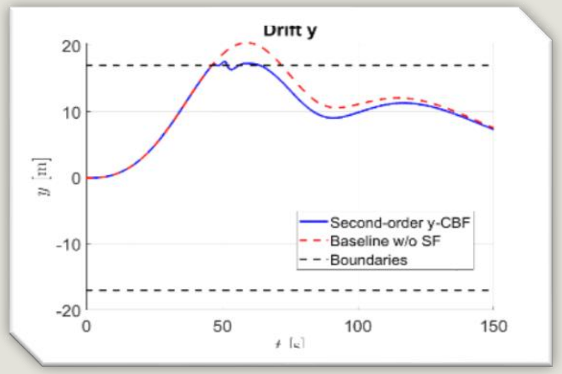
Indra Space

Robust Safety Control

Development of Safety Filter based on robust Control Barrier Functions to address safety during launch

- CBF designed to bound drift & maintain attitude stability
- CBD active only at the boundary





06

Concluding remarks

INDRA

GNC

- a **core enabler of space sustainability**, supporting safe and efficient operations for the full mission lifecycle (launch, orbital, recovery)
- a **strategic capability** for Europe’s future autonomous and resilient space operations.

💫 THANK YOU! 💫

🧑‍🚀 José Vasconcelos jmvasconcelos@indracompany.com