ESA's Steps towards Re-Entry Technologies and Systems Reusability

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From the IXV Mission Design-To-Flight to the Pride Mission Definition

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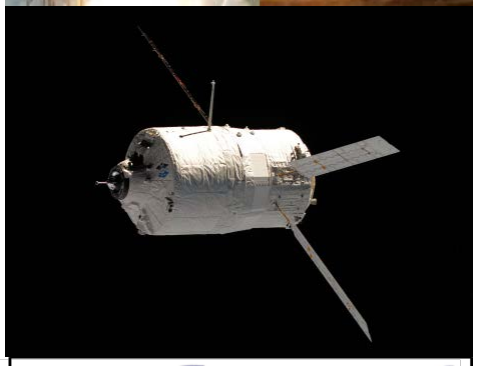
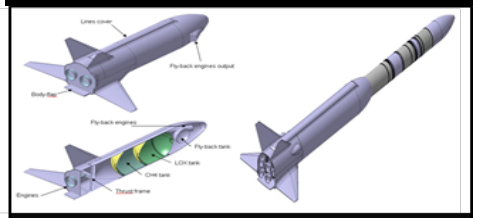
The IXV Objective

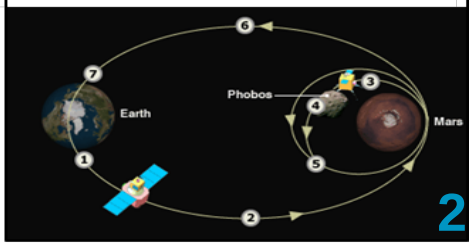
Europe has a consolidated know-how in going to orbit: the history of European success in the field of launchers, with Ariane and Vega, has consolidated the European leadership in "**access to space**".

Europe has a consolidated know-how in operating complex systems in orbit: the history of European success in all space applications (e.g. Science, Exploration, ISS servicing) has consolidated the European leadership to "**operate in space**".



Europe had limited know-how in returning from orbit: the IXV mission objective was to develop European system and technological know-how for "**return from space**", enabling future ambitious plans in the field of **reusable launchers stages**, **return from orbital infrastructures**, **planetary return missions**.





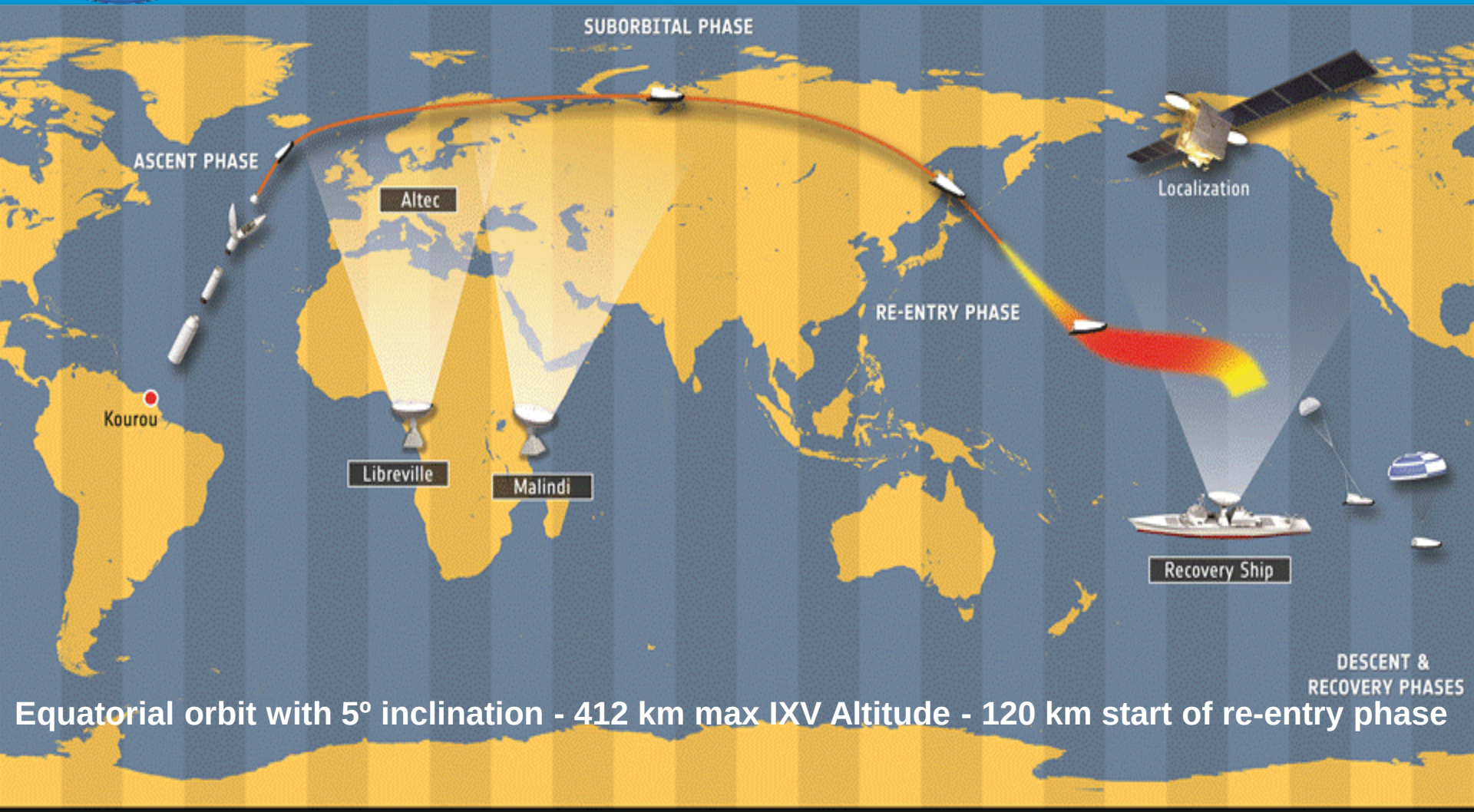
The IXV Strategy

Not only catching-up, but also stepping ahead: the strategy was to perform the "intermediate" step, from the ARD capsule flown in 1998 towards ambitious space transportation systems applications, **pioneering several "Firsts"**.

The IXV mission has pioneered:

- worldwide, a full reentry from orbital speeds with an un-winged lifting-body (increasing the performances for cross-range, down-range, and precision landing while maintaining the simplicity/reliability of capsules);
- worldwide, a full reentry from orbital speeds with large advanced reusable ceramic matrix composites hot structures (increasing the reusability/reliability with respect to other existing solutions);
- in Europe, a full reentry with combined use of rockets and flaps for flight control (increasing the controllability/maneuverability for precision landing with respect to the flown ARD capsule);
- in Europe, a full reentry with advanced aerothermodynamics experiments through a wider corridor than the ARD capsule.

The IXV Mission Overview

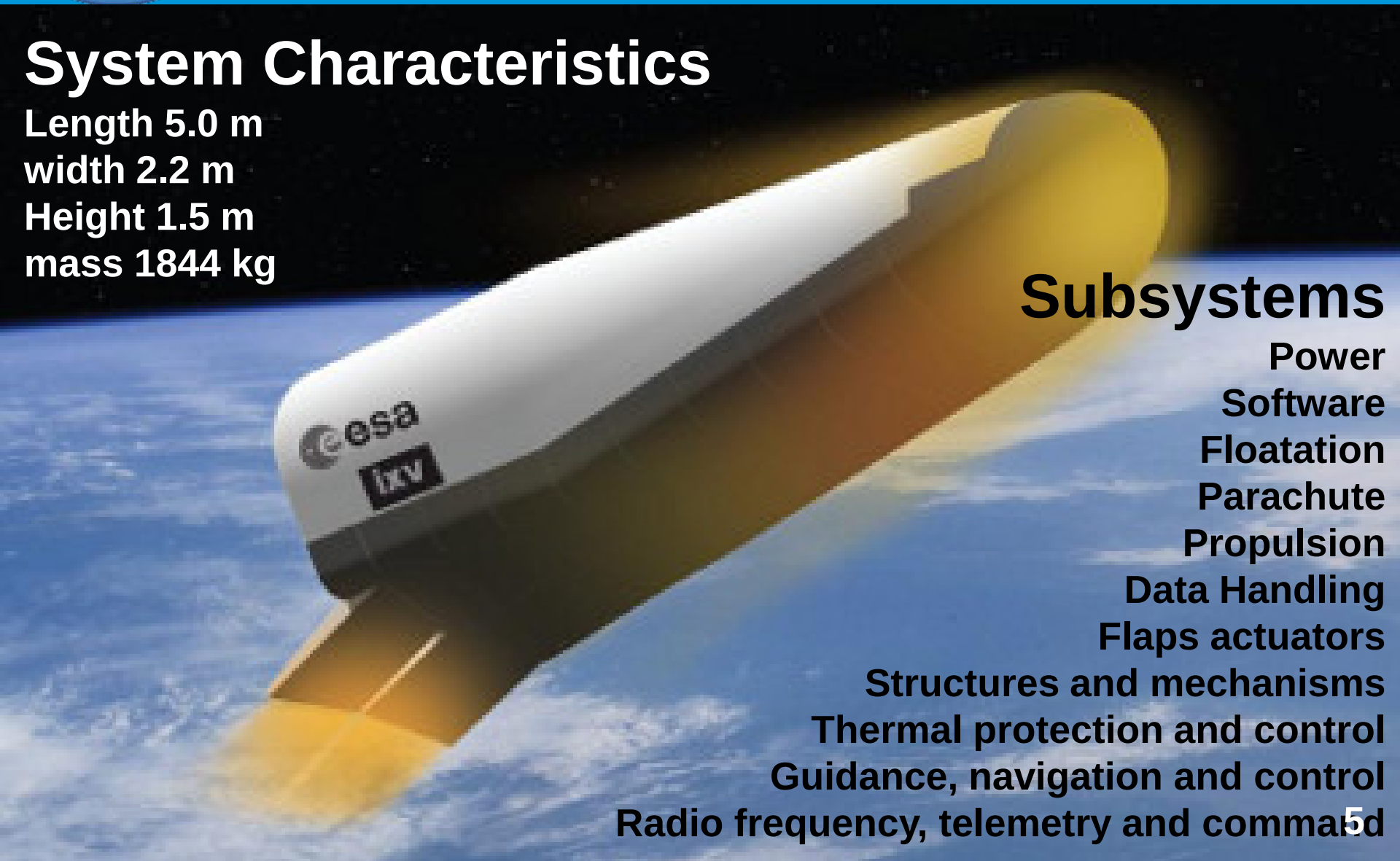


Equatorial orbit with 5º inclination - 412 km max IXV Altitude - 120 km start of re-entry phase

The IXV Space Segment

System Characteristics

Length 5.0 m
width 2.2 m
Height 1.5 m
mass 1844 kg



Subsystems

Power
Software
Floatation
Parachute
Propulsion
Data Handling
Flaps actuators
Structures and mechanisms
Thermal protection and control
Guidance, navigation and control
Radio frequency, telemetry and command

The IXV In-Flight Experiments

The **In-flight Experiments** were the mission driver, integrating more than 300 conventional and advanced sensors, including an infra-red camera pointing to the flaps region.

OBJECTIVES	EXPERIMENTS
AERODYNAMICS AEROTHERMODYNAMICS *Investigation and quantification of aerodynamic and aerothermodynamic phenomena during atmospheric reentry*	Continuum Flow High Altitude Aerodynamics Flush Air Data System Base Flow-field General and Cavity Heating Wall catalysis Flap ATD+SWBLI Jet Flowfield Interaction Laminar to Turbulent transition IR Camera Temp Mapping Slip Flow/Skin Friction
THERMAL PROTECTION *Validation of thermo-mechanical performance in re-entry conditions*	C/SiC Nose Cap C/SiC Shingles C/SiC Body Flap Ablative TPS Junctions Seals
FLIGHT MECHANICS & GNC *Models validation (Vehicle Dynamics, FPCS, RCS, AED, MCI). Performance and margin verification*	Vehicle Model Identification
FLIGHT HARDWARE *Validation of performance and reusability assessment*	Thermal Protection components Avionics components Propulsion components Structural components Mechanisms components

MEASUREMENTS

EXPERIMENTAL SENSORS

Type S Thermocouple	105
Type K Thermocouple	89
Absolute Pressure Sensor	37
Differential Pressure Sensor	2
Displacement Sensors	12
Strain Gauges	48
Infra Red Camera	1
Inertial Motion Unit	1

EDAR Experiment Data Acquisition & Recording

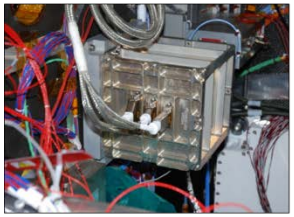
One Data Acquisition Unit Master
Four Data Acquisition Units (DAUs)
One Ethernet Switch
Two Solid State Recorders
One Exp Telemetry Transmitter
Two Exp Telemetry Antennas
Four Redundant Recorders on DAUs
IR camera Data Handling Unit

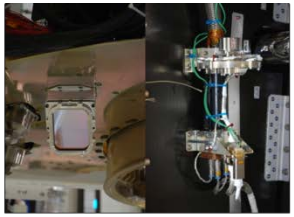
HOUSE KEEPING SENSORS

Ceramic Shingle with Platinum Thermocouples integrated

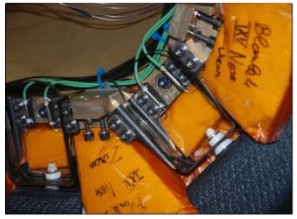
Ceramic Shingle with Pressure port piping through insulation

Nose with bundles of sensors routed (TCs, Pressure, Strain Gauges)

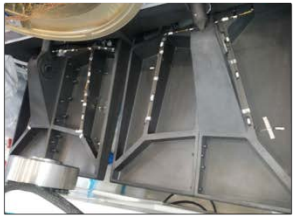

Infrared Camera Data Handling Unit

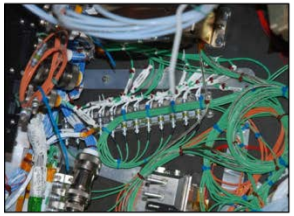

IRC Periscope (Left) – Infra Red Camera with Filter Wheel (Right)

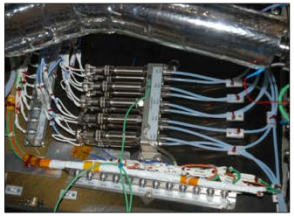
Displacement Sensors and TPS insulation


Nose Metallic Stand-Off with strain gauges and thermocouples

Ceramic Hinge TPS with Thermocouples bundle


Ceramic Flap with Platinum Thermocouple integrated


Front Bulkhead Thermocouple bracket


Shear Panel Pressure Sensors Manifold

Front Bulkhead Thermocouple bracket

Going through the IXV Mission

The Space Segment Preparation

Kourou

The Ground Segment Preparation

The Countdown

On the launch day the IXV flight segment was activated at 09.28.30 UTC for a lift-off at H0 = 13:00 UTC. After successful progression through the launch chronology, at H0-8 minutes the authorization to perform the transition to internal power was not granted due to a RED concerning the Launch Range, and the new H0 was postponed by 40 minutes and set at 13:40 UTC.

At the new H0-8 minutes the authorization to perform the transition to internal power was granted. At the new H0-4 minutes the synchronized sequence was correctly resumed, and at the new H0-2 minutes the IXV final configuration for lift-off was enabled.

The Lift-off

The VEGA lift-off occurred nominally at 13:40 UTC, the VEGA-IXV separation occurred at 13:59 UTC, and the following four main mission phases occurred with respect to lift-off time (new H0):

1. **IXV in-space operations phase**, *from new H0 + 1130 sec;*
2. **IXV experimentation phase**, *from new H0 + 3899 sec;*
3. **IXV descent phase**, *starting from new H0 + 5112 sec;*
4. **IXV recovery phase**, *starting from new H0 + 5796 sec.*

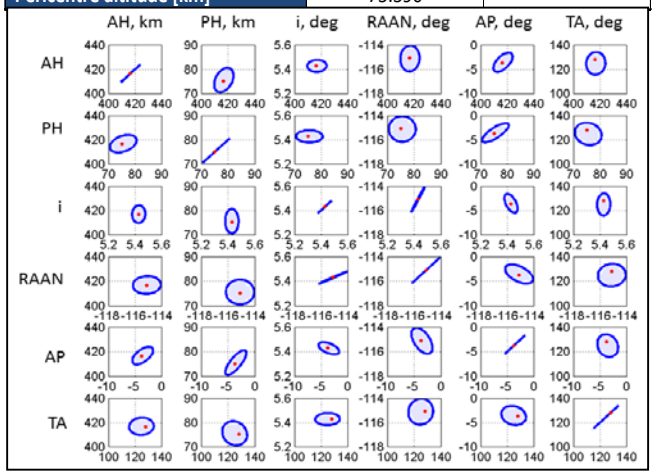
The Space Segment Performance

1. IXV in-space operations phase

The VEGA separation conditions are confirmed extremely close to the predicted ones, remaining within the standard variations, enabling the IXV to start its mission from the nominal conditions.

Following the separation from VEGA, the IXV performed successfully all the planned in-space operations (i.e. telemetry transmitters activation, propulsion system priming, flaps control system activation) according to the nominal flight programme, preparing itself for the experimental phase, reaching the entry interface position at 120 km altitude with extremely high precision, whose minor differences are all within the standard variations, enabling the IXV to start its experimental phase from the nominal conditions.

	PREDICTED	FLOWN
Separation Time [sec]	1079	1130
Semi-major axis	6624.285	6623.870
Eccentricity [-]	0.0257477	0.0257689
Inclination [deg]	5.429	5.430
RAAN wrt Vega/Kourou [deg]	-62.315	-62.314
Argument of periapsis [deg]	-3.563	-3.742
True anomaly [deg]	124.797	128.058
Apocentre altitude [km]	416.708	416.431
Pericentre altitude [km]	75.590	75.051

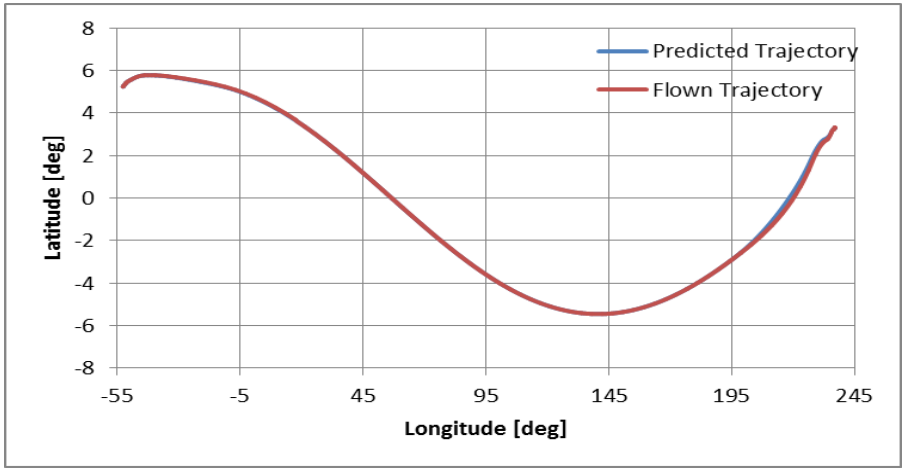


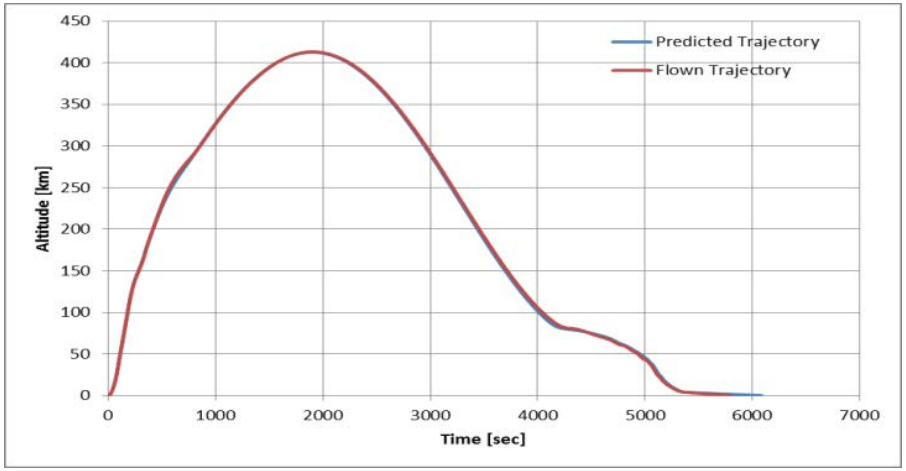
	PREDICTED	FLOWN
Separation Time [sec]	3874.34	3899.3
Geodetic altitude [km]	120.00	120.00
Geodetic latitude [deg]	-4.48	-4.40
Geocentric longitude [deg]	173.39	174.77
Flight path velocity [m/sec]	7435.16	7437.89.
Flight path angle [deg]	-1.21	-1.16
Flight path heading [deg]	86.70	86.58
Angle of Attack [deg]	42.43	46.7451497245401
Angle of Sideslip [deg]	1.26	-0.90
Bank Angle [deg]	1.24	-0.52

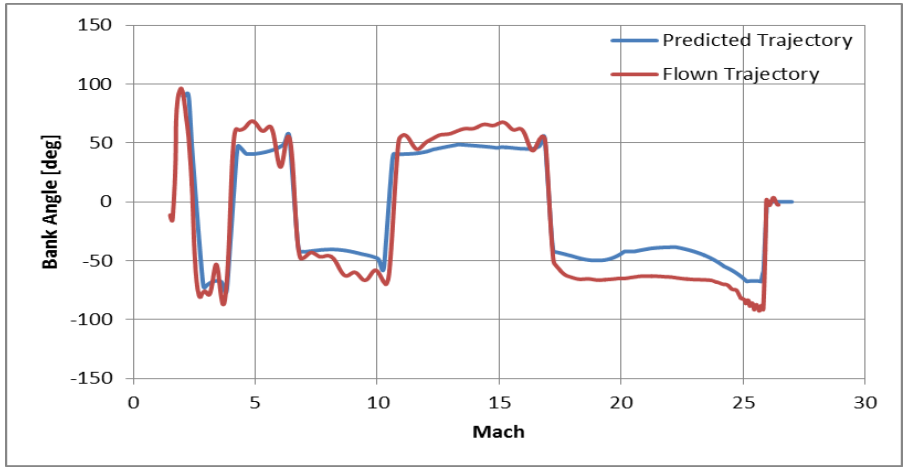
The Space Segment Performance

2. IXV experimental phase

The IXV has flown a fully nominal trajectory extremely close to the predictions with respect to all key trajectory parameters (i.e. altitude, latitude, longitude, Mach numbers, bank angles), enabling the fulfillment of all experimentation objectives.





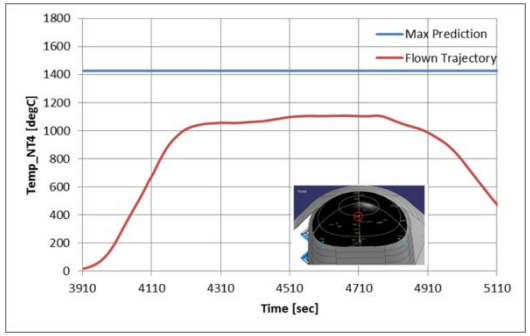


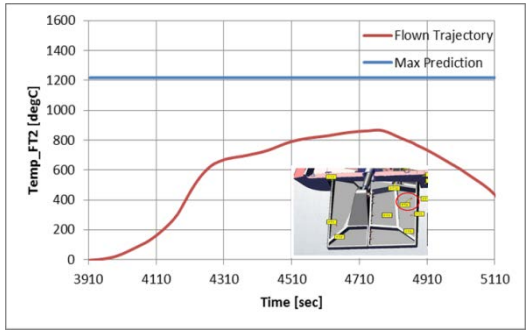
The Space Segment Performance

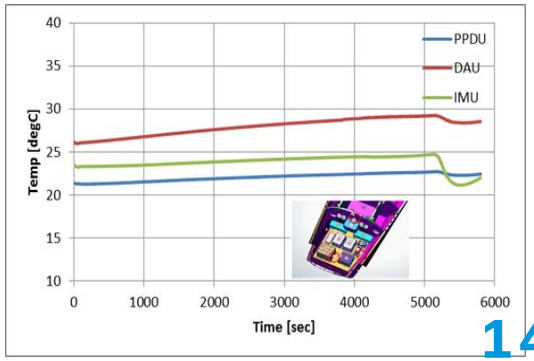
2. IXV experimental phase

The analysis of the experimental data is revealing very interesting findings and confirmations:

- External temperatures lower than those considered during the design and development to cope with the uncertainties (e.g. real-gas effects, catalysis effects, transition effects).
- Internal temperatures within the limits of the operating ranges of all avionics components, in line with the system thermal management performances predictions.
- Propulsion fuel consumptions higher than those predicted, compensated by higher aerodynamic performances of the system.
- Higher visibility performances (i.e. lower blackout), enabling enhanced flight-to-ground communications.
- Out of more than 300 sensors, only one redundant thermocouple has failed during the flight, with no impact on the experimentation objectives.



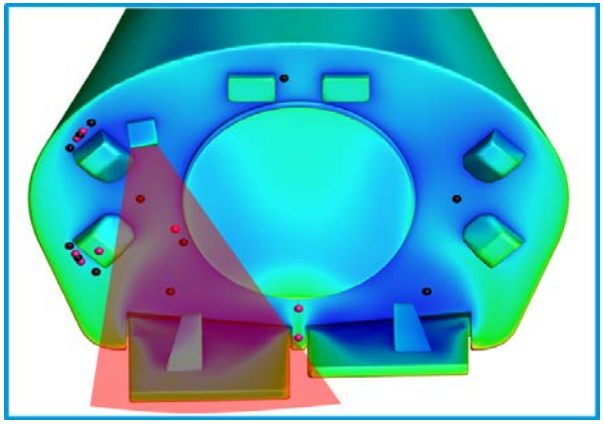




The Space Segment Performance

2. IXV experimental phase

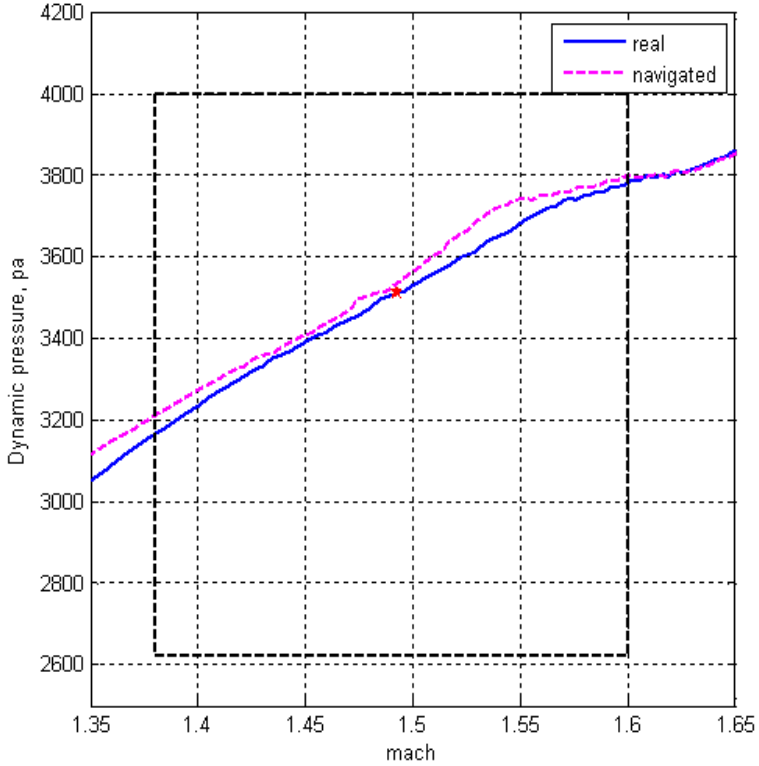
The IXV Infra-Red Camera placed at the back of the spacecraft to monitor the flaps heating has registered unprecedented flight data throughout the whole mission from hot re-entry (left picture below with visible plasma) to landing (right picture below with visible sea).

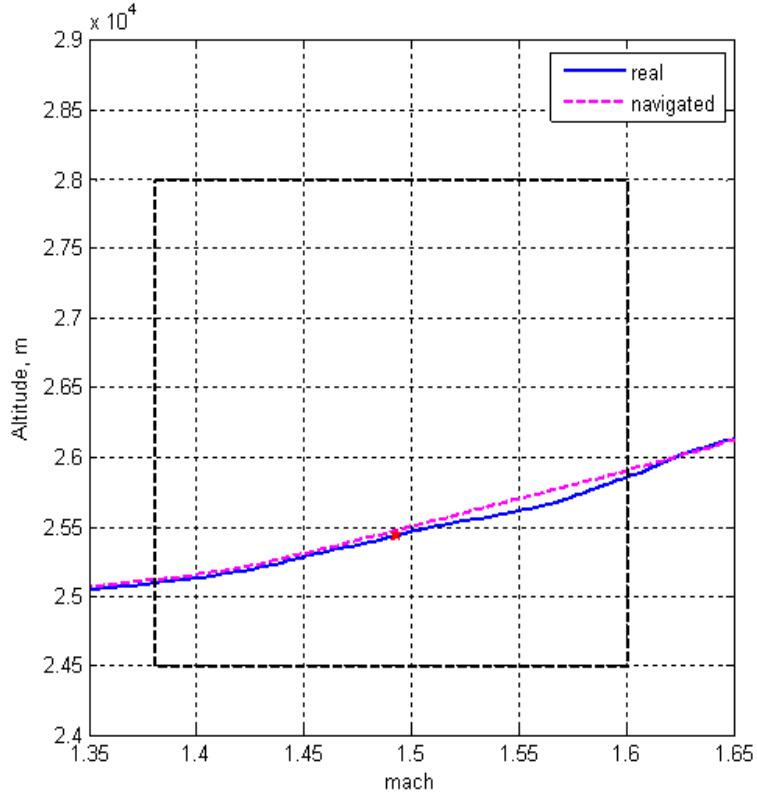


The Space Segment Performance

2. IXV experimental phase

The IXV has completed the experimentation phase with the successful firing of the parachute mortar for the extraction of the supersonic stage occurred within the nominal envelope of mach-pressure/altitude conditions.

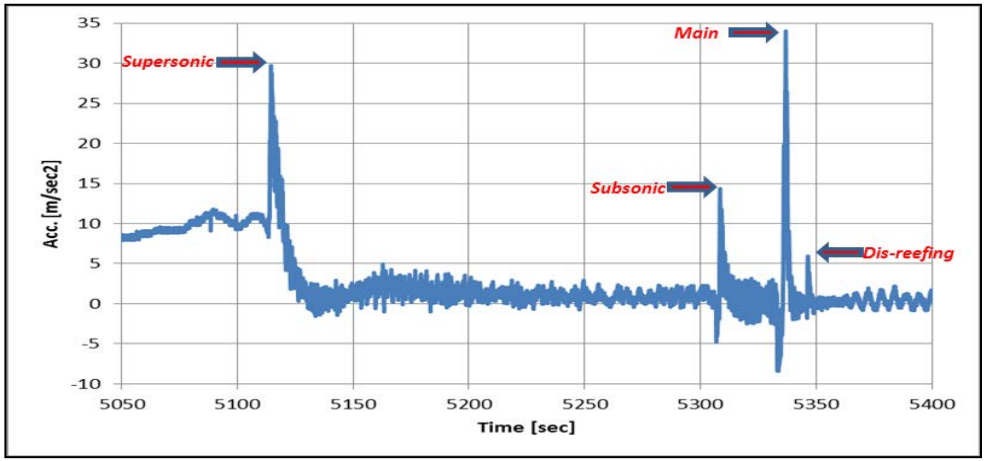


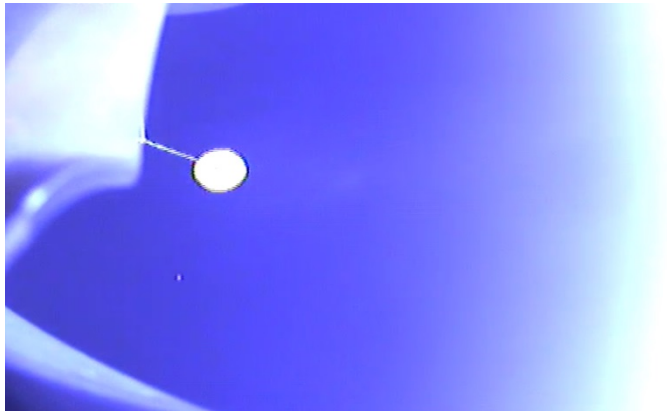


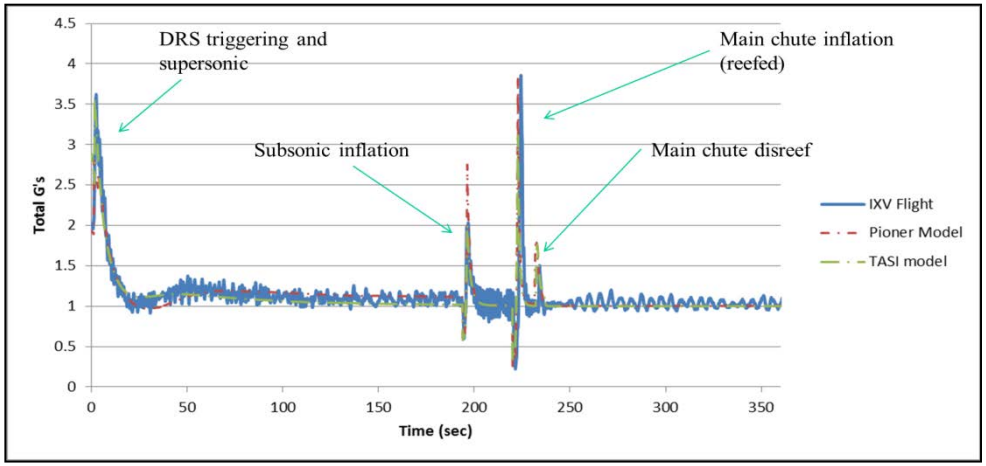
The Space Segment Performance

3. IXV descent phase

The IXV parachute mortar firing was followed by the nominal deployment of the parachute supersonic stage, subsonic stage and main stage, including main stage dis-reefing, as shown in the figures reporting the history of the decelerations produced by the stages deployment.



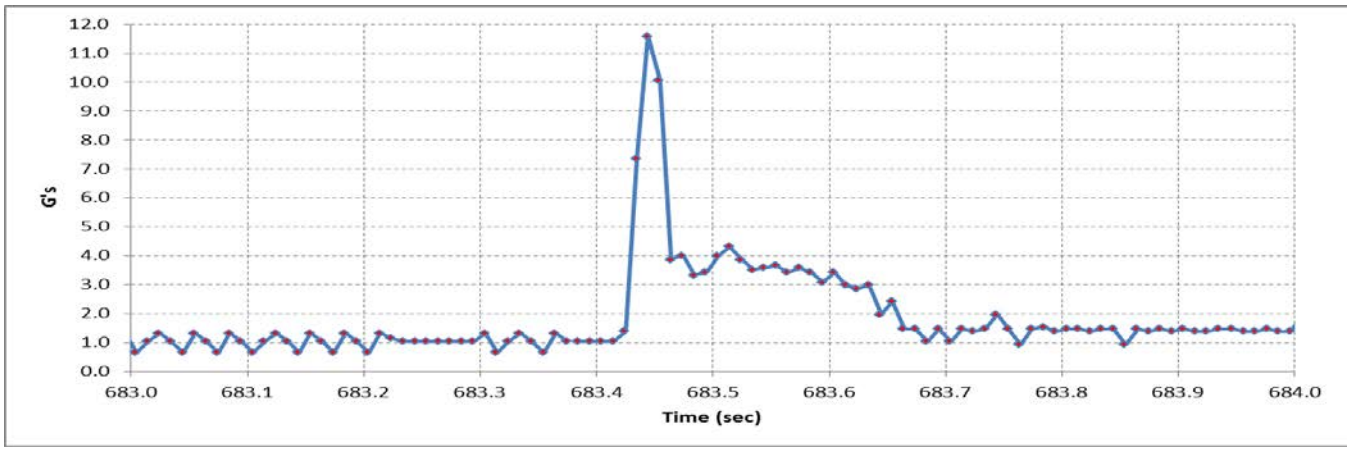




The Space Segment Performance

3. IXV descent phase

A visual detection of the IXV under the parachute was possible for about one minute from the recovery ship through the binocular, before disappearing in the clouds. Despite the nominal deployment of all parachute stages, a speed slightly higher than the prediction was recorded on-board at the splash-down, after the loss of telemetry from the spacecraft at the horizon, with a corresponding increase of the impulsive load impacting the spacecraft. Investigations are ongoing to understand the origin of this slightly higher speed relative to the sea (e.g. unpredictable spacecraft-to-wave relative angles at impact).



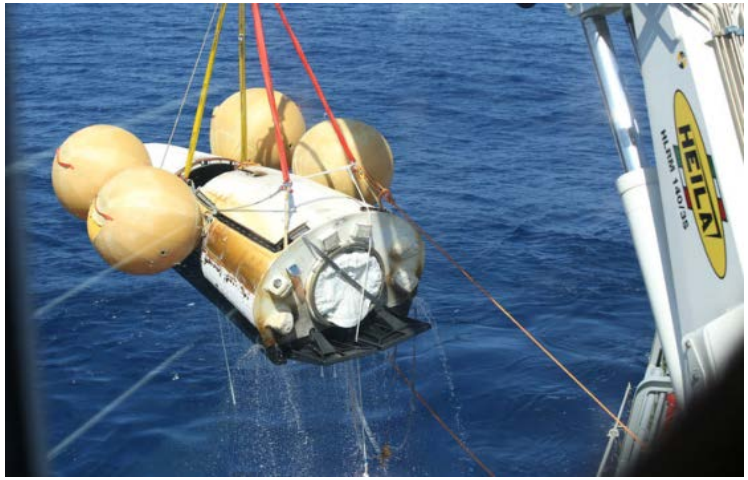
IXV Increased Impulsive Load at Splash-down

The Space Segment Performance

4. IXV recovery phase

Following the completion of the descent phase up to splash-down, the divers approached the spacecraft to perform the hoisting and recovery operations with a sea-state 4. The long waves of the Pacific induced rough recovery operations pushing the spacecraft in close contact with the divers boats engines propellers.

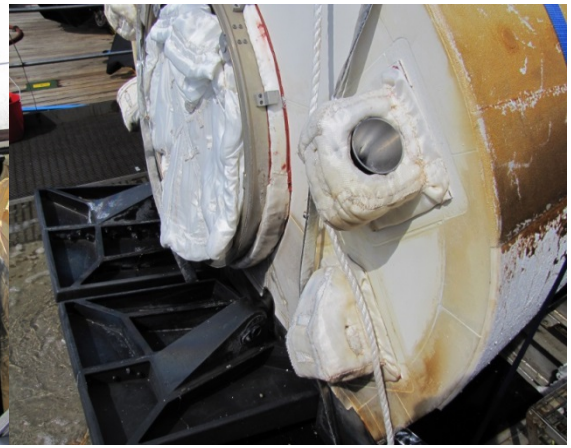
After completion of the recovery operations, the visual inspection has shown overall a very good status of the entire spacecraft, though with some local post-flight damages to the TPS.



The Space Segment Performance

4. IXV recovery phase

After securing the spacecraft on board, the spacecraft doors were opened, the passivation procedure was executed, the telemetry recorders cards were retrieved, and the spacecraft was prepared and packed for the long sail to Europe.



The Ground Segment Performance

On the launch day the IXV Ground Segment was activated in parallel to the IXV Space Segment. The analysis of the ground segment performances is revealing very interesting findings and confirmations:

- the overlap between the Libreville and Malindi Stations coverage was rather good;
- the Malindi Station visibility started and ended at elevation values below the mask, close to the theoretical maximum for 0º elevations;
- the Naval Station acquisition of signal from the recovery ship occurred at about 0.56º, earlier than expected by the blackout phase and very low above the horizon;
- all visibility windows have allowed the acquisition of all real time data plus multiple cycles of all playback data transmitted by the spacecraft.

	AOS	LOS
Separation [sec]	1130.01	
Libreville [sec]	1151.11	1510.11
Malindi [sec]	1409.11	2027.11
Naval [sec]	4816.11	5795.11
Splashdown [sec]	5796.92	

The Achievement of the IXV Mission Objectives

All flight hardware and all flight data was successfully recovered, through space segment telemetry transmission to the ground segment, and on-board recording, with the confirmation that the flight data is complete and consistent among the various sources.

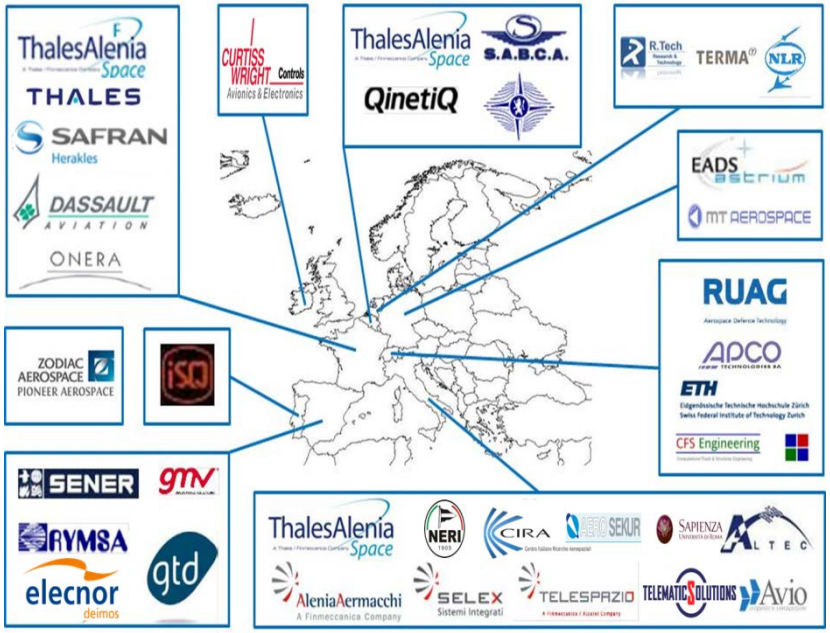
The IXV system, and all associated technologies, have successfully performed the whole flight program in line with the commanded maneuvers and trajectory predictions, performing an overall flight of approximately 25.000 km including 8.000 km in hot atmospheric re-entry environment with automatic guidance, starting from an orbital velocity of ~7.5 km/sec (Mach=27), concluding with precision landing.

100% of the IXV mission, system and technologies objectives have been successfully achieved.

The Spacecraft Today

Thanks to European Partnership

The Industrial Organization has integrated competences from ~40 European industries, research centers and universities under the leadership of Thales Alenia Space (I) for developing an experimental mission requiring industrial, technological and scientific expertise.



Many thanks go to the whole Industrial Organization for the true partnership established with ESA for the successful achievement of the IXV mission objectives within the stringent time and budget associated.

Special thanks go to the participating States Delegations whose support, trust and vision made this challenging mission possible in Europe.

Introducing the PRIDE Mission

The PRIDE Programmatic Objective

The highest programmatic objective is to define and develop an affordable **reusable European space transportation system** to be launched by VEGA-C, able to perform experimentation and demonstration of multiple payloads and technologies required for future application missions in Low Earth Orbit, and to return safely on ground for re-flights.

The **System** shall benefit to the maximum extent possible from the IXV experience and address progressive technological challenges with limited risks and financial efforts for Europe.

The **Payloads** shall encompass, without being limited to:

- Exploration technologies experimentation and demonstration;
- Orbital infrastructures servicing experimentation and demonstration;
- Earth observation experimentation and demonstration;
- Earth science experimentation and demonstration;
- Micro-gravity experimentation and demonstration;
- ….

The PRIDE Step-1

The PRIDE Step-1 Participating States include Italy, France, United Kingdom, Spain, Switzerland, Sweden, Romania, Portugal, and Ireland. In addition, discussions with Belgium are progressing to harmonise activities from the ESA GSTP programme as successfully done within the IXV development, and with Germany have started with the objective to harmonise activities from DLR/R&D programme.

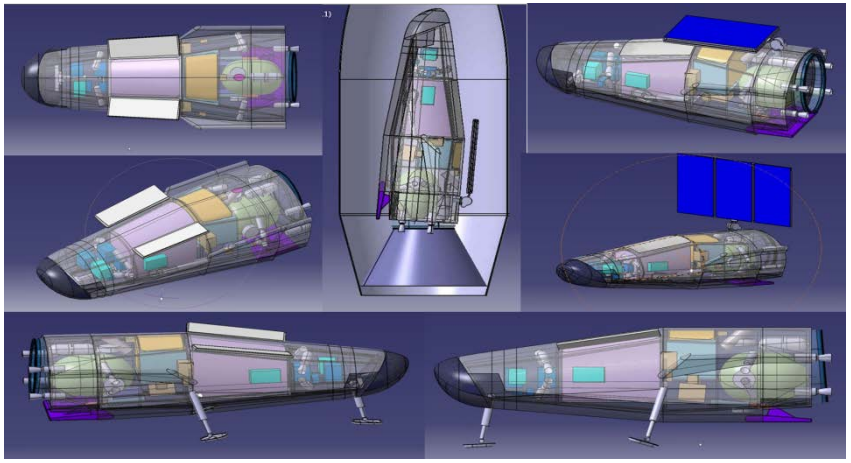
The PRIDE Step-1 Funding is sufficient to timely complete the programme step-1 activities, and prepare the step-2 for the development to be submitted for approval (in part or in full) at next Council at Ministers level in 2016.

The PRIDE Step-1 Activities include the Mission and System definition, and early maturation of associated critical/enabling technologies, and encompass two phases: an institutional phase and an industrial phase. More precisely:

- The institutional phase is reaching completion, performed with the support of the ESA Concurrent Design Facility up to the month of June 2015 jointly by ESA and experts from National Institutions, with the objective to consolidate the High Level Mission Requirements to be made applicable to the subsequent industrial phase;
- The industrial phase is planned to start by September 2015 at the latest.

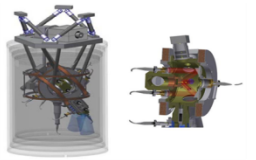
Today's Status of the Institutional Phase

An IXV-derived system with ≥ 300 Kg of payloads capacity is feasible for multiple orbital applications, including ISS altitudes/inclinations:



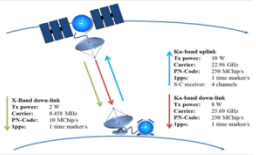
Cold Atom Interferometer Technology Demonstrator

- Initiator: SRE
- Objective: to probe violation of the Universality of Free Fall / Weak Equivalence Principle
- Instrument: atom interferometer



Microwave Link for Ground Clock Comparisons

- Initiator: SRE
- Objective: to probe the Sun and the Moon gravitational redshift through ground clock comparisons
- Instrument: microwave link instrument and GNSS receivers



Modulated Optical Retro-reflection Experiment (MORE)

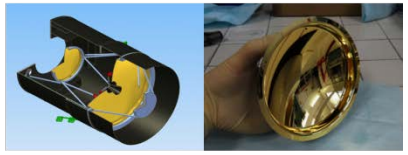
- Initiator: SRE
- Objective: to test in-orbit a bi-directional laser link providing a passive very low-power optical communication
- Instrument: corner-cube retro-reflectors

Laser Communication Terminal In-orbit Demonstrator

- Initiator: TIA
- Objective: to test in-orbit intersatellite link performance of evolved version of Laser Communication Terminal
- Instrument: Laser Communication Terminal or Optel M

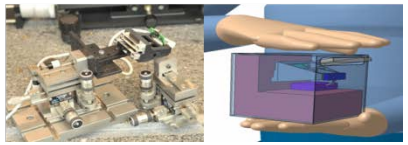
STREEGO

- Initiator: TEC
- Objective: to test in-orbit an innovative high resolution and extremely compact optical payload
- Instrument: STREEGO optical payload



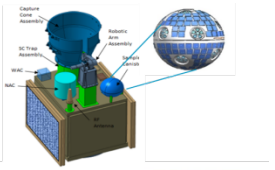
HYPERCUBE

- Initiator: TEC
- Objective: to test in-orbit a miniaturized hyperspectral telescope
- Instrument: HYPERCUBE optical payload



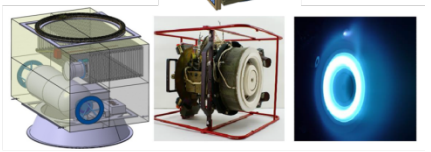
Mars Sample Return In-orbit Demonstration

- Initiator: SRE
- Objective: to demonstrate key critical technologies of the actual MSR mission (autonomous GNC for rendezvous and capture uncooperative target)
- Instrument: sample canisters and capture mechanism



VEGA Electric Propulsion Module Demonstrator

- Initiator: LAU
- Objective: to test in-orbit technologies for future VEGA electric propulsion modules
- Instrument: Electric propulsion module



Space Station Experiment Return

- Initiator: HSO
- Objective: to test in-orbit a retrieval concept for space station cargo or experiments download
- Instrument: Retrieval system

Thank You!