The Design and Realisation of the IXV Mission Analysis and Flight Mechanics

R. Haya Ramos, G. Blanco*, I. Pontijas*, D. Bonetti*, J. Freixa*, C. Parigini**
*E. Bassano**, R. Carducci***
*M. Sudars***, A. Denaro***, R. Angelini****
*Salvatore Mancuso*****
**DEIMOS SPACE S.L.U., Ronda de Poniente, 19, 28760 Tres Cantos, Madrid, (Spain).*
***Telespazio Spa (Italy)*
****Thales Alenia Space Italia Spa (Italy)*
***** European Space Agency (ESA) HQ (France)*

Abstract
The Intermediate eXperimental Vehicle (IXV) is a suborbital re-entry demonstrator successfully launched in February 2015 focusing on the in-flight demonstration of a lifting body system with active aerodynamic control surfaces. This paper presents an overview of the Mission Analysis and Flight Mechanics of the IXV vehicle, which comprises computation of the End-to-End (launch to splashdown) design trajectories, characterisation of the Entry Corridor, assessment of the Mission Performances through Monte Carlo campaigns, contribution to the aerodynamic database, analysis of the Visibility and link budget from Ground Stations and GPS, support to safety analyses (off nominal footprints), specification of the Centre of Gravity (CoG) box, selection of the Angle of Attack trim line to be flown and characterisation of the Flying Qualities performances. An initial analysis and comparison with the raw flight data obtained during the flight will be discussed and first lessons learned derived.

1. Introduction

The Intermediate eXperimental Vehicle (IXV) is a re-entry demonstrator whose objective is to tackle the basic European needs for re-entry from Low Earth Orbit (LEO), consolidating the knowledge and expertise necessary for the development of future European re-entry systems. It was successfully launched by 11th February 2015. The IXV is a technology platform that represents a step forward with respect to the Atmospheric Re-entry Demonstrator (ARD), flown in October 1998, with an increase in-flight manoeuvrability permitting the verification of technologies over a wider re-entry corridor and with aerodynamic surfaces employed actively to trim and manoeuvre the vehicle, [1].
In order to fulfil the technology experimentation and validation objectives, a number of experiments have been flown on-board the IXV. These experiments include the Thermal Protection System (TPS), the TPS instrumentation, the aerothermodynamics (ATD) and aerodynamics (AEDB). In addition to these, the IXV provides a basis to mature, consolidate and prove European GNC technologies for re-entry vehicles.
The IXV vehicle was injected by Vega in an equatorial suborbital trajectory to reach an entry velocity at the Entry Interface Point (EIP, 120 km altitude) above 7.4 km/s. After injection, the IXV flight was comprised of three main phases; orbital, re-entry and descent. The re-entry phase for the IXV vehicle corresponds to a guided lifting entry beyond 7000 km ground track up to the deployment of a 3 stages parachute system, with the IXV flight terminating with splashdown on the Pacific Ocean using a flotation system to recover the vehicle from a ship.
The challenges of the IXV Mission analysis and Flight Mechanics are common to those for re-entry vehicles performing a first flight, where the Mission must be robust to high levels of uncertainty in the vehicle characteristics, like aerodynamics and aerothermodynamics.
The suborbital nature of the mission strongly couples all of the phases and hence phase by phase analyses are not applicable. To cope with this challenge, an end to end approach has been implemented in Mission Analysis in order to properly identify the design values applicable to all phases and to consider the coupling effects. A strong interaction with the System, AEDB/ATD and GNC teams is also a key element for the maturation of the mission scenario.
Disciplines like the Mission and Flight Mechanics design have followed the vehicle since the conceptual design up to the operations. In IXV, the role of Mission Analysis and Flight Mechanics has mainly covered design (mission, vehicle

configuration...) and the provision of inputs to build the specification of system and subsystems. After the Critical Design Review, the role changed from design to design update and verification as well as the provision of inputs for the detailed design of different subsystems. This activity ended by the System and Qualification Acceptance Review (SQAR). During the preparation of the launch campaign the activities were related to the provision of flight predictions to support the operations, selection of on-board parameters and final go ahead decisions in the mission control centre. This paper summarises the design and validation of the mission Analysis and Flight Mechanics of the IXV submitted to the SQAR before the start of the launch campaign. The details on the transition from the design performances to the flight predictions used to support the launch campaign during operations are covered in [3]. An initial analysis and comparison with the raw flight data obtained during the flight will be discussed and first lessons learned derived.

2. The IXV Vehicle and Mission Overview

The IXV shape and size are shown in Figure 1. The IXV is a 5 m long lifting body weighing 1.9 Tons with a lift-to-drag ratio of 0.7 in the hypersonic regime and, distinct from other re-entry vehicles such as ARD, is actuated through the combination of two body flaps mounted at the aft windward side of the vehicle and RCS thrusters, [2].
The IXV mission is sketched in Figure 2 and can be described as follows: the vehicle is launched from Kourou onboard the Vega launcher and then injected into a suborbital trajectory after separation of the upper stage (AVUM). The IXV then performs a ballistic phase with an apogee of about 413km, coasting up to the Entry Interface Point (EIP), defined at 120 km altitude, which defines the boundary of the sensible atmosphere. Attitude control during this orbital phase is carried out by means of the Reaction Control System (RCS). The conditions at the EIP are typical of LEO return missions, with co-rotating velocities beyond 7.4 km/s (26700 km/h).
The IXV then performs a guided gliding re-entry from the EIP until reaching the conditions for the Descent and Recover System (DRS) triggering, at which time the supersonic chute is inflated. Attitude control during the re-entry phase is carried out by means of flaps primarily, combined with the RCS.
The supersonic chute is deployed at the DRS triggering conditions of about Mach 1.5 at an altitude of 25.5 km, shortly after which the descent phase of the flight begins with a 3 stages parachute system. The flight terminates at splashdown in the Pacific Ocean, with a flotation system maintaining IXV in conditions suitable for the ship recovery.

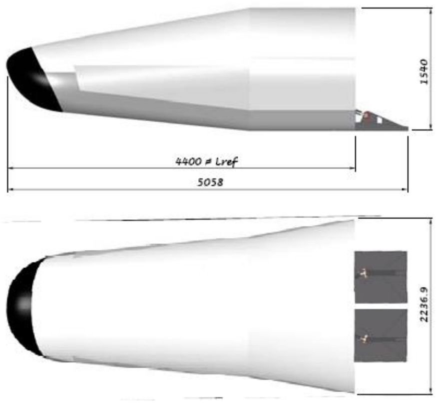

Figure 1: IXV vehicle shape and dimensions

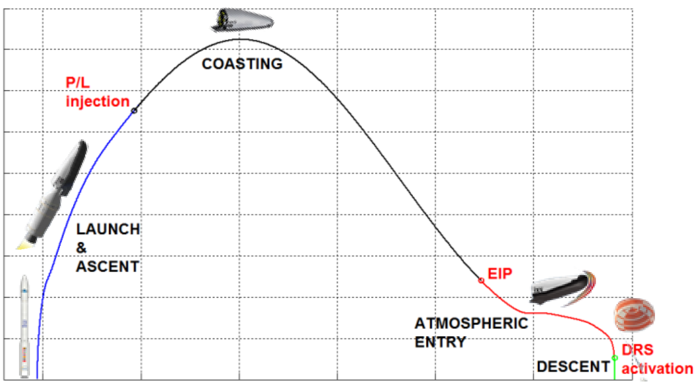

Figure 2: IXV mission overview

3. Vehicle Configuration

In a hypersonic vehicle the angle of attack profile is strongly linked with the mission feasibility and hence its selection and assessment cannot be uncoupled from the trajectory design. The objective is the selection of a feasible Centre of Gravity (CoG) location (longitudinal and vertical axes) that provides an aerodynamic performance compatible with mission requirements and the identification of the associated entry corridor. This process provides the nominal Angle of Attack (AoA) profile during the entry and identifies the available entry corridor for trajectory design.
The CoG analysis relies on the identification of a CoG region compatible with the trim capability and Flying Qualities requirements (static and dynamic stability, controllability). This domain includes uncertainties on aerodynamics, AoA, inertia properties, dynamic pressure and CoG location. The optimum solution, expressed as a CoG box, is designed to achieve high performances and margins and to be robust against aerodynamic dataset interpolation and extrapolation.
The regime is split into hypersonic and supersonic domain, with the only difference that the trim line is fixed to 45º in the hypersonic regime due to thermal constraints and in the supersonic part a wide range is inspected in order to select the adequate AoA profile. The candidate CoG locations are those compatible with both regimes. The selected CoG box is shown in Figure 3. It is compatible with both the supersonic and hypersonic regime, including rarefied flow, and with the layout capabilities.
The angle of attack corridor associated to this CoG box allows the selection of a trim line (Figure 4) as a compromise of different factors like robustness against uncertainties and modelling in the aerodynamic dataset, stability during the parachute deployment, controller tracking needs, uncoupling of longitudinal and lateral manoeuvres and not to counteract natural dynamics.

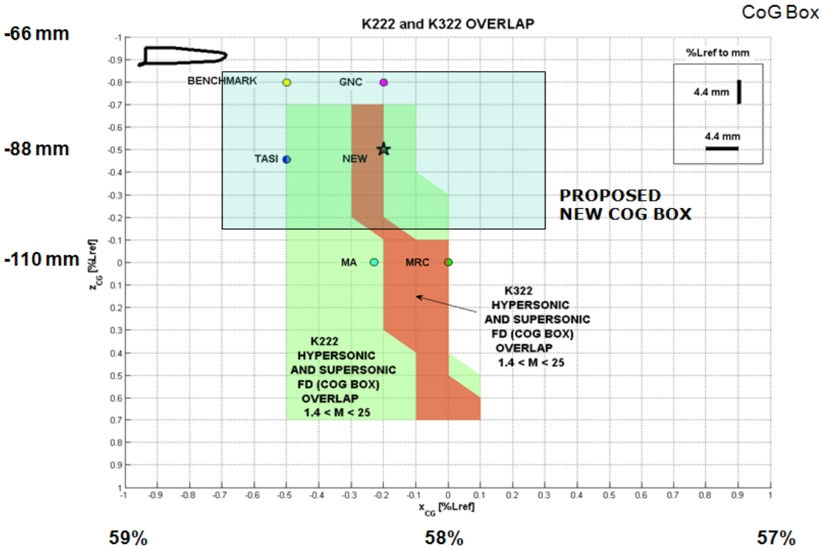

Figure 3: Feasible domain for the Centre of Gravity

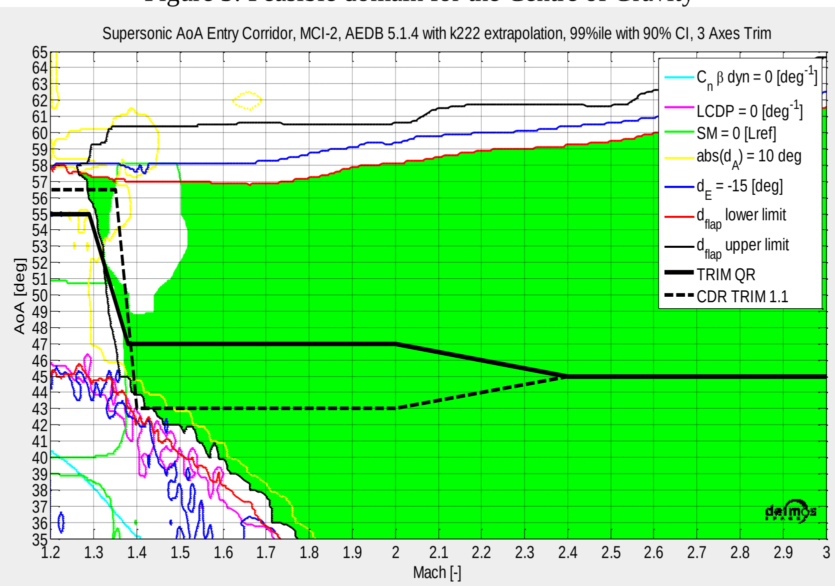

Figure 4: Angle of Attack corridor and trim line

4. End To End Trajectories

The computation of the reference trajectory requires a single end to end optimisation process from lift-off to the triggering of the Descent and Recovery System (DRS) compatible with all of the Mission and System constraints with adequate margins for GNC operation. The considered constraints include IXV thermomechanical limits during entry and descent, ascent constraints, DRS activation limits, safety restrictions to Entry Interface Point (failure footprint), stages splashdown, mass margin policy, visibility from ground stations and mission duration, [6].
This multiphase problem, where on one side we have the staging of the launcher and on the other the re-entry phase is a Full Optimal Control Problem that involves several parameters and control profiles. The software used is based on the DEIMOS Sequential Gradient Restoration Algorithm (SGRA). The SGRA is an indirect full optimal control algorithm that allows the optimisation of a control profile along with a determined set of parameters having an effect on the problem under study. A single end-2-end optimisation from launch to parachute opening was modelled.
A feasible end to end suborbital trajectory with an apogee around 413 km (Figure 5 and Figure 2) was calculated, providing margins for the GNC operation within the entry corridor (Figure 6) and being compatible with large launcher injection dispersions. All the constraints, included safety, are respected. Thermal constrains at the vehicle nose and at the flap, including passive to active oxidation limit for C-SiC TPS material and transition to turbulence, lead to a narrow corridor. It required a complete redesign of the trajectories after the PDR with a new structure of the solution in order to find a feasible flight profile with margins for the CDR, as shown in Figure 6. The resulting optimised injection condition for Vega has been used as request to the Launcher Authority, who has validated it in all of the launcher mission analysis loops. In addition, several design trajectories selected within the entry corridor have been calculated to support the design of the different subsystems, in particular the Thermal Protection System (TPS).
As long as aerothermodynamics (ATD) is one of the drivers for this mission, accurate models coming from the AEDB/ATD Team have been integrated to increase reliability and robustness of the trajectory (Figure 7). This element has enabled an automatic validation from an aerothermal standpoint of the calculated trajectories, [4].
The trajectory has been calculated with accurate models for Vega, IXV, the parachute System and the environment.

Figure 5: Reference trajectory ground track

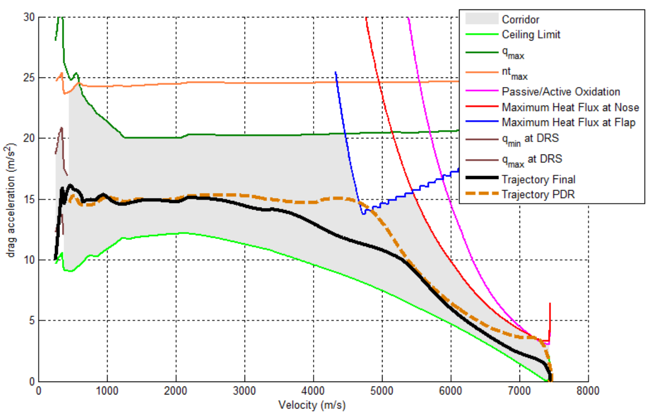

Figure 6: Reference trajectory and entry corridor

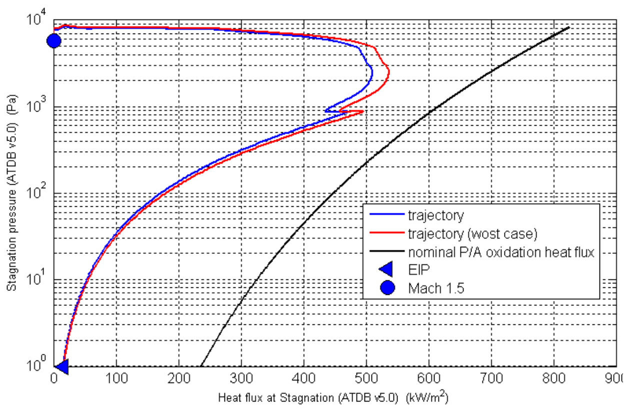

Figure 7: Nose TPS passive to active nose oxidation limit

1. Flying Qualities Performances

The vehicle configuration design, i.e. the CoG location and trim line is validated before it is provided as an input for the Mission and GNC design disciplines. This validation from a Flight Mechanics perspective is carried out with a Flying Qualities performance assessment, which does not require trajectory propagations.

The Flying Qualities performances are evaluated with dedicated Monte Carlo simulations in order to characterise the trim, stability and control characteristics and margins as input to GNC activities. Results presented in this section are based on a Monte Carlo campaign of 4000 shots including uncertainties on aerodynamics, AoA tracking, inertia properties, dynamic pressure, CoG location and GNC allocation in all regimes.

The evaluated Flying Qualities comprise trim characteristics, static and dynamic stability, dynamic couplings, spin tendency and hinge moment needs. Figure 8 and Figure 9 show, for example, the 99% range of variability (blue: lower limit; red: upper limit) with 90% confidence level for the trim sideslip and the static margin, while Figure 10 shows the variability of the left and right flap deflections. The static margin is defined as the distance to the neutral point of the vehicle, i.e., where $C_{mcg\alpha} = 0$. The results of the campaign verify and validate that an optimal and robust solution has been designed for the current CoG achieving good overall performances with margins. The AoA corridor is verified and good performances are validated down to Mach 1.4, with no saturations on the control surfaces, acceptable sideslip variability and no relevant dynamic instabilities. Mach 1.4 is therefore confirmed as end of the DRS window.

The FQ performances have been validated afterwards with the results of the 6 Degrees of Freedom (DoF) GNC Monte Carlo, in particular the trim performance. As shown in Figure 11 for the hypersonic elevator deflection, the variability from the Flying Qualities performance assessment properly predicts the variability obtained with GNC results and the margins assumed in the FQ analyses are deemed appropriate.

This advance of the GNC performance and of the characterisation of the plant to be controlled allowed the early identification of Worst Cases for a certain Flying Quality (ex: longitudinal stability) which were used to run dedicated robustness GNC test on those conditions, [7].

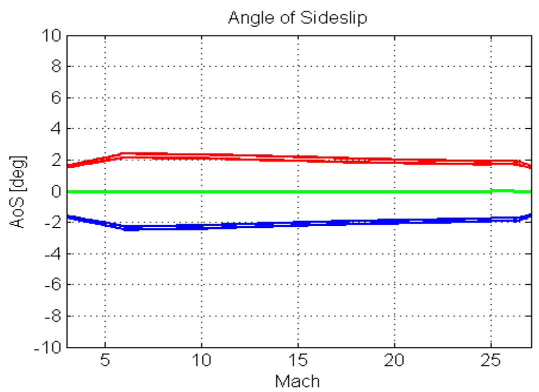

Figure 8: Sideslip variability in supersonics

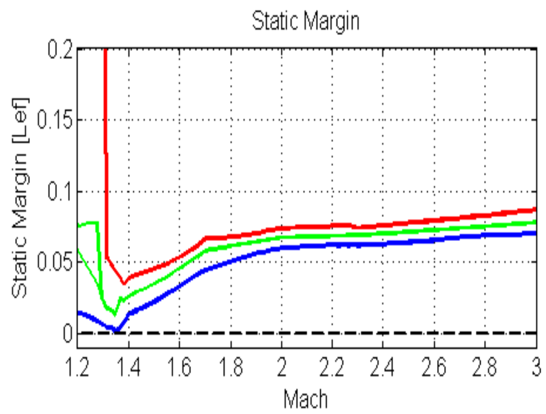

Figure 9: Longitudinal stability prediction in supersonics

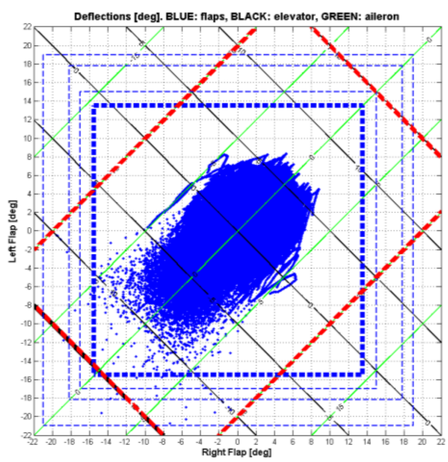

Figure 10: Control surfaces deflection domain in hypersonics

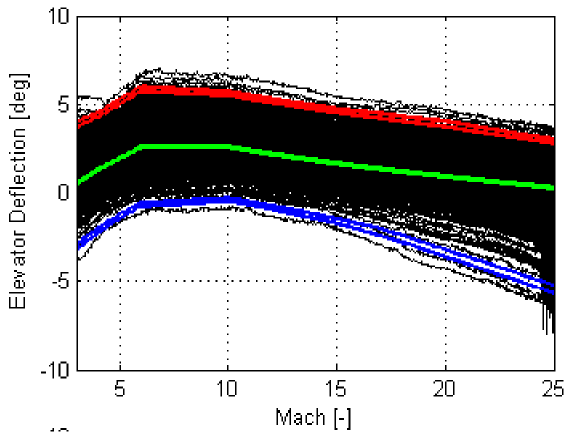

Figure 11: Validation of FQ trim predictions with 6DoF GNC results

2. Mission Performances

The performance and robustness of the mission is validated using a full simulation from separation to splashdown in the baseline mission scenario with all subsystems operating within normal range of variability.
The performances of the mission have been assessed through an intensive end-to-end Monte Carlo campaign of 4000 shots from the IXV separation of the AVUM up to the splashdown as early input before the detailed GNC tuning loops. They comprise the ballistic orbital arc, the guided entry and the descent under the pilot, supersonic, subsonic and main (reefed) parachutes. These simulations included full Guidance in close loop and Navigation and Control performance models tuned with GNC detailed results for the orbital en entry phases. They have been conducted considering uncertainties in the injection conditions, environment and vehicle characteristics (mass properties, aerodynamics). The descent under parachutes was modelled with 6DoF dynamics to account for the coupling between the IXV and the drogues. Entry simulations included realistic deflections of the control surfaces according to FQ predictions.
It has been demonstrated that the constraints are fulfilled, in particular ATD (Figure 17), DRS box (Figure 16) and descent (Figure 14) loads. The Guidance is able to cope with the large dispersions at EIP (±510 km, 99% with 90% confidence level) induced by the launcher injection errors (Figure 12) leading to an accuracy at DRS triggering lower than 3 km after more than 7000 km of gliding flight within the atmosphere (blue shots, Figure 13). Landing accuracy at splashdown accounts for 26 km descent under parachutes with no guidance, leading to less than 15 km dispersion considering any potential wind along the year and Quasi Biennial Oscillation (QBO) effects.
The results of the 6DoF GNC campaign run at the end of the tuning loops provide similar performances taking into account the difference in terms of uncertainties and models. This performance assessment shows that there are still considerable margins with respect to the system trajectory constraints, except for the DRS deployment window where the dispersed performances are close to the limits due to the small deployment box allocated.

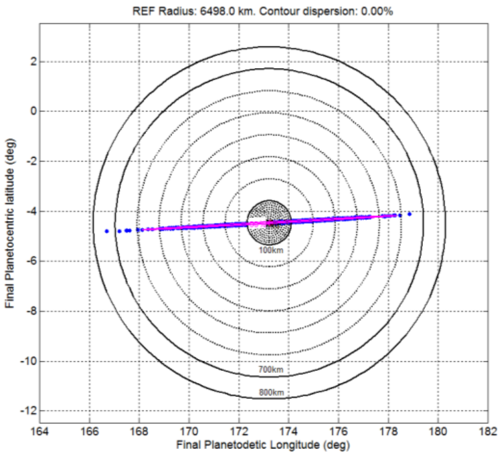

Figure 12: Dispersions at EIP

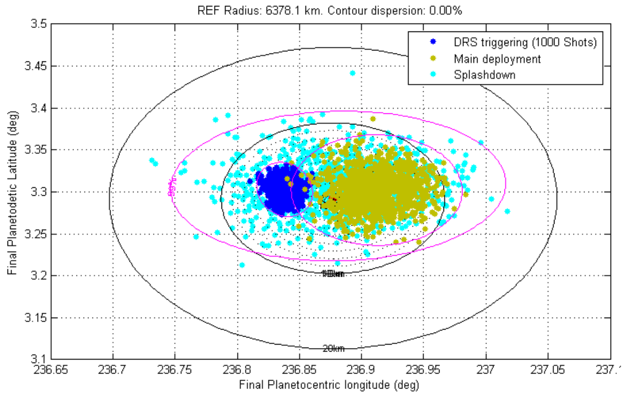

Figure 13: DRS triggering, main deployment and splashdown dispersions

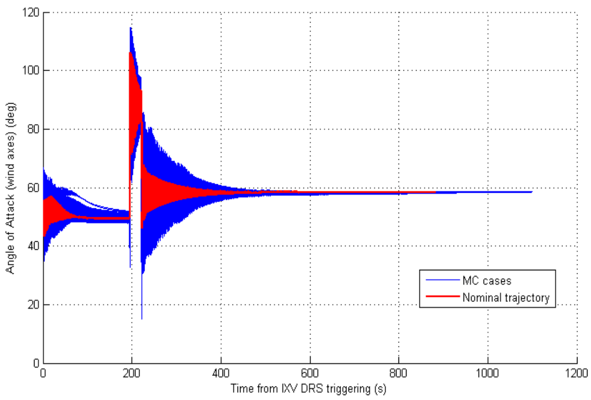

Figure 14: Angle of attack during descent under parachutes

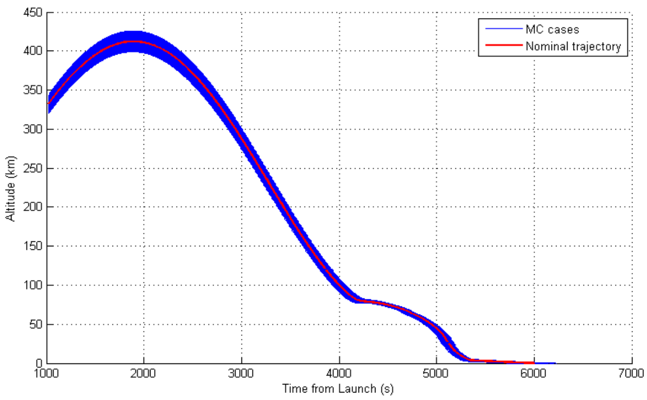

Figure 15: Altitude from separation to splashdown

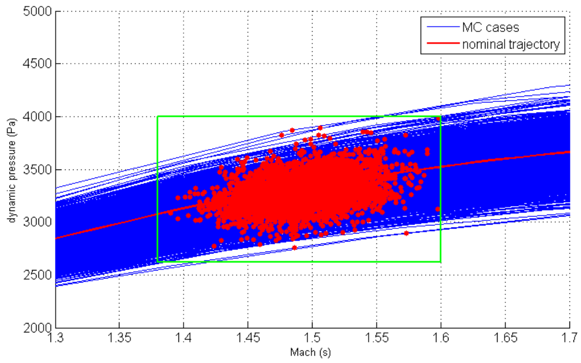

Figure 16: Compliance of DRS window

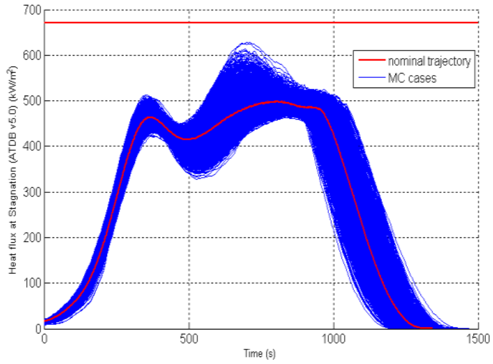

Figure 17: Heat flux at nose during entry

3. Safety Footprint

In addition to the footprint for the nominal scenario presented in previous section, in case of failure the corresponding non-nominal footprint has been calculated. Safety is one of the key aspects in the mission. First, we are dealing with a suborbital flight in which large regions are overflown by the vehicle; second, large injection dispersions have been considered at design level to cover the fact that Vega is a brand-new launcher performing a non-standard mission; third, the experimental nature of the flight requires additional safety margins.
As a result one of the drivers since the PDR for the design of the mission has been to ensure that no islands fall inside the failure footprint of the vehicle. It is challenging as failure can occur in any part of the mission and many small islands surround the region of the entry interface point (EIP) in the Pacific Ocean.
The failure case analysed corresponds to a complete GNC loss that can occur in any moment of the flight between the separation from the AVUM and the DRS triggering. A Monte Carlo campaign of more than more than 140000 shots has been run based on free 6DoF propagation of the IXV with the failure (initial condition) occurring at any moment of any of the nominal scenario Monte Carlo trajectories. Advance statistical methods for low probability events estimation has been applied to estimate stable 10^{-5} and 10^{-7} boundaries.
It is noticed that there are no inlands within the 10^{-5} footprint and only inhabited islands within the 10^{-7} footprint, fulfilling the safety objectives and goals imposed to the mission (Figure 18).

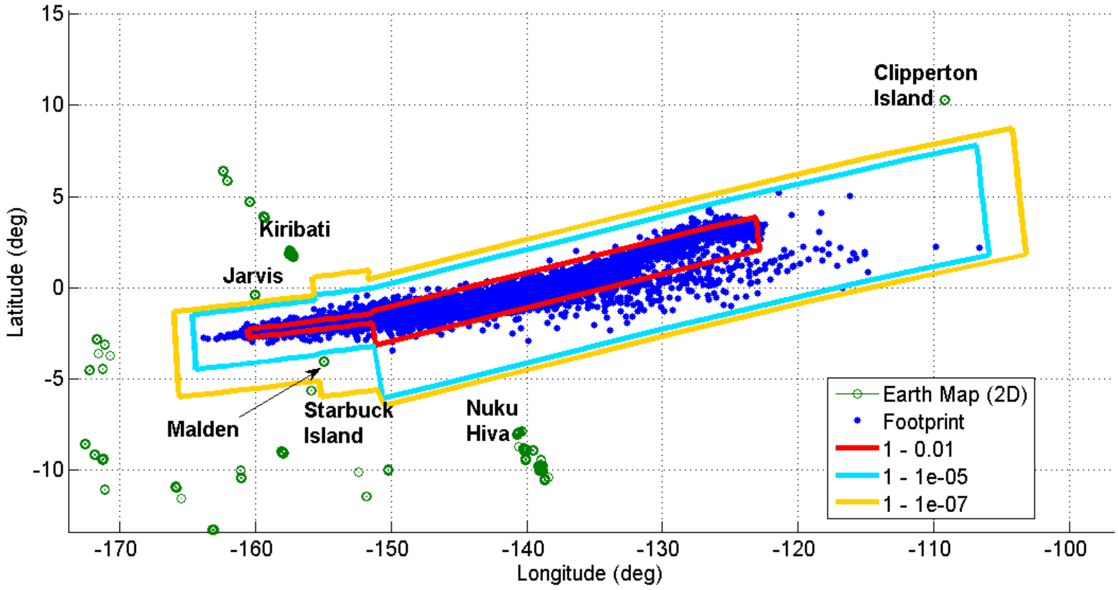

Figure 18: GNC failure footprint.

4. Visibility

The first objective of the visibility and link budget analyses is to guarantee that the vehicle is able to download to the network of ground stations the telemetry (TM) with the In Flight Experimentation (IFE) and Vital Layer data. The second objective is to guarantee the link between the GPS constellation and the IXV, as GPS is used by GNC to perform navigation updates (no hybridisation). Even if the vehicle is designed to be recovered, telemetry downlink is a key element not only for the monitoring of the flight but also for the data recovery in case of contingency or any issue with the data recorders. Thus, visibility has been integrated within the mission design since the first steps.

Geometric visibility stands for the evaluation of the existence of a line of sight between the IXV and a given station considering the station antenna mask and IXV antennae masks; link budget refers to the possibility of data transfer between the IXV and a given antenna including geometric visibility constraints and power aspects (gain and losses).

The visibility analyses take into account the limited number of ground stations, the non-isotropic antenna radiation patterns for telemetry, the black-out due to ionisation of the flow field around the antennas, the RF silence after separation, the vehicle tumbling during the RCS activation as well as the safety requirements in order to define the safe area to place the recovery ship ensuring TM reception.

Different ground station networks and antenna polarizations have been evaluated through efficient geometric visibility analyses that include simplified and conservative performance models of the link budget (i.e. simplified antenna radiation patterns or models of the black-out interval). Figure 19 shows the visibility window with 90% confidence level for the Libreville and Malindi ground stations derived from the 4000 trajectories of the Mission Performances Monte Carlo campaign. These results are validated through more CPU time consuming and detailed analyses of the link budget for selected cases both in nominal and worst case conditions. The carrier to noise signal at the Libreville and Malindi ground stations shows margin during the visibility intervals with respect to the threshold (Figure 20).

Based on the results obtained, the following layout has been consolidated: Libreville and Malindi as fixed ground stations (antenna shared with Launcher Authority) to track the vehicle for at least 900 s since AVUM separation; one mobile station placed on the recovery ship (located 25 km North of the nominal IXV splash-down for safety and performances reasons) to cover the final part of the flight for more than 1000 s; cross polarization antenna to achieve the longest contact times.

Several islands were traded-off to install a mobile station for tracking the pass though the Entry Interface Point. It was part of the baseline up to CDR but finally it was dropped by the SQAR. Thus, a telemetry gap of 45 minutes between the last orbital contact and the first acquisition from the recovery ship was predicted. GPS visibility was guaranteed with at least 7 GPS satellites visible during the orbital arc and 4 after the black out in worst case conditions. Black-out for the TM antennas was expected to occur within 94 to 56 km, which was out of the recovery ship visibility window.

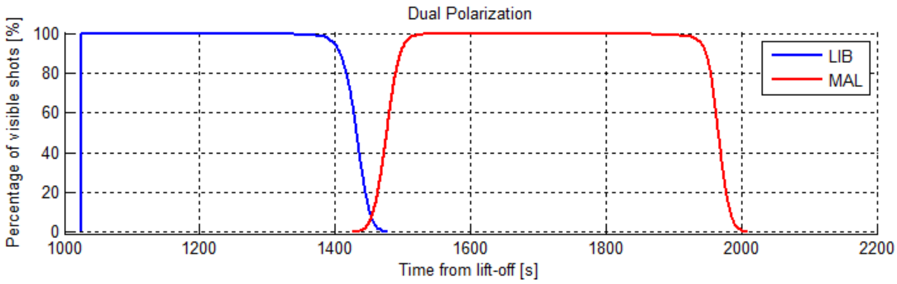

Figure 19: Visible intervals from fixed stations (4000 MC shots stats)

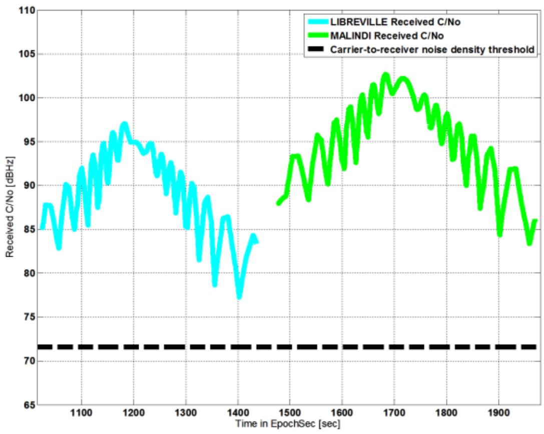

Figure 20: Results of IXV link budget C/N0 for cross polarization during the orbital arc

5. Operations

The Mission Analysis and Flight Mechanics activities evolved after the System and Qualification Acceptance Review milestone to support the launch campaign. As a result of the better knowledge of the system and operations at the end of the system qualification, uncertainties and dispersions were reduced with respect to the design and verification range. The objective is to obtain a more precise description of the expected performance during the day of launch to adjust the different operational procedures.

One example is the atmosphere, whose variability around the day of launch is much more reduced than the variability along the whole year used for mission and GNC design and validation. It builds up what is called Flight Predictions, which are the source for both the preparation of the launch campaign and the support to the final go/no-go decision at the mission control centre, [3].

Several loops of flight predictions were conducted starting from the successful SQAR in September up to the beginning of the launch campaign to cope with the following updates: launch delay from November 2014 to February 2015 due to launcher safety verifications; system and subsystem updates (e.g. measured mass properties) and the consolidated system status. It included delta analysis loops to update the on-board wind tables needed by the navigation function to improve the Mach number estimation at the DRS deployment.

During the launch campaign the following activities were conducted: analysis of weather conditions, particularly in the range 25-30 km altitude; confirmation of the navigation wind table stored on-board and computed several weeks before the launch using dedicated balloon measurements; computation of go/no criteria based on historical weather measurements and forecast; evaluation of the ISS-IXV collision risk as the IXV apogee exceeds the altitude of the ISS orbit; update of the predicted trajectory (splashdown coordinates and timeline) to support ship operations and to feed the Trajectory Propagation and Visualisation Tool (TPVT) used in operations. These activities started 1 week before launch and ended 1 h before the lift-off with the final go-ahead due to weather conditions.

During the flight of IXV, Mission Analysis was active as Flight Dynamics Support console (FDS) in the Mission Control Centre (MCC) in Turin, providing independent estimation of the launcher injection orbit accuracy based on the IXV telemetry, high fidelity propagation in background covering orbital (3DoF), entry (4DoF) and descent (6DoF) phases independent from the TPVT to benchmark the splashdown coordinates and, in case of contingency, dedicated predictions.

The go/no-go criteria for atmosphere conditions at the altitude of the parachute deployment was based on the radiosonde data obtained from high altitude (beyond 32 km) balloons. Twelve balloons were released during the days and hours before the flight to confirm the validity of the on-board Navigation wind tables generated several weeks before using a pre-flight wind model. The inspection of the wind against the design boundaries was not sufficient. Therefore, an evolved go/no go criteria based on the combined effect of wind and atmosphere into the expected navigation Mach error was developed. Two additional indicators were developed in order to base the go-ahead decision on the common voting of 3 criteria.

Figure 17 shows the navigation Mach error criteria derived from the available radiosonde measurements and associated to the pre-loaded on-board wind table. All the balloon data fell within the DRS deployment window (grey box in the picture). The pink line is the last measurement that led to the final go ahead decision due to weather 1 h before launch.

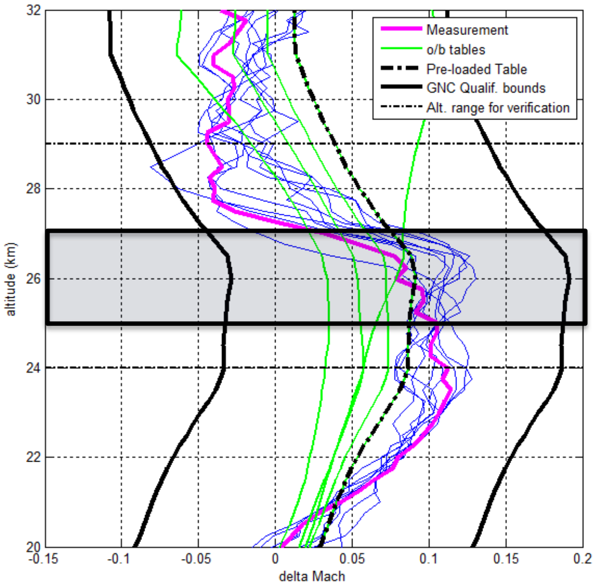

Figure 21 Mach error criteria developed to support the go ahead decision due to weather.

6. Flight Performance

The IXV was launched by 11th February 2015 at 13:40 UTC. The mission was successful and the vehicle was recovered as planned. The data transmitted though the real time telemetry and displayed at the Mission Control Centre (MCC) controls is provisional waiting for the complete post-flight data analysis actually under preparation. However, some general observations can be released in advance.
The green status due to meteo was confirmed by the TPVT and FDS consoles based on last sounding at L-4 h. The launch was delayed 40 minutes due to a last-minute correction in the launcher operations. The flight was highly nominal at system level: all systems worked (RCS, TPS, GNC, parachutes, floatation devices, communications…) leading to the compliance of the mission objectives.
Separation occurred 1130 s after lift-off, which was within the expected range. Telemetry signal was acquired 21 s later as predicted as there was a radio frequency silence of 20 s after separation to not to interfere with the AVUM operations. GPS was acquired 220 s after separation once attitude was stabilised. Good injection accuracy of the launcher in terms of trajectory was noticed and confirmed with the processing of the IXV GPS data from telemetry.
No reception gap between Libreville and Malindi ground stations was noticed. Telemetry transmission occurred within the pre-computed intervals and GPS was available in orbit. Due to the geometrical configuration of the IXV thrusters, a non-negligible residual delta-V induced by the operation of the RCS in the orbital phase was noticed.
Reception of the signal at the recovery ship occurred when the IXV was just above the horizon at around 60 km altitude, confirming that the antennas were already out of blackout as predicted in CFD analyses. Afterwards, the vehicle performed four bank reversal manoeuvres and the pre-release mode 0 deg bank manoeuvre showing a bank profile with the same structure as the latest predicted trajectory. GPS was available during these manoeuvres up to the end.
High accuracy at splashdown was noticed. The difference between the splashdown location predicted by the last trajectory propagated by Mission Analysis at the MCC after separation was in the order of ~1-2 km. Taking into account that IXV performed an uncontrolled descent under parachutes from ~26 km, this is a high mark. Therefore high accuracy at the DRS triggering expected, which is the main interest from a GNC performance standpoint.
The triggering of the pilot drogue practically occurred at the predicted value: Mach ~1.49 instead of Mach 1.5 at an altitude of 25.5 km instead of 25.44 AMSL. Spiralling motion was observed as expected during the supersonic drogue phase. Descent under the main parachute occurred shorted than predicted, however still well within the requirements. Loss of signal from the ship was noticed 1.5 s before splashdown.

7. Conclusions

IXV has been successfully flown past 11th February 2015, setting a new milestone in European Re-entry technology demonstration. The IXV programme is tasked with the development, maturation and demonstration of European knowledge and expertise for re-entry systems. The Mission Analysis and Flight Mechanics is challenged by several factors like the coupling between all the mission phases, the narrow corridor driven by aerothermal constraints, the large uncertainties, the safety restrictions and the compatibility with the Vega launcher.
Mission Analysis and Flight Mechanics activities have companied the vehicle all along its lifecycle, from design to verification, from verification to prediction and from flight prediction to operation, i.e. from paper to flight. A feasible End to End scenario from Lift-off to splashdown was designed and validated, covering trajectory, safety and visibility aspects. A Robust Flight Mechanics solution to achieve the desired Flying Qualities was provided in support to the Vehicle configuration. The validation loop has been closed with the successful flight of IXV. This scenario has been a relevant source for the specification of the different subsystems and to verify the performances as long as the production phase evolved. Tight interaction with the system prime, responsiveness and pro-activeness have been fundamental assets to cope with last minute changes and to ensure flight readiness.
The successful flight of IXV has not only qualified system and subsystems technology, but also the design methodology that for instance DEIMOS has been developing in the areas of Mission Engineering, Flight Mechanics and GNC during the last 12 years of activities in planetary entry projects, [9].
The general design guideline was to advance as much Flight Mechanics and GNC requirements during the definition of the vehicle and the generation of the mission scenario in order to reduce the design loops as much as possible in number and extent. It requires the use of advanced Flight Mechanics methods and the high fidelity simulation since the first design steps. This philosophy has been applied and validated during the Phase C2/D/E/F including the flight.
Waiting for the detailed postflight data, the mission can be qualified as nominal in terms of Mission Objectives.
The key elements of the chain (launcher, TPS, GNC, parachutes, balloons, communications and recovery) performed nominally, successfully flying the product tree produced by the mission analysis and flight mechanics activity, which is neither hardware nor software but mainly specification.

The availability of the postflight data will reveal in detail the performance of each subsystem, the margins and the lessons learned from which a strong consolidation of the European knowledge is expected for the future challenges. It is fully applicable also to the Mission analysis and Flight mechanics disciplines.

8. References

[1] Tumino, G. at al. 2008. The IXV Project. The ESA Re-Entry System and Technologies Demonstrator Paving the Way to European Autonomous Space Transportation and Exploration Endeavours. *59th International Astronautical Congress*, *Glasgow*, IAC-08-D2.6.1.

[2] Angelini, R. et al. 2012. IXV System - Development Status and Main Features. 18th AIAA/3AF International Space Planes and Hypersonic Systems and Technologies Conference, Tours, France.

[3] Haya, R. et al. 2015. Mission Analysis and Flight Mechanics Performances of IXV from Design to Flight. *5th International* ARA Days, Arcachon, France.

[4] Mareschi, V. et al. 2011. Intermediate Experimental Vehicle, ESA Program IXV. ATDB Tool and Aerothermodynamic Characterization. *7th Symposium on Aerothermodynamics for Space* Vehicles, Brugges, Belgium.

[5] Haya, R. et al. 2011. Coupling between the Mission Analysis and Flight Mechanics of IXV and the Aerothermodynamics Database Tool. *7th Symposium on Aerothermodynamics for Space Vehicles*, Brugges, Belgium.

[6] Bastante, J.C. at al. 2010. End to end Optimisation of IXV trajectory via Multiple-Subarc Sequential Gradient Restoration Algorithm. *61st International Astronautical Congress, Prague, Czech Republic*.

[7] Haya, R. et al. 2014. IXV Worst Case Flying Qualities and Control Testing. *9th International ESA Conference on Guidance, Navigation & Control* Systems, Oporto, Portugal.

[8] Marco, V. et al. 2015. The IXV Guidance, Navigation and Control Subsystem: development, verification and performances. *European Conference for Aerospace Sciences (EUCASS). Krakow, Russia*.

[9] Haya, R. el al. 2005. Flight Mechanics Methods and Tools In Support Of Atmospheric Entry Design Process. *European Conference for Aerospace Sciences (EUCASS). Moscow, Russia,* (3.01.04).