The IXV Ground Segment Design, Implementation and Operations

*MARTUCCI DI SCARFIZZI Giovanni**
*BELLOMO Alessandro**
*MUSSO Ivano **
*SANTORO Gianfranco***
*BILLIG Gerhard****
*GALLEGO SANZ Josè Maria*****

**ALTEC – Advanced Logistic Technology Engineering Center*
Corso Marche, 79, 10146 Turin, Italy
***Thales Alenia Space-Italy*
Strada Antica di Collegno, 253, 10146, Turin, Italy
****ESA/ESOC-European Space Operations Centre*
Robert-Bosch-Straße 5, 64293 Darmstadt, Germany
*****ESA/HQ (LAU-PI)*
52, rue Jaques Hillairet, 75012 Paris, France

Abstract
The Intermediate eXperimental Vehicle (IXV) is an ESA re-entry demonstrator that performed, on the 11th February of 2015, a successful re-entry demonstration mission. The project objectives were the design, development, manufacturing and on ground and in flight verification of an autonomous European lifting and aerodynamically controlled re-entry system.

The key elements of the IXV mission were: launch from Kourou with Vega, a quasi-Equatorial trajectory followed by a re-entry and splash down in the Pacific Ocean.
Four flight phases are foreseen: Ballistic, Re-entry, Descent and Splash down.

This paper describes the concept, architecture and operations of the ESA Intermediate Experimental Vehicle (IXV) Ground Segment and outlines the main operations and lessons learned during the preparation and successful execution of the IXV Mission.

1. Introduction

The Intermediate eXperimental Vehicle (IXV) is a re-entry demonstrator that performed a successful atmospheric re-entry mission on the 11th of February. The project objectives were the design, development, manufacturing and on ground and in flight verification of an autonomous European lifting and aerodynamically controlled re-entry system.

The key elements of the IXV mission are: the use of Vega as launcher, a lift off from Kourou (French Guyana), a quasi-equatorial trajectory followed by an atmospheric re-entry and splash-down in the Pacific Ocean.
The IXV flight phases are: Ascent, Separation, Ballistic Phase, Re-entry Phase, Descent Phase and Splash down.

The IXV Ground Segment has been composed of the following major elements: the IXV Mission Control Center (hosted at ALTEC premises), the IXV Ground Stations (located in Libreville, Malindi and aboard the Recovery Ship) and the IXV Communication Network.

The Mission Control Center (MCC) was developed making a massive usage of virtualization techniques. This solution has permitted to host the IXV MCC upon the existing ALTEC Mission Support Center infrastructure, operative since 2001 for ISS support, and to run in parallel the two virtualized environments.
The MCC provided infrastructure, tools and applications that have been used during the IXV mission for TM monitoring, storage, processing, displaying and detailed trajectory prediction. The MCC was the central node of IXV Ground Segment and it was interconnected with all Ground Segment elements, providing thus the required infrastructure for coordination and support, during IXV operative mission phase.

The IXV Ground Stations supported the IXV space to ground communications, i.e. tracking the Spacecraft, receive and locally record TM and send selected data, in real time, to the Mission Control Center. The IXV Ground Stations Network concept was based (with exception of the ASI Malindi Station) on the use of a transportable TM kit, that, once connected to desired antennae (either reused from other Ground Station, like Libreville, or rented or procured for the program) permitted to receive data from the spacecraft.

The IXV Communication Network provided the necessary infrastructure to allow reliable communications between the IXV Mission Control Centre and the IXV Ground Stations and the launch site (located at Guyana Space Center CSG, Kourou). The IXV Communication Network was IP based, and relied on satellite and terrestrial physical links for interconnecting its nodes, with several technologies.

In the following the main actors involved in the operations of the IXV Ground Segment elements, together with the description of the architectural choices, are provided.

2. Responsibility: sharing among involved teams

The IXV project is an ESA Programme within the Launchers Directorate. Within the IXV project; ESA was the final customer.

Operations were conducted following the concept of an integrated team, with responsibilities and roles shared among agency and industries.

In particular ESA had the responsibilities of the mission operations covering the following roles: Mission Director (MD), Operations Director (OD), Spacecraft Operations Manager (SOM), Recovery Operations Manager (ROM), Flight Safety, Ground Operations Manager (OM), Flight Dynamics Manager

Thales Alenia Space (TAS), as IXV Prime contractor, was appointed with the responsibility for the design consolidation, development and integration of the vehicle. TAS provided all the mission flight control team specialists in support of ESA

ALTEC had the responsibility for the development, management and operations of the IXV Ground Segment, needed to provide all required capabilities for IXV mission support. In particular ALTEC covered the role of Ground Controller (GC) as well as the role of Ground Station Manager (Libreville, Recovery Ship). For these station an ESA representative was present in situ to overlook operations and for advisory purposes and coordination. The Malindi ground station was indeed managed by an ASI team.

ALTEC was supported during operations of the Ground Segment team by Telematic Solutions, covering ground station specialist roles, and Telespazio, providing IXV Communication network support.

3. Ground Segment Operations Concept

IXV Ground Segment Operations were organized as follows:

- Mission Director, Launch Support and AIT team located at Centre Spatiale Guyannese (CSG)
- Operation Director, Flight Control Team and Ground OPS managers located at IXV Mission Control Center (MCC), hosted at ALTEC premises;

- Stations operators located at IXV Ground Stations (including one embarked on recovery ship)
- Recovery Operations manager and Recovery Operations team located on the recovery ship.

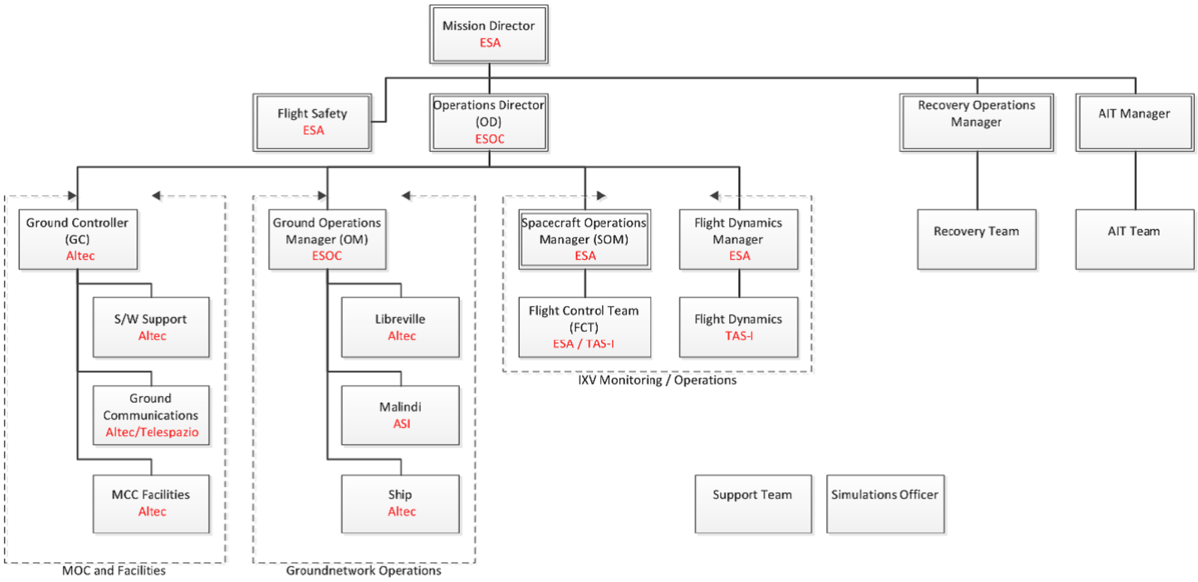

Figure 1: IXV Ground Segment Operations Organization

As outlined in the IXV Flight Operations Procedures the overall responsibility for the IXV mission was undertaken by the IXV Mission Director, located at CSG in the Jupiter control room at Kourou.

The ground segment operation team was headed by the Operations Director (OD), who was responsible for the overall operations of the ground segment. He reported to MD and interfaced with Safety Manager (also located at Jupiter in Kourou), who had a representative at the MCC with an active Safety Console. During the countdown, he interfaced the Assembly Integration and Test (AIT) Manager, who was in charge of preparing the spacecraft for launch. Finally he was in contact with the Recovery Operations Manager, as the MCC acted as relay communication system between Recovery Ship and CSG.

The Operations Director was supported at MCC by the following operators:

- The Spacecraft Operations Manager (SOM), who had the responsibility for the monitoring of the spacecraft parameters and the provision of the status of the spacecraft during the flight phases as well as support during the recovery. In his role he was supported by the Flight Control Team, with specialists covering the following disciplines and susbsystems mission specialists:
    - Thermal Control System (TCS);
    - Guidance Navigation and Control (GNC);
    - Software S/S;
    - Power S/S;
    - Reaction Control System (RCS);
    - Flap Control System (FpCS)
    - Descent and Recovery System (DRS)
- The Flight Dynamics Manager, supported by the Trajectory Propagation and Visualization Tool (TPVT) operator, that was in charge of the live monitoring of the vehicle trajectory and the propagation of the splash-down site;
- The Ground Controller (GC), who was in charge of the MCC facilities monitoring, computer, ground communications and mission control software and coordination of the Ground Control team (GCT);
- The Ground Operations Manager (OM), who was responsible for the operations of the ground station network. The OM was supported by the local ground station operations teams;
- A Support Team, consisting of specialists both for space and ground systems.

3.1 Mission Control Center – MCC

The IXV MCC has the responsibility to conduct and coordinate up to the complete recovery of the spacecraft on board the recovery ship and completion of the post recovery activities. In particular MCC will monitor IXV trajectory, coordinate Ground Stations operations and remotely support recovery. MCC will also host the Trajectory Propagation and Visualization Tool (TPVT) by means of which it will be possible, using real time TM received from Ground Station in visibility, to perform spacecraft (S/C) trajectory propagation and to distribute it to the other Ground Stations, in order to ease the tracking of IXV, once in their visibility.

Figure 2: Operation Director console

The IXV Mission Control Center, hosted in ALTEC center premises, Turin Italy provided main functionalities for controlling and operating the IXV ground segment.

In particular the Ground Controller console provided access to Mission Control System control services; in particular through the SCOS2000 console of the two redundant processing chain servers. From such console it was possible to determine which virtual channels to route to SCOS2000 clients, to be distinguished between pre launch phases, where Complete SLE service was used, flight phase, where instead Timely mode was preferred. Also from here an additional NIS client was started, for both Primary and Redundant NIS servers, as an operational backup for OM (see later). GC console also gave ability to monitor overall MCC systems (availability, CPU/Memory load, time synchronization with NTP server). This was achieved through a monitoring and management console where all these info were gathered altogether and displayed in a single synoptic. GC console also controlled and coordinated video reception from Recovery Ship and video re-distribution toward CSG and through the broadcast service that aired the IXV mission in SAT tv. Last but not least from the GC console the Network and Data Interface Unit (NDIU) control GUI (WebGSS) was operated.

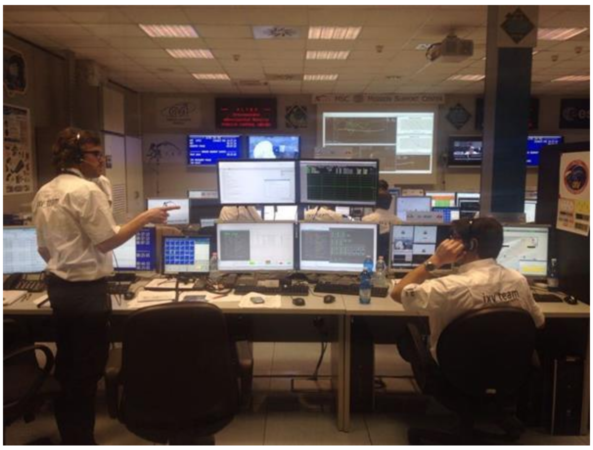

Figure 3: GC console and GCT

The Operations Manager console had access to the Network Interface System (NIS) client control interface, for both Primary and Redundant chains. Such console provided the possibility to select which flow, coming from either ground stations or NDIU had to be routed toward SCOS2000 for its processing. In particular several operation setups have been exercised during the mission, as initial testing activities were performed using the so called dataflow mode. For flight phase, the NIS system was configured with Process and Input mode for the various ground stations. This means that Libreville was set in process mode and all the others, being in input mode, were already bound and start and ready for TM data transfer.

The Trajectory Propagation and Visualization Tool console had acces to the TPVT system. This was composed by a propagation tool that was initially configured with nominal trajectory and, throughout various mission phases, was fed with realtime data coming from:

- VEGA DO data, sent from CSG and relayed to ALTEC through the Liberville TM kit, by means of a serial to UDP/IP converter;
- IXV realtime position data, read from telemetry by the TPVT through an ad hoc implemented SMF interface. This feed can be further subdivided in two main data groups:
    - GPS data
    - IMU data

TPVT tool produced also IXV DO data, that was exploited by Naval ground station for program mode acquisition. TPVT console was completed by the TPVT Visualization system. This system, fed with data produced by TPVT, displayed the computed position of the IXV over global 2D and 3D globe maps. Such video contribution was also provided to CSG for realtime displaying to operators and authorities sitting in Jupiter room.

Figure 4: Flight Control team

3.2 Ground Stations

IXV Ground Stations were in charge of tracking the S/C, receive and record TM and send it to MCC.

IXV Ground Stations operation teams (with the exception of Malindi whose service was offered and managed directly by ASI) were organized with the following concept: IXV ground station manager, reporting to the OM, was supported by the TM kit operator, the Antenna operator (for naval station only) and advised by the ESA representative.

Figure 5: Libreville team

The Ground Station Manager held and overlooked to all communication with OM and MCC. The station manager reported to OM about system statuses and AoS/LoS times. Station manager also coordinated activities within the IXV Ground Station, that is all tasks and activities performed by Ground Stations operator had to be coordinated by/with the Ground Station Manager

The TM kit operator(s) was in charge of operating the TM kit. In particular the monitoring of CORTEX system health and status and operations of the MCC Space Control Protocol (MCCSCP) were part of the operator’s duties. MCCSCP was the tool developed ad hoc for SLE interfacing with MCC NIS system. This tool added SLE interfacing capabilities (for SLE RCF online services, timely and complete modes) to the CORTEX RTR PTM, typically used during Ariane and Vega missions. The TM kit operators of the naval station had, moreover, the task to monitor DO PC and DO data quality to be possibly exploited by Naval antenna for IXV tracking.

Figure 6: Malindi team

The Antenna operator had the task to monitor and control the Naval antenna. In particular it had to configure and implement the acquisition strategies of the vehicle, by selecting the ACU working modes (program track, autotrack, waiting point with azimuth scanning). In order to aid acquisition of signal from the vehicle the antenna was equipped with two feeds: a main one devoted to nominal operations, with high gain and very directive aperture; the other one, characterized by large beamwidth and lower gain, instead had to be used in case of difficulties during tracking of IXV. The antenna operator had the duty to select which feed to use to track the vehicle.

Figure 7: Naval Station and Recovery Operations team

4. IXV Mission

Throughout the week before launch a high wind measurement campaign was conducted from Recovery ship through the use of measurement balloons. Data received was then sent to MCC via IXV Communication Network IP Sat provider, and analyzed by Flight Dynamics specialists. This measurement campaign aimed at identifying and predict as much precise as possible the weather condition of the day of the launch. Moreover this prediction helped in determining which data settings to upload into the system for GNC, in order to properly consider wind effects during re-entry and descent phases.

IXV Ground Segment preparation started at H0 8 hours, when all internal MCC and ground stations equipment started to be activated.

In particular MCC started the preparation of its internal system and the configuration of the Mission control Room in mission mode. This meant in particular the startup of both SCOS2000 servers with NIS S/S, the startup of all SCOS 2000 clients, the startup of internal voice links and video system and the startup of the TPVT, trajectory, propagation and visualization tool. Moreover the links toward Kourou were started.

At the same time Ground Stations were conducting their internal tests. These included stations' configuration check, stand alone validation and local loop data flows.

At H0 minus 6 hours and 30 mins voice connectivity with Recovery operations manager, aboard the recovery ship, was established, while a first link with ground stations was implemented via IP satellite provider (INMARSAT for Libreville and Naval Stations) and via ASINET for Malindi. Through this link an initial end to end simulation between Ground Stations and MCC was conducted, simulating the whole mission profile, starting from Libreville AOS.

At around H0 minus 3 hours the IXV SpaceCraft was activated and TM started to flow and to be displayed at MCC. This was obtained thank to the use of an NDIU provided by ESA and remotely controlled by GC in Turin. Thanks to this link all Flight Control Team sitting in MCC was able to control, and support AIT team in Kourou, during vehicle activation sequence.

During this preparation phase several status checks occurred between Mission Director in Kourou and Operations Director in ALTEC. Operations Director in particular gathered Subsystems information through relevant operators, e.g. Ground Stations status was reported to OM by each single station manager.

At H0 minus 2 hours the latest results from high altitude wind measurement (balloon launched at H0-4 hours) were provided to MCC.

The IXV was launched with VEGA at (H0) 13:40 UTC of the 11th February 2015, from Kourou. Initial launch time was originally foreseen at 13:00 UTC of the same day but the launch was posed on hold at H0-4 min.

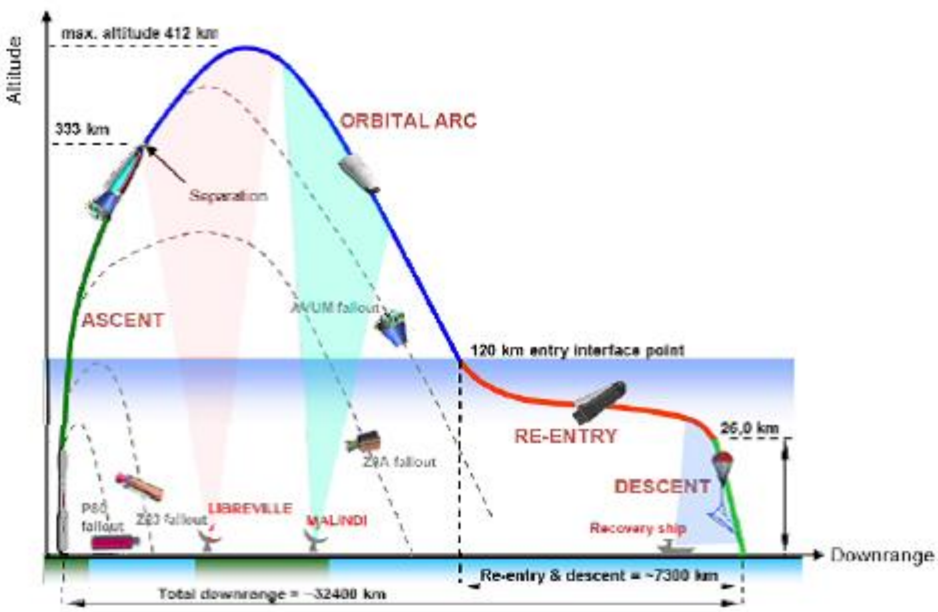

Figure 8: IXV Main Flight Phases

After H0+1151 sec Libreville Station Manager has reported the Acquisition of Signal (AOS) from the S/C and data has begun to be displayed in MCC. Some overlapping of visibility windows between Libreville and Malindi occurred as Malindi Acquisition of Signal started at H0+1409 while Libreville Visibility windows ended at H0+1510 secs. After Malindi Loss of Signal (occurred at H0+2027 secs) the S/C flew over an area not covered by IXV Ground Stations for about 45 minutes. Naval station declared Acquisition of Signal at H0+4816 secs with a Loss of Signal of 5795 secs. During all visibility windows the MCC monitored the data coming from the S/C.

Figure 9: IXV after splashdown

During descent phase and after splashdown a video link was established between recovery ship and MCC, in order to support recovery operations and to show the IXV vehicle after its flight. Splashdown occurred at H0 + 5796 secs and IXV was successfully recovered by Recovery Ship after a couple of hours from splashdown

From a ground operational perspective all systems worked as expected, and performances of the systems were well within the margins considered during design and development phase. MCC systems had permitted to FCT to monitor in realtime mission events and TM (during visibility windows), with no particular issues encountered. TPVT systems proved to be very precise in following the real mission evolution and spacecraft trajectory; its use has been very helpful to have a visual feedback on spacecraft position and mission phase. The IXV communication network has worked well in relaying data to MCC; and all dress-rehearsal and mission simulation were conducted nominally. Ground Stations performances were beyond the expected ones: visibility windows were larger than expected and especially naval station granted an AoS that occurred well before the expected ones, proving that adequate margins were taken into account when considering blackout windows. Moreover the naval station kept in tracking of S/C well below the expected values of LoS.

5. Conclusions

The IXV mission was successfully conducted on the 11th of February 2015. The Ground Segment has been operated by a joint/integrated team composed by ESA and industry operators. All ground segment systems worked as expected and permitted to FCT to monitor TM from S/C as well as to predict splashdown coordinates. All Ground Segment industrial team is ready to further support agency in upcoming cornerstones toward the mastering of re-entry systems.