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Intermediate experimental vehicle, ESA program aerodynamics–aerothermodynamics key technologies for spacecraft design and successful flight

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ABSTRACT

With the aim of placing Europe among the world's space players in the strategic area of atmospheric re-entry, several studies on experimental vehicle concepts and improvements of critical re-entry technologies have paved the way for the flight of an experimental space craft.

The successful flight of the Intermediate eXperimental Vehicle (IXV), under ESA's Future Launchers Preparatory Programme (FLPP), is definitively a significant step forward from the Atmospheric Reentry Demonstrator flight (1998), establishing Europe as a key player in this field.

The IXV project objectives were the design, development, manufacture and ground and flight verification of an autonomous European lifting and aerodynamically controlled reentry system, which is highly flexible and maneuverable.

The paper presents, the role of aerodynamics aerothermodynamics as part of the key technologies for designing an atmospheric re-entry spacecraft and securing a successful flight.

1. Introduction

The IXV is designed to fulfill a set of high level requirements and objectives that have been iteratively discussed and jointly defined by the Agency and Industry.

The main technical and programmatic constraints that define the project are:

- Perform the atmospheric re-entry with a lifting configuration controlled by combined thrusters and aerodynamic surfaces.
- Perform verification and experimentation of a well defined set of critical re-entry technologies and disciplines (e.g. aerodynamics, aerothermodynamics, thermal protections, hot structures, guidance, navigation and control, …).
- Concentrate the verification and experimentation in the hypersonic and high supersonic flight domains.
- Perform landing and recovery of the vehicle at sea and in an "intact" state to allow post flight inspection and analysis.

The IXV configuration is a lifting body type vehicle as shown in Fig. 1.

It is a lifting platform characterized by a L/D factor of approximately 0.7 in hypersonic regime, where two body flaps are used for aerodynamic control. The vehicle is equipped with a descent and recovery system including a set of parachutes, floatation and localization devices.

The resulting nominal ETE trajectory is shown in Fig. 2, where the maximum altitude is set at ~435 km in the ballistic arc. It provides a velocity at the entry gate equal to 7450 m/s and a flight path angle of $-1.6°$, fully representative of a re-entry from low-earth-orbit (LEO) missions.

Under ESA control, Thales Alenia Space Italy is leading the industrial organization gathered by more than 30 European partners.

One important component of the system loop involved AED (Aerodynamic), ATD (AeroThermoDynamic).

The development of robust aerodynamic and aerothermodynamic data bases is carried out for securing the aeroshape definition and providing reliable nominal and sizing data for

Abbreviations: AEDB, Aerodynamic Data Base; ATDB, AeroThermodynamic Data Base; IFE, In Flight Experiment; CFD, Computational Fluid Dynamic; FES, Flight Engineering System; WTT, Wind Tunnel Tests; TAS-I, Thales Alenia Space Italy; ESA, European Space Agency; FQA, Flying Quality Analysis; GNC, Guidance Navigation and Control; ETE, End to End; SWBLI, Shock Wave Boundary Layer Interaction; TPS, Thermal Protection System

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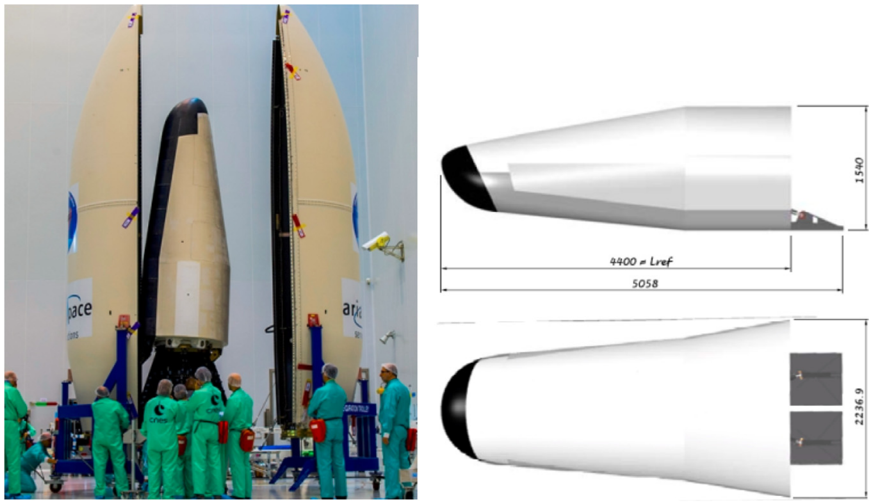

Fig. 1. Intermediate experimental vehicle, general layout (courtesy of ESA).

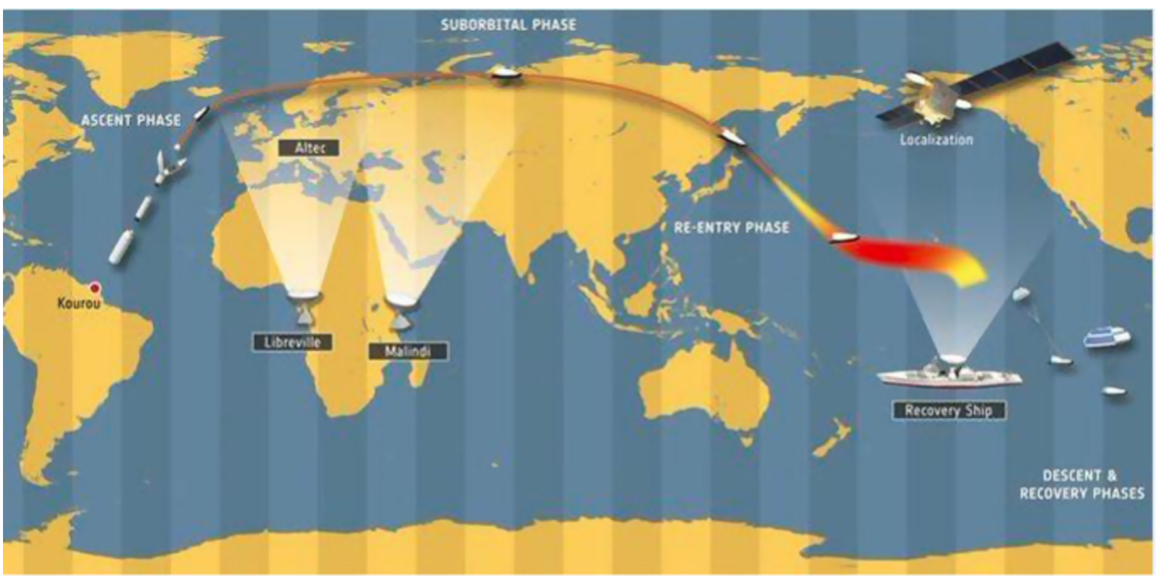

Fig. 2. Intermediate experimental Vehicle, mission general overview (courtesy of ESA).

TPS (Thermal Protection System) and vehicle dimensioning purposes. During the design phase, only ground prediction tools are used for assessing the general aerothermodynamic characteristics of the IXV vehicle in flight. Moreover above Mach number 10, ground prediction tools like wind tunnel facilities are not able to reproduce all parameters involved at flight condition. Having any flight data for validation, the extrapolation ground to flight strategy is based only on CFD.

For designing a hypersonic spacecraft, a close loop among AEDB, ATDB and mission analysis is mandatory for consolidating the aeroshape. At each iteration, the AEDB and ATDB are providing data for mission analysis, FQA / GNC and TPS activities as well. Potential critical points are solved by analyzing in depth the data predicted at different levels of the system loop. AEDB and ATD are the providing data to be used as inputs for the In Flight Experimental (IFE) plan as well.

Among the different objectives of the mission, the IXV vehicle is a flying test bed able to retrieve flight data for validating the various prediction tools used for the design [1].

As shown in Fig. 3, the AEDB provides the aerodynamic data to be used by the mission analysis which gives as output the Mach number, altitude, angle of attack sideslip aileron and flap setting for each re-entry trajectory point. Then using the ATDB, for any flight trajectory point, a pressure and thermal mapping is computed to be used for in flight sensors location. Finally considering one of the flow field phenomena to be occurred in flight, the shock wave boundary layer interaction phenomena (SWBLI), the Fig. 3 displays the evolution of the boundary layer separation zone for various flap setting at Mach number 17.75 enabling to define the more promising IR camera and thermocouples location as well.

Within the IXV programme, the AED/ATD and IFE plan definition activities are under Dassault Aviation responsibility and involving RTECH, CFSE, UNIROMA, NLR, VKI (for CFD activities), STARCS, ONERA, VKI (for WTT activities) and RUAG, ONERA, CIRA, ETHZ, VKI (for In flight Experiments) as shown in Fig. 4.

2. AED aerodynamic [4,5]

Design and data basing studies require the prediction of forces on the « clean » aircraft (i.e. with no control surface deflections), of the derivatives of these forces with the attitude and motions parameters (primarily angle of attack and angle of sideslip), and