ESA RE-ENTRY BLACK BOX

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ABSTRACT

This paper describes the status of the ESA study aimed at designing a standard Re-entry Black Box (RBB) targeting LEO spacecraft and launchers upper stages.

The study should lead to a standard design, robust enough to withstand different re-entry environments, and flexible enough to adapt to the needs and requirements of various re-entry missions. It should fulfil primarily the following dual function: experimental data collection during re-entry (e.g. temperature, heat flux, Mach number) and "Black Box " type of device, allowing for the recording of the spacecraft's trajectory data. The latter feature would help to identify the events of an accident for spacecraft designed to survive re-entry and might be used as reference data in case of litigation and liability issues.

This paper provides insight into the project status, the current preliminary design and future prospects expected.

1. STUDY CONTEXT

1.1. Introduction

The need for actual re-entry measurements originates in the combination of several factors. The growing number of operating satellites and space debris (there are currently more than 600,000 objects larger than 1cm on orbit around the Earth), the implementation of de-orbitation requirements for objects being launched into orbit, safety requirements and safety concerns, and the need for a better understanding of actual re-entry environments (in terms of technology enhancement as well as models/tools upgrade) make it crucial today to significantly improve our knowledge of multi-disciplinary phenomena involved in atmospheric re-entry. Testing is not always feasible, very often expensive, and does not constitute a fully representative re-entry environment.

The concept of the Re-entry Black Box (RBB) originates in the conjunction of all the above mentioned factors. The baseline is a small, lightweight, disposable and inexpensive (based on COTS equipment) device collecting data during re-entry and transmitting it via commercial satellite network before impact. The RBB will be attached to the host vehicle by low melting point materials that can be selected so that separation occurs at the requested altitude.

Such a device would allow ESA to flight test miniature sensor systems recording various types of data, validating thermal protection systems and other re-entry technologies, as well as calibrating models and tools. The RBB could also provide an independent path for data transfer while making use of external sensors: it is indeed also envisaged that wireless sensors implemented on the host vehicle could transmit data directly to the RBB, enabling the retrieval of data related to the re-entering spacecraft even in case of uncontrolled re-entry.

1.2. Existing systems

A similar device for experimental use is already in development in the US. It is the so-called Re-entry Break-up Recorder (REBR) from The Aerospace Corporation (see Fig. 1). It is a small device (weighing less than 2kg, of about 30cm diameter) aimed at collecting re-entry data. Once implemented on a re-entering spacecraft, it detaches from the spacecraft's structure during re-entry at approximately 78km of altitude (melting temperature of its attachment device), collects data during re-entry, transmits these data by phone via the Iridium satellite network from an altitude of 30km (where the small capsule starts to slow down thanks to its geometry) until impact (about 400 seconds later). The device is not retrievable and it is not designed to survive impact.

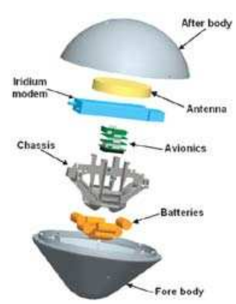

Figure 1. REBR (Aerospace Corp.)

Other miniaturized re-entry capsules have also been flown, such as the Mars Microprobes from NASA, also called Deep Space 2, of dimensions similar to the REBR's (see Fig. 2). The NASA Stardust capsule, or

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the German MIRKA spherical device can also be mentioned here.

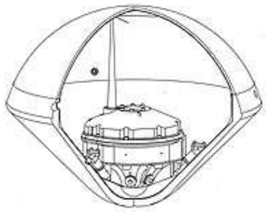

Figure 2. Mars MicroProbe (NASA)

1.3. Study Objectives

This study is an ESA General Studies Programme Fast Track activity. It is a relatively short-duration project aimed at providing a thorough market survey, feasibility assessment and preliminary system design.

The RBB system should fulfil a dual function as described here after:

- “Black Box” type of device, recording critical data related to the host vehicle (e.g. trajectory data, temperature, heat flux, pressure, accelerations,...) in order to characterize its re-entry and support the investigation of potential malfunctions. Destructive and non-destructive re-entries trigger off different separation times.
- experimental data collection related to the RBB free-flying re-entry.

Even though a wide field of applications is being targeted, the study should lead to a standard conceptual design :

- single set of functions/features (with sensors package and parameters to be adjusted and fine-tuned to the host vehicle and its mission scenario);
- simple interface to the host satellite or upper stage (e.g. REBR low melting point attachment device);
- single design fulfilling wide scope of re-entry missions and targeting primarily LEO satellites and launchers' upper stages.

2. SYSTEM OVERVIEW

2.1. Design considerations

The overall targeted weight is in the order of 2-3kg, considering a diameter of less than 30cm. This would lead to a ballistic coefficient of about 50-100kg.m^{-2}, meaning a re-entry duration of 8-10min.

The main subsystems are the following:

- On-board computer and data processor
- Power system
- IMU and GPS
- Embedded sensors
- Wireless sensors and antennae
- Transmission modem and antenna
- Ground support equipment (data acquisition and processing unit)
- Attachment device

2.2. Mission Profile

Fig. 3 shows the expected trajectory profile based on preliminary simulations and rough assumptions as to the aerodynamics of the system (REBR-like shape). It considers a typical release from a LEO satellite at an altitude of 60km, recording data (from 120km altitude) till about 30km, from where the trajectory becomes flatter, extending the time span during which the RBB uplinks its compressed data to the satellite network, for further transmission to ground.

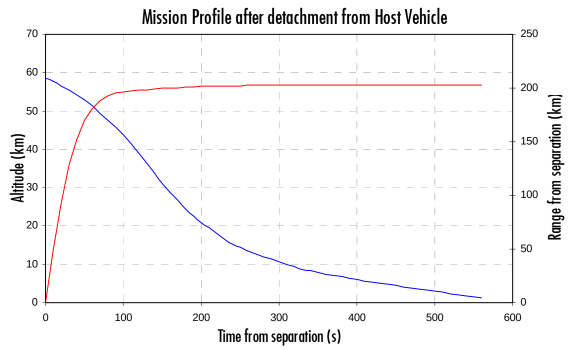

Figure 3. Expected Mission Profile after separation from a LEO satellite re-entry

The expected sequence of events during a satellite controlled re-entry is the following:

- Idle Mode (prior to 120km altitude)
- Activation prior to re-entry and data acquisition phase (120-30k)
- Data transmission prior to ground impact (30-0km)

This mission profile is very much dependent on the type of host vehicle and vary by a great extent from one mission to another.

2.3. Multi-disciplinary optimisation

The development of a standard design implies significant effort put on the optimisation of a system that is subject to many different constraints and related to several different fields all inter-related. The main constraints are summarized here below:

- Robustness (launch/re-entry loads, long-duration flights, various temperature environments, break-up or fragmentation events,...);
- Aerodynamics design and TPS constraints (center of gravity position, nose radius, subsonic stability). No active control means are foreseen;
- Power limitations (battery size and lifetime constraints, e.g. ATV docked periods of several months);

- Communication (satellite network uplink capability, data sampling rate and resolution, black-out phase, antenna visibility,...);
- Overall cost, reliability, availability and ITAR-free constraints, and miniaturization.

In addition, safety and integration constraints have to be considered:

- External interface reduced to a minimum (structural, operational,...);
- Mass and volume constraints;
- Non-interfering and safe integration within host vehicle;
- Activation constraint (manual from crew in case of ATV, or manual from ground, automatic from sensors).

3. WAY AHEAD

The outcome of the study strongly depends on potential users identified at this stage. Preliminary discussions currently imply the need for a dual design, adapted to the two main application types targeted (LEO satellites and launchers upper stages). The two environments being so different (different mechanical and thermal loads, different time scales, types of data, primary or secondary recording means in each case,…), that the initial standard concept might have to be split into two distinct designs.

Other considerations, such as the large range of specifications between destructive and non-destructive re-entries, or the gap between COTS and flight-proven items, also make it crucial to consider a set of different designs to fulfil the wide scope of applications targeted.

Other flight opportunities now have to be investigated, such as launchers suborbital stages, ISS jettisoned items (both of safety interest), or even test flights on sounding rockets.

Integration exercises are currently taking place in ESA to try and coordinate the flight of the REBR (Aerospace Corp.) into ATV-2 and possibly other European vehicles, paving the way to future integration of the ESA RBB into launch vehicles and satellites.

4. REFERENCES

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