A Black Box for Launchers

The Demise Observation Capsule

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The Demise Observation Capsule (DOC) aims to provide an in-situ observation platform of re-entry processes in order to gain a better understanding of rocket upper-stage re-entry trajectories (*how*), footprints on ground (*where*), and disintegration processes upon break-up in the Earth's atmosphere (*when*). The DOC is a novel ESA-funded project being led by Science [&] Technology (S[&]T) in Delft, working together with several consortium partners across Europe.

Artist impression of the Demise Observation Capsule during re-entry.

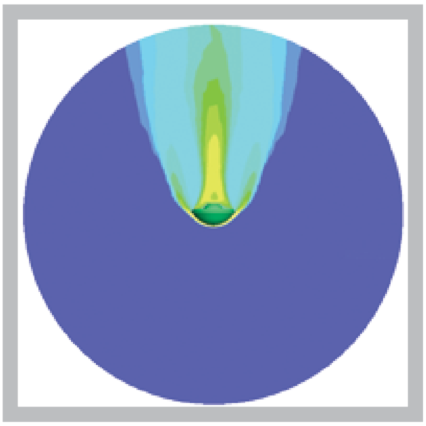
Details of the break-up process, such as the altitudes at which key events occur and the dynamics at play, are currently largely unknown and unobserved. It is very difficult to place instrumentation or persons either on ground or in the air close to a re-entry event. This is mainly due to the large uncertainties in the trajectories of the uncontrolled debris involved, eventually leading to a high risk of someone or something getting hit by falling debris. The impossibility of predicting the exact timing and placing of re-entry debris, with unknown size and weight, results in a range of challenges, including increased risks of on-ground damage and fatalities. In many cases, these risks cannot be mitigated through existing models or simulations, as these often do not model the break-up in high enough detail and are unvalidated. Therefore, these models' results typically give an unrealistic view of the impact point and do not give any information on the footprint of the upperstage debris. In previous ESA programs, so-called SCARAB analysis tools have been developed to model, amongst others, the disintegration of a VEGA launcher upper stage. However, SCARAB analyses are not fully validated at present, meaning that there is no flight data to compare to the models. Therefore it is unknown to what level the models represent reality. To solve this deadlock, DOC aims to provide direct observation information on the processes involved in re-entry and through this improve the modelling of launch vehicle break-up, reducing overall mission risks.

Goals

DOC will provide information in three main areas: the footprint area, the trajectory flown and the break-up of the launcher stage to which it is attached. Improvements in the knowledge of the footprint area will aid the launcher providers in adhering to the regulations, as well as improve of public safety. Reduction in impact footprint size will also allow for a smaller area to be closed off during launch operations, possibly allowing for a reduction in launch and insurance costs. Typical launch safety requirements dictate a casualty probability of less than 1 in 10,000. Many launch vehicles are fairly close to this limit simply due to their size, requiring extensive analysis to prove compliancy.

During re-entry, plasma build ups block any external radio communication until the launcher has sufficiently slowed down. However, once slowed down, the launcher has (or at least should have) already disintegrated, making any communication from the launcher systems impossible. For DOC to be able to downlink data, it features heat shields to survive this violent phase of the flight. In other words, the capsule acts as a 'black box' for the launcher. All of the measured trajectory data (including positioning, accelerations and photographs) from passivation of the launch stage, through

Occasionally, parts of launchers unexpectedly re-enter and survive the harsh conditions to reach the ground. [NASA]



CFD analysis performed at INCAS.

Demise Observation Capsule project logo.

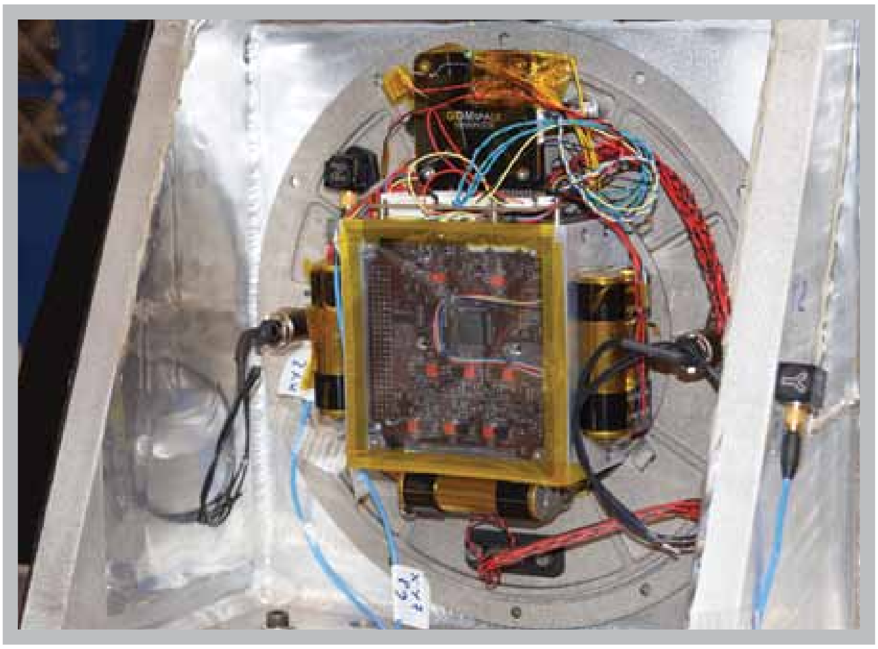
release of the capsule from the stage until impact with the ocean will be downlinked by DOC.

The downlinked data will provide real-life data for the validation of re-entry models and the understanding of re-entry physics. Additionally, it will offer inputs on structures, aero-thermodynamics and materials for corresponding databases. Eventually, this will lead to obtaining data for engineers to 'design to demise'. If this goal of designing the launcher to demise completely during re-entry is achieved, ocean pollution and ground-based risks due to launchers will be reduced or even become a thing of the past. Furthermore, a reduction in cost can be achieved by avoiding the need to recover any large debris that does not immediately sink. Potentially, the data could also be used to provide information to insurance companies.

Finally, the break-up of the launcher stage to which DOC is attached can be (partially) reconstructed with the data and images DOC provides. It will document the key fragmentation events and provide a reconstruction of the break-up's chain of events.

DOC's Flight Profile

The mission profile for the maiden flight of DOC is as follows. First, the flight hardware is integrated with an upper stage and launched, during which time DOC is completely turned off. Only at the completion of launcher passivation, the phase where the launcher uses its last remaining propellant to manoeuvre into a trajectory for demise, does the launch vehicle send a signal to DOC to wake up. After doing so it performs basic system functionality checks and initiates its measurements. During the first part of the upper stage re-entry DOC remains attached to the host vehicle. During fragmentation of the host vehicle, the capsule separates from the launcher and photographs are made, all while continuing sensor measurements. After the black-out phase of re-entry, DOC sends the collected data via a communication network service to the ground. It continues collecting data and transmits until impact, which is expected to result in its destruction. If the transmitting capabilities remain intact after impact, DOC will continue to send data until battery power is depleted.



The Engineering and Qualification Model (EQM) of the Demise Observation Capsule on the shaker during testing at CIRA.

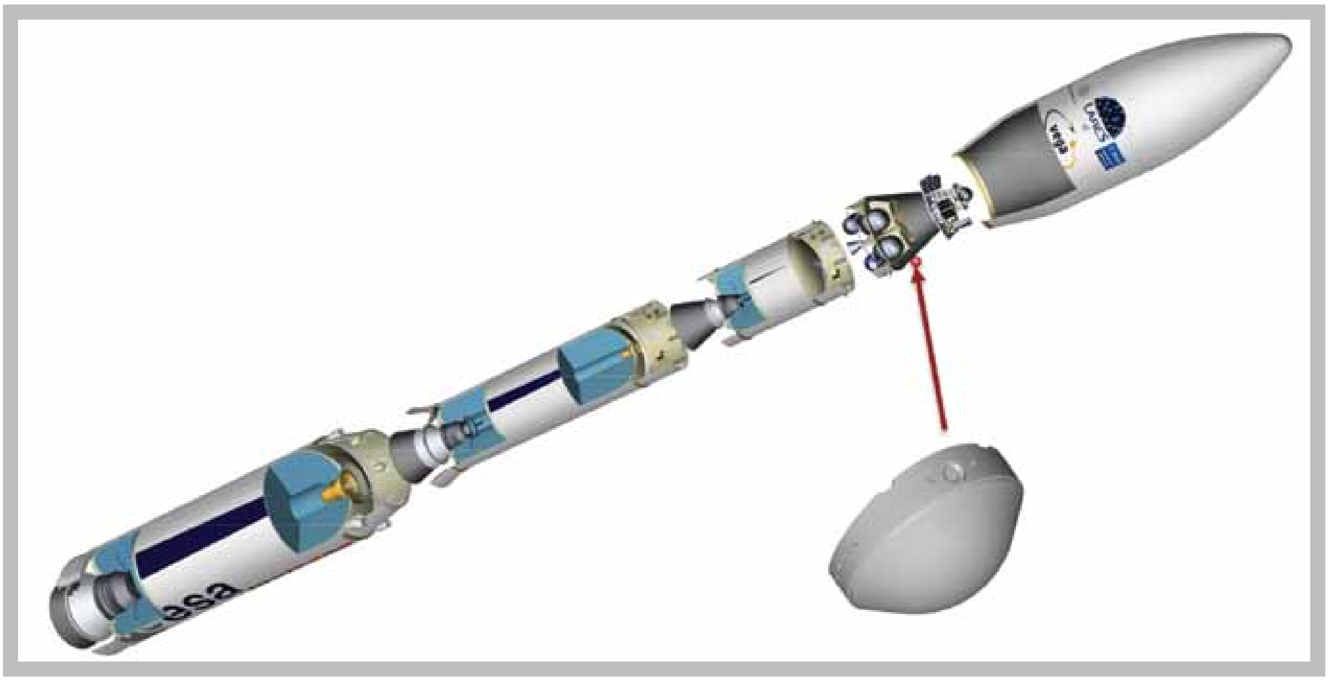
The Consortium

The mission is developed, qualified and commissioned by the European Space Agency in the frame of the Future Launcher Preparatory Program (FLPP), and is conducted by a consortium consisting of seven partnering companies spread over Europe. Science & Technology B.V. (S[&]T) in the Netherlands provides the project management and the overall system engineering. CIRA, located in Italy, designs and manufactures the structure of DOC and provides the consortium with the mechanical testing. INCAS based in Romania performs all aero-thermodynamic and trajectory analyses for re-entry. GomSpace A/S in Denmark is responsible for the avionics, sensor design and their integration. ESC Aerospace GmbH in the Czech Republic provides the on-board software for the DOC. Ædel Aerospace GmbH in Switzerland performs independent software validation and verification. ELV SpA, based in Italy, provides consultancy for designing the interface with the VEGA launch vehicle, in addition to providing input regarding the launch environment and safety measures.

The Capsule

The capsule will be a robust, optimised and modular design compatible with a multitude of launch vehicles and stages, where the main interest lies in the 3rd and 4th stages of launchers (which reach the highest altitudes and re-entry speeds). The capsule will be attached to the launcher by a host vehicle interface (HVI), which is also completely enshrouded in thermal protection materials, ensuring a safe flight while the capsule is still attached to the host vehicle/launcher.

As DOC is a rideshare item, it will have no impact on the launcher payloads or operations, including during the flight operations as well as the preparatory activities before the launch. It will only separate



The proposed location of DOC on the VEGA's AVUM upper stage.

from the stage in a safe and controlled manner after the latter has been passivated and defragmentation is thought to have started. In essence this means that there will be no impact on the payload of the launcher, as DOC's mission only starts when the payload is already injected into orbit. The on-board software is designed for autonomous mission performance and recognition of the timeline to ensure in-flight data transfer.

The flight-ready capsule will contain a large suit of versatile and extendable electronics developed for use in CubeSats, which results in very efficient use of available space. As a result DOC will have a total mass of only approximately 10 kg, and a diameter of just about 35 centimetres.

Both the host vehicle interface and the capsule will contain observation cameras. As the images need to be transferred to the capsule from the host vehicle camera before the connection is lost, only very few photos will be taken with the host vehicle interface camera. The camera placed within the capsule itself will be able to make a multitude of images. Here a choice can be made between high-resolution and low-resolution images. With the former, only one or two images could be transferred to the ground, depending on the link quality. When low-resolution images are selected, at least four or five will be transmitted.

DOC will only contain equipment and components that are not covered under any arms treaties to make sure it will be able to fly on any launcher (especially in the field of re-entry vehicles, where the technology shows many parallels with the technology in ballistic missiles, regulations are very strict). DOC will be able to provide data that will enable users to improve their current models of launch vehicle re-entry and break-up. Due to the capsule's versatility and modularity, many different launchers and missions can covered using DOC with only minor alterations. As the sensor suite is extendable, launcher providers can request alterations to provide the information they are most interested in.

Future Work

The exact mission profile is currently being finalised by ESA and the DOC consortium. In the meantime, tests are going to be performed to verify, amongst others, communications and sensors. Possibilities for flights are still open, although initial options include launches on sounding rockets and balloon drop tests from the launch complex in Kiruna, Sweden. The earliest flight opportunities on an orbital launcher such as VEGA or Ariane 5 are in 2019/2020.

To conclude, DOC will provide a glimpse into the unknown territory of re-entry physics. By measuring the trajectory of the capsule, the output of various sensors and by taking pictures in-flight, the capsule will provide answers to the how, where and when of launcher re-entries. This in turn makes it possible to reduce launch costs, and more importantly, increase the safety of spaceflight.

For more information and contact:
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Reducing man-made debris

With over 18,000 pieces of man-made space debris larger than 10 centimetres orbiting Earth, it is not an uncommon occurrence for some of it to re-enter the Earth's atmosphere. What is uncommon however is for the debris to reach the Earth's surface. Propellant tanks are very common perpetrators due to their shape: they tumble very easily in the oncoming airstream, which distributes the heat load over the structure, keeping it relatively cool. Results like those from DOC are required to optimise the design of components such as propellant tanks, to make sure they disintegrate at a safe altitude, before they are able to hit someone or something.