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Overview of the DRACO Development Status

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Abstract

The Destructive Re-entry Assessment Container Object (DRACO) project is an ESA mission with the aim of improving the understanding of spacecraft demise processes. DRACO consists of a fully representative satellite that will undergo a controlled destructive re-entry from Low Earth Orbit. The satellite hosts a dedicated instrument that will measure a variety of parameters on specific objects of interest within the host during the re-entry, in addition to recording visual and infrared imagery. The instrument also includes a capsule designed to survive the destructive re-entry and transmit the obtained data back to ground. The current paper provides a general status overview of the ongoing developments of the DRACO mission.

Keywords: *destructive re-entry, break-up, capsule, observation*

Nomenclature

ATV – Automated Transfer Vehicle
BUC – Break-Up Camera
CDF – Concurrent Design Facility
CMC – Ceramic Matrix Composite
DDCU – Demise Data Collection Unit
DRACO – Destructive Re-entry Assessment Container Object
EIP – Entry Interface Point
ESA – European Space Agency
IMU – Inertial Measurement Unit
LEO – Low Earth Orbit
REBR – Re-Entry Breakup Recorder
TPS – Thermal Protection System
VASP – Vehicle Atmospheric Survivability Project
VAST – Vehicle Atmospheric Survivability Tests
VKI – Von Karman Institute for Fluid Dynamics

1. Introduction

Due to the increased launch traffic into Low Earth Orbit (LEO) and the adoption of space debris mitigation requirements, the volume and number of spacecraft and launcher stages re-entering the Earth's atmosphere and undergoing a destructive re-entry process are increasing. Strict design and operational requirements are usually in place to limit the risks to persons and infrastructure on-ground, associated with the debris and fragments generated by destructive break-up. The multi-disciplinary physics that govern these processes are however poorly understood.

The current methodology for assessing the on-ground casualty risk associated with re-entering spacecraft relies heavily on re-entry simulations. These simulations are largely based on extrapolation of sparse data points, leading to a significant degree of uncertainty in risk assessment. While a few notable flight experiments, such as VAST/VASP (1971-1973) [1], [2], REBR (2012)[3], i-Ball (2012), and ATV-5/BUC (2014) [4], have shed some light on the behaviour of representative large-scale spacecraft during re-entry, the majority of the current knowledge on spacecraft demise processes is derived from ground-based tests in (plasma) wind tunnels that act as anchor points for simulations.

To address these uncertainties and advance our understanding of spacecraft re-entry, the Destructive Re-entry Assessment Container Object (DRACO) project has been initiated by the European Space Agency. DRACO will consist of a representative satellite that will undergo a controlled destructive re-entry, and which will host a break-up recording instrument to capture this demise processes in-situ.

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Differently from the previous flight experiments mentioned above, the host spacecraft itself and its internal components undergoing destruction will be instrumented with an array of sensors and specific zones of interest will be observed using visual and infrared cameras. The data will be stored within a re-entry capsule to be released from the demising host platform as late as possible and designed to survive the re-entry. Upon safe release, the re-entry capsule will deploy a parachute and will transmit the data back by a satellite communications relay link. The aim is to generate and collect an order of magnitude more data than previous flight experiments.

This articles provides an overview of the current development status of the DRACO mission and system.

2. DRACO Mission

The DRACO mission was initiated with an internal feasibility study at ESA's Concurrent Design Facility (CDF), looking at the benefits of a proposed flight experiment to assess the re-entry break-up environment of a satellite. After successfully confirming the feasibility and benefits, based on the needs of the scientific community, the Industrial Phase A/B1 was kicked-off to further define the mission and system. Additionally, a number of development activities have been initiated in parallel to support early definition and de-risking of critical technologies.

2.1. Objectives

The DRACO mission has as overall aim to be the first space mission purposely dedicated to investigating re-entry safety issues associated with the destructive atmospheric break-up events of a representative satellite. The main objective of the mission is to record in-situ and characterise the full-scale physical processes that lead up to the break-up of a satellite and its components in the dynamical regimes not accessible in ground-based facilities. This top-level mission objective can be further broken down as follows:

i. Design a satellite, instrument, and record the physical behaviour during its own destruction upon atmospheric break-up, representative of an uncontrolled re-entry from LEO.

ii. Use a small satellite platform that is representative for space missions as object of study by instrumenting the components expected to fail between 70 and 100km in altitude based on the current (extrapolated) understanding of the physics.

iii. Design and employ the next generation of re-entry break-up recording instruments to record measurement data during the atmospheric re-entry and breakup, survive the re-entry break-up process and transmit the stored data back to ground.

iv. Test and demonstrate in flight the behaviour of spacecraft components produced under the "design for demise" engineering paradigm.

2.2. Mission Scenario

The DRACO spacecraft will initially be launched on a European launch vehicle into a Low Earth Orbit. During the initial orbital phase, used for some check-out activities, DRACO will remain connected to a re-ignitable upper stage or kick-stage. This initial phase is expected to last only a few orbits/hours, after which DRACO will be put into a (shallow) re-entry trajectory and separated from its upper or kick-stage. As the goal is to be representative of an uncontrolled re-entry from LEO, a flight path angle of less than -1°, at the Entry Interface Point (EIP) of 120 km altitude, is targeted. The re-entry itself will however be well controlled to target a specific re-entry footprint in an uninhabited area, such as the South Indian or South Pacific Ocean, to ensure meeting the applicable reentry casualty risk requirement of less than 10^{-4}.

Prior to the EIP, the data collection mode shall be started to initiate the recording of measurement data of various instrumented components by the dedicated break-up recording instrument. A large number of sensors (more than 200), consisting of thermocouples, contact switches, strain gauges, pressure sensors, and others, will be distributed around the spacecraft and located on various objects of interest which could shed light on the demise process of a satellite. In addition to the intrusive sensors on the objects of interest, a number of cameras will be included and focused on specific areas of interest to acquire contextual information about the re-entry process.

The sensor and camera data will be recorded and processed by the break-up instrument's Demise Data Collection Unit (DDCU), hosted within a dedicated TPS-protected compartment. The DDCU will store and forward the data to a small re-entry capsule, also included in this compartment, that will be separated from the demising host spacecraft and designed to survive the remaining re-entry. Upon deployment of a parachute, necessary to increase the capsule's descent duration before splashdown, data transmission through a satellite relay network will occur to retrieve the gathered spacecraft demise data.

In order to maximise the scientific output of the DRACO mission, a remote observation campaign of the re-entry will be performed using an instrumented airborne platform. This should provide additional information on the spacecraft break-up and fragment creation, and spectrographic footprint of the demise process. Similar campaigns were previously performed for the STARDUST, ATV-1 and Hayabusa re-entries[5], [6], [7].

An overview of the various mission profile phases and simplified system concept of the break-up instrument is presented in Fig 1 and Fig 2 respectively.

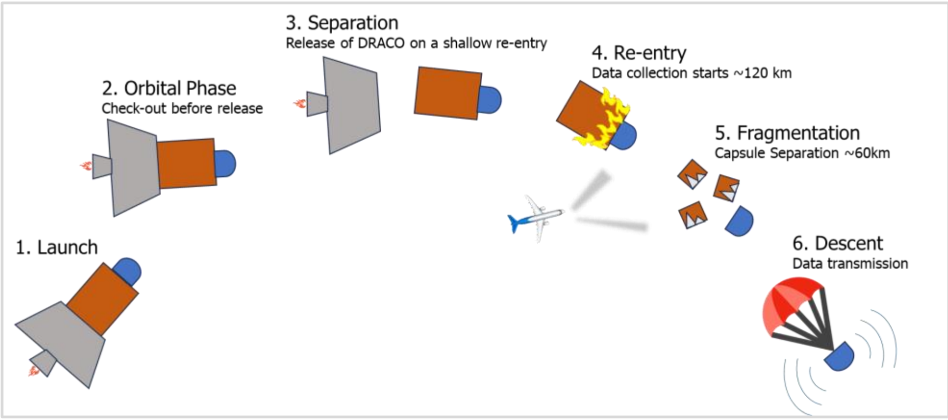

Fig 1. Overview of the DRACO mission profile.

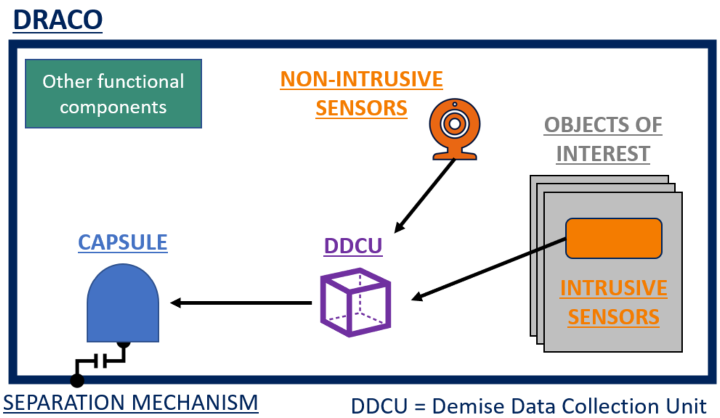

Fig 2. DRACO System Concept.

3. Development Status

The DRACO mission and system is in the preliminary design phase (Phase B), and is currently being developed by means of a number of Industrial activities: definition of the mission and host spacecraft, under responsibility of Deimos Space (ES); development and breadboarding activities of a (generic) break-up instrument, under responsibility of Fluid Gravity Engineering (UK); and design of the re-entry capsule aero-shape and thermal protection system, under responsibility of the Von Karman Institute (VKI) for Fluid Dynamics (BE).

3.1. Host Spacecraft

The host spacecraft of the DRACO mission will be a fully representative small satellite based on the Mini4EO Lite platform from Deimos Space, which is being further developed as part of the project. This platform will provide a low cost solution for small satellite missions.The total wet mass of the DRACO spacecraft, including dedicated break-up instrument and its re-entry capsule will be 150-200 kg and will fit within the platform envelop dimensions of approximately 1 m × 1 m × 1.5 m. While the components of the satellite platform could in principle be fully functional, the host spacecraft is foreseen to be largely inactive, as it only needs to be representative in terms of materials and structural design to yield representative observational data on the demise process.

As part of the host spacecraft, several objects of interest will be identified to be instrumented in detail. These objects will be the main focus for the measurements and observations by the re-entry break-up instrument. Likely objects of interest could be a propellant tank, structural elements, mirrors, etc. In addition to the platform itself as object of study during the destructive break-up, further objects of interest are to be added to maximise the knowledge gain for the DRACO mission. The objects will include marker materials with strong emission signature to get verifiable insights on the fragmentation process, carbon-fibre-reinforced polymers-based structure representative for composite overwrapped vessels to provide a flight demonstration of the "design for demise" technique targeting such objects, and specific material samples. The final list of objects of interest will be consolidated during the ongoing activities.

Besides the definition and design of the host platform, system-level analyses (i.e. destructive re-entry simulations) have been performed to provide requirements for the break-up instrument that will observe and measure the demise processes.

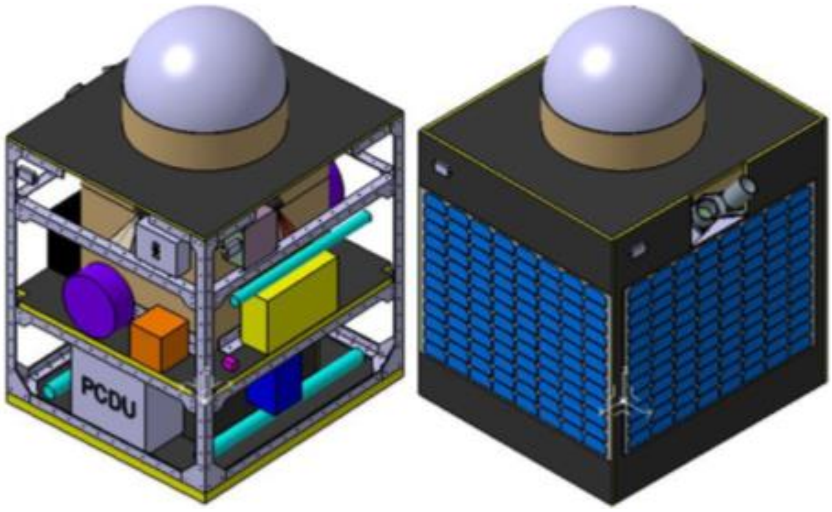

Fig 3. Conceptual design of the DRACO host spacecraft.

3.2. (Generic) Break-up Instrument

As described earlier, the host spacecraft undergoing the demise process during re-entry will be fully instrumented and its break-up recorded through the dedicated break-up instrument. The break-up instrument consists of a variety of sensors and (visual/infrared) cameras, the DDCU and a re-entry capsule. The DDCU will record, process and store the incoming data streams from the sensors and cameras. A prioritisation algorithm will prioritise recorded camera images to maximise the likelihood of getting the most interesting data points through the limited data downlink. The exact prioritisation algorithm still needs to be developed, but could for example be based on largest perceived change in an image sequence, last image before camera failure, sudden brightness increase, etc.

After processing, the DDCU will forward the data, and continuously updated data priority list, to the re-entry capsule which has onboard storage that will hold the data and transmit it back to ground once released. Release of the capsule will be able to be triggered independently by the DDCU, once it stops getting sensor inputs, by the capsule, once it detects the DDCU has stopped functioning, and by the separation mechanism itself using a built-in timer back-up. The released capsule will deploy a parachute after its free-flying phase, after which the stored and prioritised data will be sent to ground by means of a satellite relay network through an L-band communication system. Inertial Measurement Units (IMUs) included within the DDCU and the capsule will allow for the rebuilding of the demising spacecraft's trajectory and re-entry capsule flight trajectory.

The design and development of the break-up instrument yield a number of difficult technical challenges, such as the robust prioritisation of the incoming scientific data; operation and survival of the instrumentation within a demising host; reliable data downlink of a capsule during re-entry; etc. In order to de-risk parts of the instrument, a breadboard of the instrument is being developed and will undergo functional (and limited environmental) testing in the second half of 2024. The breadboard model encompasses the sensors, DDCU, capsule OBC and the communication system but excludes the relevant thermal protection, capsule structure and parachute. The thermal protection system (TPS) needed to keep the instrument functional for a sufficiently long enough time is investigated in another parallel technology development activity.

3.3. Capsule Aero-shape and Thermal Protection System

A dedicated technology development activity is investigating the aero-shape of the re-entry capsule that is part of the break-up instrument. The definition of a suitable aero-shape will ensure the aerodynamic stability, both static and dynamic, needed for stable flight and for reaching suitable conditions at parachute deployment. Several different capsule shapes with previous flight heritage (such as REBR, Hayabusa, Huygens, among others) have been considered and are being investigated. One critical element for the DRACO capsule is to have an absolute monostable attitude as the initial release state (attitude and rotational rates) of the capsule will be unknown and the capsule will have no active control system. It is therefore imperative that the capsule does not have a secondary stable attitude in reverse flight and will naturally return to a forward-facing attitude to ensure the front-shield TPS is facing the incoming flow.

The material options for the capsule's front-shield and back-shield TPS are also being investigated in this dedicated activity, but no baseline solution has been selected yet. The back-shield TPS will need to be radiotransparent to allow the capsule's antenna to communicate with the satellite data relay network. For the front-shield TPS, cork-based materials might be less suitable due to the potential deposition of outgassing products on the instrument cameras. One additional consideration for the capsule TPS is that it should ideally be resistant to potential impacts of the debris field it might be flying through.

In addition to investigating the capsule's TPS, the thermal protection/insulation of the instrument sensors and harness and DDCU is also being studied in this technology development activity. The measurement sensors, cameras and harness will need to have dedicated thermal protection to maximise their operational lifetime/duration while the spacecraft around them burns up and breaks apart. As a spacecraft break-up altitude between 70-80 km is expected based on previous observations, the target altitude to which the sensors, harness and DDCU should survive is at least 70km.

Similarly to the capsule TPS, a fixed baseline solution has not yet been decided. However, promising materials for the TPS of the DDCU and cameras are graphite felts, carbon-fiber-reinforced carbon, and oxide-oxide Ceramic Matrix Composites (CMC). For thermal protection of the sensor harness, a potential baseline could be woven/braided sleeves of ceramic textiles or alternatively aluminium oxide (Al_2O_3) ceramic tubes to route harness through. A series of tests of the various thermal protection options will be performed at the VKI Plasmatron under representative aerothermal conditions, which will feed into the final down-selection of the TPS.

3.4. Remote Observation Campaign

It is foreseen to set up a remote observation campaign for the DRACO re-entry – similarly to what was done for the re-entry of ATV-1[2] – to extend the scientific return of the mission, and allow correlation of the in-situ measurements and remote observation results. The scope and outline of such a campaign is however still to be defined.

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[2] ATV-1 reentry, https://www.esa.int/ESA_Multimedia/Videos/2015/02/ATV-1_reentry. Retrieved 13-10-2023.

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