RE-ENTRY SCIENCE NEEDS

This document assessed the amin contributions from different communities working on re-entry topics (modellers, ground testing, observers, operators, manufacturers, air-traffic control authorities) as collected at the 6th International Space Debris Re-entry workshop on 15th January 2025 at ESA / ESOC.

Introduction

The expected number of launches and spacecraft re-entries crossing the Earth's atmosphere to and from space raise concerns for the future. The atmospheric re-entry of return capsules and crewed space objects has been under continuous study since the beginning of the space age. Nowadays, also the monitoring of the re-entry of space debris objects and the prediction of re-entry break-up processes has become part of nominal operations and mission design. This allowed ESA to collect bit-by-bit a heterogenous dataset of different type of re-entries that aims to support model validations, more accurate re-entry predictions and ultimately more reliable re-entry risks assessments.

6th International Space Debris Re-entry Workshop Objectives

The objectives of the workshop were three-fold:

OBJ-1 Take stock of community activity

- Modelers, operators, ground testing facilities, observers
- Measurements, model validation, re-entry physics

OBJ-2 Facilitate and further improve exchanges

- Understanding other re-entry community groups´ needs
- Strengthening the re-entry community

OBJ-3 Understand community data needs

- Build datasets
- Enable data sharing mechanisms and policies
- Identify desirable missing data

The workshop was divided into three subtopics: Modelling, Science of re-entry, Observations & Ground testing.

During the Modelling topic workshop, the discussions were centred on the known and identified gaps based on the state of the art. Four main areas were tackled:

1. Material models: properties of interest such as emissivity and catalicity; atmospheric pollution models to characterise particles and their interaction with the atmosphere.
2. How the type of re-entries drives the demise behaviour and hence the ablation model characterisation and the interactions with the flow, i.e. aerothermodynamic models.
3. Uncertainties in both drag coefficients estimations and atmospheric models. Topic of particular importance as it is known that main source of re-entry predictions come from the uncertainties on the atmospheric models.
4. Type of re-entry risk analysis tools to use for re-entry and demise predictions.

During the Science of Re-entry topic workshop, the main objective was to trigger questions that will support the re-entry phenomena characterisation and get a better understanding of the fragmentation process that an object experiences whilst re-entering. In other words, to enlighten the knowledge of the atmosphere and re-entry object dynamics in general.

During the Observations & Ground Testing topic workshop, three main aspects were covered:

1. Observation techniques, coordination and orbit determination, to understand how different type of sensor measurements could support re-entry object orbit determination to improve re-entry predictions in the last days/moments of the event.
2. Wind-tunnel test and how these experiments can support the validation of re-entry risk assessment tools.
3. Exploitation of re-entry event measurements to understand what the community can obtain and shape the pipelines to go from the raw measurements into different levels of post-processing data.

Community needs

Based on the workshop discussions among the different re-entry community actors, these are the identified data needs per topic area:

- Materials Models, uncertainties & re-entry predictions and risk assessment tools:
    - Understand material impact on the atmosphere and inclusion in climate models.
    - Catalicity is required to rebuild Plasma Wind-Tunnel test with glass materials; emissivity and radiation are key to improve demise observability.
    - Stochastic analyses of simple models preferred for uncertainties assessments compared to more complex models in high fidelity simulation tools (i.e. many simple models simulations Vs. few complex models simulations).
    - In-situ measurements for atmosphere calibration, specifically in the thermosphere.
    - Missing air-traffic management procedures and inclusion in the models to assess collision risks associated with dense flight corridors and individual flight paths.
    - Reduce atmospheric uncertainties by including the effects of high significant space weather activity in short-term re-entry prediction operation pipelines.
    - Spacecraft attitude characterisation during re-entry to understand its role in the initial fragmentation process at the entry interface point.
    - Reduce destructive break-up altitude uncertainties by better characterisations of connections and joints.
    - To combine simple and high-fidelity tools: MC simulations with simple tools to assess the limits on the uncertainties; then high-fidelity meaningful simulations selected based on simple simulations outcome.
    - To include stochastic assessments to compute the probability of a re-entry event to happen in a specific area.

- Re-entry physics:
  - Joints thermal – mechanical - chemical characterisation to understand fragmentation mechanism processes via testing and simulations.
  - Systematic simple tests to first understand how forces and temperatures are coupled and then to understand oxidation under different pressure conditions.
  - To understand the oxidation role in the demise/break-up processes.
  - To get contextual information of the trajectory along the re-entry path (attitude, position and rotational rates) and local flow conditions (altitude and dynamic pressure) by means of IMU mounted on spacecrafts.
  - To understand the free-molecular heating process of the rarified flow (beginning of the fragmentation).
- (Plasma) Wind-tunnel testing:
  - To conduct many simple tests to support emissivity characterisation at wide temperature range.
  - To obtain accurate spectra measurements from Plasma Wind-Tunnel.
  - To derive a procedure to support extrapolation to in-flight conditions.
- Remote Re-entry Observations:
  - To include brightness modelling on the assessment of instrumentation to be used
  - Required attitude information to produce better re-entry predictions
  - Temperature and attitude profile on a tumbling spacecraft by telemetry data and/or remote sensing data.
  - Larger observation arcs from different on-ground sensors for better orbit determination
  - Data sharing platform to support collection of re-entry related data for further exploitation.
  - Raw to post-processed data products required: high temporal resolution, TM and HK, CCSDS format, real-time raw data, drag coefficient, geometry information, attitude, manoeuvre information, reflectivity information.

Available datasets from past re-entry events

- Controlled ATV-1 re-entry on 29th September 2008
- Uncontrolled GOCE re-entry on 11th November 2013
- Uncontrolled AVUM upper-stage re-entry on 2nd November 2016
- Semi-controlled Aeolus re-entry on 28th July 2023
- Uncontrolled Beesats re-entries on 2023-2024
- Uncontrolled ERS-2 re-entry on 21st February 2024
- Uncontrolled OPS-SAT-1 re-entry on 22nd May 2024
- Targeted Cluster II FM2 re-entry from HEO on 8th September 2024