AIRBORNE OBSERVATIONS OF RE-ENTRY BREAK-UP: RESULTS AND PROSPECTS

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ABSTRACT

Airborne observation of re-entering space debris is the fundamental tool for the assessment of the performance of re-entry break-up simulation software. Successful campaigns for the analysis of ATV-1, Hayabusa, WT1190F and CYGNUS OA6 show the potential of these observation campaigns. Improvements in the strategy of future observation campaigns of controlled re-entries are required to increase the outcome of the observation with respect to re-entry break-up. For example, waste containers could be arranged so that the spectral signature of specific materials can be identified and used as a re-entry break-up marker. This paper is presented as a poster at the 7th Space Debris Conference and contains an overview for observation mission planning, some exemplary results and serves as a starting point for future investigations.

Key words: re-entry; ISS; CFD.

1. INTRODUCTION

The very last maneuver at the end of life of large spacecraft is the destructive re-entry into the Earth's atmosphere. It is the only way to avoid big space debris uncontrolled on orbit. Usually, the spacecraft is directed with appropriate deorbit maneuvers to an entry trajectory so that any surviving components land in a sparsely populated area, commonly the *South Pacific Ocean Uninhabited Area* (SPOUA). This destructive re-entry maneuver is predicted by particular software tools [3, 2]. The only way to analyze the prediction accuracy is to compare the calculated data against occurring re-entries. Some of these events are observed by scientist aboard aircrafts. The probably best test case in the past was the entry of the first European re-supply spacecraft of the International Space Station (ISS), the automated transfer vehicle ATV-1 *Jules Verne*. Two aircrafts were aligned to observe the re-entry with a variety of instruments to analyze the break-up events and identify objects and their individual trajectories [5, 4].

Flight observation missions represent the best possibility for verification and validation of the break-up model. IRS have been involved in every flight observation mission since Stardust, including ATV-1, Hayabusa, WT1190F, and Cygnus OA6 as well as being the science lead for the ATV-5 observation which was canceled at the last minute due to an on-board power failure of ATV-5 [1, 8, 9].

This paper is presented as a poster at the 7th Space Debris Conference. It provides the strategy for airborne observations with some future steps e.g. the observation of the re-entry of the ISS [12].

2. AIRBORNE OBSERVATION

The design of an airborne observation depends on several boundary conditions. First, the location and trajectory of the object has to be known. Besides the budgetary situation, the time until the event occurs is important for setting up a campaign. The experimenters are chosen based on their instrument's features with respect to the science goals and the experience in such missions.

In case the science and agency teams agreed on an airborne campaign, the typical scenario foresees to analyze first the aircraft options. In the past, three kind of aircraft were used: NASA's DC-8 experimental aircraft, a Gulfstream V, and a Bombardier Global Express. Figure 1 show the three aircrafts. There were also other experimental aircrafts involved in airborne observations, e.g. for meteor observation [10] .

Depending on the aircraft selection and the mission statement, the experimenters are chosen. In NASA's DC-8, a wide variety of windows can be mounted. This allows to chose experiments with a variety of spectral susceptibilities. In normal aircraft windows, the standard window does not allow to observe in the UV.

The advantage of commercial aircrafts (Bombardier or Gulfstream) is that these aircrafts are available all around the globe and with their nominal range, almost every point on Earth can be reached. The team who flew the last observation missions (CYGNUS OA6 and WT1190F) are now pretty experienced in installing complex hardware in regular business jets. Figure 2 shows exemplary the

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Figure 1. Aircraft options flown in the past (Upper: DC-8, Middle: Bombardier (with the crew from the CYGNUS OA6 observation), Bottom: Gulfstream V (as flown for the WT1190F observation)).

mounting of sophisticated cameras aboard a Bombardier Global Express.

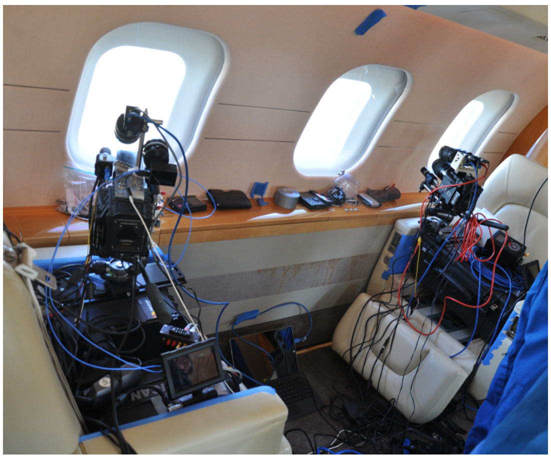

Figure 2. High resolution video imaging during CYGNUS OA6 (Experimental Setup of R. Dantowitz from Dexter Southfield).

An important aspect of the organization of the observation campaign is the actual entry of the object. Based on the re-entry path predictions, the aircraft's flight path is designed. Figure 3 shows the predicted re-entry trajectory for the ATV-5 flight and the flight path of the observation aircraft (NASA's DC-8). The position of the aircraft is often defined by its position with respect to the altitude of the entering aircraft. This in turn defines the earliest observation possibility when the object arises on the horizon. The SPOUA is indicated in the figure to illustrate the area where space debris can impact ground without danger.

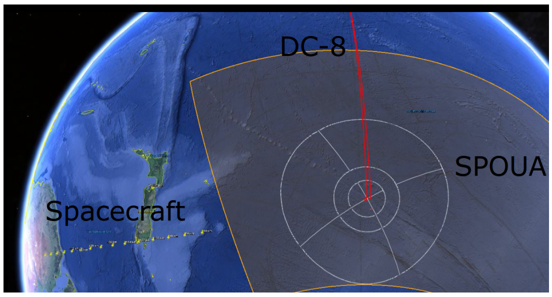

Figure 3. Predicted flight path of ATV-5 and observation flight path (plot based on data provided by J. Bacon (NASA).

Meanwhile there are computer tools available to calculate the apparent view out of an aircraft's window. This is very useful for the experimenters to align the optical setup to the window. For the very long re-entry flight of the CYGNUS OA6, the experiments were even moving in lateral direction in front of the window (see the rail in Fig. 2). Fig. 4 shows the predicted view of the ATV-5 re-entry in a DC-8's aircraft window. More recently, ESA's Space Debris Office published an improved program which connects the output of the re-entry break-up prediction (for example SCARAB) with the flight trajectory of the aircraft and the view out of a window. This way, a complete simulation of the view to the destructive re-entry out of the aircraft's window is possible. Figure 5 shows a single frame of a simulated fragment trail of the ATV-5 re-entry.

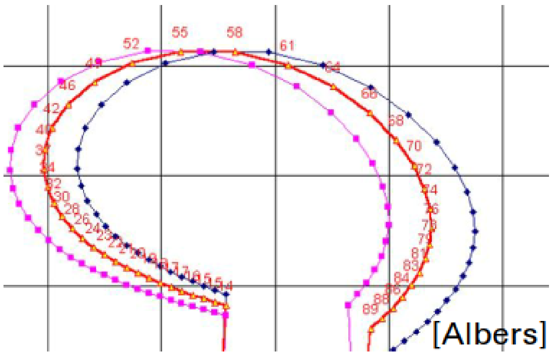

Figure 4. Predicted apparent view out of a DC-8 window during the ATV-5 observation (courtesy: J. Albers).

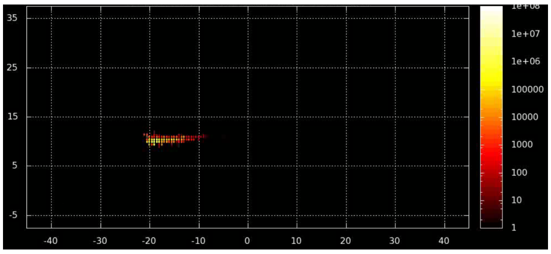

Figure 5. Predicted apparent view of the space debris of ATV-5 out of a DC-8 window during the ATV-5 observation [9].

3. EXEMPLARY RESULTS

The team from IRS' High Enthalpy Flow Diagnostics Group (HEFDiG) participated in all observation campaigns since Stardust. Some results are presented on the poster.

3.1. ATV-1

The *Slit* system was an improved version of the system flown already during the Stardust observation [11]. The system with an ICCD camera observed a 120 nm wavelength interval in the UV focusing on the front object of the re-entry. The radiation was analyzed with respect to the continuum background in the spectrum. Figure 6 shows the temperature evolution during re-entry. It can be

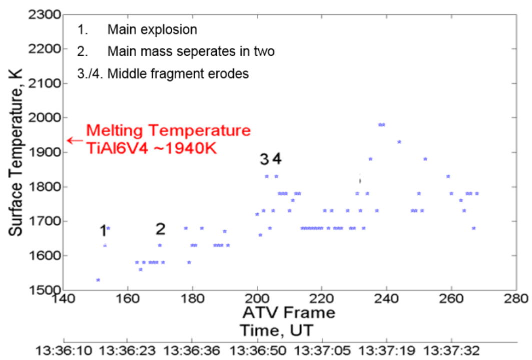

Figure 6. Apparent temperatures during ATV-1 re-entry.

seen that the measured temperatures reach the maximum temperature of titanium alloys.

3.2. Hayabusa

For the observation of Hayabusa a completely new system called FIPS was installed aboard NASA's DC-8. The campaign of the HEFDiG team was funded by the German Aerospace Center aiming at measuring the translational temperature of the plasma flow around the vehicle [8]. Figure 7 shows the measured spectra from the spacecraft at an altitude of about 78km. Although the

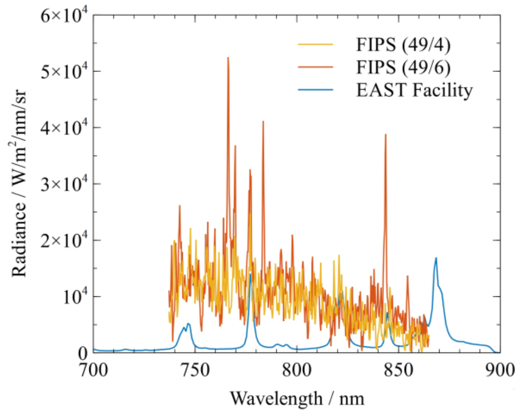

Figure 7. Measured spectra of the entering spacecraft at an altitude of 78 km (49/4 and 49/6.

line broadening investigation was not feasible to the required extent, the data set allowed to compare the flight to ground testing data acquired at NASA Ames and IRS [6].

3.3. WT1190F

During the design of the ATV-5 observation campaign, we developed a new system at IRS based on an Echelle spectrometer. This allows the detection of a large wavelength interval at high pixel resolutions [7]. The system was installed on the flight observation of WT1190F aboard a Gulfstream V. The system did not perform suc-

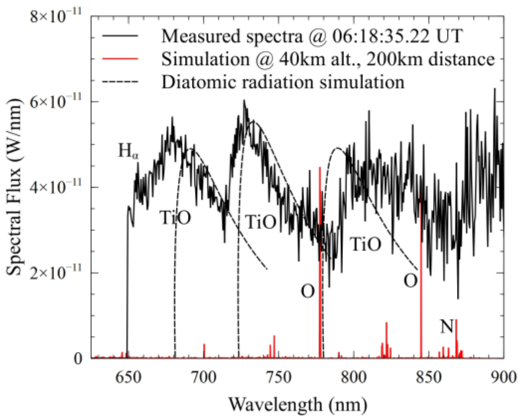

Figure 8. Measured spectra during the WT1190F campaign [1].

cessfully during this observation. However, our tools for spectral data analysis were applied to the excellent data from Ron Dantowitz' team [1] and plotted in Fig. 8. The simulation of the spectral bands allows to identify the molecular radiation of the entering spacecraft.

3.4. CYGNUS OA6

The system applied during WT1190F was also used for the observation of the CYGNUS OA6 transporter. The setup's function this time was nominal, but the radiation of the entering object was very faint. Even long integration times made the analysis of spectra very challenging. The analysis of the spectra using some very simple tools show that the molecular bands can be clearly identified (see Fig. 9).

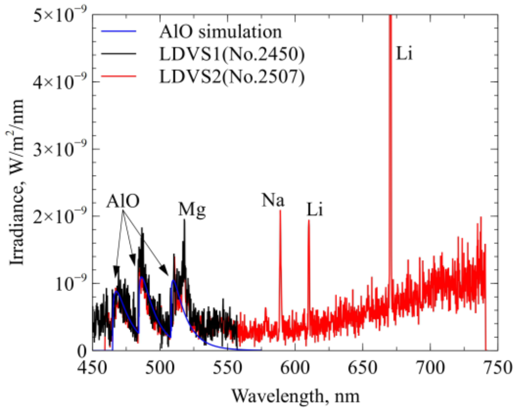

Figure 9. Measured spectra during the CYGNUS OA6 campaign.

4. FUTURE PROSPECTS

It is shown with this poster that the observation of entering spacecraft has a high potential for the analysis of spacecraft's re-entry behavior with respect to break-up scenario, fragment identification and fragment distribution.

Future missions can be improved by combining the know-how of the experimenters with the requirements of the debris team. Then, a re-entering spacecraft can be a test case for the community of entry modelers. One suggestion is to arrange the waste containers in the spacecraft to measure the spectral signature as a distinct event during the entry observation. This allows the identification of fragments based on their spectral signature.

The entry of the ISS in about 10 years is probably the biggest challenge for an observation due to the size of the station and the shallow entry it will fly. This results in a very long trail of entering space debris. It will be a particular challenge to observe this by only one single aircraft.

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