DEBRIS COLLISION ALERT SYSTEM

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ABSTRACT

In the last decade the space debris issue has been in the spotlight as the number of artificial objects orbiting around the Earth is steadily on the growth. Currently, about 2.000 of operating satellites are in the orbit, most of which are destined to re-enter the atmosphere and hopefully burn out.

The fragmentation of a space vehicle during re-entry to the Earth, whose position is always uncertain, can be very dangerous to the air traffic, population and to high-risk industrial plants. Within this context, the company Aviosonic Space Tech, is developing a unique System for Space Debris position awareness during both uncontrolled and controlled space vehicles re-entry.

The patented Debris Collision Alert System (DeCAS) is a system for the protection of the population, of critical ground facilities and air traffic from space debris which is generated after a re-entry of a space vehicle.

In 2017 DeCAS was part of D-SAT mission for its first in-orbit concept demonstration.

1 INTRODUCTION

As required by international agreements, at the end of their operational life, satellites have to be removed from protected orbital regions (i.e. LEO) by re-entering the Earth atmosphere. The atmosphere is dense enough to dissolve most objects owing to air resistance and heat, but in some cases between 10% and 40% of mass survives and impacts the Earth's surface, posing serious hazard to air traffic, people and their property.

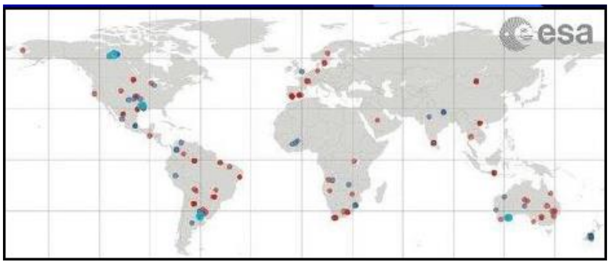

Figure 1. Locations of recovered space debris (ESA)

Several events, like the Shuttle Columbia disintegration over NAS (National Air Space), GOCE and Phobos-Grunt uncontrolled re-entry and China Space Station end-of-life re-entry, are inducing space agencies to adopt more restricted Space Debris Mitigation (SDM) policies to minimize the risk for population. However, the effectiveness of the current SDM plans is hindered by the following limiting factors:

- **The impossibility to precisely predict the impact area of surviving fragments:**
  it depends on several factors, such as the ballistic coefficient of the fragments, local winds, atmospheric conditions. Currently, only rough estimations of the fragment impact area can be made;

Figure 2. China Space Station Tiangong-1re-entry area prediction

- **The high cost of safety measures in case of dangerous satellite re-entries**:
  Very wide areas potentially concerned have to be closed (with strong direct and indirect economic costs), also due to the inaccurate calculation of the footprint area. In 2012 EUROCONTROL (European intergovernmental organization for air traffic management) was notified by Russian authorities to close the whole Europe airspace for two hours for the re-entry of the Russian Phobos-Grunt (calculated cost ~€20 Million).

- **The increasing risk caused by the large number of satellite re-entries on the Earth**:
  Even a falling fragment of 300 grams and/or 10 cm length can be catastrophic for an aircraft (US Federal Aviation Administration data), and over the last decades, more than 1,400 tons of materials have survived re-entry.

Proc. 1st NEO and Debris Detection Conference, Darmstadt, Germany, 22-24 January 2019, published by the ESA Space Safety Programme Office
Ed. T. Flohrer, R. Jehn, F. Schmitz (http://neo-sst-conference.sdo.esoc.esa.int, January 2019)

Precise knowledge of debris hazard regions and real-time falling duration would enable the air traffic managers and controllers to guide the affected aircraft away from the hazard area before the debris from the breakup would reach the altitude at which aircraft are flying. The computation of hazard regions must be sufficiently conservative in accounting for uncertainties in both the debris properties and ambient conditions to ensure that aircraft are adequately protected.

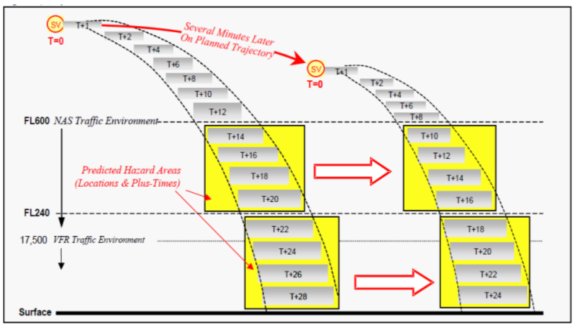

Figure 3. Calculated mean time for space debris to reach National Air space traffic environment

With the increased number and turnover of satellites, this is pushing higher the risk for casualties, and the worldwide collision risk with space debris for flights has been estimated in 3x10-4 (the generally acceptable risk in aviation is 1x10-7).

While space agencies are adopting increasingly stricter policies for mitigating risks associated to space debris impact, satellite operators are in search for reliable solutions able to enhance safety measures in the re-entry phase, ensure compliance with regulations, and minimize the impact on spacecraft design performances and costs.

Figure 4. Columbia debris footprint

2 FOOTPRINT PREDICTION

A precise propagation of debris to the ground is not practical for many reasons. There is insufficient knowledge of the initial state vector, ambient wind conditions, and the key parameters including the ballistic coefficients. In addition, propagation of all debris pieces to the ground would require extensive computer time.

Several methods have been developed to analyse the debris re-entry trajectories and the risk posed to air traffic, people and the property on the ground. In the last years, papers presenting new methods for the estimation of debris dispersion due to space vehicle breakup at high altitude during launch or re-entry have been issued, taking into account mostly a statistical approach. However, to accurately forecast the footprint area, exact information on the breakup momentum as well as real-time environmental data are required.

3 TECHNOLOGIES FOR SPACE DEBRIS TRACKING AND MITIGATION

3.1 Radar, Optical and Laser

Currently, the monitoring of the re-entry phase of space vehicles is performed only for large space vehicles which are considered potentially dangerous in case they fall on sensitive areas. There are basically three different observing techniques for keeping track of space objects in the proximity of Earth atmosphere:

3.1.1 Radar systems, either through ground stations or satellite networks. Radars can detect and track debris objects larger than 10 cm up to an altitude of ~2,000 km. The main drawback is that to ensure a wide space coverage, the network needs to rely on several ground stations disseminated on the Earth's surface, which makes them very expensive to build and maintain. In order to identify and discriminate satellites and space debris, they need to operate at very high frequencies, with related high energy consumption and electromagnetic noise.

3.1.2 Optical observations. Optical telescopes catch the sunlight reflected from debris larger than ~1 m, and are usually used for monitoring higher Earth orbits, up to ~40,000 km. The use of digital image processing enables automated observations and near-real time analysis. Even in this case, there are structural issues linked to high costs for the facilities, as well as inaccuracy in both the detection and tracking of objects.

3.1.3 Laser observation. Short laser pulses are transmitted towards a satellite or space object, and then are reflected back from reflector prisms installed on-board. The return pulses are detected by telescopes, obtaining the distance of the object very precisely. This method is hindered by the difficulty to track falling objects, whose orbits change very rapidly, thus making it difficult to point the laser beam accurately.

The above systems are very expensive to build, run and maintain and present three key technical drawbacks:

- Even when they accurately track the re-entering object, orbit predictions are highly inaccurate, with a positional error in the re-entry point of up to 5,000 km even few minutes before the break up in the atmosphere.

- None of them is able to effectively cover 100% of the Earth's surface.
- None is able to determine in real-time the impact area of fragments surviving breakup in the atmosphere.

  Currently, only few software tools perform analysis for determining space vehicles impact risk, based on trajectory and atmospheric models. These tools are highly theoretical, with very limited calibration data, and are used solely for risk evaluation purposes before the launch (e.g. providing info on the mass and objects expected to survive, expected impact velocity, etc.).

3.1.4 Design for Demise. This debris mitigation approach has been introduced recently, however experiments conducted by ESA showed that further work on both the demisable elements and improvement on the re-entry tools is a necessary next step to reach the goal.

4 DEBRIS COLLISION ALERT SYSTEM SOLUTION

Aviosonic is developing DeCAS (patented), the first high-precision monitoring system for tracking space debris during the re-entry phase, able to precisely determine both the break-up moment and the area interested by the subsequent fragmentation, and promptly notify safety agencies about potential danger for air traffic, sensitive area, people and property.

DeCAS is a small, lightweight device, based on the principle of the black box in aircraft, and avails of standard space technologies for data broadcasting. It is fitted inside or outside space vehicles (i.e. satellites and launchers) and remains in a dormant status until it is activated by specific triggers during the re-entry phase (at an altitude of around 200 km). It survives the break-up phase and collects the data necessary to determine the footprint area with progressively higher accuracy. An alert message is then sent from DeCAS to a satellite chain to be relayed toward the ground stations.

DeCAS is the first high-precision monitoring system for tracking space debris during the re-entry phase, directly from Space Vehicle.

4.1 Use of DeCAS technology

DeCAS provides the following unique benefits:

- **Enhanced security for governments and population**: DeCAS generates a timely alert message which includes break-up time, high accuracy forecast of footprint coordinates and time to impact. This information can be overlaid on a map to be used by national and international safety agencies: civil and military aviation (to close very restricted areas and avoid collisions), civil protection centres (to protect cities, buildings, facilities, etc.), and high-sensitive infrastructures.

- **Easy-to-install Space Debris Mitigation (SDM) technology for satellite operators and manufacturers**: thanks to its minimum weight and volume, DeCAS can be fitted in both launchers and satellites to monitor the re-entry phase.

Knowing the break-up moment and tracking the debris in real time allow maximum accuracy of the position and footprint area forecast of a re-entering vehicle, since the prediction is based on actual data collected during all the re-entry phase by the DeCAS smart fragment.

DeCAS enables to easily monitor all the upper stage components and satellites, thus enhancing world agencies' capacity to monitor and mitigate potential risks, which currently is focused only on shuttles and a few big satellites/space vehicles. It will minimize risk for air traffic, people, property, and support space operators in reducing the casualty risk of their missions and complying with international regulations.

5 IN ORBIT CONCEPT DEMOSTRATION

The DeCAS concept system and communication chain architecture were tested during the D-SAT space mission by using the hardware of the D-SAT satellite to reproduce the DeCAS software and hardware functional system. The mission was launched in June 2017 with an 11-week test flight plan.

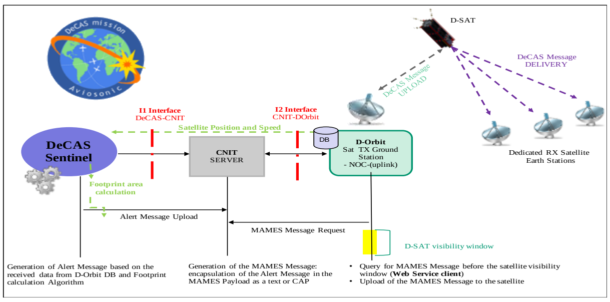

Figure 5. DeCAS in orbit concept demonstration mission architecture

A number of uncontrolled re-entries was simulated by sending the D-SAT a trigger message which in turn generated a message towards the ground with the necessary parameters to define its footprint. Once the message was received by the ground stations, it was processed by the software, which calculated the position of the footprint and made a prediction of the time and the area of impact on the ground.

When the danger area was defined, the DeCAS message was encapsulated, uploaded to the satellite and broadcast to the ground using an emergency protocol. This second phase had the aim to verify the possibility of using an emergency protocol for the transmission of DeCAS messages which allows their validation and authenticity.

The third aim of this mission was to simulate a network of ground stations able to receive the signal, process it and transmit the information to all potential customers and agencies.

DeCAS was able to process 98% of these messages in real time

The alerts reproducing the fragment impact area have successfully completed the entire process, thus validating the software architecture in relevant environment (TRL 7).

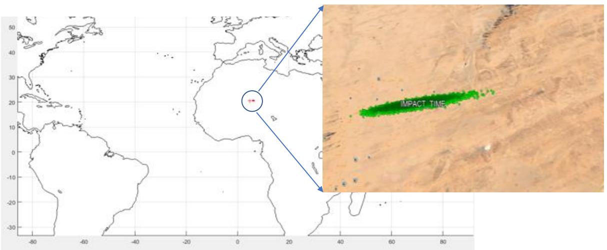

Figure 2. Footprint visualized on Google Earth of the fragments area of the D-SAT satellite during the in-space validation of the DeCAS system

6 USE OF DECAS AND REFERENCE MARKET

DeCAS system could be used to support space debris monitoring activities during the re-entry phase in the following environments:

Civil Protection Centers around the world;

Sites of the population potentially affected by falling fragments:

Atomic, Chemical and Electrical power plants, oil and gas platforms, dams, space and military sites, production and special sites, ports and airports etc;

Timely inform of the imminent collision of aircraft with space debris:

All the civil and military aviation (Airlines, Air Traffic Control, general aviation etc);

Coverage of the areas where the Air Traffic Control service is not available:

Air traffic on intercontinental routes and areas not covered by the air traffic services, large sea vessels on intercontinental routes;

As a supplementary system to the future contingency procedures for international flights (long-haul flights) during the launch and re-entry of Space Vehicles.

7 CONCLUSION

The use of an on-board debris monitoring system, like DeCAS, is recommended because it allows the accurate spotting of the break-up point, as well as real-time monitoring of the environmental conditions surrounding the descent trajectory and, thus, provides a more reliable and exact prediction of the debris footprint area. This device can be used as a stand-alone or complementary solution to existing or future space debris monitoring technologies as it does not require any modification of the existing infrastructure.

8 ABBREVIATIONS AND ACRONYMS

DeCAS - Debris Collision Alert System

LEO – Low Earth Orbit.

NAS – National Air Space

SDM – Space Debris Mitigation.

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