PROJECT PERIODIC REPORT

Grant Agreement number: 263248

Project acronym: DEORBIT SAIL

Project title: De-Orbiting Satellites using Solar Sails

Funding Scheme: Collaborative Projects

Date of latest version of Annex I against which the assessment will be made:

2010-12-20

Periodic report: **1st** ☐ **2nd** ☐ **3rd** ☒ **4th** ☐

Period covered: **from** 01 March 2013 **to** 31 October 2014

Name, title and organisation of the scientific representative of the project's coordinator:

Guglielmo Aglietti, Professor, University of Surrey

Tel: + 44 - 1483 683417

Fax:

E-mail: g.aglietti@surrey.ac.uk

Project website address: http://www.deorbitsail.com

I, as scientific representative of the coordinatorof this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  ☐ has fully achieved its objectives and technical goals for the period;

  ✓ has achieved most of its objectives and technical goals for the period with relatively minor deviations;

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website is up to date, if applicable.

  ✓ is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Guglielmo Aglietti

Date: 31/10/2014

For most projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

3.1. Publishable summary

Project context

The uncontrolled growth of the space debris population has to be avoided in order to enable safe operations in space for the future. Space system operators need to take measures to conserve a space debris environment with tolerable risk levels, particularly in Low Earth Orbit (LEO) altitude regions.

DeOrbitSail is a cubesat mission to demonstrate in-space deployment of a large thin membrane sail and drag deorbiting using this sail. The DeOrbitSail design is intended for space debris prevention, although both drag sailing and solar sailing have additional applications in aerobraking and solar sail propulsion.

This project's approach is to modify solar sail deployment technology for use as a satellite and/or rocket upper stage deorbiting system. The effectiveness of such deorbiting device is predicted to be high at altitudes lower than 1000 km for minisatellites (20 to 500 kg) if deorbiting time constraints of 25 years are being considered. The same design will also be capable of using solar radiation pressure as a deorbiting force above the 1000 km mark. In contrast with JAXA's spin-deployed deep space solar sail, IKAROS[1], DeOrbitSail will deploy and maintain its shape with relatively stiff structural booms. This project is a pathfinder mission that hopes to create options for deorbiting of satellites and forward the cause of solar sail propulsion.

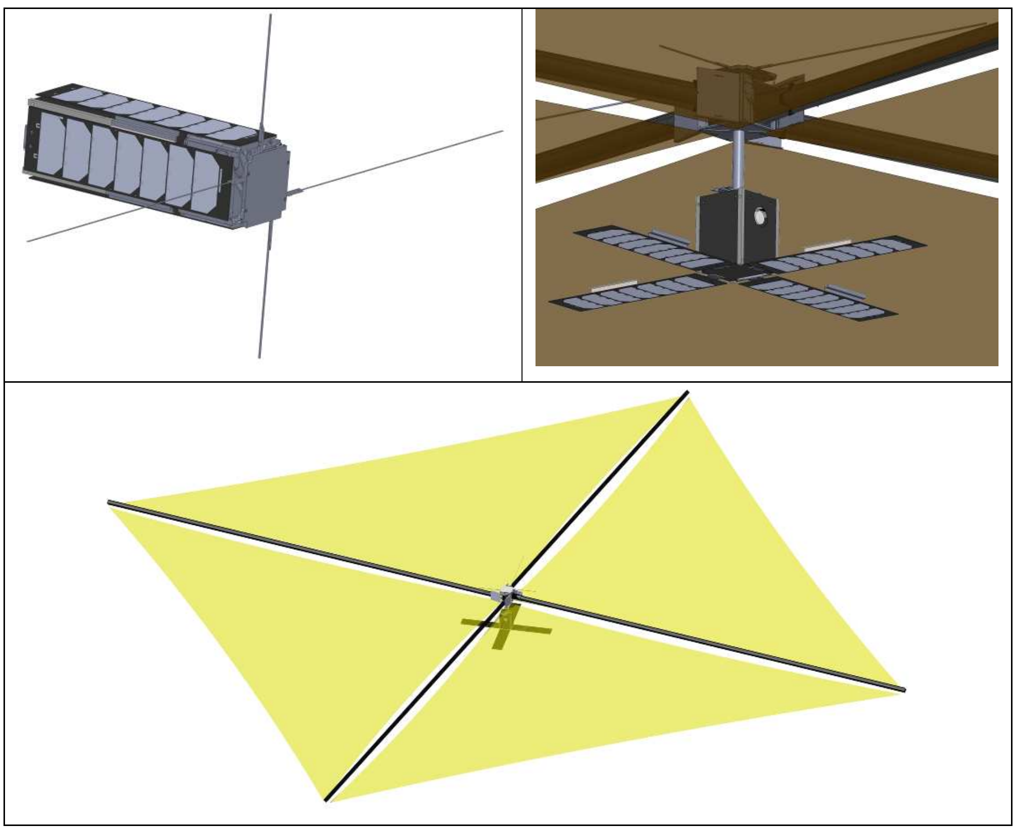

Figure 1: Three views of DeOrbitSail: before deployment, after deployment close-up, and after deployment from a distance.

[1] *Flight status of the IKAROS deep space solar sail demonstrator*. **Tsu, Y. et al.** 2011, Acta Astronautica vol. 69, pp 833-840

Project objectives

The project objectives are to provide research in the field of deorbiting as well as a demonstrated and verified design for deorbiting of satellites and debris, and effective and efficient propulsion technologies, based on sails.

The initial objectives of this project will be fulfilled by the production, launch and operations of a satellite that will deploy a large sail membrane, but, with the re-scoping of the M36, those objectives changed in terms of production and delivery of a tested, ready-to-flight spacecraft that will deploy a large sail membrane. As proposed, the satellite form factor will be that of a 3U cubesat, and the sail will be a square shape formed of 4 triangles, supported by 4 deployable booms.

The top-level requirements are therefore:

DeOrbitSail shall demonstrate drag deorbiting of a nano-satellite.
Deorbiting shall be accomplished by drag on a deployable sail of approximate area 25 m^2 (16 m^2 after the re-scoping).
The DeOrbitSail satellite shall be able to stabilize the attitude of the satellite so that the sail is perpendicular to the velocity direction.
The satellite shall have a communications link to a ground station from where commands can be sent and telemetry can be requested.
DeOrbitSail shall be able to record and transmit attitude angles and rates.
The deployed state of the sail shall be verifiable.
DeOrbitSail shall demonstrate drag deorbiting from an initial circular orbit at 650 km to demise in Earth's atmosphere within 120 days.
The DeOrbitSail satellite shall be compatible with existing an launcher from ISIS.

Even if the re-scoping of the month 36 removes the launch requirements, the consortium found a launch opportunity and intends to perform the last acceptance test in December with the aim to accomplish the launch and operational tasks, even if those are outside the duration of the contract.

Description of work and results to date

The first eight months of the project established basic requirements and a theoretical background. The following twelve months have been devoted to design, prototyping, and analysis of the DeOrbitSail spacecraft. In the final 18 months, a Qualification Model and a Flight Unit were developed and tested.

In its final configuration, DeOrbitSail's payload subsystems are the deployable sail and the attitude determination and control system. Prototypes of both of these systems have been manufactured and tested in the last year. The 3U cubesat volume goal is the critical design driver. A standard ISIPOD deployer for a 3U cubesat is the source for the volume requirement; its deployer dimensions are 10 by 10 by 34 cm. On DeOrbitSail, the available 34 cm edge is divided into three sections: the bus, which houses the control electronics and ADCS; the sail storage area, which will be filled with the folded sail membrane; and the carbon fibre booms, which are housed in a motorized deployer. The electronics bus is equally divided between the ADCS and all other electronics (comprising the onboard computer, power system, and radio).

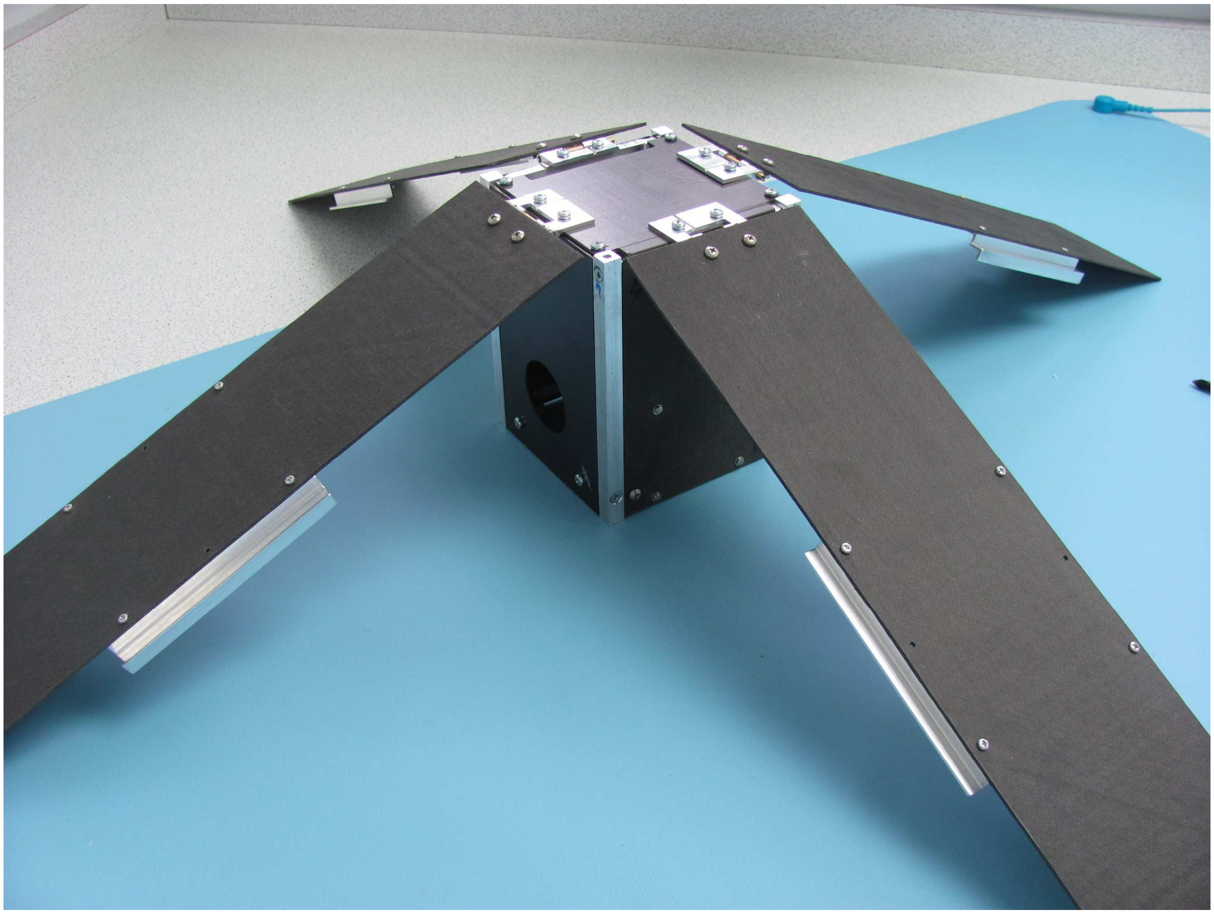

Figure 2: DeOrbitSail Qualification model: Assembled Chassis with solar panels .

Stellenbosch University is the lead design team on the ADCS. Three-axis control will be provided by a set of three magnetorquers and a single momentum wheel. Attitude determination is provided in two stages: rough detumbling and fine pointing/stabilization. During detumbling, direction is established suing data from a magnetometer and six coarse sun sensors. After detumbling, a finer determination of attitude can be made by the sun and horizon cameras. At launch, these are blocked by the deployable solar panels, which will be deployed after detumbling.

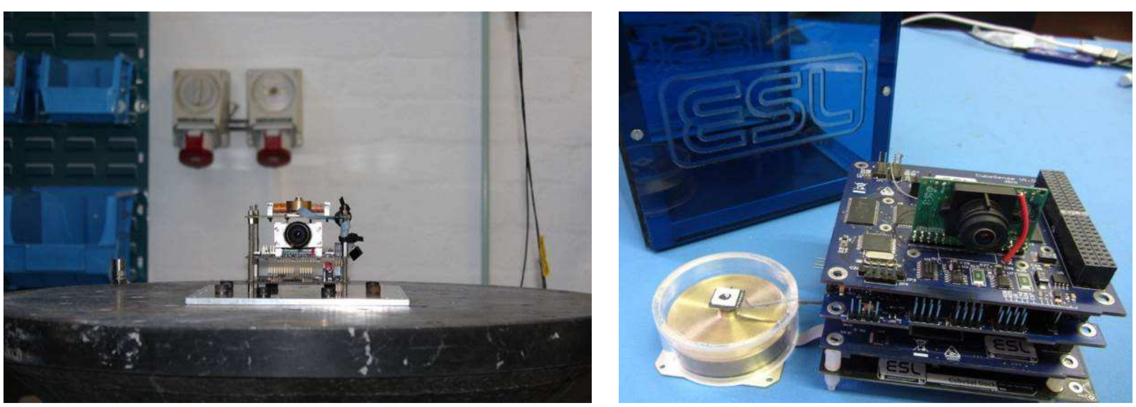

Figure 3: The prototype ADCS stack in vibration testing (left0 and hardware-in-the-loop testing (right).

DLR, a project partner, has a long history with deployable boom design. The booms and deployer developed at DLR for DeOrbitSail are the smallest version of these booms to date. Multiple prototype deployers and booms have been produced and tested, with good results.

Figure 4 Deployed Sail

A carbon-fibre-reinforced polymer (CFRP) structure has been designed and prototyped for DeOrbitSail. This structure provides good weight savings and stiffness, which is particularly important to the large cantilevered deployable solar panels. Commercially available systems have been selected for power and communications; DeOrbitSail will use a NanoPower P31U power system and an ISIS VHF downlink/UHF uplink radio with a deployable antenna. The onboard computer, CubeComputer, and its software have been developed alongside the ADCS.

The main activities of the third period were Assemble, Integration and Validation ones. The functions of those activities were to validate the DeOrbitSail mission.

Due to the availability of COTS components and the large mission to mission similarity a protoflight approach was proposed for the system AIV. This means that a single Protoflight Model (PFM) was produced for the mission. Next to the PFM there is also an EM available in the lab to provide a platform for software development, and a QM for the Structural test (e.g. vibration, deployment etc.).

The way in which the AIV phase was approached was in line with ECSS[2] and NASA[3] experience. Some basic strategies that were proposed are:

- TLYF: Test Like You Fly
- Testing of interfaces/harnessing early in the AIV process
- TVAC test all (new) RF/High power systems
- Rigorous anomaly tracking; Finding root causes
- Rigorous, timely, test setup and test result documentation

There is a large similarity between missions and mostly a very limited difference between COTS EM and FM hardware. Therefore a strong focus on development and debugging on EM boards

[2] European Cooperation for Space Standardization, *ECSS-E-ST-10-03C - Testing.*
[3] *NASA Systems Engineering Handbook (NASA/SP-2007-6105 Rev1)*

was used, minimizing the ‘tinkering’ required on the flight hardware to the verification of the correct implementation of the software on the FM and the actual environmental and functional testing.

The general strategy of testing was in line with what one could expect and is using the standard levels of verification (in order of preference):

- Test (including demonstration)
- Analysis (including similarity)
- Review of design
- Inspection

The initial integration was performed in a lab environment, under a laminar airflow cabinet, to reduce the overhead of working in the clean room. Once the satellite flight preparations started the satellite was moved to the clean room for thorough cleaning, final integration and flight preparations.

Future work

Even if the re-scoping removes the WP4, the consortium’s aim remains to accomplish the last tasks, including launch and on-orbit operation. For this reason, the next months’ anticipated work includes the launch of DeOrbitSail and orbital operations. There is a number of data packages that will be collected during operations:

- Photographs of the deployed sail, to be taken by the nadir camera
- Two-line elements during the decay of the orbit, which will independently confirm the effectiveness of the deployed sail at lowering the orbit
- Telemetry data, which will confirm the functioning of the ADCS

A number of important results have been and will be obtained before the launch of the satellite. Some of the anticipated results are:

- A flight-readyness design of a complete deorbiting system with independent power, attitude control, and communications
- A final design of a deployable sail system that can be launched by a standard 3U cubesat launcher
- Experimental ground demonstration of the function and reliability of a sail deployment system for a 4 x 4 meter sail (5 x 5 before re-scoping)
- A final design and qualification testing of an attitude determination and control system for a sail propulsion system

A recent report on the forecast of satellites to be launched from 2010-2019 estimates that over 1000 satellites will be launched in the next 9 years. If one includes the launch vehicles needed to launch these satellites, we have at least 2000 possible high value targets for deorbiting (it will be illegal to launch without having a deorbit system. Beyond the deorbiting market, deployable technologies can have applications that include solar arrays, deployable antennas, rover masts and space power arrays. Critical points to provide in this new deorbiting market are the cost-effectiveness and the reliability of solutions that have been demonstrated in space.

Contacts and project partners

The DeOrbitSail website can be found at http://www.deorbitsail.com .

The project partners are:

EADS Astrium (Bordeaux, France)
Athena SPU (Athens, Greece)
DLR (Braunschweig, Germany)
Innovative Solutions in Space (Delft, The Netherlands)
Middle East Technical University (Ankara, Turkey)
University of Patras (Patras, Greece)
Stellenbosch University (Stellenbosch, South Africa)
Surrey Satellite Technology Ltd (Guildford, UK)
Surrey Space Centre (Guildford, UK)

The coordinating partner is the Surrey Space Centre at the University of Surrey. Questions can be directed to Prof. Guglielmo Aglietti (g.aglietti@surrey.ac.uk).