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MINI IRENE - DEPLOYABLE HEAT SHIELD FOR SUBORBITAL FLIGHT TEST

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ABSTRACT

MINI Irene is the Flight Demonstrator of IRENE, a new-concept capsule with a variable geometry, originally conceived by ASI to widen the range of available platforms to retrieve payloads and/or data from low Earth orbit.
This paper, after a short introduction of the patented IRENE deployable heat shield concept and benefits, shows the ongoing activities that will lead to the sub-orbital flight. The description is focused on the structural activities, both numerical and experimental), and on the avionic systems.

Keywords: Re-entry, heat-shield, deployable, TPS.

1 INTRODUCTION

IRENE, the Italian Reentry NacElle, is a capsule concept, equipped with a patented deployable heat shield aimed at a drastic reduction of Ballistic coefficient. The following image shows an early concept for the IRENE.
Low ballistic coefficient turns into reduction of the peak heat flux and mechanical load.
Because of this, commercial materials can be used for the main Thermal Protection System (TPS). The deployment is achieved with an umbrella like structure and a blanket able to resist at high temperature.

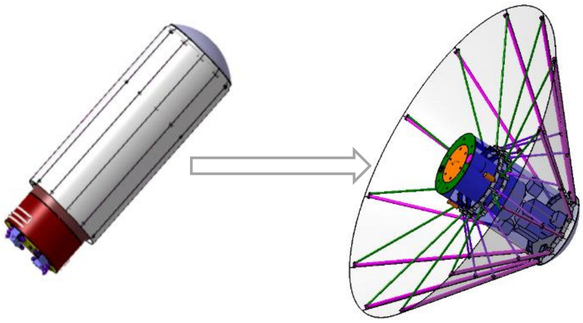

Figure 1: IRENE Deployment early concept

One characteristic of the IRENE concept, is that the blanket is in contact only with the extremities of the rods (or struts) of the umbrella.

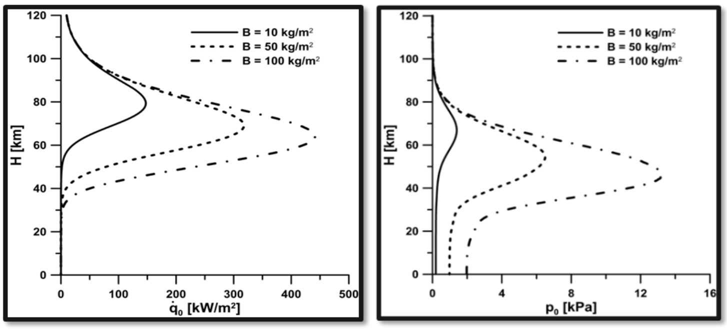

Figure 2: Stagnation pressure and heat flux v.r.t. altitude for different ballistic coefficients capsules.

The diagrams shown in the figure show how the reduction of the ballistic coefficient cause the reduction of heat flux and stagnation pressure. It is possible also to prove that the pressure and heat flux peaks occurs at higher altitude, when the atmosphere is more rarefied.

2 BACKGROUND AND CURRENT STUDIES

The deployable TPS idea is not new. Many inflatable and mechanical systems have been and are currently under development for several different mission typologies:

- Satellite deorbit.
- Landing large mass on planet with thin atmosphere (Mars).
- Entry planets with thick and dense atmosphere (Venus).

Italy has developed some activities in the field of the mechanically deployable heat shield since the 2001. In that year, the Italian Space Agency ASI founded a Feasibility study for a deployable re-entry system. In the frame of this activity A Flexible TPS material and complementary ceramic foam for the nose have preliminarily been tested in the SPES hypersonic wind tunnel at the University of Naples. Then a subsystem test, including both the Nose and flexible TPS material, has been executed in CIRA SCIROCCO PWT. The next figure shows two images acquired during the test campaigns.

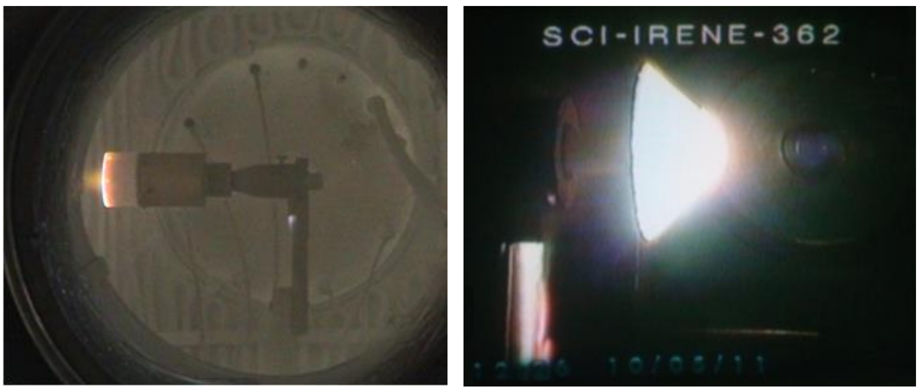

Figure 3: Material test on the left in SPES and subsystem test in SCIROCCO on the right.

Other studies have been focused on the development of a scaled down prototype of IRENE, named MINI-IRENE, for suborbital flight on MAXUS sounding rocket and the current

deployment logic has been conceived. During this activities a ground demonstrator has been also been realized.
Related research at the University of Naples Federico II are focused on aero-thermodynamics, CFD and DSMC studies, aerodynamic control of de-orbit trajectories, cubesat end of life systems, drop tests.
Universities, CIRA and industries, in the frame of the new funded Aerospace District of Campania Region (DAC), are also currently involved in the study of a 20-30 Kg class air-launchable micro-satellite with a flexible deployable and controllable aerobrake, with aerodynamic de-orbit and re-entry capability.

Figure 4: Ground demonstrator and 3D model of the MAXUS-MINI-IRENE deployed capsule.

The following figure shows some CFD analyses results and pictures of a 3D printed test model that has proven the subsonic dynamic stability in several drop tests.

Figure 5: University of Naples activities: CFD analyses. 3D printed model used for drop tests.

3 CURRENT ACTIVITIES

At present is in place the negotiation for a 24 months GSTP founded contract. The new project, that will bring the IRENE idea to flight, is articulated in the following main phases:

- Design and realization of a Flight Demonstrator (FD) for suborbital flight.
- Design and realization of a Ground Demonstrator (GD).
- Plasma Wind Tunnel test of the GD.
- Ground qualification of the FD.

- Flight test on VSB-30 rocket of the FD.
- Recovery and post flight analysis.

The FD shall be even more scaled down because the VSB-30 is smaller than MAXUS. The flight test shall be representative of the aeromechanical part of the flight but not of the thermal part of a LEO re-entry.
The GD shall be representative of the material and of the mechanisms of the FD in order to achieve an overall TRL equal to 6.
The capsule shall be dropped by the payload stage of a VSB-30 Rocket after the burn out of the second stage during the ascent, at 65 seconds from the lift off at an altitude close to 83km at a speed of about 1700 m/s.
The fight would continue up to a 250km altitude. The landing is scheduled 860 seconds after the separation from the Launcher.

Figure 6: From left to right: The VSB30 Rocket; a launch from ESRANGE base, expected trajectory

The following diagrams below compare the dynamic pressure, the acceleration and the heat flux experienced by a same capsule in a LEO re-entry trajectory, on a MAXUS flight test and on a MAPHEUS VSB-30 flight.

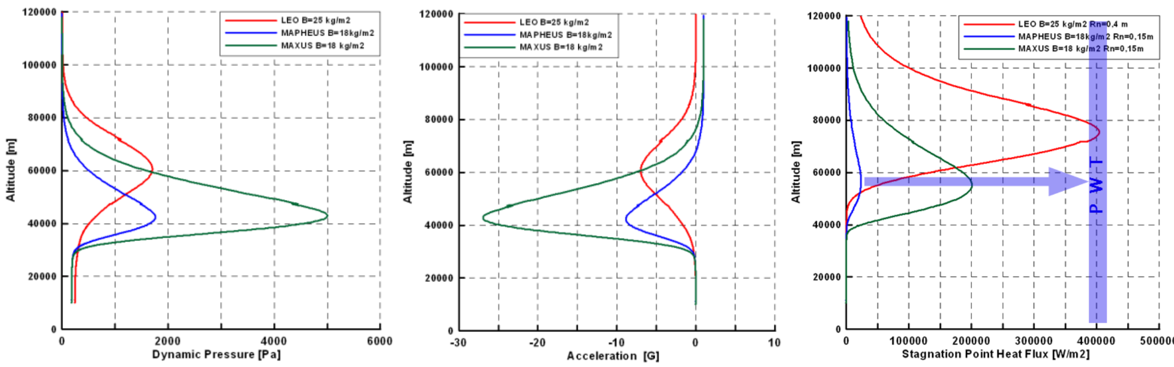

Figure 7: Dynamic pressure, acceleration and heat flux experienced by a same capsule in a LEO re-entry trajectory, on a MAXUS flight test and on a MAPHEUS VSB-30 flight

The VSB-30 sounding rocket flight is not sufficiently energetic for achieving significant heat fluxes on the TPS. Because of this, a PWT test is needed in order to achieve TRL 6 in a relevant

environment. The Ground Demonstrator that will be tested in PWT will be representative not only of the materials, but also of the mechanisms of the flight model. While the PWT test carried on in 2001 was a test on the materials, the current test is a test on the TPS and deployment mechanisms subsystem and shall be executed for matching as much is possible the real LEO re-entry thermal environment. Even if not representative of the thermal part of the flight, the analyses show that the aerodynamic environment encountered in the VSB-30 flight is very close to the LEO entry. The flight will then prove the structural worthiness of the whole system and the aerodynamic characteristics.
It is here important to underline that the previously planned MAXUS flight was less representative of the LEO entry because even if it is more energetic the LEO het fluxes are not matched, while the aerodynamic environment is excessively severe because the steepness of the trajectory.

3.1 3D modeling and FEM analyses

Design is carried out by means of 3D CAD and CAE systems. FEM non linear models are used for the thermal and structural design.

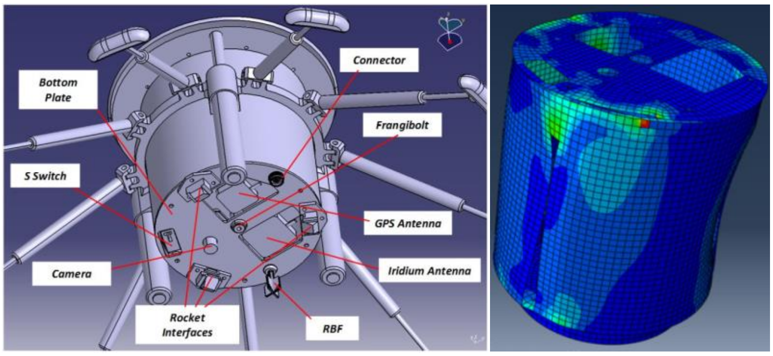

Figure 8: 3D Model of the structure without the flexible TPS on the left. One of the early configurations of the avionic bay under launch loads, on the right.

The flexible TPS has a primary structural function in IRENE. A specific test campaign has been carried out at CIRA on TPS samples. Complex explicit models are used for the prediction of the flexible TPS behavior, when it is preloaded by the deployment and when it is loaded by the dynamic pressure. One of the most sensitive part of the design is how the flexible TPS transfers loads on the structure.

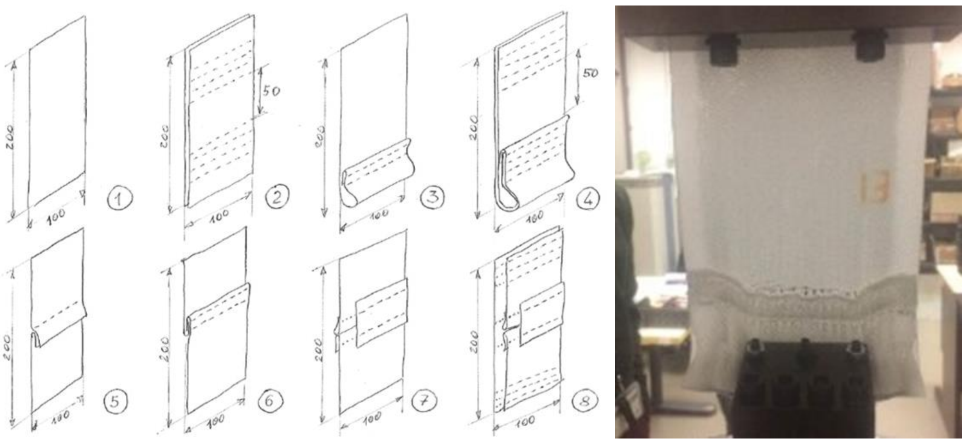

Figure 9: Pencil sketch of some of the samples used for the test campaign, and one of the samples during the test. It is possible to see how sewing affects the behaviour of the material.

The test campaign has shown that the material has very different behavior when it is loaded along the warp, the fill, or along an intermediate direction. This made necessary to implement complex explicit FEM models for simulating the behavior of different sewing solutions.

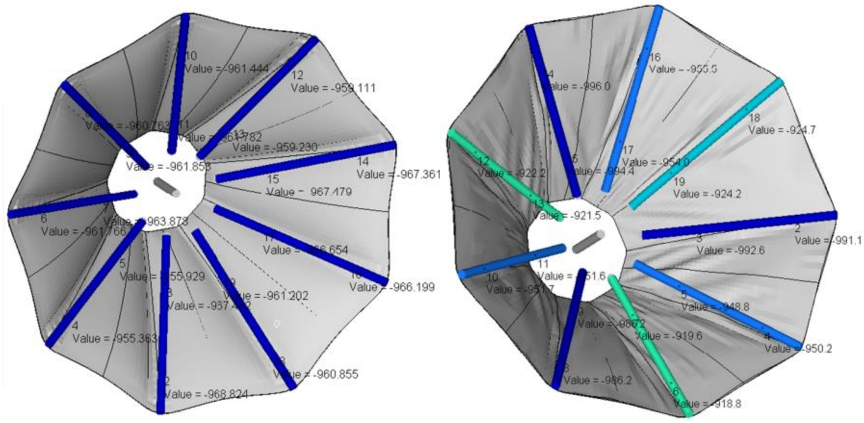

Figure 10: FEM explicit models of the flexible TPS.

The image shows two different schemes of sewing under the same load conditions. The results show that the sewing scheme has a large effect on the TPS behaviour.

3.2 Avionics and beacons.

The whole MINI IRENE avionics is conceived in order to be intrinsically safe. The batteries shall be disconnected from all the systems by a mechanical switch that will be closed at the separation of the capsule.

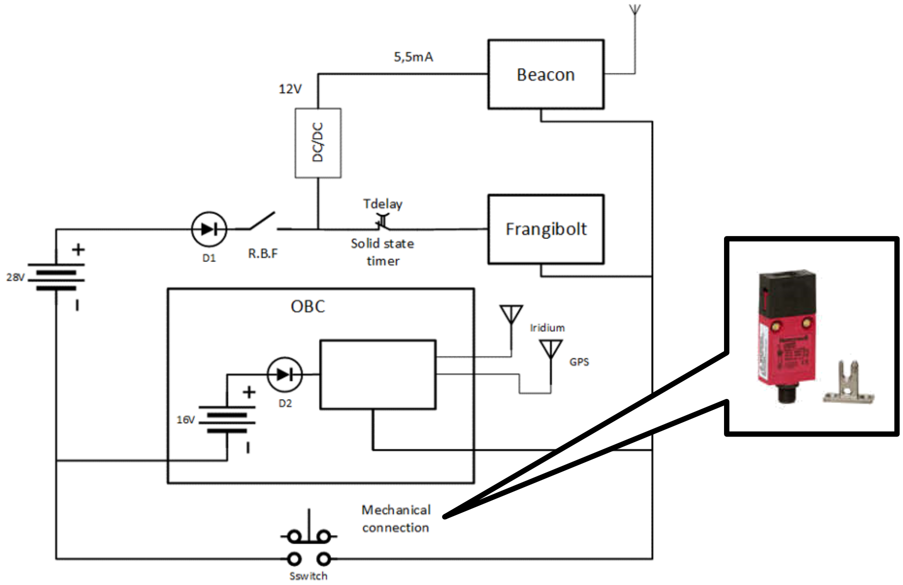

Figure 11: Schematic representation of the avionic system.

One of the most critical part of the mission is the capsule recovery.
The On Board Data Handling system is conceived for storing in internal memories all the data acquired during the flight, including video and images.
Only part of these data are transmitted on ground via IRIDIUM constellation.
Test are currently running on a breadboard composed by an evaluation board with microcontroller (AT32UC3C0512C), a debbuger and an IRIDIUM modem.

Figure 12: Breadboard fully representative of the flight hardware used for testing and software development.

The transmitted data will be enough to evaluate the effectiveness of the deployable heat shield, and for the localization of the capsule by the last transmitted GPS position. An accurate mission reconstruction can be carried out only with the use of the data stored in the internal memory. Therefore, three redundant localization systems shall be implemented:

- GPS data during the flight.
- Commercial beacon transmitter. (range 2-15 km).
- R-Fid systems used for avalanche recovery. (range <200m).

Figure 13: Beacon transmitter components and receiving antenna.

The beacon system has been tested in urban environment up to 2km and has been also tested for a crash landing at 25m/s impact speed at CIRA.

Figure 14: Man equipped with searching antenna and various shapes of R-Fid system

The R-Fid system has a limited range, but since it does not require onboard power, it can permit the localization of the capsule even when the onboard power will be depleted.

4 CONCLUDING REMARKS

The project is currently running on schedule. The Preliminary Design Review (PDR) has been successfully closed in March. The Critical Design Review (CDR) should occur within the current year. The detailed design is almost concluded, and breadboards of many parts and mechanisms have been already manufactured and are currently under testing. This will permit to approach the CDR with almost all the critical mechanisms not only designed, but also already realized and tested, at least in room conditions.

The manufacturing of the Flight and Ground Demonstrator shall start just after the CDR. The GD will reuse many parts of the breadboards and the FD will undergo a complete space qualification campaign at CIRA.

5 ACKNOWLEDGEMENTS AND REFERENCES

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