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Mini-IRENE, a successful re-entry flight of a deployable heatshield capsule

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Abstract. This paper presents some of the results of the suborbital flight of the Mini-IRENE Flight Experiment (MIFE), flight demonstrator of the IRENE technology. A capsule equipped with a deployable heat shield was successfully launched with a VSB-30 suborbital rocket, achieving an apogee of 260 km, a peak deceleration of 12g and surviving the landing with successful retrieval. A huge set of telemetry data was acquired, including GPS, attitude, temperature, acceleration measurements. The capsule showed aerodynamic stability at all flight regimes. The derived drag coefficient was different from the predicted one, possibly due to flexible aero-brake deformation.

Introduction

The paper describes the main outcomes of the qualification flight of Mini-IRENE, a capsule launched with a Maser sounding rocket on 23rd November 2022 during the SSC S1X3-M15 campaign. The flight has represented the clou of the Mini-IRENE Flight Experiment (MIFE) project [1], funded by the Italian Space Agency (ASI) and managed by the European Space Agency (ESA) in the framework of a GSTP (General Support Technology Program). The project aimed at increasing the ripeness of an innovative technology for atmospheric (re-)entry up to TRL 6, developed by the companies of the ALI consortium, CIRA and University of Naples Federico II, as part of the wider IRENE program [2], and featured by an innovative deployable heat shield, resulting in a very low ballistic coefficient, allowing the exploitation of off-the-shelf materials for the thermal protection system, because of the acceptable heat fluxes, mechanical loads and final descent velocity [3]. The IRENE program aimed at developing a low-cost re-entry capsule, able to return payloads to Earth from the ISS and/or short-duration, scientific missions in Low Earth

Orbit (LEO). MIFE was the latest phase of the IRENE program, with the objectives to design and test a Ground Demonstrator (GD) for the thermal qualification in a Plasma Wind Tunnel, and realize a Flight Demonstrator (FD) to be qualified in a sub-orbital flight with a Sounding Rocket.

All the qualification tests have been performed successfully. The GD was qualified in the CIRA Scirocco Plasma Wind Tunnel for the thermal loads of a specific re-entry mission; the FD has successfully achieved the two main objectives of the sub-orbital flight mentioned above after ejection from the sounding rocket, namely the verification of the stability in every flight regime and the resistance of the heat shield under the thermal and mechanical loads due to the impact with the atmosphere.

This paper is focused on the analysis of the re-entry flight based both on recorded data and telemetry data. The recorded data have been retrieved from an Inertial Unit and a sensors suite while the telemetry data were transmitted to ground even in the supersonic regime.

The suborbital flight

A CAD model of the FD is shown in Fig. 1a, in the deployed configuration. For the launch, it was stowed inside an external shell composed of three panels, as shown in Fig. 1b.

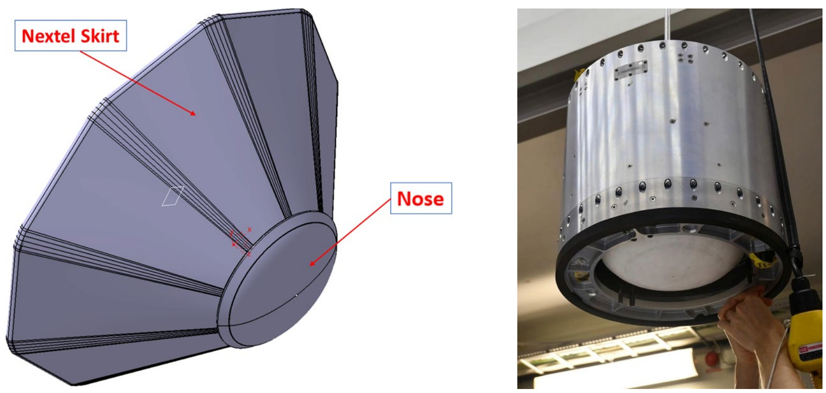

Fig. 1 (a) CAD of the deployed capsule, (b) picture of the stowed capsule before launch.

The capsule was launched from the Esrange base, in Sweden, on 23rd November 2022, onboard a VSB-30 rocket, in the Maser 15 mission (Fig. 2a). The capsule successfully completed its suborbital flight, with a correct aero-brake deployment, and was retrieved few minutes after landing thanks to GPS coordinates and telemetry data provided even after ground impact (Fig. 2b). The capsule trajectory was monitored by GPS and is compared with the nominal predicted trajectory in Fig. 3. A slightly lower apogee than expected was achieved (257 km instead of 261 km). The trajectory showed a sharp deviation in east direction, which was attributed to wind (thanks to balloon measurements) and not to any asymmetry in the capsule aerodynamics. Video recordings, together with magnetometers and accelerometers measurements, demonstrated that MIFE did not lose stability nor tumbled in any flight regime, even in the critical transonic phase. A significant spin rate was measured at the beginning of the continuum regime, possibly due to minor geometrical asymmetries in the TPS or center-of-mass unbalance.

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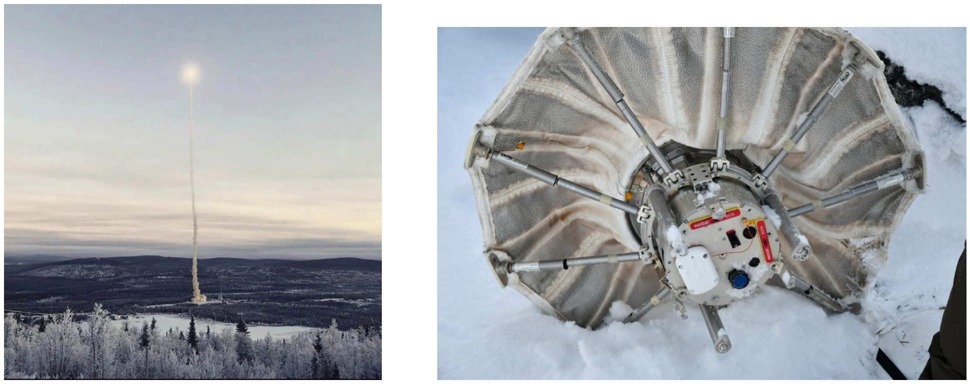

Fig. 2 (a) A picture of the launch, (b) the capsule retrieved after landing

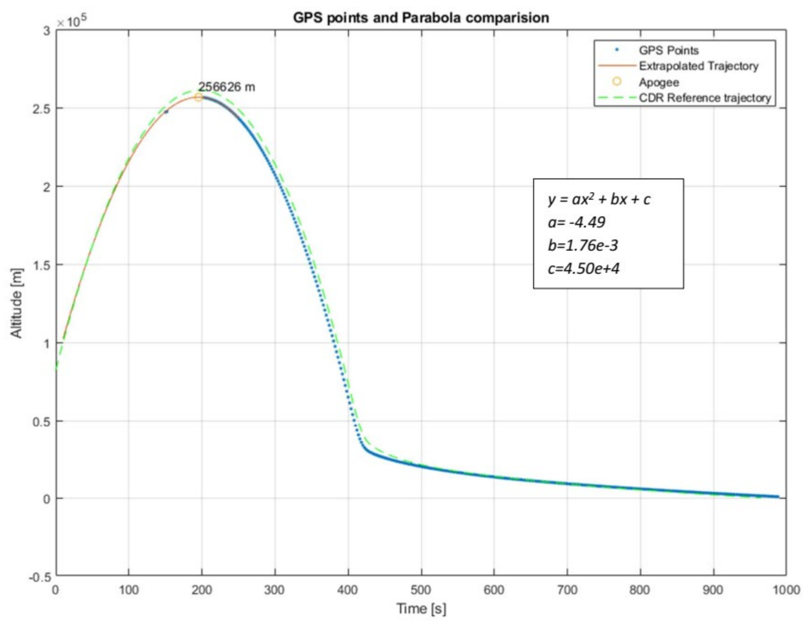

Fig. 3 Capsule parabolic trajectory, measured and predicted

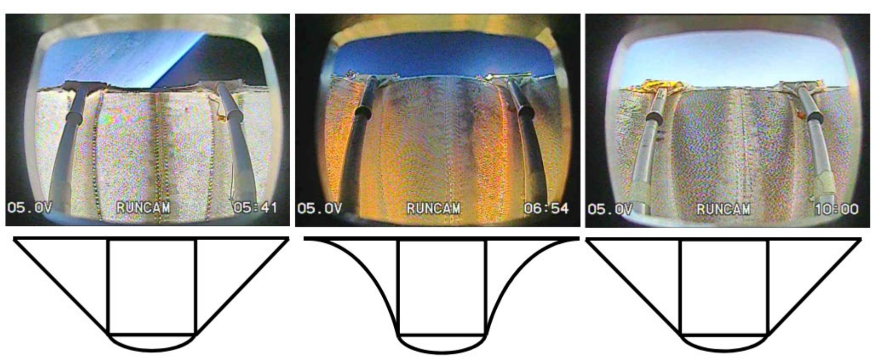

Fig. 4 Three images of the flexible TPS in free fall, during the peak of dynamic pressure, and during the final part of the flight; and a schematic representation

The capsule deceleration was higher than expected (12g versus 10.5g), and the peak of dynamic pressure occurred at a lower altitude. This allowed testing the system in a even harsher aerodynamic environment, which caused a deformation of the flexible TPS (Fig. 4), that had not been taken into account in the derivation of the aerodynamic database. This may be one of the reasons for the differences between the expected and rebuilt drag coefficient, whose trend with Mach number from supersonic to subsonic regime is shown in Fig. 5. The “flight” drag coefficient, computed on the basis of velocity and acceleration measurements, is lower than nominal in supersonic and higher in subsonic, even when considering a ±10% error on the standard atmospheric density used for the calculation. Further analyses, including CFD simulations of the aerodynamics of the deformed TPS, will be carried out for a deeper understanding of this discrepancy.

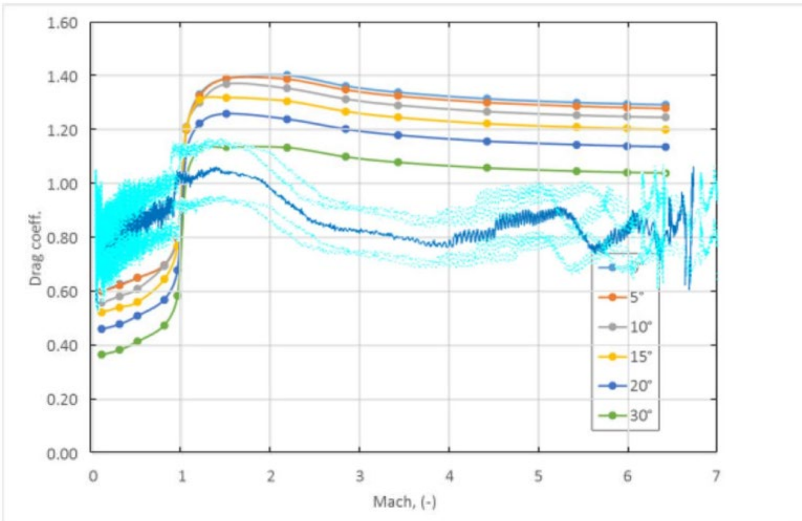

Fig. 5 Drag coefficient estimated based on flight data (blue line), with ±10% uncertainty (light blue lines), compared with numerical aerodynamic database, versus Mach number

Conclusions

The Mini-IRENE Flight Experiment (MIFE) project was successfully concluded with the suborbital launch of the flight demonstrator, which achieved all the mission objectives, including effective separation from the launcher, complete mechanism deployment, aerodynamic stability at all regimes, capsule survival to the aerothermodynamic loads, telemetry data acquisition and capsule retrieval after flight. Flight data analysis is still ongoing for a full comprehension of the capsule behavior and to learn important lessons for the future design of an orbital system based on the IRENE technology.

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