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Aerodynamics and flight mechanics activities for a suborbital flight test of a deployable heat shield capsule

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A B S T R A C T

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. The main characteristics of IRENE is the “umbrella-like" deployable front structure that reduces the capsule ballistic coefficient, leading to acceptable heat fluxes, mechanical loads, stability and final descent velocity. Following the feasibility studies carried out since 2011, with also preliminary Thermal Protection System materials tests in plasma wind tunnels, the objective is now to design and build a Flight Demonstrator and a Ground Demonstrator to prove, with a suborbital flight and with a Plasma Wind Tunnel (PWT) test campaign, the functionality of the deployable heat shield. The Flight Demonstrator shall be included as a secondary payload in the interstage adapter of a VSB-30 launcher from ESRANGE, then ejected during the ascent phase of the payload section, perform a 15-min ballistic flight, re-enter the atmosphere and hit the ground. The Ground Demonstrator, representative of the Thermal Protection System of the Flight Demonstrator, shall be instead exposed to a heat flux similar to that expected for an atmospheric re-entry from low Earth orbit inside the SCIROCCO Plasma Wind Tunnel at CIRA. The paper, after a short description of the mission profile both for orbital and suborbital flights, focuses on the aerodynamics and flight mechanics activities held for the suborbital flight and PWT test campaigns.

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 [1], [2], [3], [4], [5].

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, that allows relatively small dimensions at launch and a sufficient exposed surface area in re-entry conditions, and a blanket able to resist high temperature as shown in Fig. 1.

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, thus limiting the thermal loads on these structural elements.

The diagrams in Fig. 2 show how the reduction of the ballistic coefficient causes the reduction of heat flux and stagnation pressure. It can be also noticed that the pressure and heat flux peaks occur at higher altitude, when the atmosphere is more rarefied. The ballistic coeffcient (B) is defined as:

$$B = \frac{m}{C_D * A} \quad [1]$$

Where m is the mass, C_D is the drag coefficient and A the cross-sectional area. It is the measure of the ability of a body to overcome air resistance

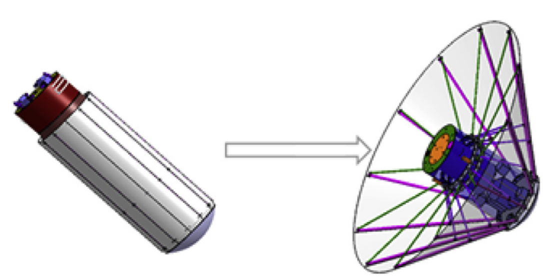

Fig. 1. IRENE Deployment early concept.

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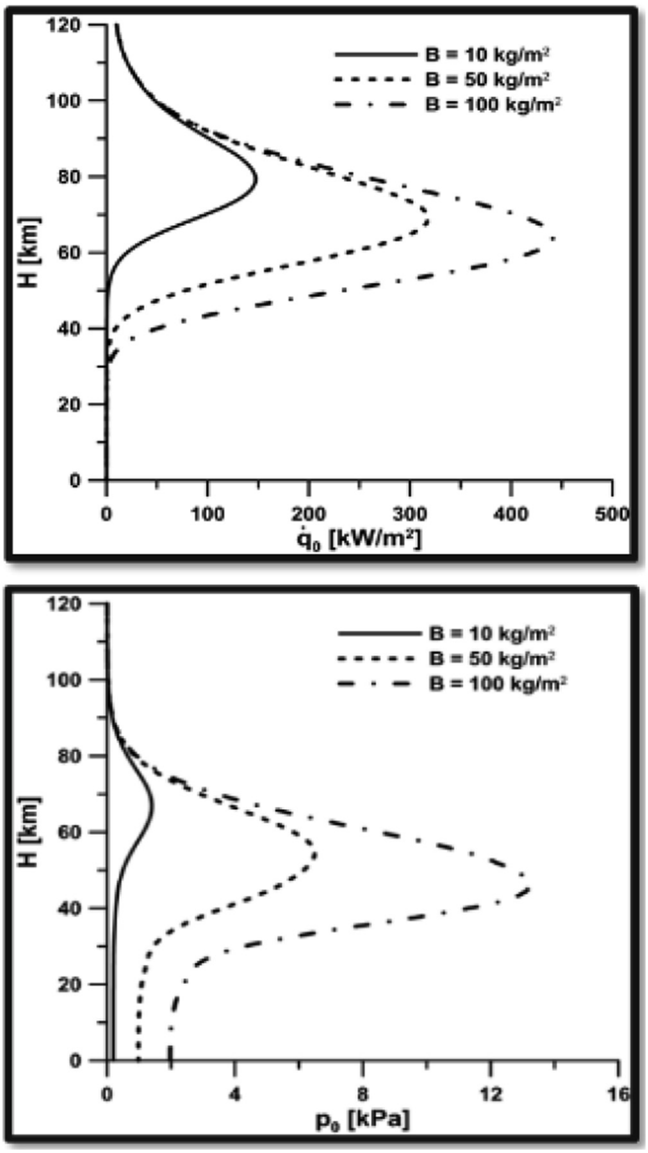

Fig. 2. Stagnation pressure and heat flux w.r.t. altitude for different ballistic coefficients capsules.

in flight. The higher the ballistic coefficient is, the deeper a body plunges into the atmosphere before reaching the maximum deceleration. Typical value are around 350 kg/m^2 for the Apollo command module and 430 kg/m^2 for the Space Shuttle. IRENE aims to a ballistic coefficient of only 25 kg/m^2.

2. Background

The deployable TPS idea is not new. Many inflatable and mechanical systems have been and are currently under development [6], [7], [8] for several different mission typologies:

- Satellite deorbit [9], [10].
- Landing large mass on planet with thin atmosphere (Mars) [11].
- Entry planets with thick and dense atmosphere (Venus) [12].

Italy has developed some activities in the field of the mechanically deployable heat shields since the 2001. In that year, the Italian Space Agency ASI founded a Feasibility study for a deployable re-entry system developed by ALI (Aerospace Laboratory for Innovative components) and University of Naples Federico II. In the frame of this activity, a

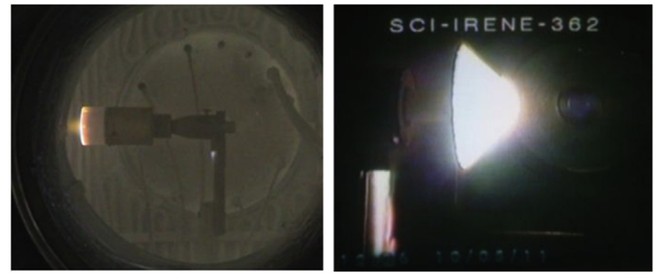

Fig. 3. Material test on the left in SPES and subsystem test in SCIROCCO on the right.

Flexible TPS material (a Nextel layer of 3 mm of thickness) and complementary ceramic foam for the nose have preliminarily been tested in the SPES (Small Planetary Entry Simulator) hypersonic wind tunnel at the University of Naples. Then a subsystem test, including both the Nose and flexible TPS material, has been executed at CIRA (Italian Aerospace Research Centre) in the "SCIROCCO" Plasma Wind Tunnel (PWT). Fig. 3 shows two images acquired during the test campaigns: ceramic foam for the nose tested in the SPES on the left and Nose and flexible TPS material tested in SCIROCCO on the right.

Consecutive studies have been focused on the development of a scaled down prototype half the size of IRENE, named MINI-IRENE, for suborbital flight on MAXUS sounding rocket. During this phase a mock-up has been realized (see Fig. 4).

In the meantime, related research was carried out at the University of Naples Federico II: aerothermodynamics was studied, by means of CFD (Computational Fluid Dynamics) and DSMC (Direct Simulation Monte Carlo) tools, aerodynamic control capability during de-orbit trajectories was investigated, conceptual design of heat shields as end of life systems for cubesats was provided [13] and drop tests were performed to study dynamic stability.

Several scenarios were investigated by numerical tools, including re-entry from Low-Earth-Orbit conditions [14], and different sounding rocket trajectories [15], spanning a wide range of flight conditions, from rarefied hypersonic to continuum supersonic and transonic. DSMC codes were necessary to investigate aerodynamics in nearly rarefied conditions (i.e. altitudes above 80 km). Useful information were obtained about longitudinal static stability behaviour, which appears to be better for a configuration with 45° aero-brake half-cone instead of 60° half-cone, although the latter could guarantee a stronger deceleration.

Furthermore, unsteady aerodynamics was studied. Fig. 5 shows two velocity contours obtained, at different time instants, by means of a transient CFD simulation of the capsule aerodynamics in transonic regime, at high angle of attack. Such analysis showed that, in these flight conditions, the flow field is oscillatory and, a result of the pressure oscillations, also the aerodynamic loads acting on the capsule experience a periodic variation. This kind of analyses are meant to give input

Fig. 4. Mock-up of the MINI-IRENE MAXUS deployed capsule.