

# KLARA: A Miniaturized, Low-Cost Capsule for satellite reentry study

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**Brief Presenter Biography:** *Paul Miailhe is an Avionics and Electrical Systems Architect at CNES (the French Space Agency). He serves as a lead technical officer for the Klara demonstration project, specifically overseeing the avionics design, electrical architecture, and platform interfaces.*

## I. INTRODUCTION (BRIDGING THE GAP IN ATMOSPHERIC RE-ENTRY MODELING)

Since the enactment of the French Space Operations Act (LOS<sup>1</sup>), French satellite manufacturers and operators must comply with strict End-of-Life (EOL) requirements. Beyond the mandatory deorbiting within 25 years for Low Earth Orbit (LEO) missions, they must conduct a rigorous casualty risk assessment. To obtain launch authorization, the calculated probability of a ground casualty must remain below  $10^{-4}$ .

To support the industry in reaching this compliance, CNES (the French Space Agency) provides a reference simulation tool, **DEBRISK**<sup>2</sup>. This software is designed to model the aerothermodynamic phenomena such as heat flux, ablation, attitude, conduction, and oxidation affecting spacecraft fragments during atmospheric re-entry.

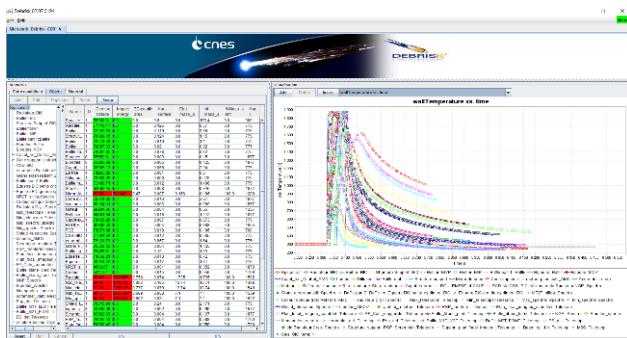


Figure 1 : Overview of the DEBRISK<sup>3</sup> software for casualty risk assessment and satellite demise analysis (Credit CNES)

However, the accuracy of these "Design for Demise" (D4D) simulations currently faces a significant hurdle: the lack of in-situ experimental data. Existing models rely heavily on ground-based plasma wind tunnel tests, which cannot fully replicate the complex, multi-physics environment of a full-scale structural breakup.

With the rapid proliferation of LEO constellations, there is an urgent need to validate these predictive models with "ground truth" data. In response, CNES has initiated the development of Klara (**K**it de mesure pour **L**A **R**entr e **A**tmosph rique) in close cooperation with ArianeGroup.

This partnership leverages combined expertise in orbital systems and atmospheric entry physics.

Klara is an autonomous, non-intrusive measurement kit designed to be integrated into various satellite platforms. Its primary mission is to capture and transmit critical thermal and dynamic data from the heart of the re-entry plasma. By monitoring the spacecraft's structural demise in real-time, Klara aims to refine fragmentation chronologies and provide the necessary insights to ensure safer and more sustainable space operations.

## II. RATIONALE: FROM "ONE-SHOT" TO "STANDARDIZED MONITORING"

### A. The Philosophy: Scalability vs. Complexity

Unlike large-scale reference missions such as Draco<sup>4</sup>, which are high cost, "one-shot" experiments dedicated to exhaustive atmospheric destruction analysis, Klara adopts a leaner, more pragmatic philosophy. The goal is not to perform a single, ultra-instrumented re-entry, but to provide a reliable, low-cost, and repeatable measurement kit.

By prioritizing a "Piggy-Back" approach, Klara can be integrated into a wide variety of satellite platforms (from 12U CubeSats to larger LEO satellites) without interfering with their primary mission. This strategy allows for a multiplication of data points across different spacecraft architectures, moving away from theoretical models toward statistically significant "ground truth" data.

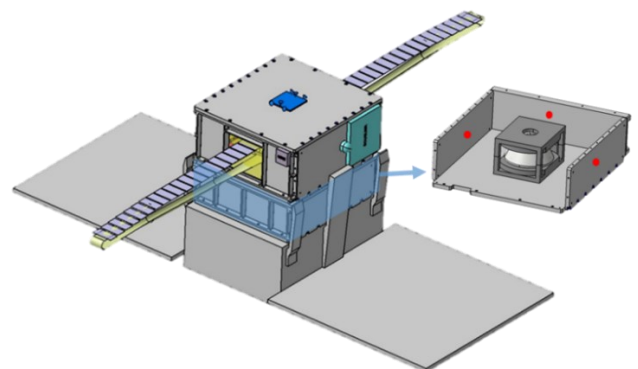


Figure 2: CAD implementation study of the KLARA payload. Phase 0 study conducted within the framework of the CNES project. (Credit CNES)

### B. Defining the "Essential" Measurement Suite

To maintain low cost and high reliability (SWaP-C constraints), Klara focuses on the most critical parameters required to validate tools like DEBRISK:

- **Localized Thermal Mapping:** A refined selection of thermocouples placed at strategic structural nodes (e.g., interface points, joints, and high-mass components) to identify the precise moment of structural failure.
- **Attitude Reconstruction:** A dedicated IMU to measure the "tumbling" rate and orientation, as the spacecraft's attitude directly dictates the heat flux distribution.
- **Resilient Data Handling:** A simplified but robust architecture for on-board storage and post-blackout burst telemetry. By buffering data during the peak ionization phase, Klara ensures that critical measurements are transmitted immediately after the radio blackout ends, before final impact or destruction. transmission, ensuring that the most vital data packets are exfiltrated before the final demise.

### III. MISSION PROFILE AND OPERATIONAL PHASES

The Klara mission is designed to be non-intrusive, following the lifecycle of the host satellite until its final destruction. The operational sequence is divided into four key functional states:

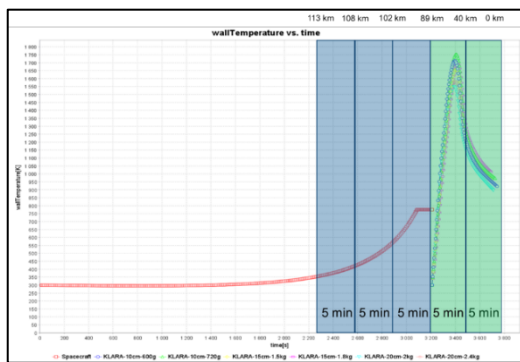


Figure 3 : Preliminary DEBRISK calculations for several capsules with diameters of 10 and 20 cm and masses ranging from 600 g to 2.4 kg. (Credit CNES)

#### A. Operational Timeline

- 1- **Stowage and Orbital Phase (Dormant State):** After launch and deployment, Klara remains in a dormant "watchdog" mode. This phase can last from 1 to 5 years, depending on the host satellite's mission duration.
- 2- **Host Passivation and Activation (Stand-by State):** Upon completion of the primary mission, the host platform undergoes electrical and chemical passivation. At this critical juncture, Klara switches to its internal power source. The system enters a stand-by mode, monitoring GNSS telemetry to detect the onset of re-entry.
- 3- **Atmospheric Re-entry (Operational State):** The scientific mission begins at an altitude of 120 km. Data collection lasts approximately 15 minutes, triggered by atmospheric pressure or acceleration thresholds. At 90~80 km, following the host's structural fragmentation, the Klara capsule separates and begins its independent descent.
- 4- **Data Recovery (Transmission State):** Once the capsule decelerates and exits the extreme heating environment of the mesosphere, a 10-minute transmission window begins. As the capsule descends through the lower

atmosphere, the onboard system exfiltrates the stored mission data via a satellite-to-satellite link (e.g., L-Band). This ensures that the high-resolution thermal and attitude telemetry is safely delivered to the ground before the capsule's final impact.

#### B. The Critical Challenge: Energy Autonomy during Passivation

One of the primary challenges in the design of Klara is the significant uncertainty surrounding the time window between the host satellite's decommissioning and the actual onset of atmospheric re-entry. To comply with LOS (French Space Operations Act), the host platform must undergo a complete electrical and chemical passivation, cutting off all external power and altitude control before the re-entry sequence.

Consequently, the Klara kit must rely exclusively on its internal battery system. Since the time between the host satellite's final shutdown and atmospheric reentry (at 120 km) varies greatly and depends on the platform, energy balance is a critical design factor. It is therefore necessary to incorporate a large battery capacity to ensure that the system remains operational throughout an unpredictable standby period. This design choice is critical and decisive for achieving a robust transition from an "out-of-service" satellite to an active in-situ measurement laboratory, while maintaining full availability for the high-frequency data collection phase, regardless of the host's deactivation schedule.

### IV. SYSTEM ARCHITECTURE: A MODULAR "PLUG-AND-PLAY" KIT

#### A. Design and Volume Optimization

Unlike traditional re-entry demonstrators that often rely on "Apollo-like" capsules or "Mars Probe" geometries, Klara adopts a Soyuz-inspired shape. This specific geometry was selected to optimize the internal volume-to-surface ratio, accommodating the substantial battery payload required for post-passivation autonomy. To ensure versatility across different satellite platforms, Klara is designed as a two-part system:

- **The Auxiliary Module (AM):** This module serves as the primary interface between the host satellite and the kit. During the orbital phase, it manages the connection to the host's Unregulated Bus (BNR) and specific command links for health monitoring. Most importantly, it acts as a concentration hub for the external thermocouple network.

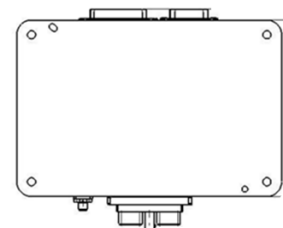


Figure 4 : 2D CAD of the Klara Auxiliary Module and Capsule interface. (Credit ArianeGroup)

- The Klara Capsule (The "Black Box"): Designed for survivability, the capsule contains the IMU for attitude reconstruction and the data management system. Aside from internal sensors, the capsule acts as a data recorder for the measurements gathered via the Auxiliary Module.

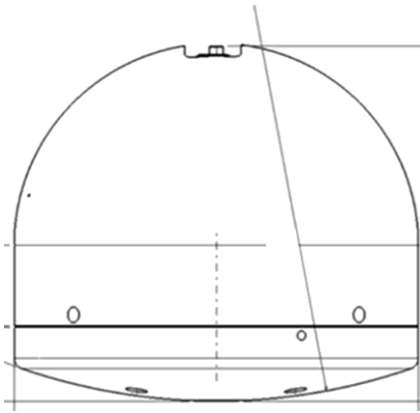


Figure 5 : 2D CAD of the Klara Capsule. (Credit ArianeGroup)

The mission relies on a gradual disintegration strategy. The Auxiliary Module is designed to be destroyed during the initial stages of re-entry. The electrical link between the AM and the Capsule is severed once the plasma penetrates the satellite's structure.

The mechanical separation is triggered by passive Hold-Down and Release Mechanisms (HDRM), such as Murphy bolts, which react to the thermal load. Once the host structure fails, the Klara capsule becomes a fully independent free-flying object, continuing its descent and starting its data transmission sequence. This modularity allows the project to adapt to future measurement needs simply by modifying the Auxiliary Module, leaving the core Capsule design unchanged.

## V. CONCLUSION AND PERSPECTIVES

The Klara project represents a strategic collaboration between CNES and ArianeGroup, aiming to bridge the gap between theoretical re-entry models and physical reality. By focusing on a low-cost, modular, and repeatable instrumentation kit, Klara offers a pragmatic alternative to complex "one-shot" missions.

The roadmap for the project is centered on a first demonstration flight scheduled for 2028. Beyond this maiden flight, the ambition is to leverage multiple flight opportunities on both satellite platforms and launcher upper stages. This approach will allow for the creation of a comprehensive re-entry data catalog, providing the international community with essential "ground truth" measurements to complement existing debris and atmospheric studies.

Furthermore, Klara's architecture is designed for evolution. The separation between the hardened capsule and the modular auxiliary interface ensures that the kit can be tailored to future sensing requirements such as advanced gas spectroscopy or visual fragmentation monitoring

without redesigning the core system. Ultimately, Klara will serve as a key enabler for Design for Demise (D4D) validation, ensuring that future space operations remain safe, compliant with the Space Operations Act, and sustainable for the orbital environment.

## ACKNOWLEDGMENT

This project is a joint development program between CNES and ArianeGroup. Both entities are co-investing in the design, maturation, and qualification of the Klara kit to support the European space sustainability.

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