# Cubesat Application for Planetary Entry (CAPE) Missions: Micro-Return Capsule (MIRCA)

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Code 592

# What is new?

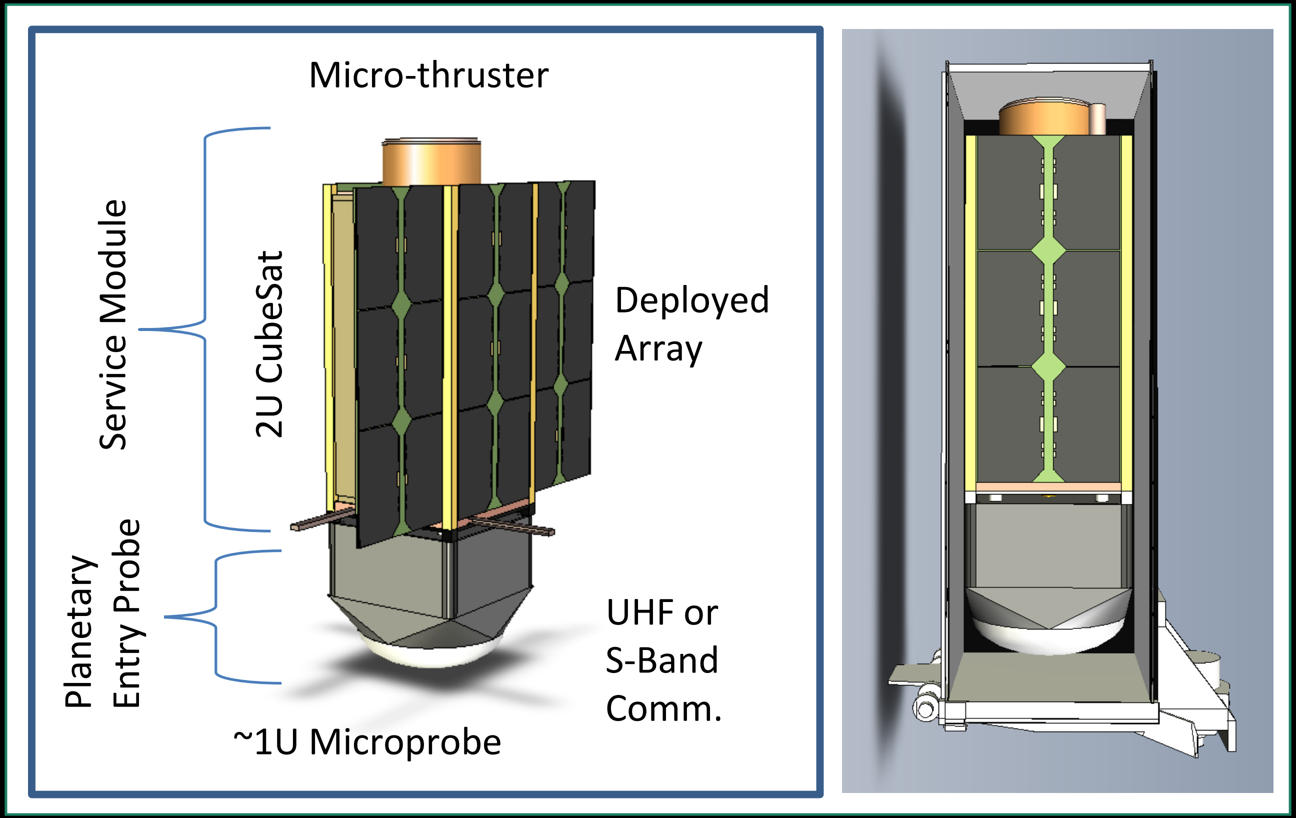
- So far, no microprobe (less than 10 kg) has entered another planetary atmosphere and successfully relayed data back to Earth.
- Although the Deep Space 2 Mars microprobes did reach their destination (total mass about 6.5 kg each), unfortunately they were lost due to a combination of delivery system failures and other unknown factors.
- GSFC, under R&D support, has been developing an inexpensive and pioneering technology based on the popular Cubesat specification.
- Slow but steady progress to date.

# Cubesat Application for Planetary Entry (CAPE) Missions

- Concept is based on the Cubesat design specification.
- Within a science operational context, CAPE probes may be sent from Earth to study a celestial body’s atmosphere, or to “land” on some high-value target on its surface.
- Either one or multiple probes may be targeted to distributed locations throughout the geographic landscape and could be released systematically and methodically from an orbiting spacecraft.
- CAPE consists of two main functional components: the “Service Module” (SM), and “CAPE’s Entry Probe” (CEP).

# CAPE Components

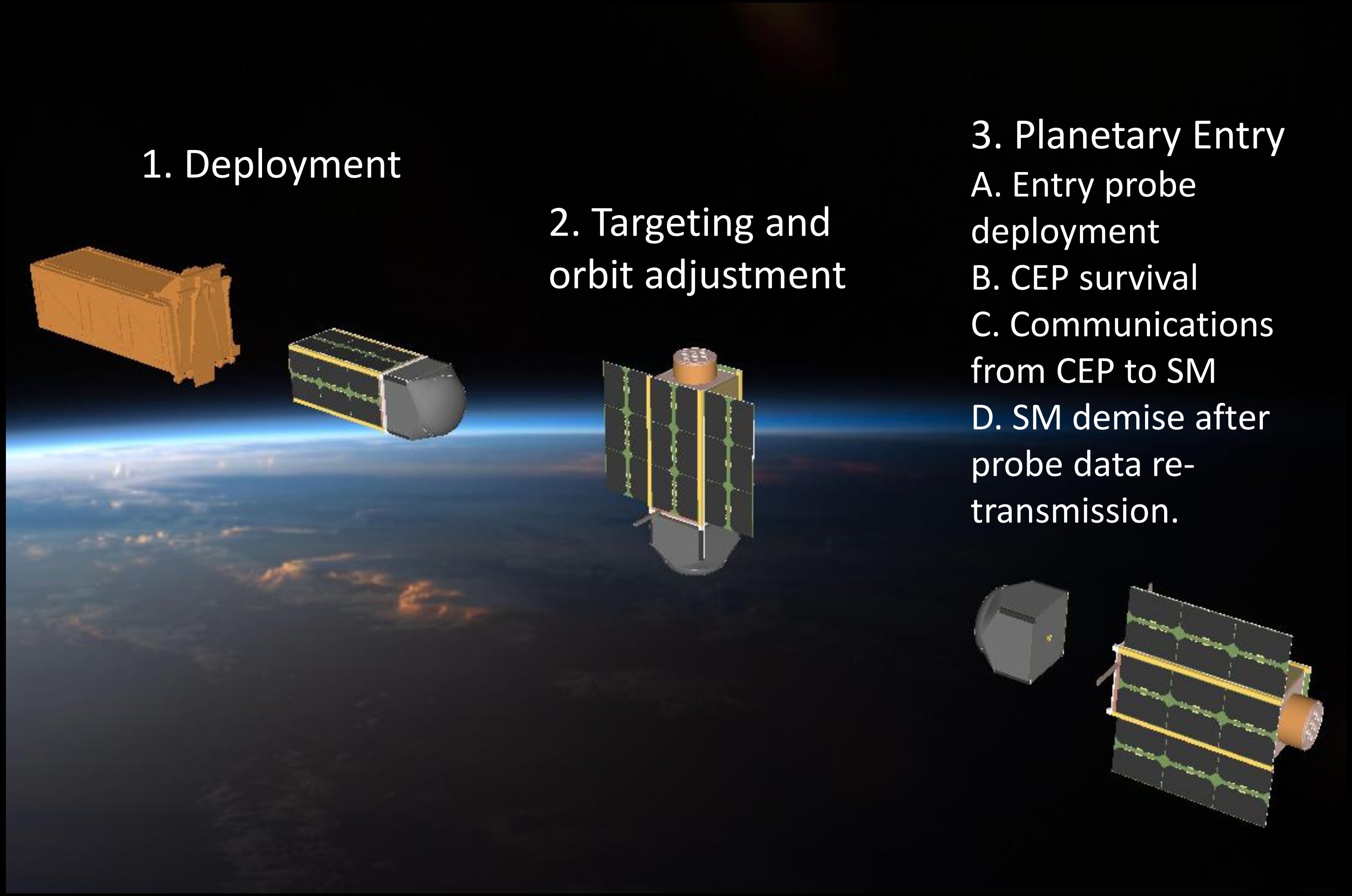
- The SM contains the subsystems necessary to support vehicle targeting (propulsion, ACS, computer, power) and the communications capability to relay data from the CEP probe to an orbiting "mother-ship".
- The CEP itself carries the scientific instrumentation capable of measuring atmospheric properties (such as density, temperature, composition), and embedded engineering sensors for Entry, Descent, and Landing (EDL) technology monitoring and assessment.




*CAPE in its deployed configuration, and stowed inside deployment system.*

# CAPE Operations Concept

- This shows a scenario where CAPE systems are carried by a “mother ship”, and sequentially released to study targets or regions of interest.
- Flexibility is provided by vehicle autonomy.
- Release on approach is another possible scenario.

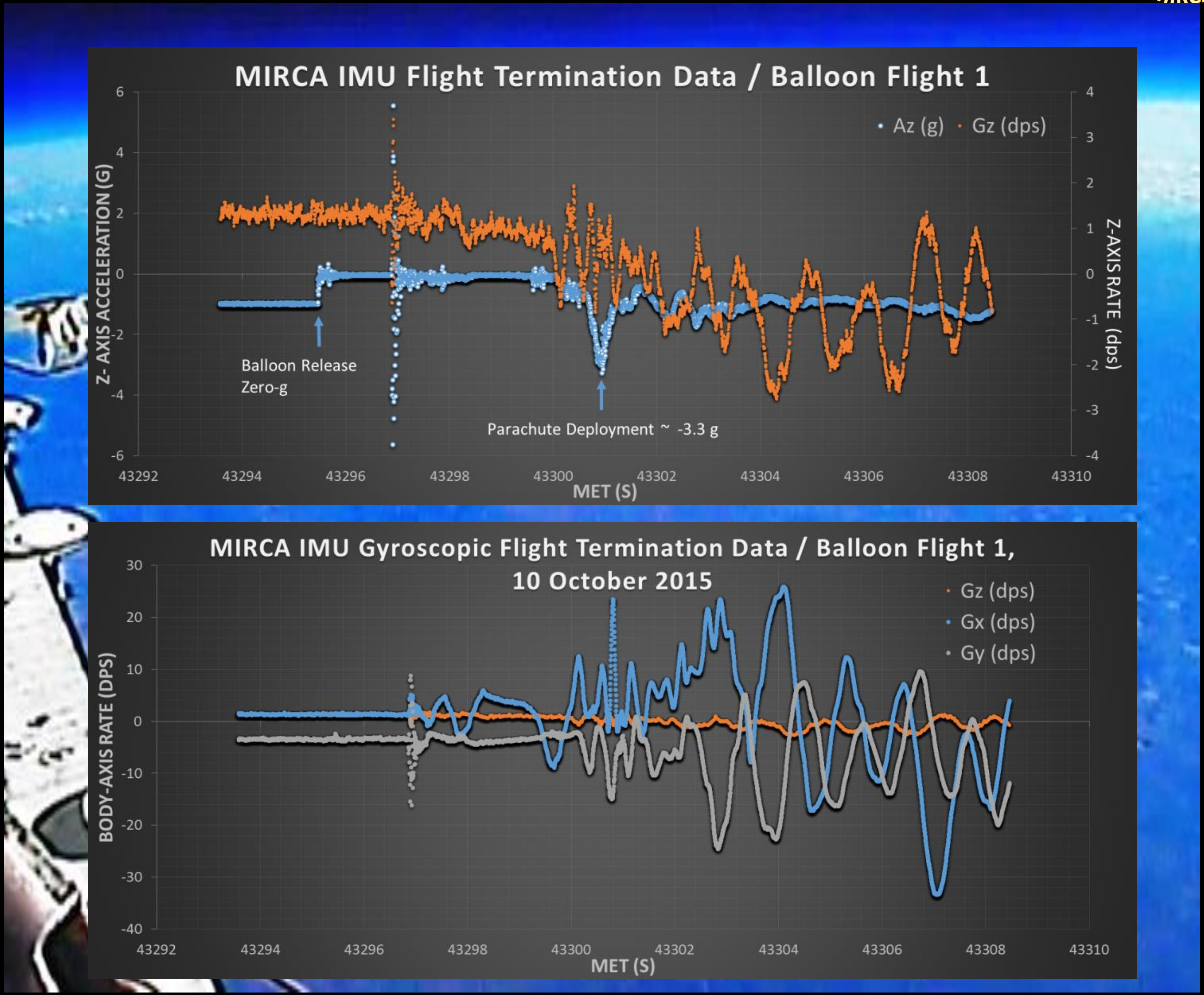


# Micro-Return Capsule (MIRCA)

- In order to reduce CAPE's implementation risks, a CEP re-entry demonstrator is currently being designed and prototyped: MIRCA.
- The first flight of MIRCA was successfully completed on 10 October 2015 as a "piggy-back" payload onboard a NASA stratospheric balloon launched from Ft. Sumner, New Mexico.

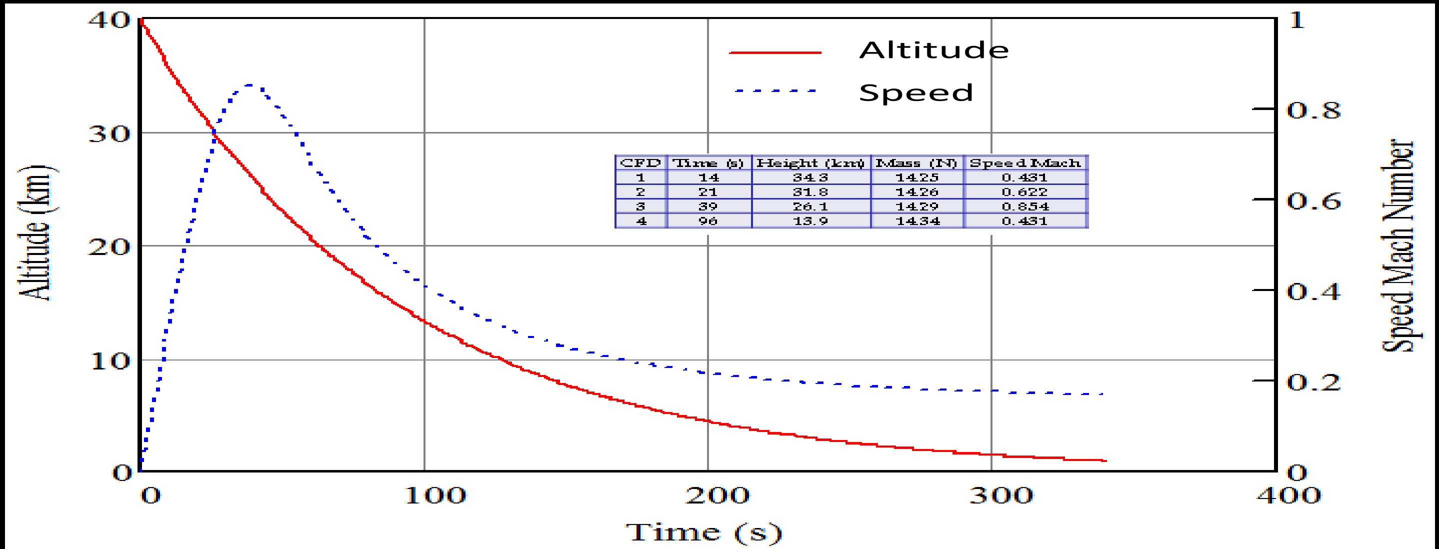
# MIRCA Flight 1 Results

- Completed verification of the Inertial Measurement Unit (IMU), single board computer, power conditioning and distribution system, communications transceiver, on-board thermal sensor, telemetry acquisition system, and flight software, all critical steps in MIRCA's development.
- Acceleration and body rate data recreate vehicle dynamics. Maximum axial (+Z-axis vertical) deceleration was about 3.3g for this flight after parachute deployment. Cyclic vehicle swinging under parachute (X and Y axes) is also evident from the IMU data

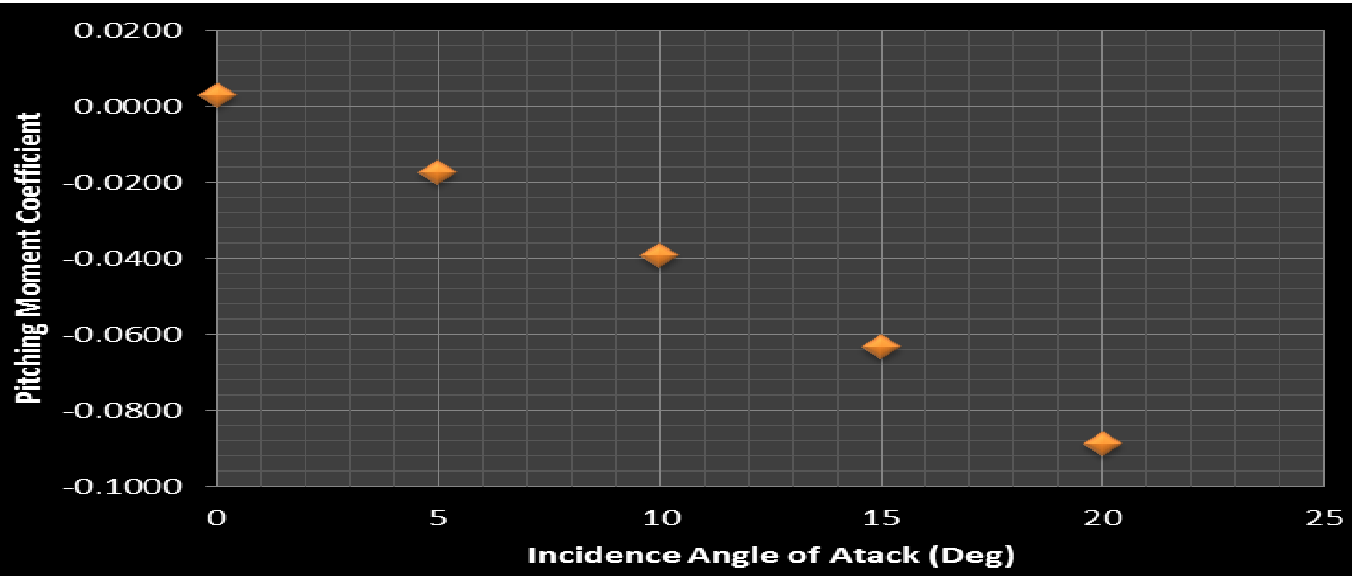


# Balloon Drop Demonstration of MIRCA

- Drop Test is scheduled for 2016 to verify real-world vehicle aerodynamics at speeds ~60-80% the speed of sound.
- Static stability conditions have been modelled via CFD analysis.

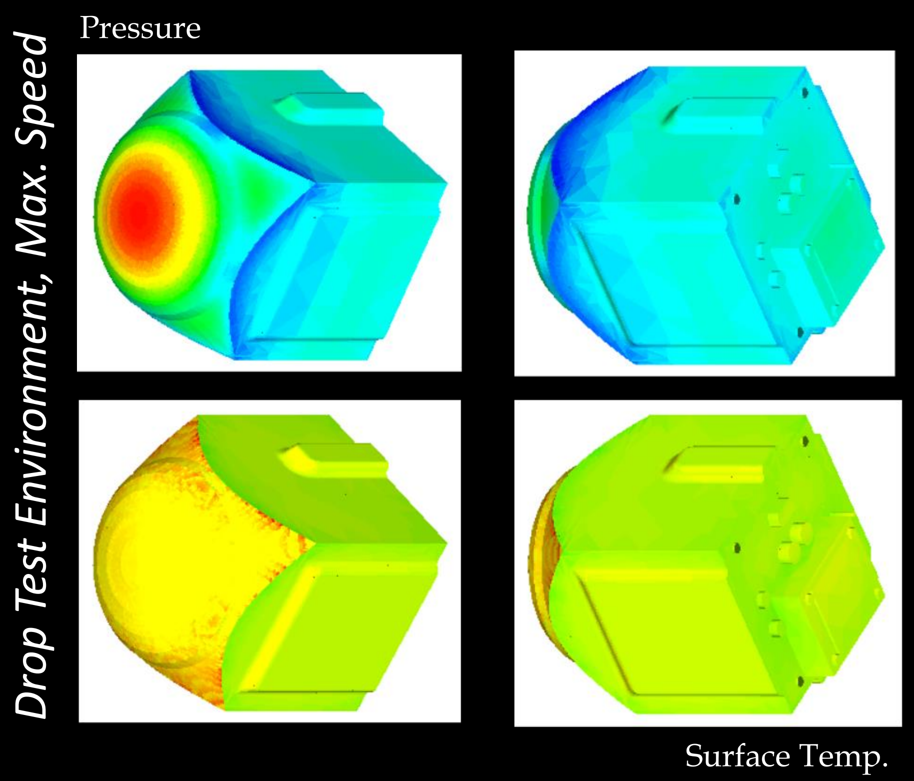


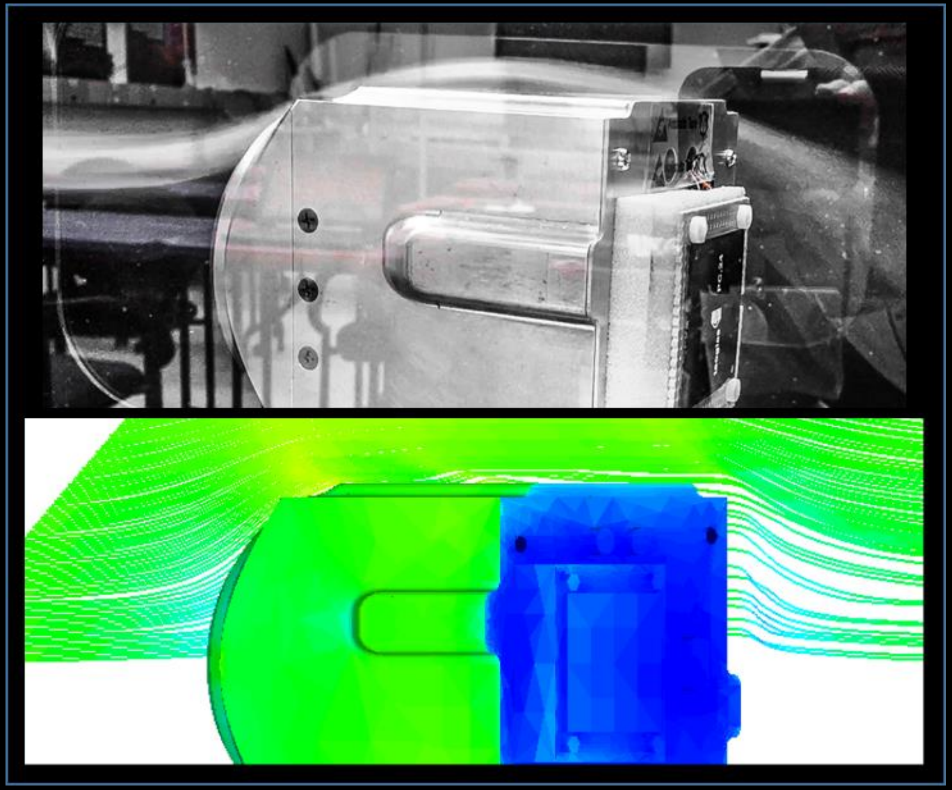

| CFD | Time (s) | Height (km) | Mass (N) | Speed Mach |
|---|---|---|---|---|
| 1 | 14 | 34.3 | 1425 | 0.431 |
| 2 | 21 | 31.8 | 1426 | 0.622 |
| 3 | 39 | 26.1 | 1429 | 0.854 |
| 4 | 96 | 13.9 | 1434 | 0.431 |



# CFD Analysis and Low Speed Test

- CFD analysis using 3-dimensional compressible Navier-Stokes equations was carried out at different altitudes and Angles of Attack (AOA).
- Predicted stagnation point pressure is ~ 1.3 atm. Maximum temperature is ~ 55° C, and average body temperature ~ 42° C.

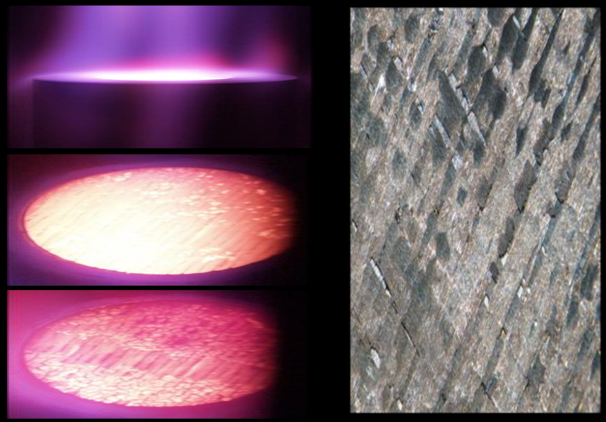


*MIRCA in wind tunnel test at NASA WFF (shown at angle of attack ≈ 20°)*

# Resin Impregnated Carbon Ablator (RICA)

## Potential Thermal Protection System Material for High Speed Entry Systems



*RICA Samples during testing at the PWK1 plasma wind tunnel (University of Stuttgart) in 2010.*

In the most extreme case, the temperature dropped from ≈3,000 to 50 ° C across 1.8 cm, demonstrating the material's thermal protection effectiveness

| RICA ID | Phenolic ~% | Carbon ~% | Density (gm/mL) | Heat Flux (MW/$m^2$) | Heat time (s) | Integrated Heat Input (J/$m^2$) | Mass Loss (gm) | Average Recession (mm) | Average Surface Temp from Pyrometer (C) | Average Thermal Gradient (K/mm) | Heat of Ablation (J/kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5C | 17 | 83 | 1.41 | 1.4 | 478 | 6.69E+08 | 7.84 | 4.218 | 1978.1 | 44.37 | 4.9E+07 |
| 5A (1) | 27 | 73 | 1.39 | 14 | 22 | 3.08E+08 | 3.33 | 1.96 | 3336.1 | 34.32 | 1.1E+08 |
| 3A | 24 | 76 | 1.36 | 1.4 | 478 | 6.69E+08 | 3.32 | 0.342 | 1962.5 | 54.50 | 8.5E+07 |
| 5B | 33 | 67 | 1.37 | 1.4 | 476 | 6.67E+08 | 3.73 | 1.217 | 1990.8 | 53.68 | 7.7E+07 |
| 3B | 31 | 69 | 1.35 | 1.4 | 477 | 6.67E+08 | 3.70 | 1.143 | 1967.5 | 51.11 | 8.5E+07 |
| (1) Tested in Air; all others tested in a Methane atmosphere (Titan) | | | | | | | | | | | |

*RICA Properties and initial test results for several samples*

# Application Example: Delivery Mass

- CAPE has potential application is many planetary in-situ measurements. Developing a comprehensive list of science targets and measurements is a necessary step in its development.
- An example mission to Mars's moon Phobos was scoped as a means to illustrate mission trades to be considered.
- The amount of propulsion system mass (dry + wet) required to deliver one versus several CAPE vehicles follows closely a linear relationship.
- It is impractical to consider launching only one CAPE vehicle to any destination. Multi-probe scenarios where the vehicles ride along as secondary payloads are most efficient.

| **Flight Data** | | **Launch 2020** |
|---|---|---|
| Departure Orbit Altitude | | 400 km |
| C3 | | 8.7 $km^2/s^2$ |
| Departure Date | | 1/1/2020 |
| Flight Time | | 0.71 years |
| Arrival Date at Mars | | 10/13/2020 |
| Departure DV | | 3.6 km/s |
| Mars Orbit Insertion DV | | 1.05 km/s |
| Delta V to Phobos Orbit | | 0.83 km/s |
| **No. CAPE vehicles to Phobos** | **Departure Mass (kg)** | **Arrival Mass at Phobos (kg)** |
| 1 | 717 | 80 |
| 2 | 764 | 85 |
| 3 | 810 | 90 |
| 4 | 857 | 96 |
| 5 | 903 | 101 |
| 6 | 950 | 106 |
| 10 | 1135 | 127 |

# Summary and Conclusions

- CAPE represents an entirely new and pioneering paradigm in planetary exploration, using the advantages and standardization common to Cubestas.
- MIRCA is clearing the way by systematically reducing the technological and operational risks associated with the application of this new paradigm to planetary exploration.
- Science/engineering partnerships are essential to this concept's advance.

# Aknowledgements


- I would like to thank the Goddard Space Flight Center's Wallops Flight Facility (WFF) for providing help and support in the manufacture of MIRCA's aeroshell, and for the planning of the balloon drop experiment. In particular, Brenda Dingwall, Phillip Cathell, Debora Fairbrother, and Gabriel Garde, among others without whom this work could not be completed. To Kathryn Browne and Gary Crum for flight software, Core Flight Executive implementation, and to Dr. Conor Nixon for his continuing encouragement.
- This presentation is dedicated to the memory of Prof. Dr. Hans-Peter Röser. May his teachings live on...