National Aeronautics and Space Administration

Goddard Space Flight Center

CUBESAT APPLICATION FOR PLANETARY ENTRY (CAPE) MISSIONS: MICRO-RETURN CAPSULE (MIRCA)

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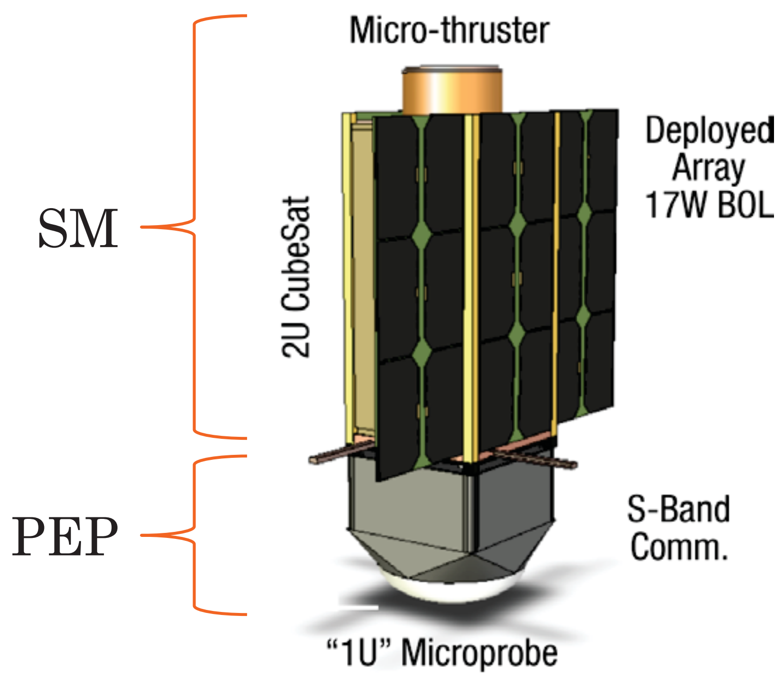
INTRODUCTION

- The Cubesat Application for Planetary Entry Missions (CAPE) concept describes a high-performing Cubesat system
  - includes a propulsion module and miniaturized technologies capable of surviving atmospheric entry heating, while reliably transmitting scientific and engineering data.
- The Micro Return Capsule (MIRCA) is CAPE's first Planetary Entry Probe (PEP) flight prototype
- This presentation summarizes CAPE's configuration and typical operational scenario.
- It also summarizes the results of GSFC's IRAD work on MIRCA's design and basic aerodynamic performance.

CAPE Configuration

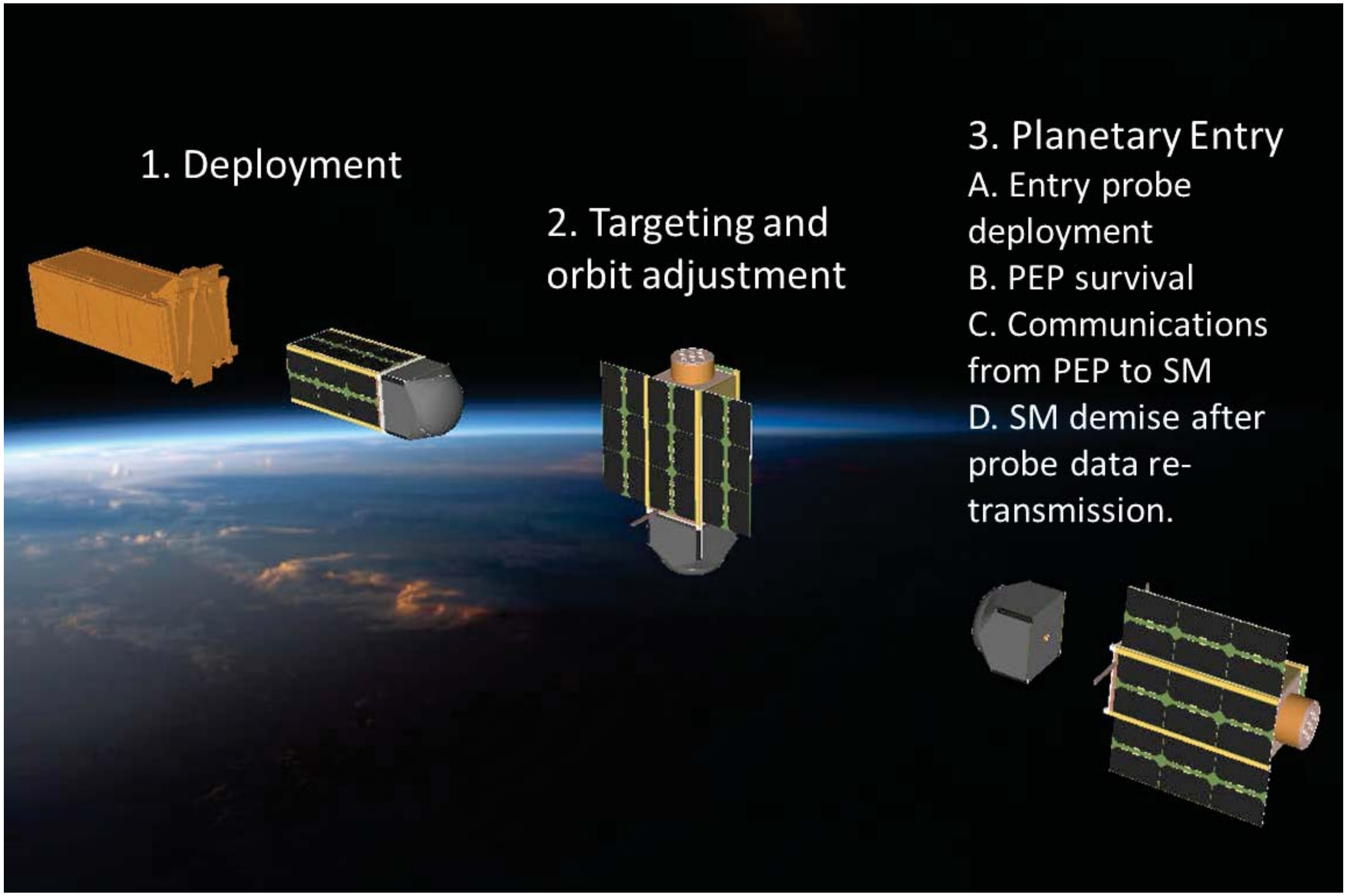
- Service Module (SM): contains the subsystems necessary to support vehicle targeting (propulsion, ACS, computer, power) and the communications relay unit.
- Planetary Entry Probe (PEP): carries the scientific instrumentation and Thermal Protection System (TPS) technology monitoring.

The total system mass is less than 5 kg. The solar array generates about 17W at 1 AU, and the system nominally consumes about 11W of power.



Operations Concept

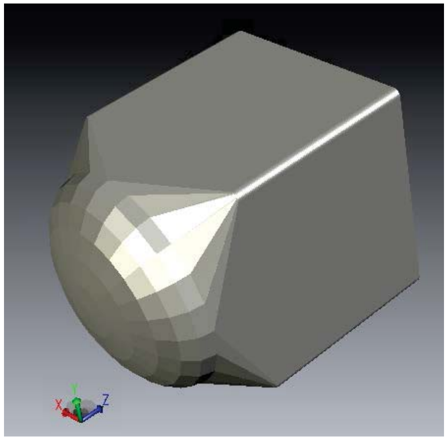
- Three mission phases are identified: 1. Deployment, 2. Targeting, and 3. Planetary Entry.



MIRCA

- Micro Return Capsule.
- First PEP re-entry demonstrator for CAPE.
- Currently being designed and implemented at NASA GSFC. Future partnerships possible.
- Fiscal Year (FY) 2014 primary objectives were to verify MIRCA's avionics architecture and aerodynamic stability.
- Accomplishments this year include:
  - Completion of avionics architecture and select electrical interface testing
  - Software system loading
  - Design and manufacturing of the vehicle's aeroshell structure prototype
  - Preliminary qualification of the vehicle's aerodynamic performance (by analysis).

MIRCA PEP prototype current aeroshell design



CAPE-MIRCA

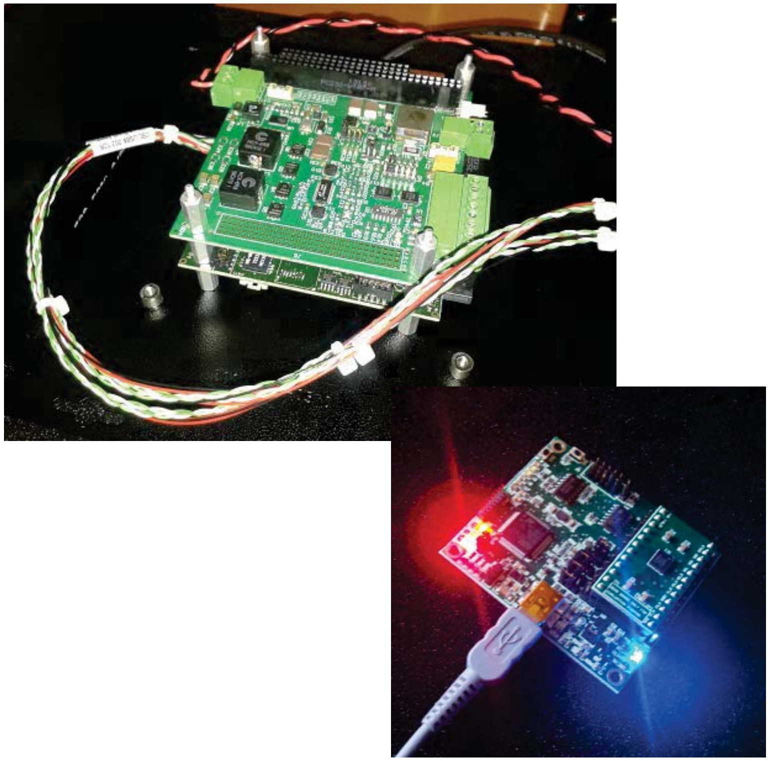
- Mission Objective: use the Low Earth Orbit (LEO) environment to demonstrate key operational aspects involved in de-orbit and atmospheric entry of a miniature planetary probe.
- Potential for university participation, bringing students and organizations with limited resources within the realm of planetary exploration.
- Expected to be ready for orbital demonstration in the 2016 time-frame.

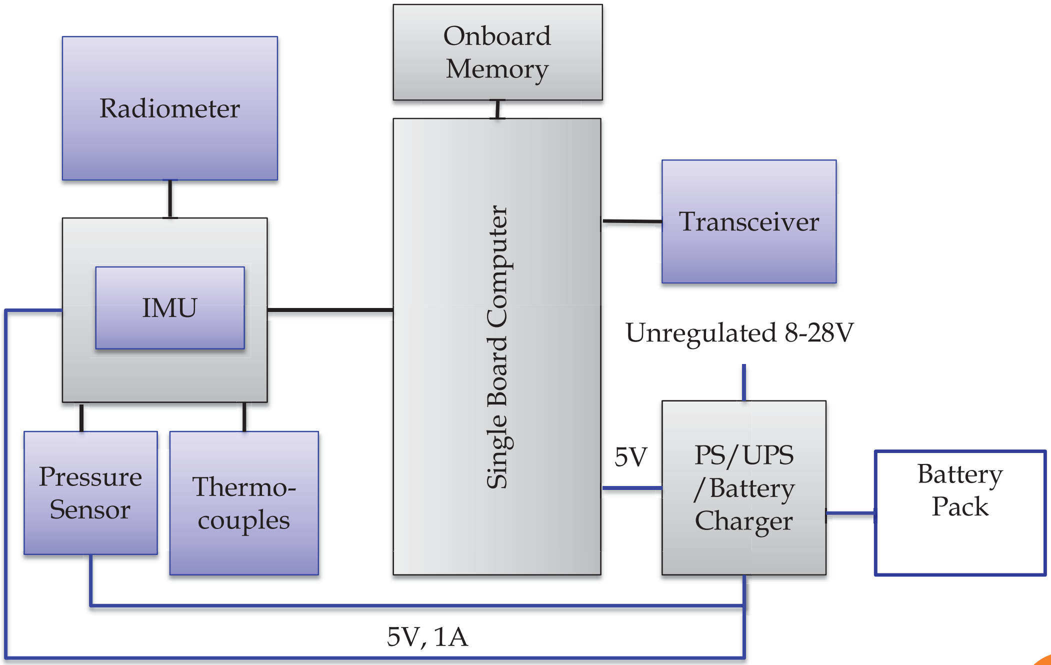
MIRCA Design Concept

- The aeroshell design is driven by the Cubesat form-factor constraints.
- The subsystem arrangement is defined by the requirement to situate the CG as much forward of the CP as possible to satisfy static stability conditions.
- Sensors included are
  - Radiometer
  - Thermocouples
  - Pressure Transducer
  - Three-axis acceleromenter
  - Three-axis gyroscope

Avionics Architecture

- Electrical Integration and Test (I&T) is nearly complete, with Processor and power boards, and battery pack fully tested. The Inertial Measurement Unit (IMU) has been tested individually, and is operational. Linux has been loaded and tested, and will be the basis for the flight software.





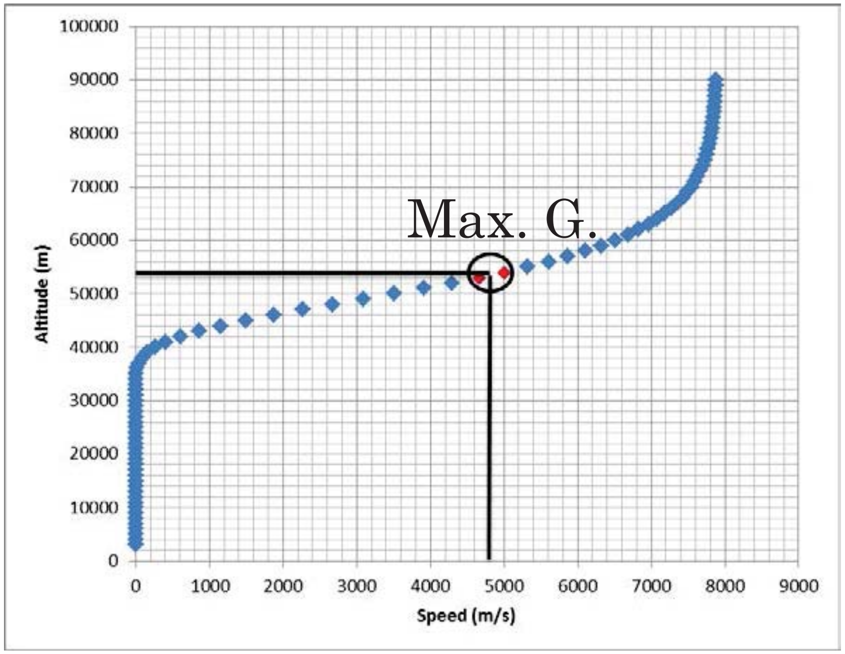
MIRCA Aerodynamics

- Flight stability is one of the most important aspects in MIRCA's performance since it affects heating, communications, and in the end, mission success.
- To estimate stability, Computational Fluid Dynamics (CFD) analysis was carried out for three different cases (prototype vehicle):
  - Drop from balloon
  - Drop from suborbital sounding rocket
  - Drop from LEO orbit
- These are cases that will serve to qualify the vehicle for planetary entry beyond Earth.
- Aero-thermal differences are a given, and will be modeled based on results from MIRCA's test plan.

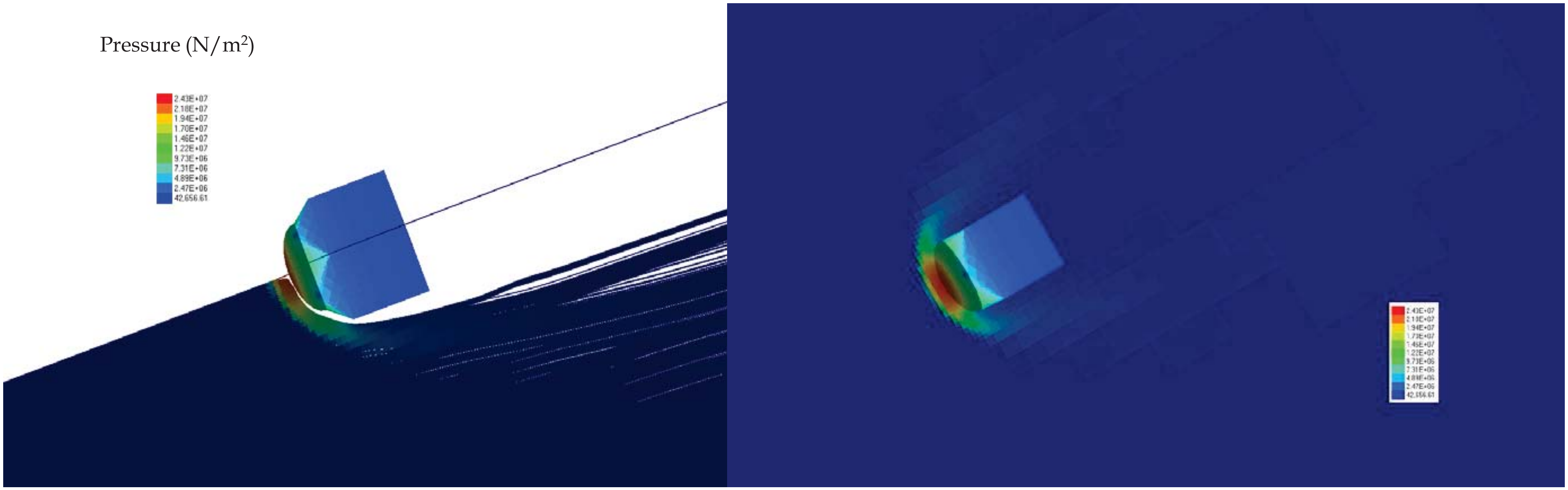
Aerodynamic / CFD Analysis – LEO Re-Entry

- Peak boundary conditions obtained from LEO entry at max. g-loading – Aerodynamic analysis using Navier-Stokes Equations at point of maximum deceleration:
  - Speed 4792 m/s (~ Mach 15)
  - Altitude 53374 m
  - Zero Initial Spin Rate
  - Medium: Air, zero angle of attack
  - Radiation Boundary Conditions

Re-Entry Trajectory



Pressure distribution and Aerodynamic Coefficients

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AERODYNAMIC COEFFICIENTS
Force Coefficients
   Lift Coefficient: -0.000255
   Side Force Coefficient: 0.000194
   Pressure Drag Coefficients: -0.534
   Lift-to-Drag Ratio: 0.000477

   Related Force Coefficients:
   CFx: -0.534
   CFy: 0.000194
   CFz: -0.000255

Moment Coefficients (about CG Reference)
   Pitching Moment Coefficient: -1.66E-06
   Roll Coefficient: -6.49E-05
   Yaw Coefficient: -3.17E-05
   Related Moment Coefficients:
   CMx: -6.49E-05
   CMy: -1.66E-06
   CMz: -3.17E-05
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AERODYNAMIC FORCES AND MOMENTS
Surface Forces
   Lift Force is: -0.0218 N (-0.0049 lbs)
   Side Force is: 0.0166 N (0.00372 lbs)
   Pressure Drag Force is: -45.69 N (-10.27 lbs)

   Related Aerodynamic Forces
   FX: -45.69 N (-10.27 lbs)
   FY: 0.0166 N (0.00372 lbs)
   FZ: -0.0218 N (-0.0049 lbs)

Moments (about CG Reference Point)
   Pitch: -1.92E-05 N-m (-1.42E-05 lbs-ft)
   Roll: -0.00075 N-m (-0.000553 lbs-ft)
   Yaw: -0.000366 N-m (-0.00027 lbs-ft)

   Related Moments
   Mx: -0.00075 N-m (-0.000553 lbs-ft)
   My: -1.92E-05 N-m (-1.42E-05 lbs-ft)
   Mz: -0.000366 N-m (-0.00027 lbs-ft)

   The Reference Area is: 0.0152 m^2 (0.164 ft^2)
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- Aerodynamic coefficients show a stable flight for zero AOA. Flow-field turbulence not prevalent for stable flight (but turbulence is a given for non-zero AOA). Pressure drag force at stagnation point ~ 3 x Weight

CFD Conclusions

- Vehicle static stability appears sound.
- Dynamic stability and turbulence effects may still be a concern, especially if the initial attitude has non-zero AOA.
- Restoring forces will take effect eventually, but high-altitude aerodynamic heating at off-nominal AOAs could be significant during re-entry.
- A small vehicle spin for initial gyroscopic stability should take care of the initial flight stage.

Summary and Outlook

- CAPE enables a broad new class of planetary entry and in situ missions, and brings planetary exploration capability to resource limited organizations, including universities and small businesses.
- GSFC is demonstrating the operational scenario involved in deploying a micro-probe in a planetary environment.
- MIRCA will serve to demonstrate the first Cubesat-sized entry vehicle.
- Continuing work in FY15, with an in-air flight demonstration of MIRCA's operational protype.
- Collaboration is possible in the future.