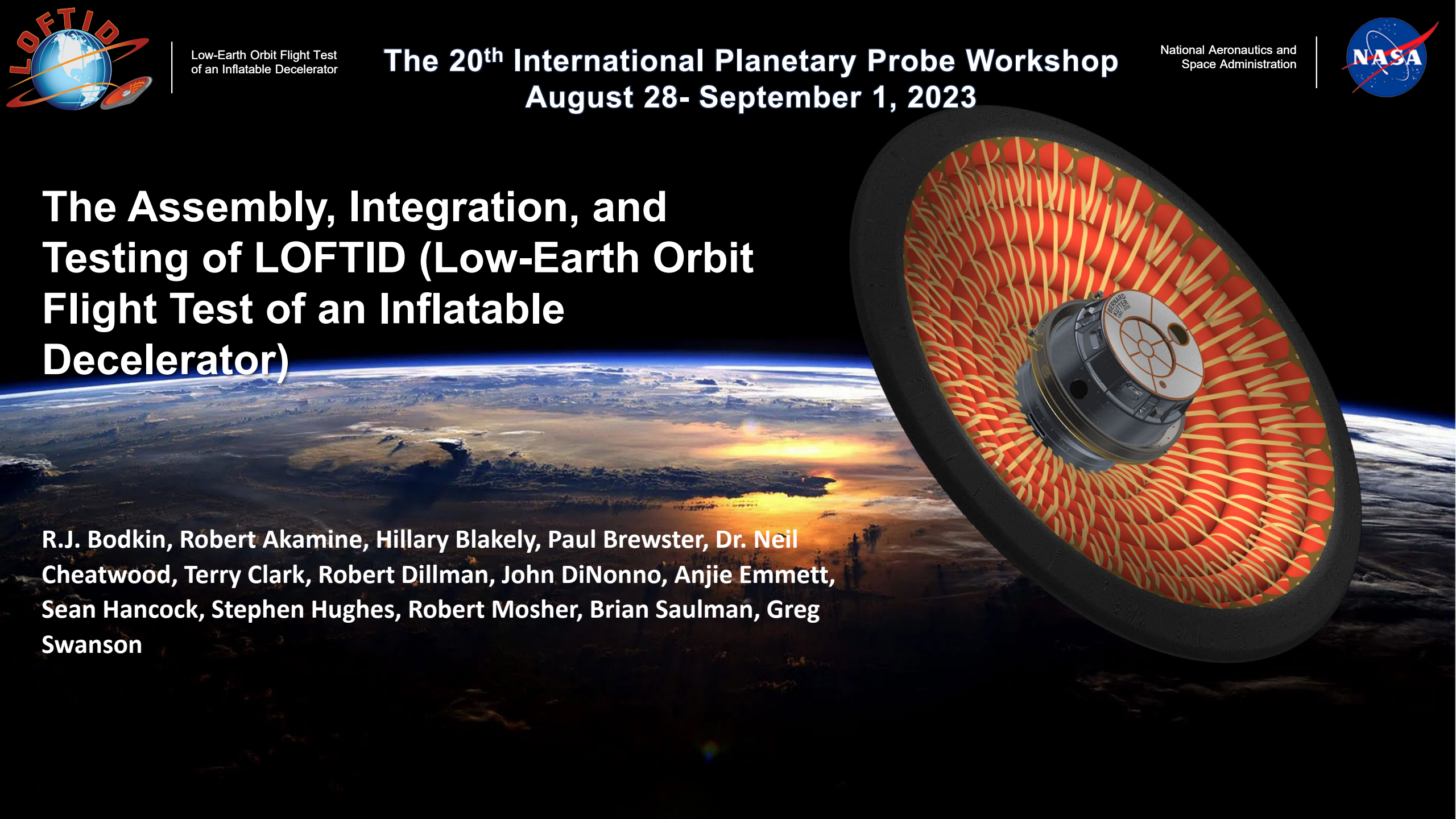


Low-Earth Orbit Flight Test of an Inflatable Decelerator

The 20th International Planetary Probe Workshop
August 28- September 1, 2023

National Aeronautics and Space Administration

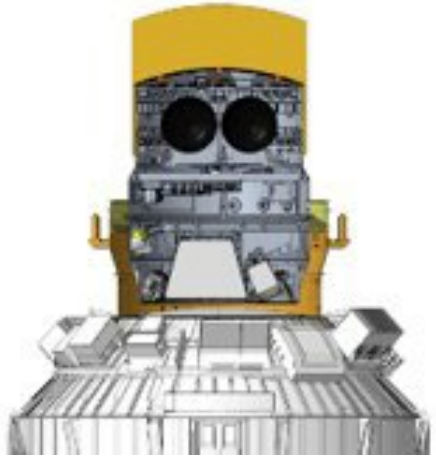
NASA

The Assembly, Integration, and Testing of LOFTID (Low-Earth Orbit Flight Test of an Inflatable Decelerator)

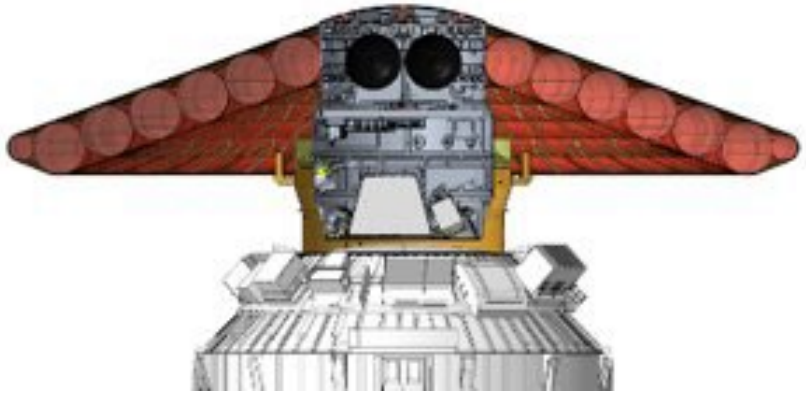
R.J. Bodkin, Robert Akamine, Hillary Blakely, Paul Brewster, Dr. Neil Cheatwood, Terry Clark, Robert Dillman, John DiNonno, Anjie Emmett, Sean Hancock, Stephen Hughes, Robert Mosher, Brian Saulman, Greg Swanson

LOFTID States

- LOFTID attached to Centaur with PASS over LOFTID after JPSS2 Deployment



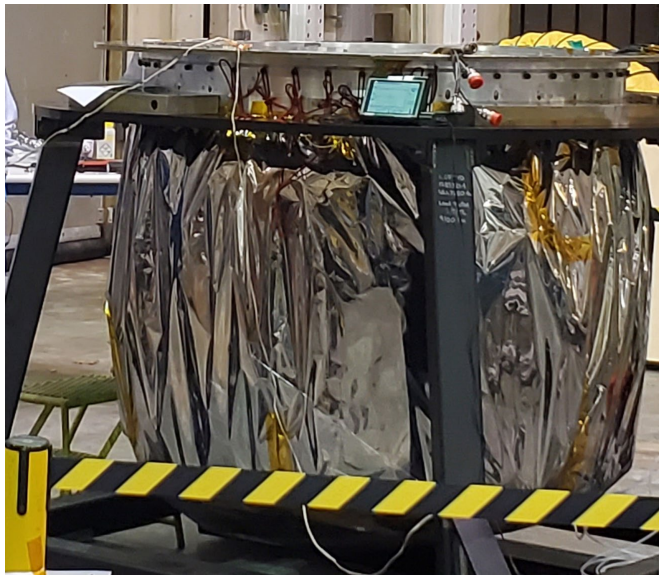
- LOFTID attached to Centaur after PASS was jettisoned



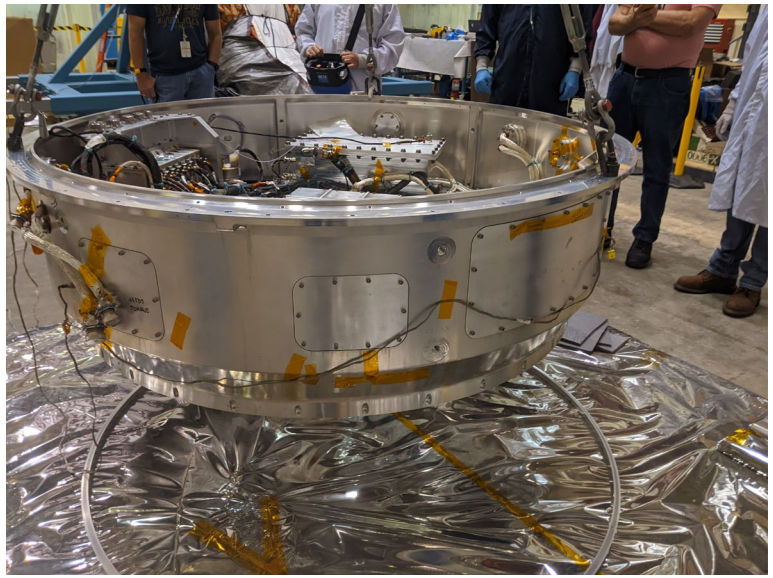
- LOFTID attached to Centaur after aeroshell inflation just prior to separation

Re-Entry Vehicle (RV) Segments

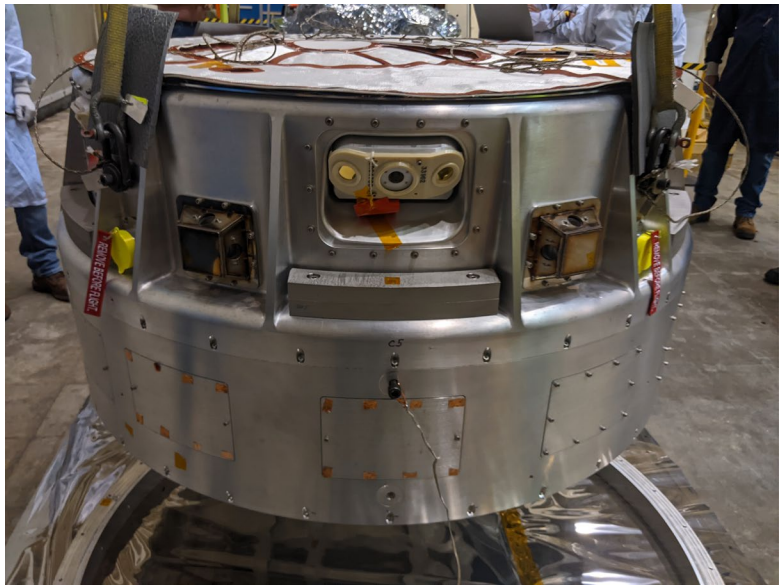
- **Forward Interface**
  - Forward Segment Radax Joint
  - Inflation System and Mid-Segment Pass-Thru
  - Aeroshell interface
  - EDU with Flight Inflation System Proto-Flight Vibration Tested
  - Flight unit Acceptance Vibration Tested



- **Mid Interface**
  - Forward Segment Radax Joint
  - Aft Segment Radax
  - Electrical pass throughs
  - RV/LV interface
  - Proto-Flight Vibration Tested

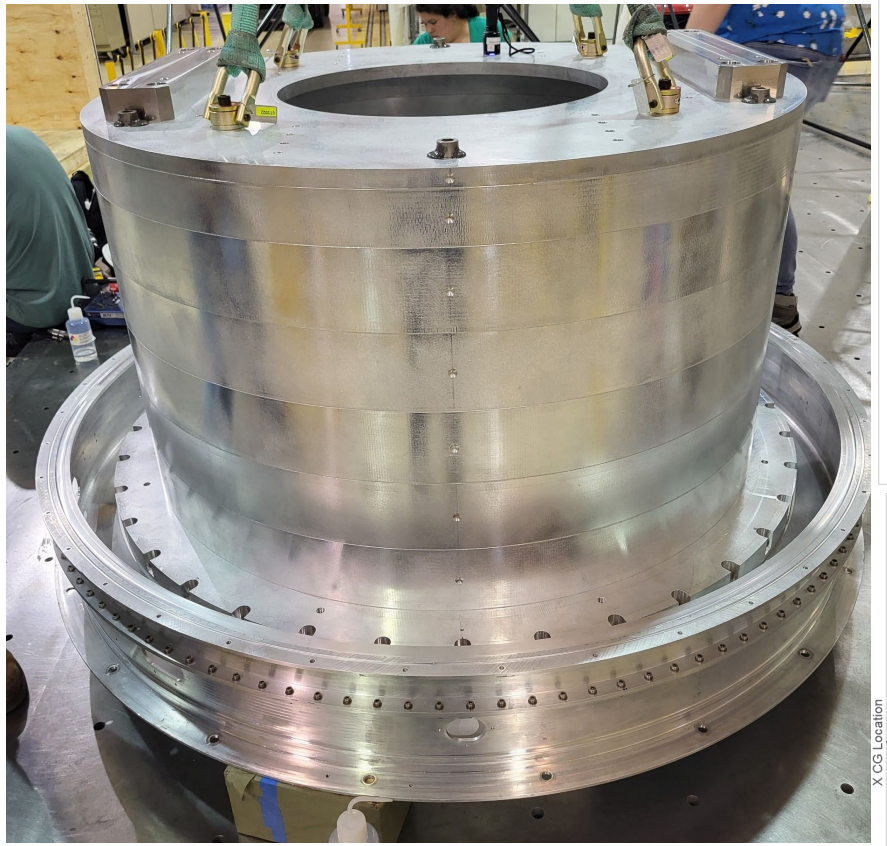


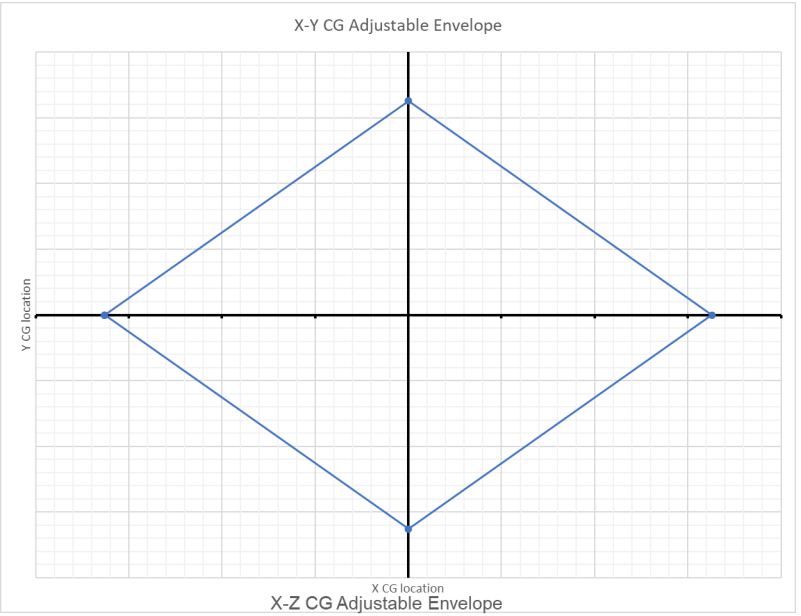
- **Aft Interface**
  - Aft Segment Radax Joint
  - Parachute System
  - Recovery Aids
  - Camera System
  - Communications Antennas
  - Proto-Flight Vibration Tested



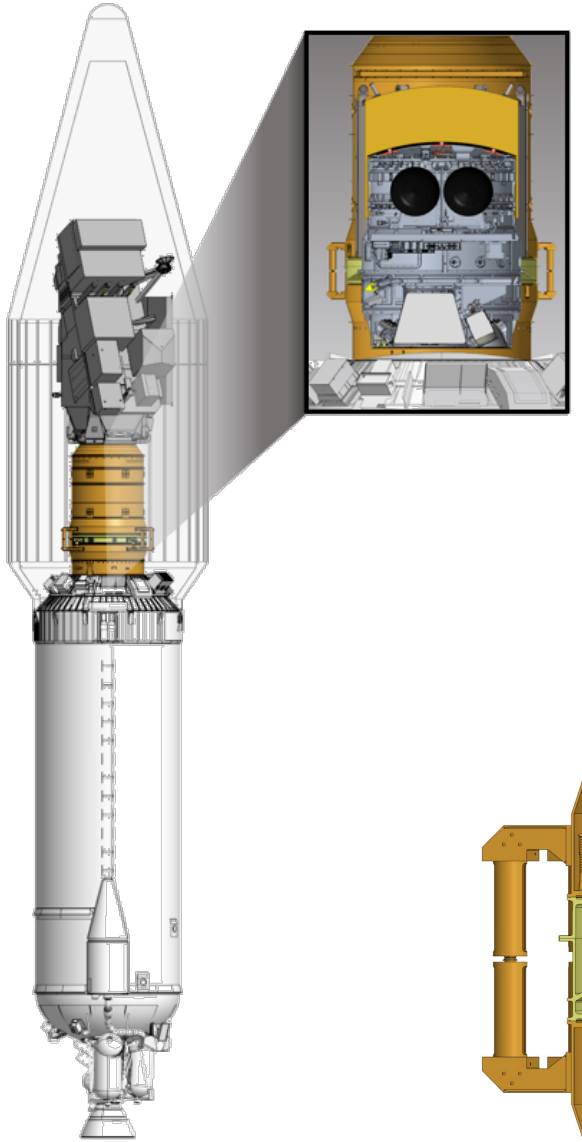
Mass Simulator

- Was required in the event Re-entry Vehicle (RV) suffered a late issue and was unable to launch
- Steel and Aluminum structure that used same launch vehicle interface as the RV
- Required to be ready prior to RV assembly
- Required large CG adjustment Range
- Sine Vibration Tested

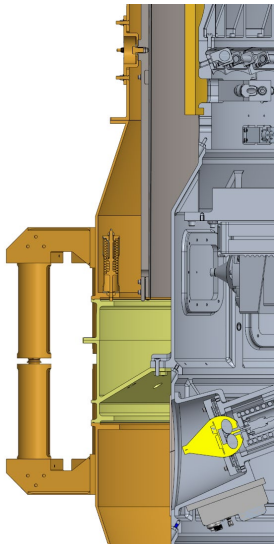


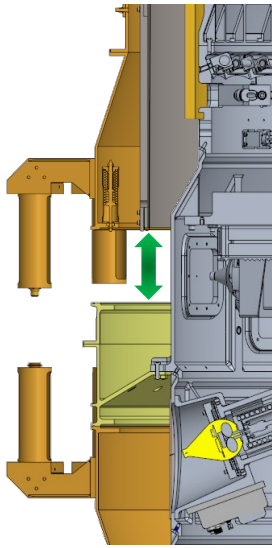


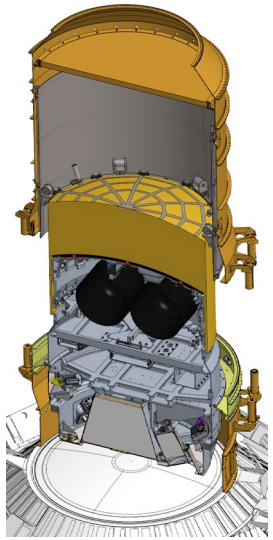
Payload Adapter Separation System (PASS) Overview



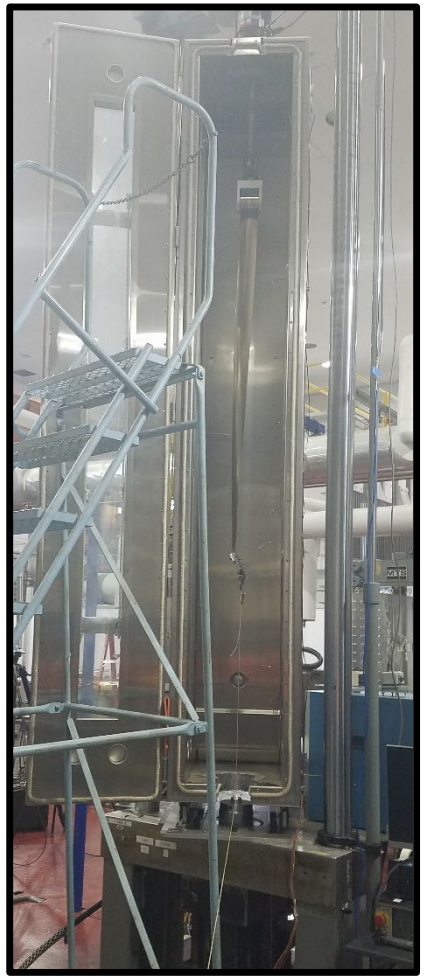
- **LOFTID rideshare configuration necessitated separation of JPSS-2 Payload Adapter Canister prior to start of LOFTID mission**
- **Joint ULA / NASA design effort**
  - Utilized ULA 1666S Separation System
  - NASA Long Stroke Separation System
    - 6x Constant Force Springs to provide positive force margin for full separation
    - Webbing to react spring force against stowed aeroshell
    - Inner Shroud to prevent damaging contact between PLA and stowed aeroshell



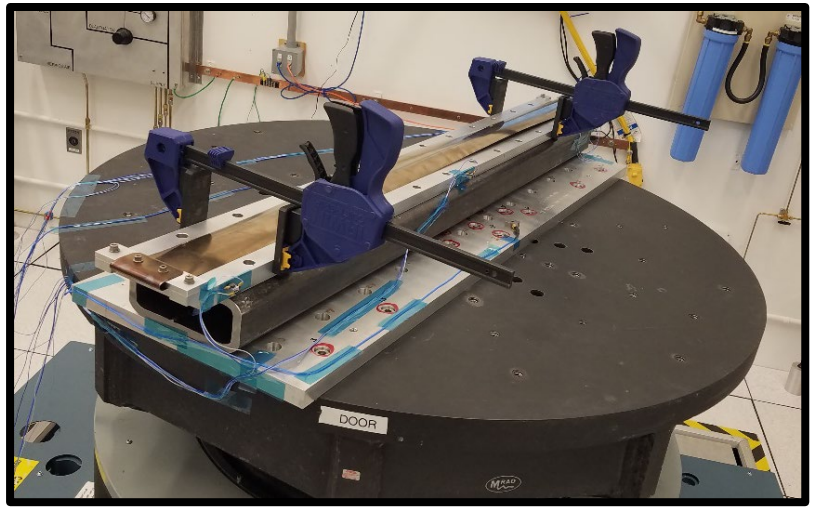


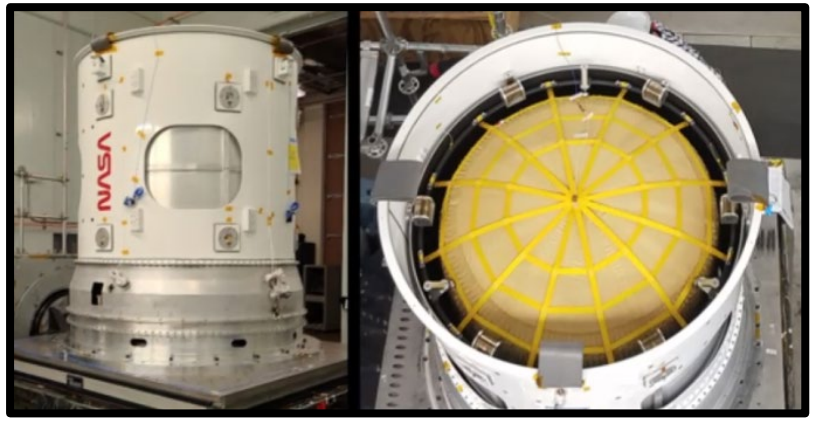


Integration & Testing



Spring Characterization





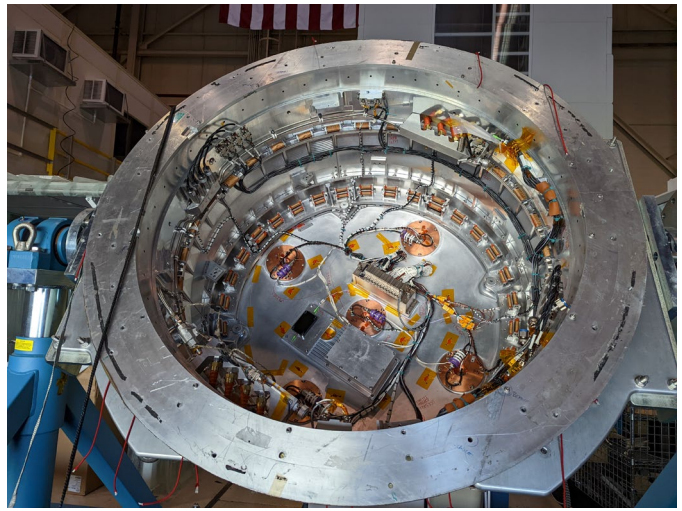
Random Vibe

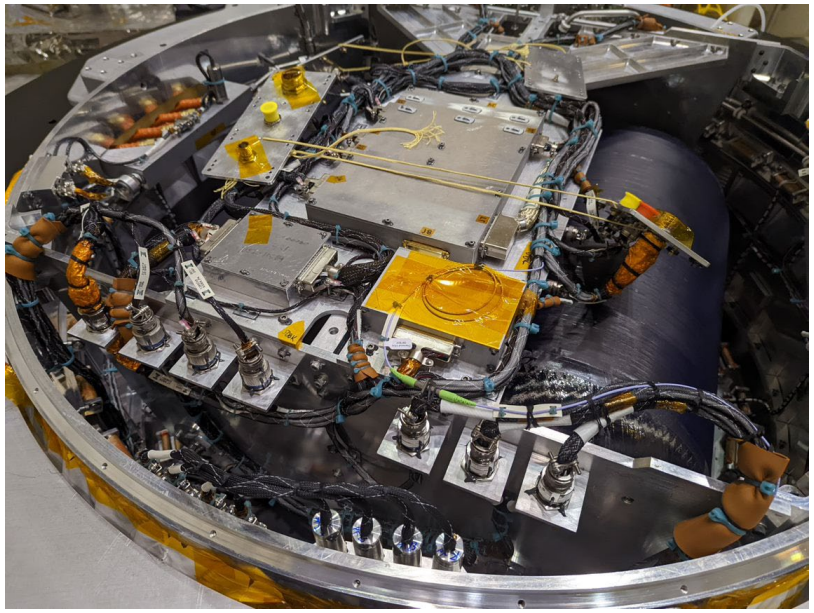
- **EDU Qualification Testing**
  - Constant Force Spring Sine Vibration
  - Constant Force Spring Characterization
  - 24 Mechanism Tests (including spring-out tests)
  - ADAMS predictive model correlation
  - Prototype Qualification Random Vibration
- **Flight Qualification Testing**
  - Constant Force Spring Characterization
  - 6 Mechanism Tests
  - ADAMS predictive model correlation
  - Prototype Acceptance Random Vibration

Mechanism Testing

Forward Segment

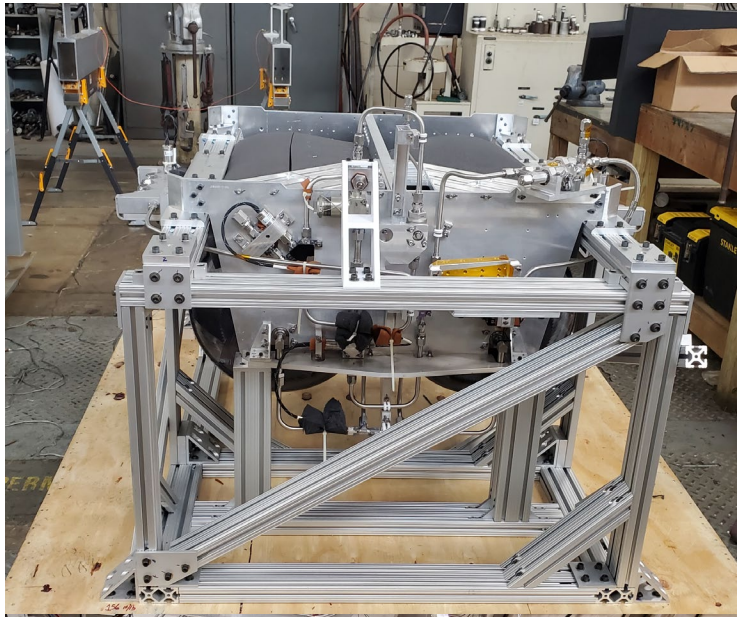
- **Electrical Integration and Checkout**
  - Contains data acquisition unit for aeroshell data
    - Technicians crimped and mated the ~150 instruments to the hardware
  - Test computers mated to the hardware verified basic instrument functionality
- **Provides interface for Aeroshell**
- **Inflation System resides in Forward Segment**

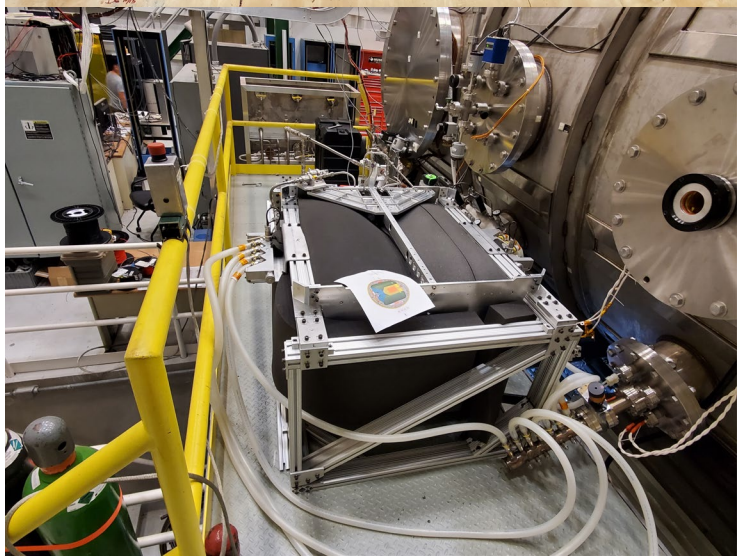




Inflation System Testing

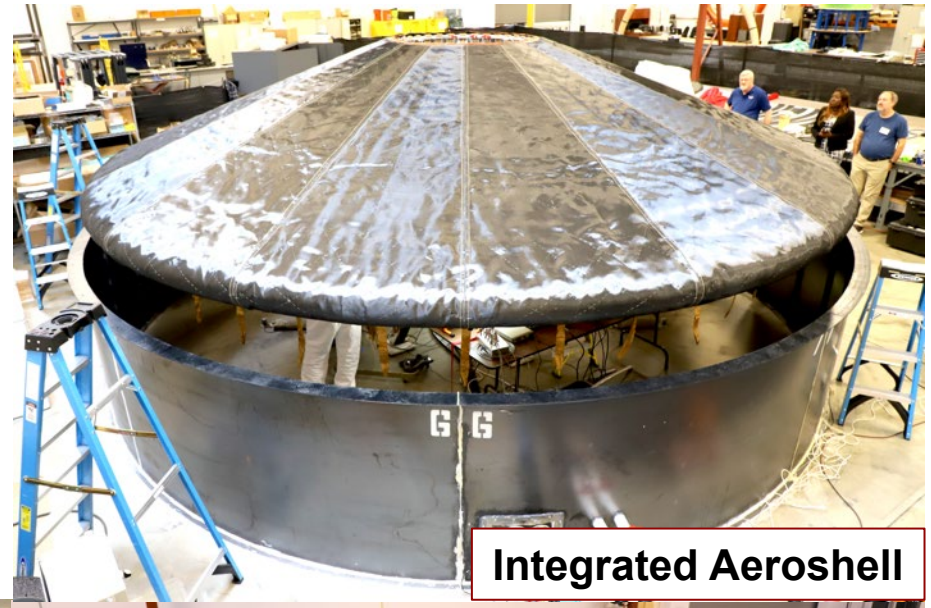
- **Performed initial settings at component level**
  - Regulators
  - Relief Valves
  - Valves
- **Modified Avionics**
  - FPGA HDL code modified for LOFTID operational parameters and modeled in simulation test benches
  - Components functionally tested with tabletop lab equipment and the deployed Inflation System Test Rack
  - Thermal cycle, thermal vacuum, and random vibe performed on components (when feasible)
- **After assembly flow testing in Sea Level Static (SLS) and into a Vacuum reservoir**
- **Testing with Inflatable Volume Simulators**





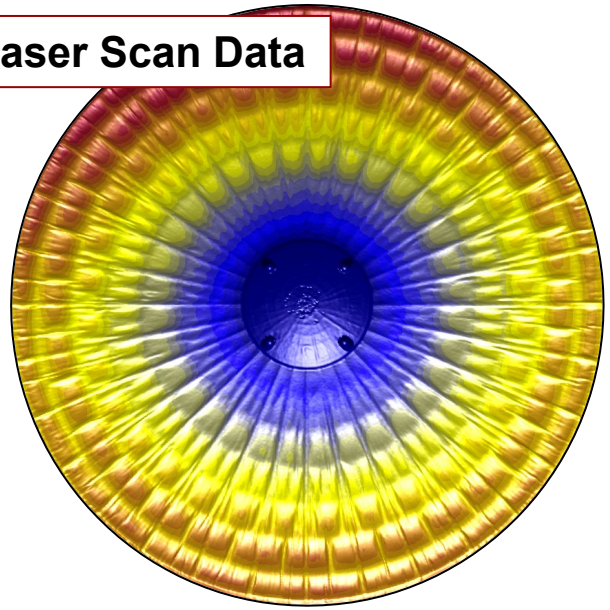
Static Load Testing – Integrated Aeroshell

- **FTPS Integrated with Inflatable Structure to Complete Aeroshell**
- **Tested to 1.5x Maximum Expected Load**
  - FTPS provides additional load carrying capacity
  - Carried design load at design Internal Pressure
- **50 Load cell Measurements**
- **8 String Potentiometers**
- **Laser Scans at each Load Case**

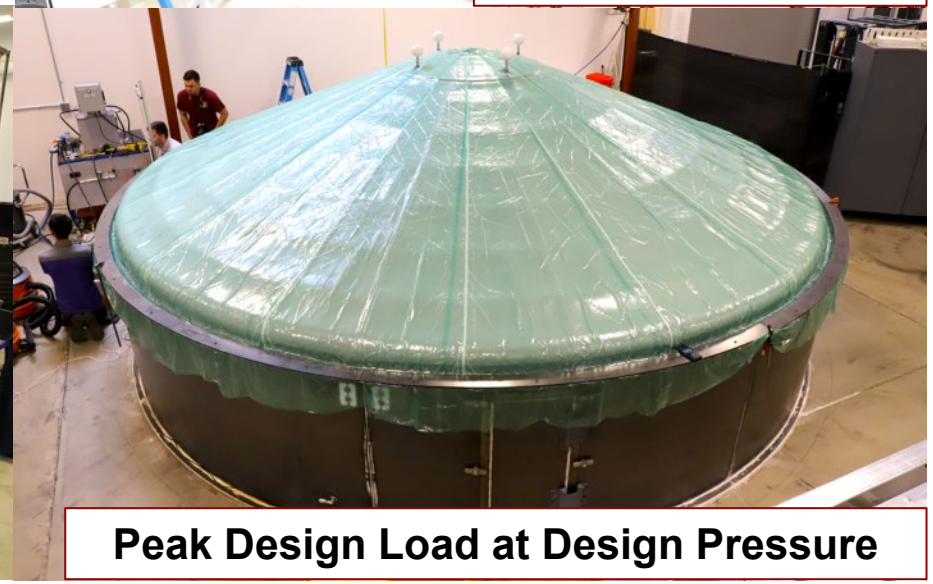


Integrated Aeroshell

Laser Scan Data

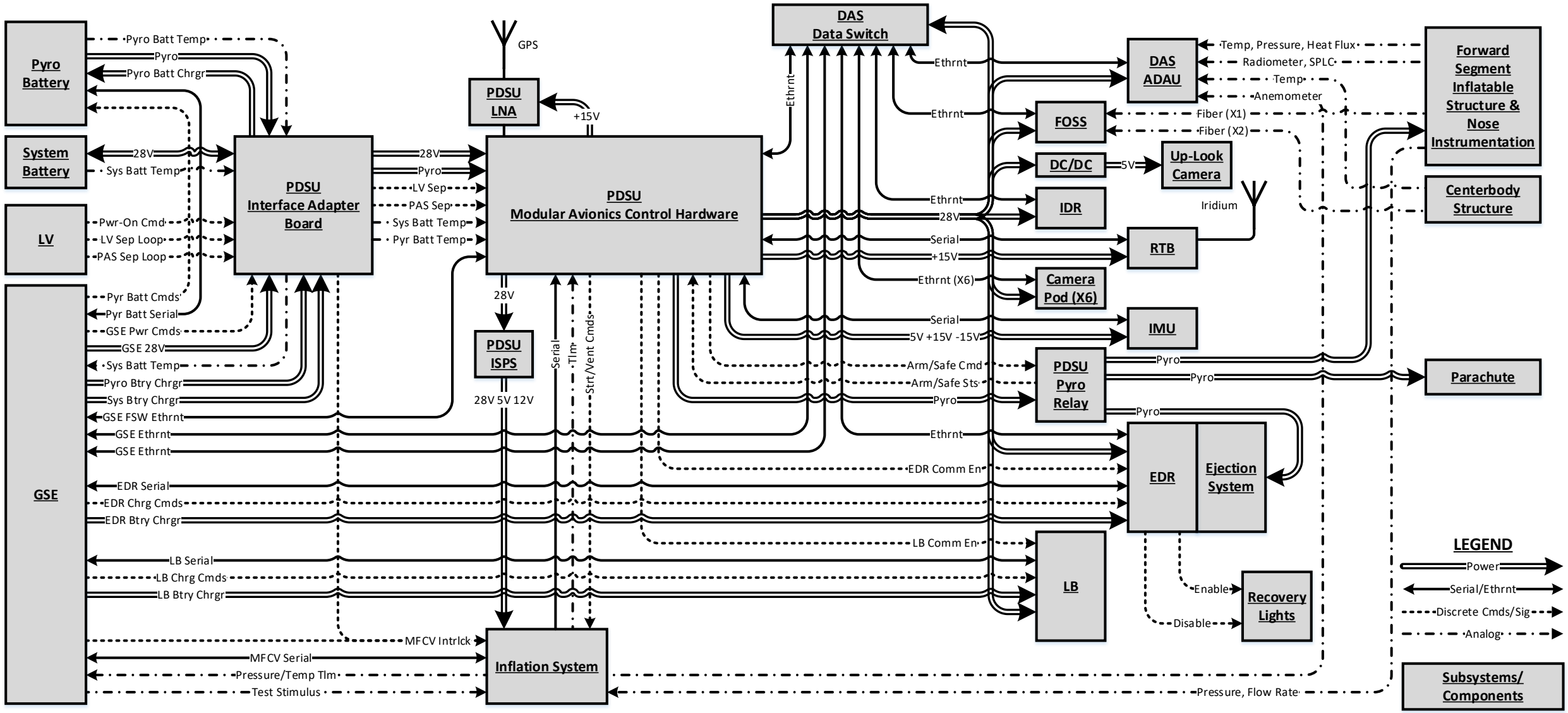


Integrating FTPS



Peak Design Load at Design Pressure

Avionics

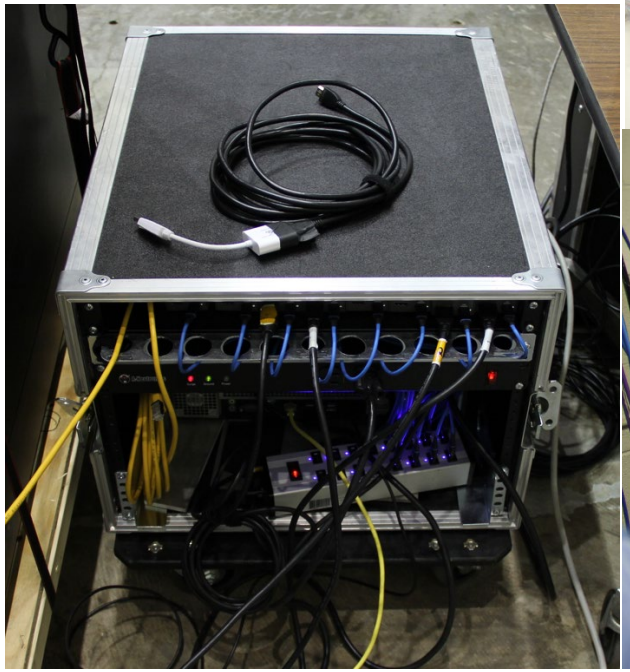

Pyro Battery
Pyro Batt Temp
Pyro
Pyro Batt Chrgr
System Battery
28V
Sys Batt Temp
LV
Pwr-On Cmd
LV Sep Loop
PAS Sep Loop
GSE
Pyr Batt Cmds
Pyr Batt Serial
GSE Pwr Cmds
GSE 28V
Sys Batt Temp
Pyro Btry Chrgr
Sys Btry Chrgr
GSE FSW Ethrnt
GSE Ethrnt
GSE Ethrnt
EDR Serial
EDR Chrg Cmds
EDR Btry Chrgr
LB Serial
LB Chrg Cmds
LB Btry Chrgr
MFCV Intrlck
MFCV Serial
Pressure/Temp Tlm
Test Stimulus
PDSU Interface Adapter Board
28V
Pyro
LV Sep
PAS Sep
Sys Batt Temp
Pyr Batt Temp
GPS
PDSU LNA
+15V
PDSU Modular Avionics Control Hardware
28V
PDSU ISPS
28V 5V 12V
Serial
Tlm
Strt/Vent Cmds
Inflation System
DAS Data Switch
Ethrnt
Ethrnt
Ethrnt
Ethrnt
28V
Serial
+15V
Ethrnt (X6)
Serial
5V +15V -15V
Arm/Safe Cmd
Arm/Safe Sts
Pyro
Ethrnt
EDR Comm En
LB Comm En
DAS ADAU
Temp, Pressure, Heat Flux
Radiometer, SPLC
Temp
Anemometer
FOSS
Fiber (X1)
Fiber (X2)
DC/DC
5V
Up-Look Camera
IDR
Iridium
RTB
Camera Pod (X6)
IMU
PDSU Pyro Relay
Pyro
Pyro
Pyro
EDR
Ejection System
LB
Enable
Disable
Recovery Lights
Forward Segment Inflatable Structure & Nose Instrumentation
Centerbody Structure
Parachute
Pressure, Flow Rate
LEGEND
Power
Serial/Ethrnt
Discrete Cmds/Sig
Analog
Subsystems/ Components

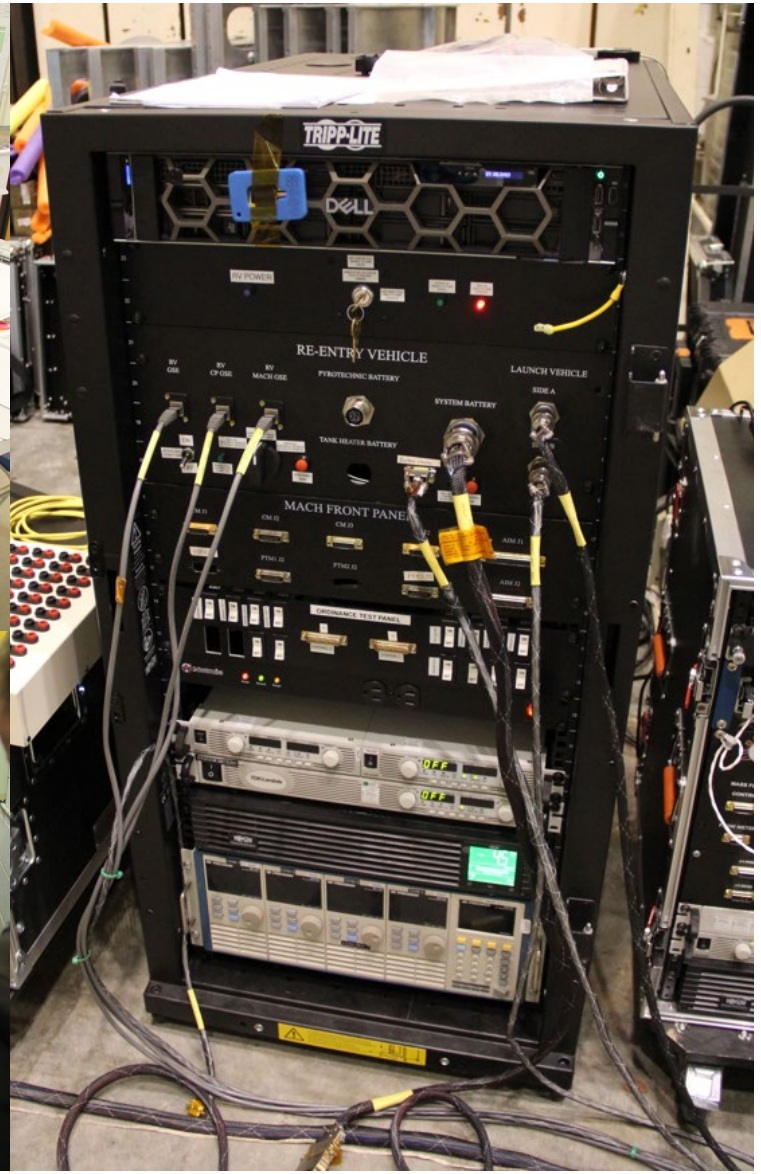
Flight Software Testing

- **MACH Flight Software**
  - Controls Mission Timeline, Power, Pyrotechnics, Data Acquisition, Real-Time Beacon GPS
  - Iterative development in five Build Cycles
  - Each Build Cycle concluded with a peer review and formal testing on Spread System
- **Data Recorder Flight Software**
  - Peer review and formal testing on Spread System
- **Camera Control Software**
  - Developed at MSFC
  - Peer review and formal testing at component level
- **FOSS Software**
  - Developed at AFRC
  - Peer review and formal testing at component level
- **Final Software Acceptance Testing**
  - Build 5 served as the final Acceptance Test with all software components integrated and tested on the Spread System prior to vehicle integration
  - All software changes after Acceptance Testing went through a Control Board Review and were tested on the Spread System before vehicle integration

Avionics EGSE – RV Test Rack

- **RV Test Rack was used for Mid-Segment and RV Level Sequence Testing**
  - Provided external power
  - Simulated Centaur, flight, and internal electrical interfaces
  - Ethernet link to RV for manual software control, telemetry, live video, and data recorder downloading



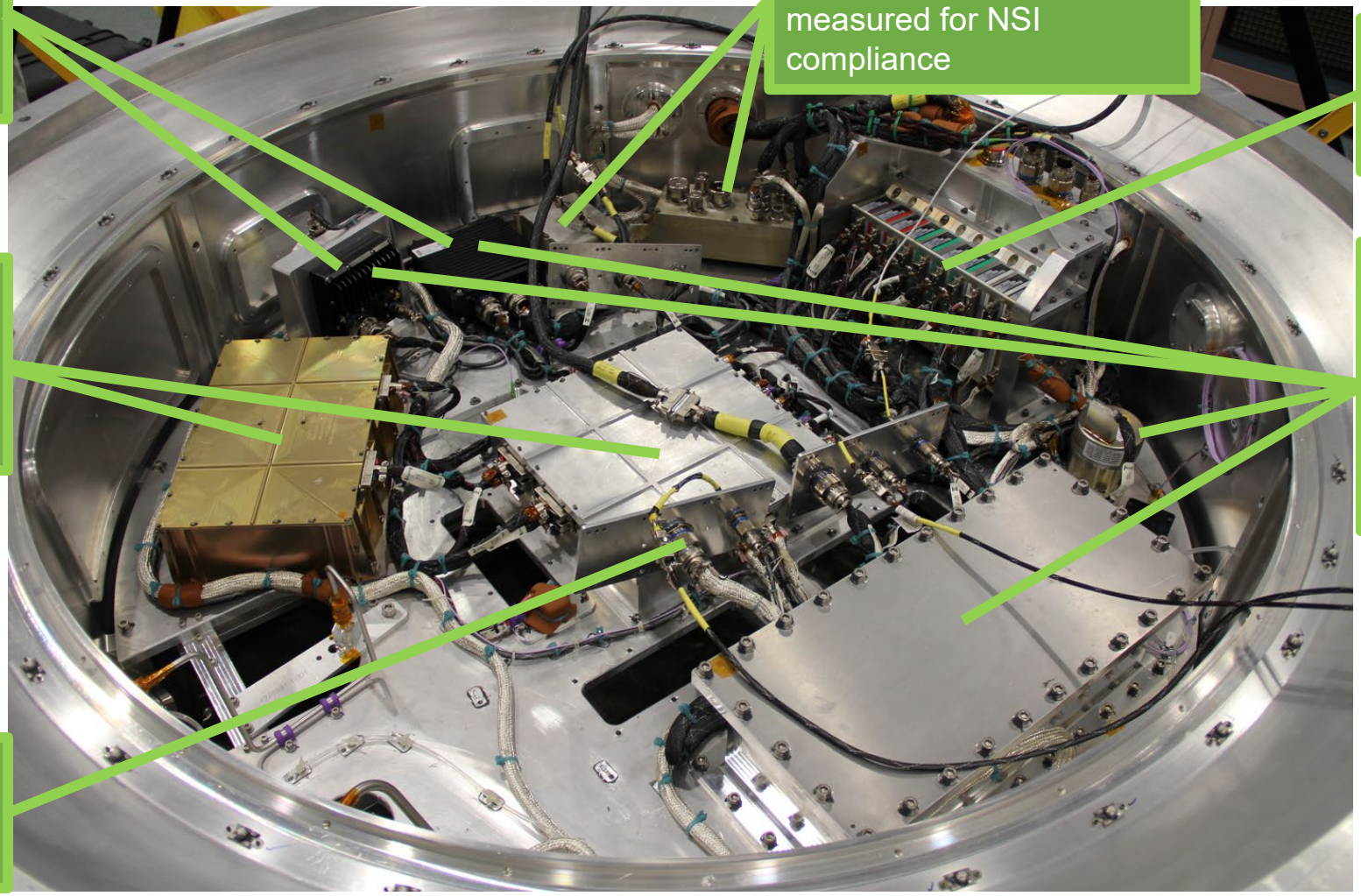


Mid-Segment Testing Overview

6.) Network bandwidth performance is stressed by data simulators which stresses the Network switch and IDR

1.) Critical ordnance firing circuits are tested and measured for NSI compliance

2.) Flight computer initializes and awaits manual commands



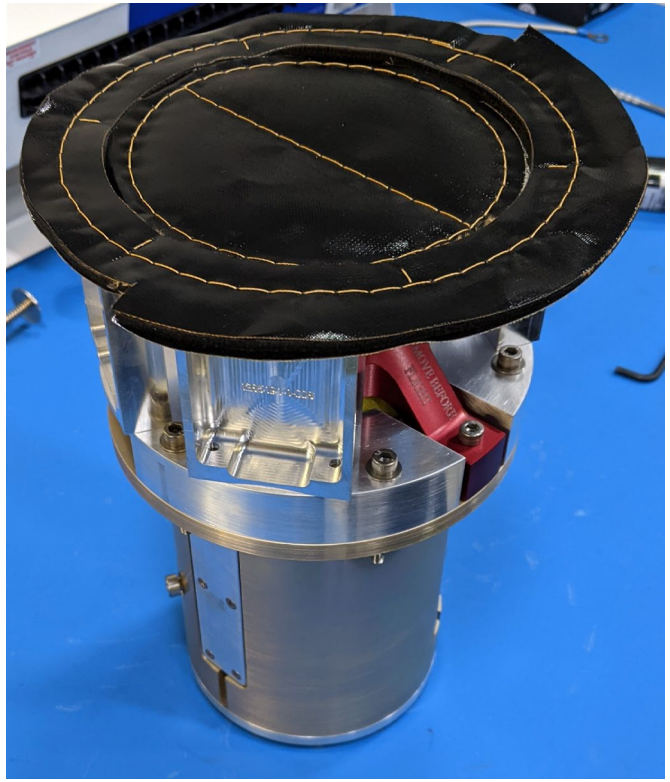
5.) Simulated power on command sent – Relays close to connect the batteries to Avionics – or – use external power

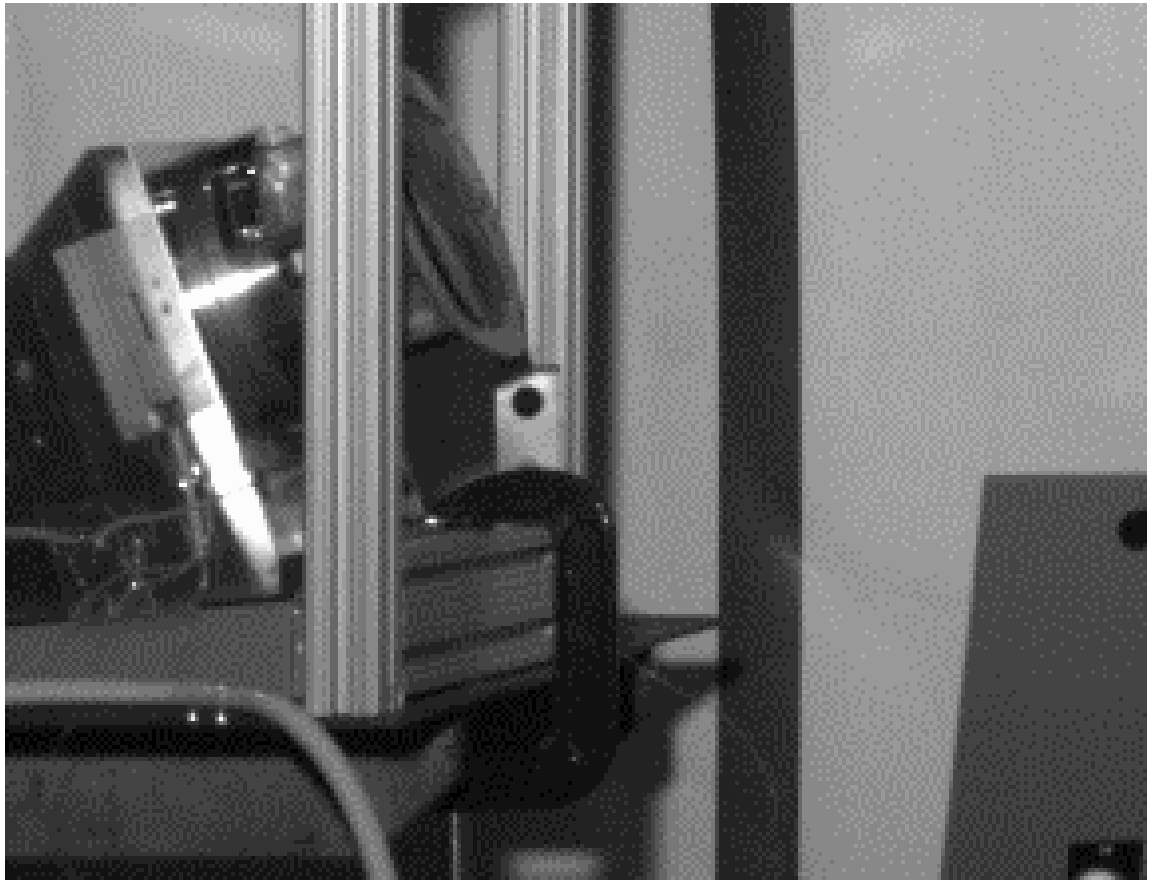
3.) Operators send manual commands to turn on the Network Switch, IDR, FOSS, and other Avionics not in the segment represented by load boxes or simulators

4.) Key commands to the Inflation System are measured at the interface

EDR Ejection Mechanism

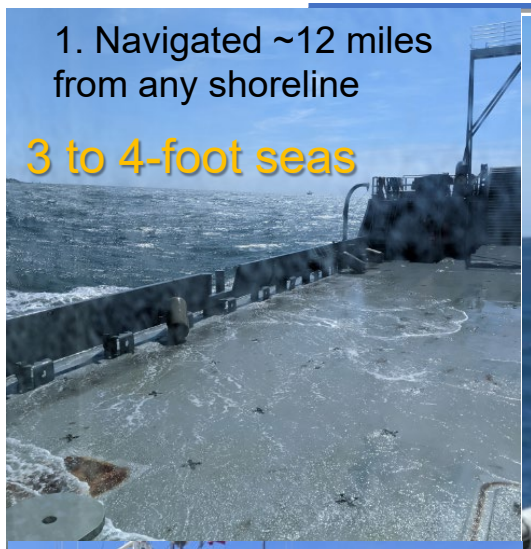
- System Vibration Qualified
- System Tested at Thermal Extremes
- Design life cycle and run-in testing performed





EDM/EDR/Locator Beacon Testing

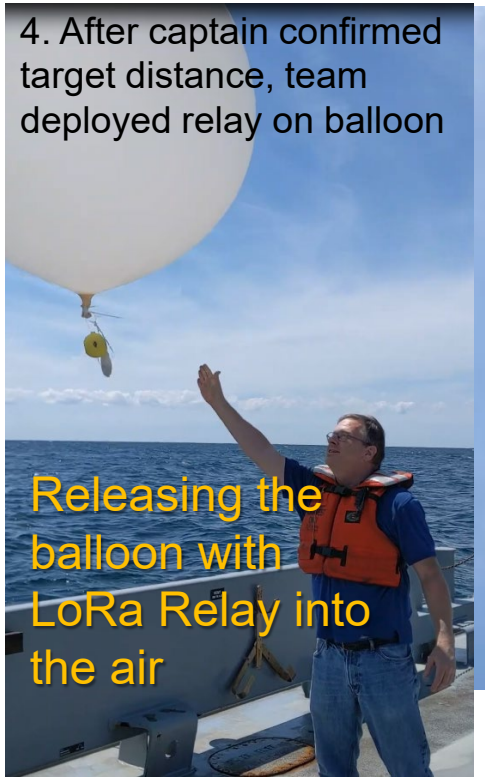
1. Navigated ~12 miles from any shoreline



2. Released EDM, re-verified connection, powered down tracking tools

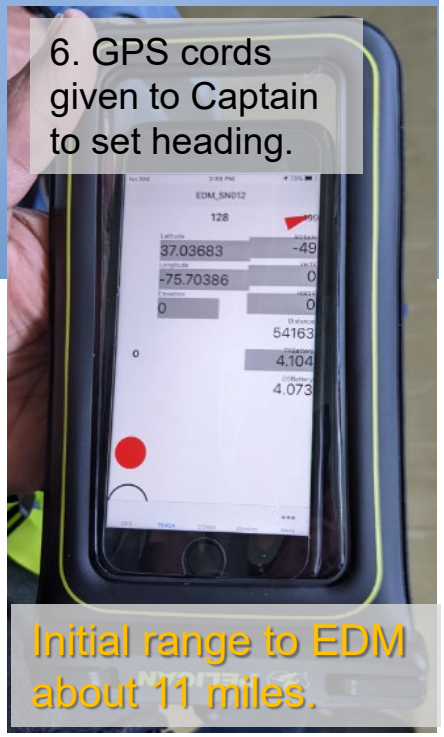
3. Navigated >10 mi from EDM drop point (heading unknown to team)

4. After captain confirmed target distance, team deployed relay on balloon



5. LoRa connection to EDM < 5 minutes after balloon launch.

6. GPS cords given to Captain to set heading.



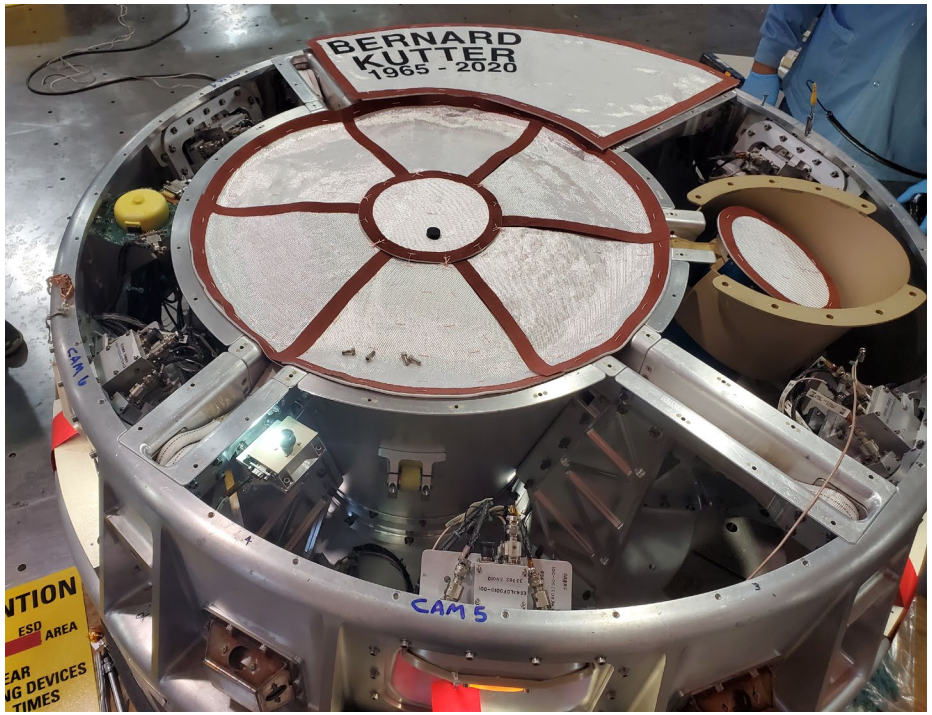
7. GPS cords updated periodically via Iridium and LoRa, given to Captain to update heading.

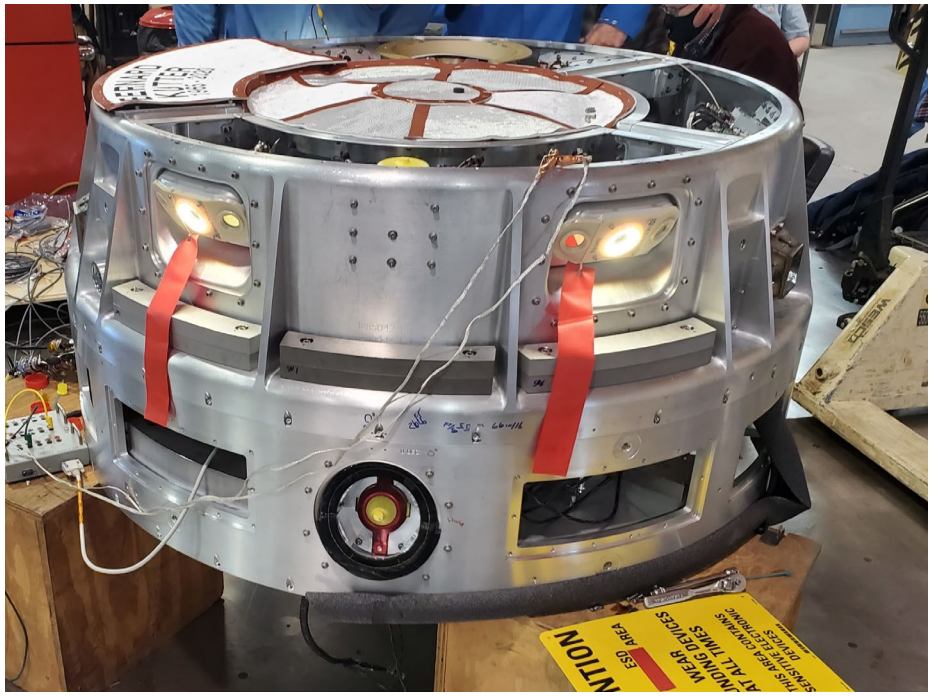
8. At ~2000’ range, slowed boat, posted lookouts.

9. Sighted at ~500’, scooped out from deck.

10. EDM successfully recovered. Returned to shore.

Aft Segment Testing





- Verified Real Time Beacon and Locator Beacon (Iridium) Transmission
- Verified GPS antenna, filter, and amplifier is functional
- Visual and infrared Camera Functions verified
- Recovery Light Functionality and battery charging verified
- Pyro Circuits initiation cables measured and verified
- Ejectable data recorder recording and data recovery functionality demonstrated

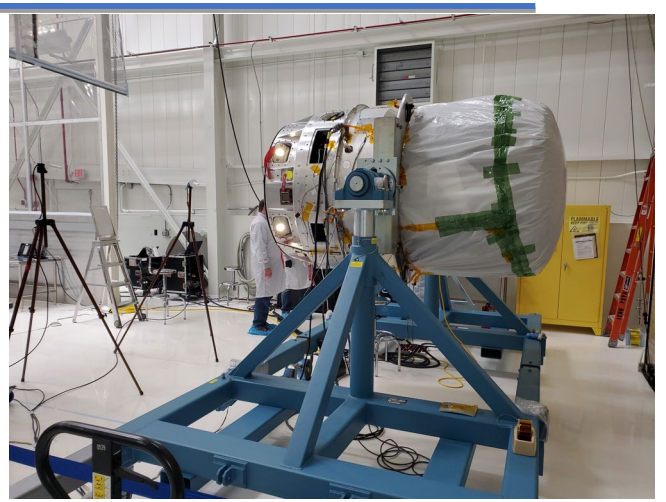
Sequence Testing and Flow Characterization

Sequence Testing

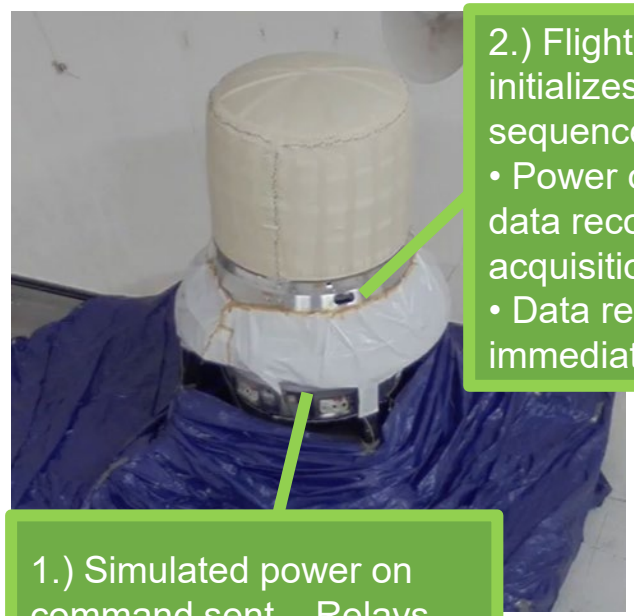
- Flight sequence ran
- RV Test Rack used to simulate launch vehicle interfaces and timing, and monitor RV status
  - Vehicle can be either internal or externally powered during testing
- Inflation system does not flow gas
  - Ran instrument simulation file to verify control response
- Iridium and GPS repeaters used to send and receive signals from/to the RV from outside building

Inflation System Characterization

- Used external pressure source
- Used file for to stimulate flow controller
- Used external flow meter to measure output flow
- Gas flow exited through vent port bypassing stowed aeroshell

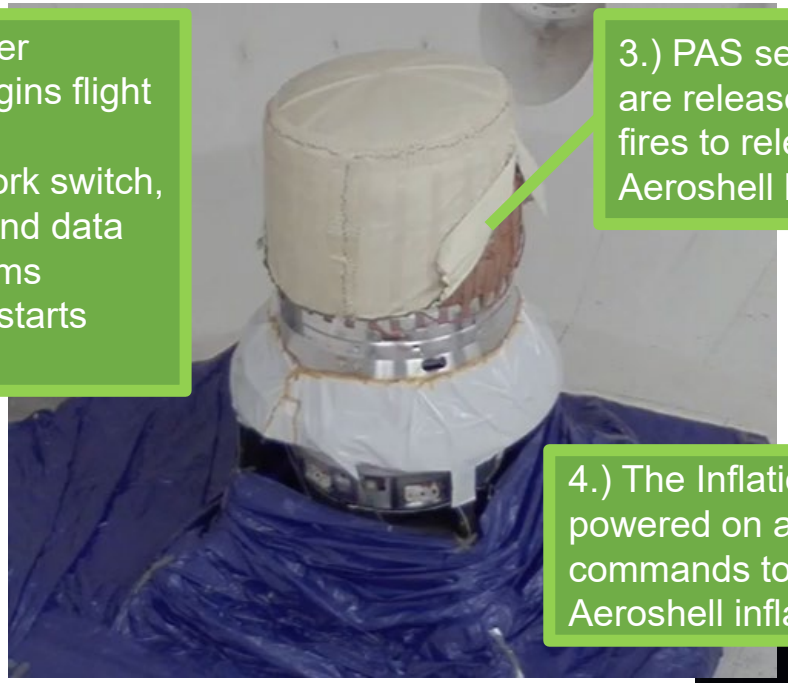


Complete System Test

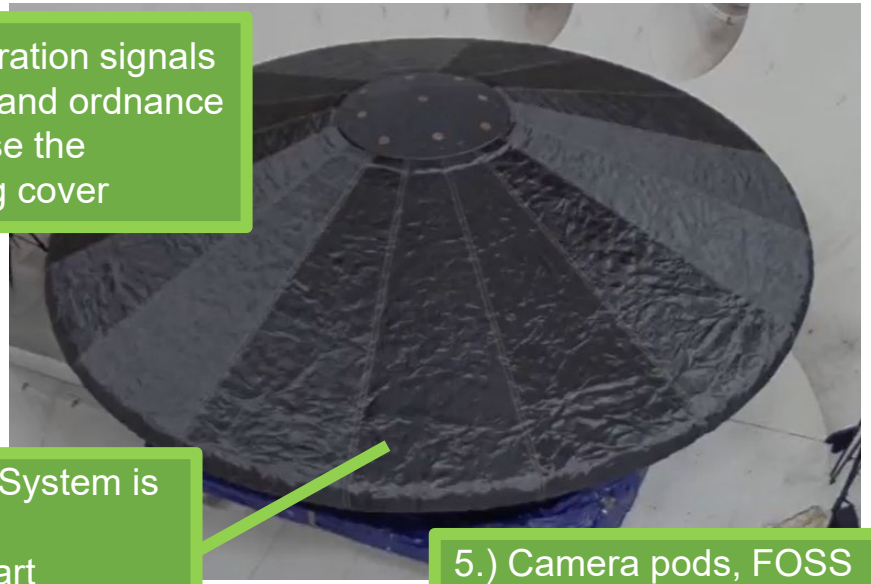


1.) Simulated power on command sent – Relays close to connect the batteries to Avionics

2.) Flight computer initializes and begins flight sequence
- Power on network switch, data recorders, and data acquisition systems
- Data recording starts immediately

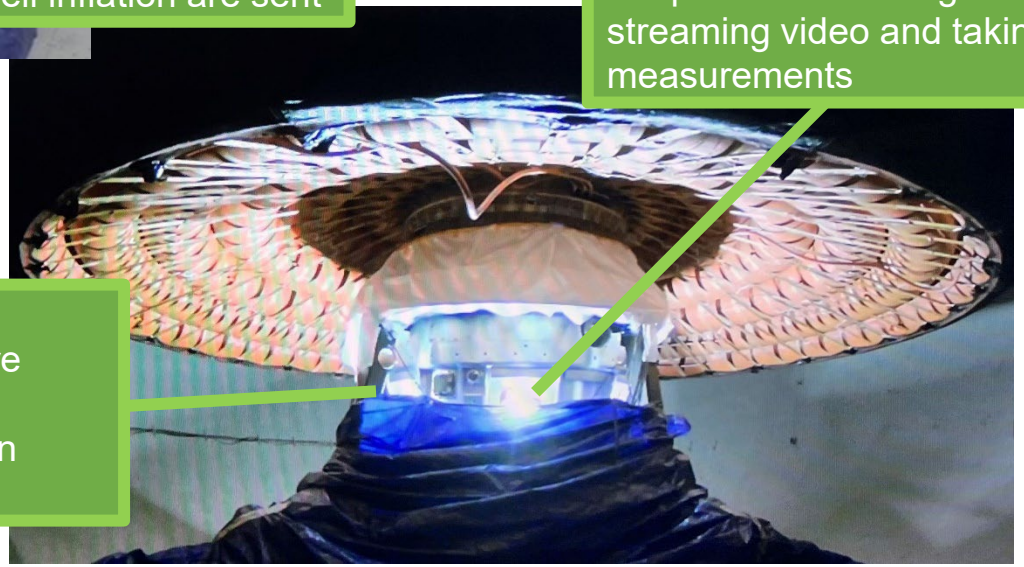


3.) PAS separation signals are released and ordnance fires to release the Aeroshell bag cover



4.) The Inflation System is powered on and commands to start Aeroshell inflation are sent

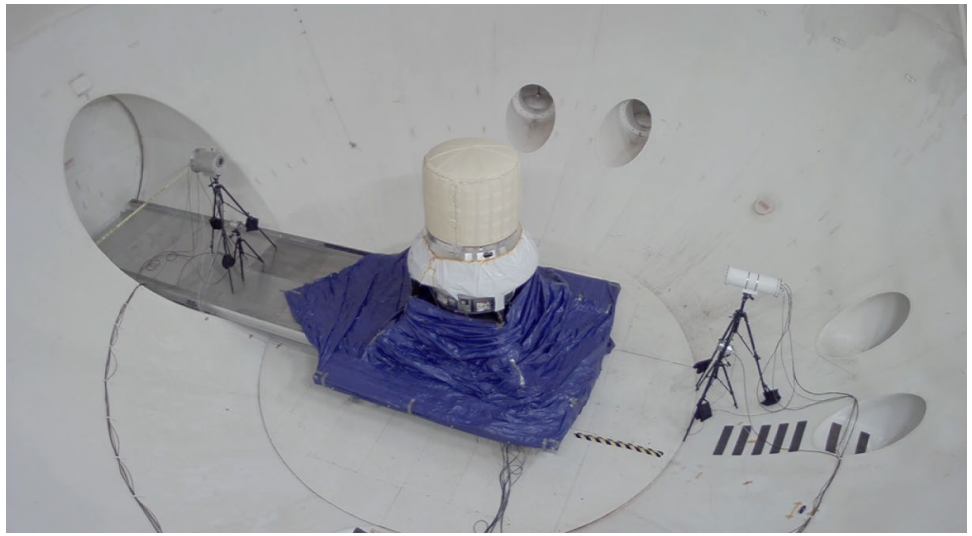
5.) Camera pods, FOSS are powered and begin streaming video and taking measurements



6.) Launch Vehicle separation signals are released and Iridium system is powered on shortly afterwards

Aeroshell CST Deployment Imagery

T=0.0



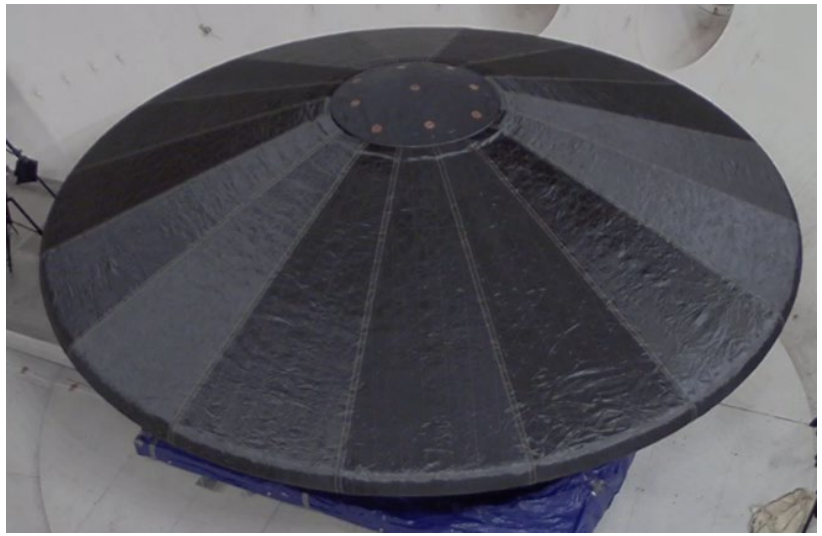
T=0.05

T=0.5

T=34.0

T=36.0

T=210.0 sec



Final Testing and Integration at Vandenberg Space Force Base

- **Final Sequence Testing**
  - RV Test Rack used to provide final checks on flight sequence programming
  - Use repeaters for Iridium and GPS receivers and transmitters
- **Final Flow Testing**
- **Loading Pyrotechnics**
- **Installed launch locks and initial inflation system fill**
- **Hand-off to ULA for Installation of the PASS and mount to launch vehicle**

Brief Mission Results

- **RV Deployed and Released nominally**
- **Inflation System performed nominally**
- **RV survived re-entry**
  - First fully successful Inflatable Aeroshell re-entry from orbital velocity
  - Largest blunt body aeroshell flown
- **Parachute deployed and separated as expected**
- **Iridium data downlink was intermittent and only received after reentry**
  - Iridium was not as reliable as hoped
    - During ground testing was hit or miss if data would be transmitted
    - Lost communications for 1 hour during EDR recovery test in relatively calm seas
- **Full aeroshell performance data was captured**
  - Some data was lost
    - Software issue not found during pre-flight testing
- **EDR was tracked and recovered after the RV**
  - Data set matched onboard RV storage until ejection
  - Some non-data recording functionality issues post flight
- **RV was successfully recovered after landing within sight of the recovery vessel**