Terminal Velocity Aerospace, LLC

A SpaceWorks Company

Technical Challenges of Small, Low Cost Re-Entry Vehicles

Dr. John Dec
Program Manager
john.dec@tvaero.com
404.991.2209

Biography - Dr John Dec

Currently the Program Manager for Terminal Velocity Aerospace, a subsidiary of SpaceWorks Enterprises, Inc. in Atlanta, Georgia. Prior to joining Terminal Velocity Aerospace, Dr. Dec was a senior thermal analyst at NASA Langley Research Center in Hampton, VA. in the Structural and Thermal Systems Branch. During his 16 years at NASA he made substantial contributions on programs such as Hypersonic Inflatable Aerodynamic Decelerator (HIAD) flexible TPS, the Crew Exploration Vehicle Thermal Protection System Advanced Development Project, NASA Engineering and Safety Center (NESC) Autonomous Aerobraking Project, Mars Reconnaissance Orbiter (MRO) Aerobraking, Mars Odyssey Aerobraking and Mars Sample Return Earth Entry Vehicle. Dr. Dec has authored numerous journal articles and conference papers related to thermal protection systems and advanced thermal analysis methods. He also served as a member of the AIAA Thermophysics Technical Committee for four years. He received his BS in aeronautical engineering from Rensselaer Polytechnic Institute and his MS and PhD in aerospace engineering from Georgia Institute of Technology.

Dr. Dec also served in the US Navy as a surface warfare qualified division officer aboard USS INCHON.

TERMINAL VELOCITY AEROSPACE BACKGROUND

1. Terminal Velocity Aerospace Background
2. RED-Data2
3. RED-4U and RED-25

Terminal Velocity Aerospace, LLC

- Part of the SpaceWorks family of companies
- Founded March 2012, located in Dunwoody, GA
- Dedicated to
  - Advancing reentry vehicle technologies
  - Enhancing reentry safety
  - Returning payloads from space
- Developing a family of small re-entry vehicles
- http://spaceworkseng.com
- http://terminalvelocityaero.com

RED-DATA2

1. Terminal Velocity Aerospace Background
2. RED-Data2
3. RED-4U and RED-25

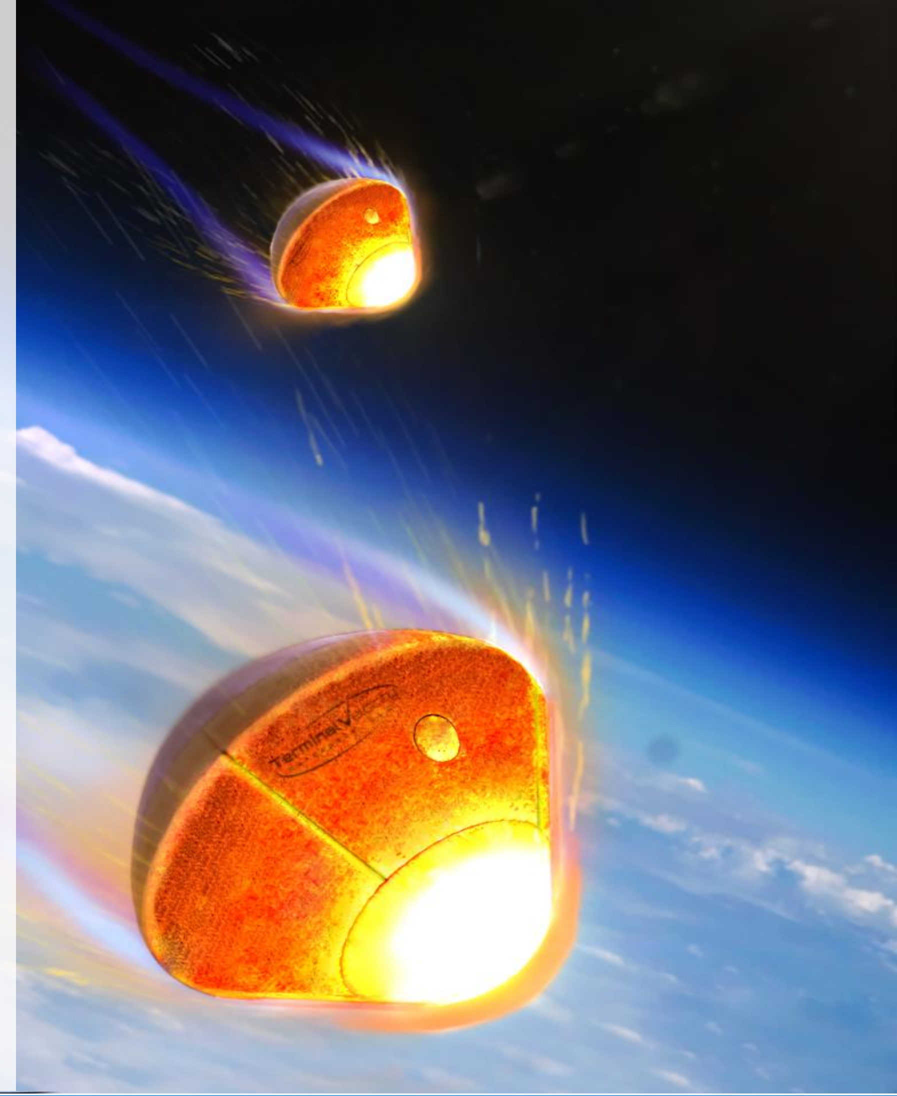
TVA RED-DATA2 FLIGHT TEST 001

RED-Data2:

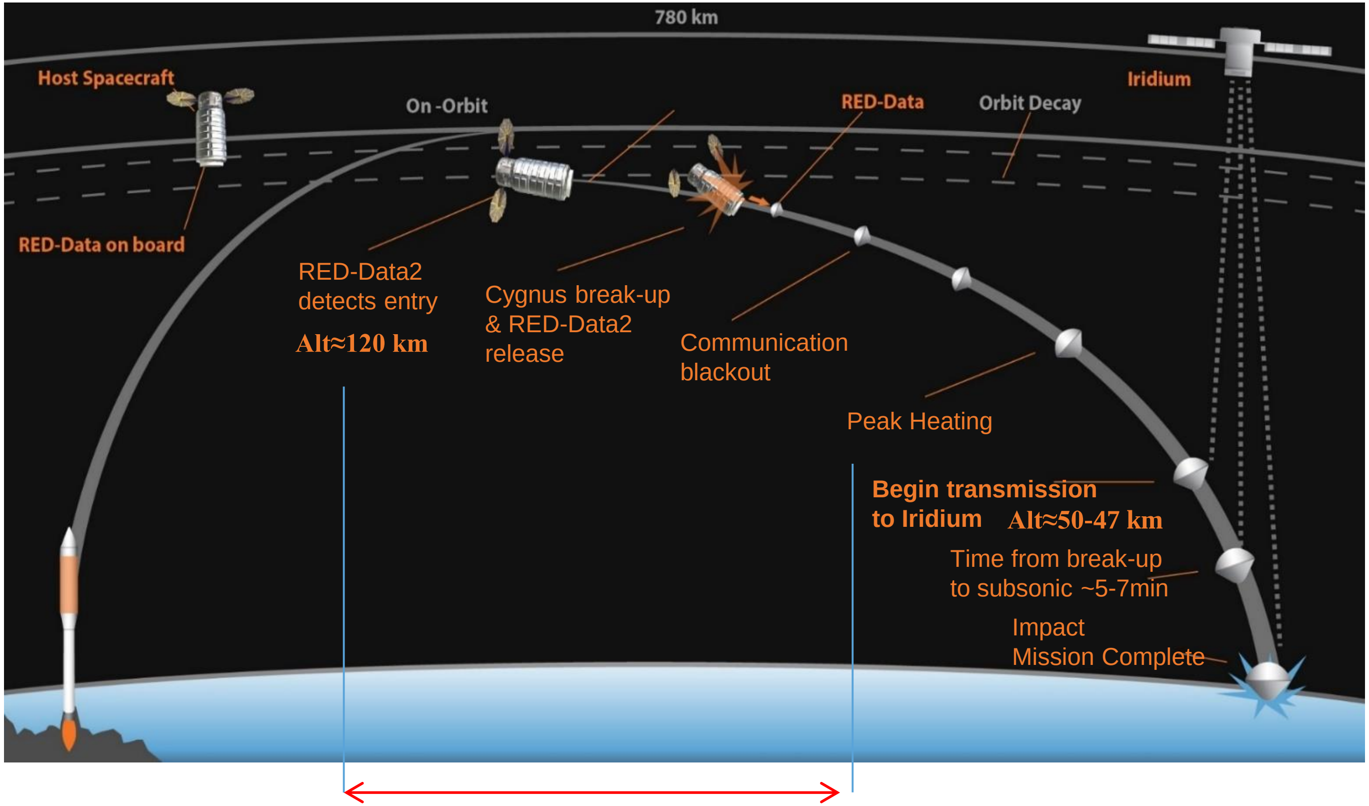
- Low mass
- Autonomous
- Aerodynamically stable design
- Break-up & TPS performance data
- Onboard data transmission

RED-Data2 First Flight:

- Launch April 18th 2017
- Cygnus unberth June 4th 2017
  - Reentry June 12th 2017
- Testing: C-PICA, C-SIRCA and Molded Avcoat (LI-2200 as a reference)



Nominal RED-Data2 CONOPS



Transmission blocked by the Faraday cage and ionization blackout.
See NASA lab EMI test data* pp.51-126

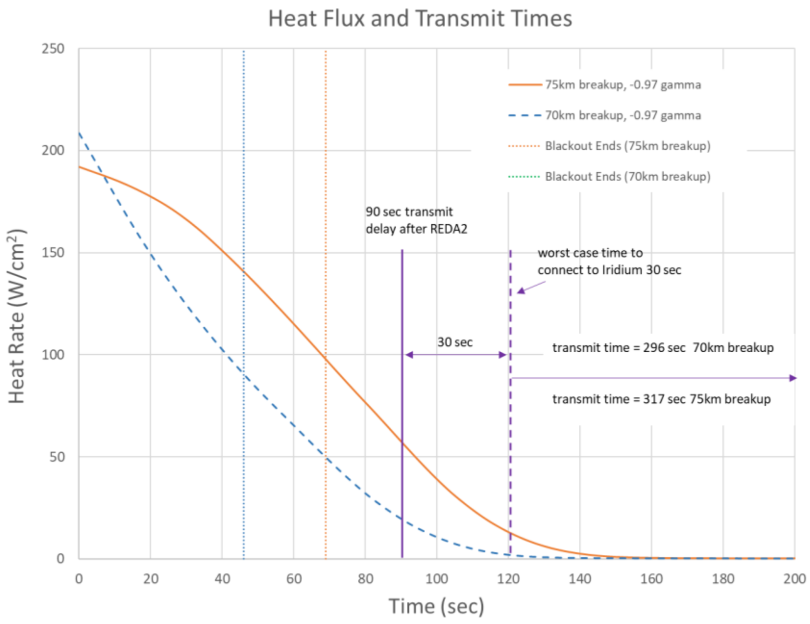
*The housing provides impact protection for the probe,
but also is the primary means with which the RF signal from the modem is attenuated while the RED-Data2 vehicle is on board the Cargo vehicle and ISS."

RED-Data2 Science Objectives

- Flight demonstration of small reentry device technologies
  - Record thermocouple data during the free flight to evaluate thermal protection system material performance
  - Provide ground-to-flight traceability between arc jet test and actual flight environment
  - Record accelerometer and gyro data during the host vehicle breakup event

RED-Data2 Technical Challenges (1 of 4)

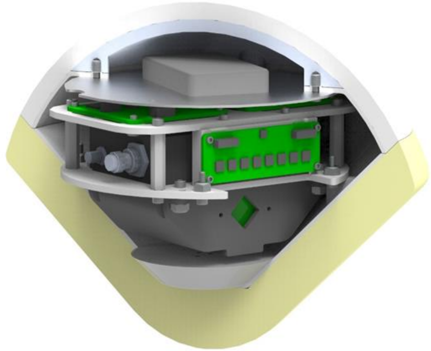
- Communications/Data Transfer
  - Challenge - RED-Data2 vehicles are expendable; they finish their mission in the ocean. Data collected needs to be transferred to the ground before impact with the water
  - Solution – utilize the Iridium satellite network as a data transfer relay while RED-Data2 is still in flight
- Data collection frequency and transmission
  - Challenge - Transfer rate limited to 2.4 kbps (300 bytes/sec), time to transmit limited between ionization blackout end and water impact
  - Solution – Re-entry detection software detects entry interface and a timer limits the amount of non-thermocouple data collected

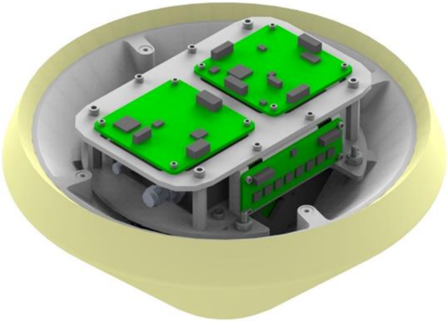


Customer desired 10 Hz thermocouple data which accounted for 160 bytes/sec

RED-Data2 Technical Challenges (2 of 4)

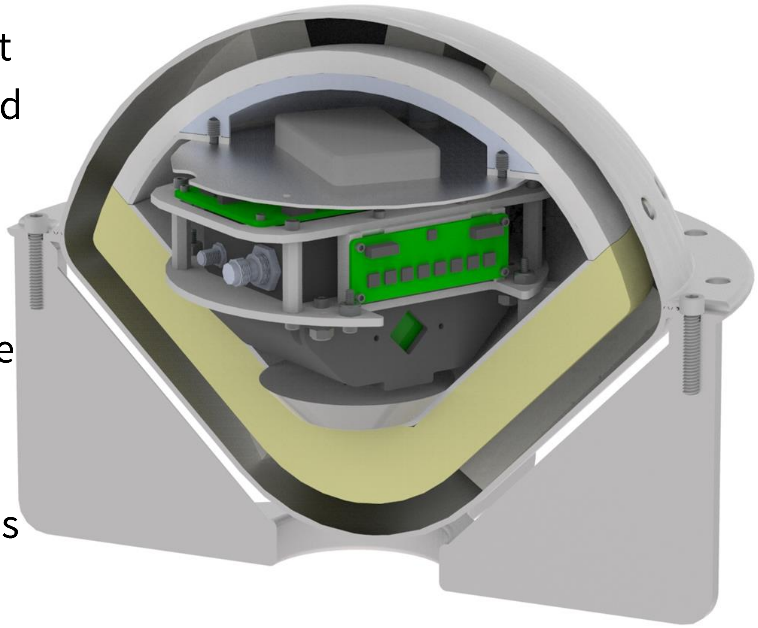
- Power Budget and Packaging
  - Challenge - Iridium modem nominally draws 1A @5V (5W), trade between time modem can be turned on and available power
  - Solution – limit power draw prior to modem activation, limit time modem is activated and transmitting. Accomplished with onboard software. When RED-Data2 is activated by the ISS crew, electronics are in a low power sleep mode ~142µW. Sleep mode terminated based on nominal Cygnus deorbit burn timeline.
  - Solution – Package as many batteries as possible within the available volume. RED-Data2 had enough space for 10 AA batteries
  - Solution – Battery selection. Energizer L91 Li/FeS_2 batteries provided the most power given the 10 battery capacity





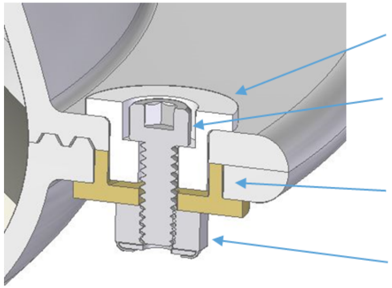
RED-Data2 Technical Challenges (3 of 4)

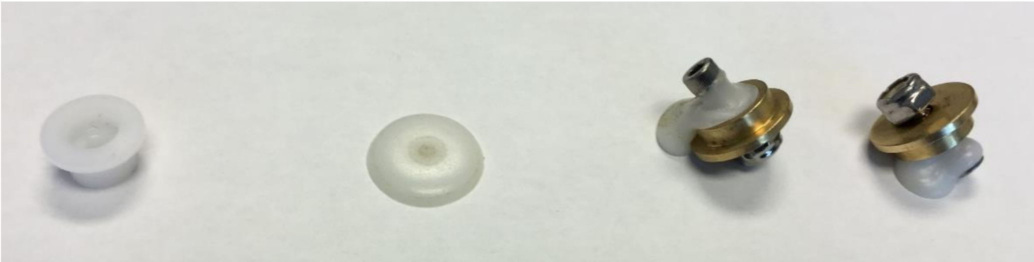
- Interface with International Space Station (Safety certification)
  - Challenge - Stringent safety requirements to operate onboard ISS dictated certain aspects of the design. RED-Data2 has an Iridium transmitter and in the event of an inadvertent transmission, it had to be attenuated to limits set by “common carrier requirements”
  - Solution – surround the RED-Data2 modem, antenna and electronics in a Faraday cage. The aluminum aeroshell of RED-Data2 encloses everything except the antenna; additional protection was required. The entire vehicle was enclosed in an aluminum shell which provided aqeduate signal attenuation as well as provide for some debris impact protection



RED-Data2 Technical Challenges (4 of 4)

- Housing Separation
  - Challenge – how to get the housing to open and release the vehicle
  - Solution – use the heat from reentry to melt Delrin® washers. Delrin melts at ~178°C which is much lower than aluminum (~650°C)





Delrin washer before and after melt test

RED-Data2 First Flight

- Unfortunately all three RED-Data2 vehicles did not return any data

- TVA performed an extensive failure investigation, however no clear cause could be identified but identified several most likely causes
  - Housing failed to open – RED-Data2 transmission could not reach Iridium satellite network
  - Impact with debris during Cygnus breakup – vehicles destroyed during breakup
  - Early re-entry detection prematurely turning on transmitter - higher than expected power draw, batteries would be drained

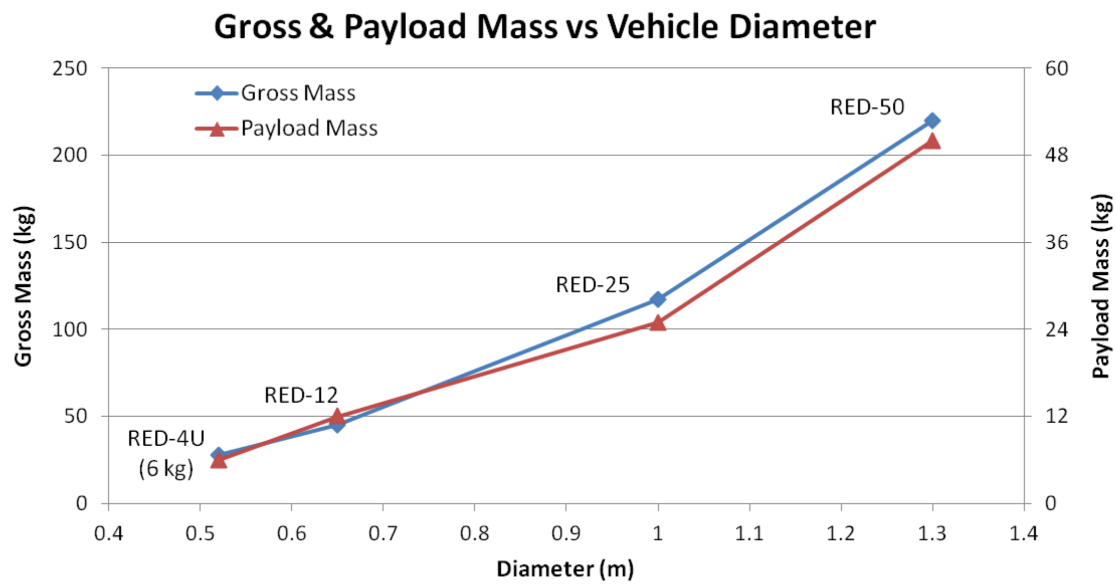
RED-4U AND RED-25

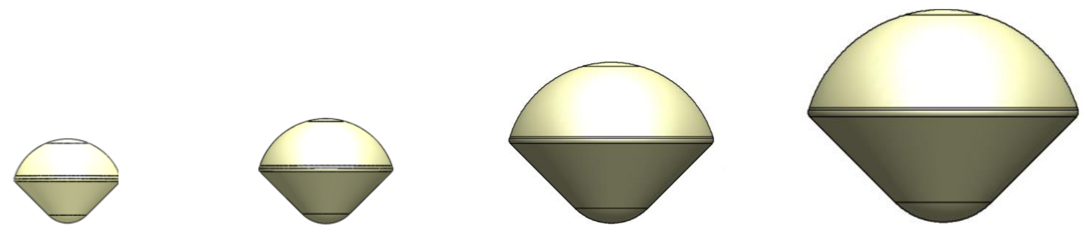
1. Terminal Velocity Aerospace Background
2. RED-Data2
3. RED-4U and RED-25

Concept Sizing Summary

Key Features:

- 45° degree sphere cone design easily scales to larger diameters
- Common heatshield materials
- Similar electronics





RED-4U (6-8 kg)	RED-12	RED-25	RED-50
28 kg	45 kg	117 kg	220 kg
0.53 m	0.65 m	1.0 m	1.3 m

RED-4U

- “On-demand” return to CONUS
- Enables high-frequency research and iteration
- Complementary to existing and emerging ISS research capabilities
- Small payload accommodations with multiple configurations

Diameter: 21.0 in (0.53m)
Mass: 62 lbs (28 kg)

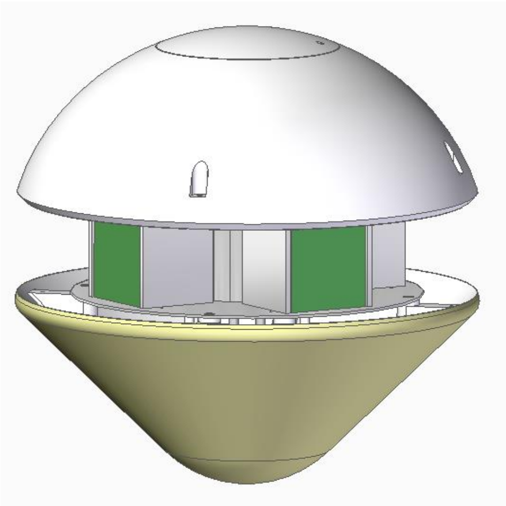
RED-4U Suborbital Test Vehicle

RED-4U Engineering Development Unit

Status: In development, suborbital drop test completed in 2015

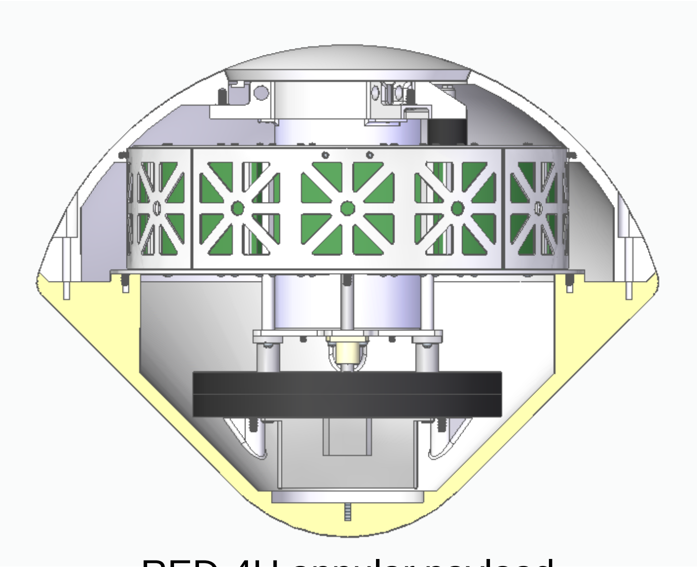
RED-4U (continued)

- Ability to open and close remotely for sample loading
- Guided parafoil parachute for precision landing
- Locator beacon



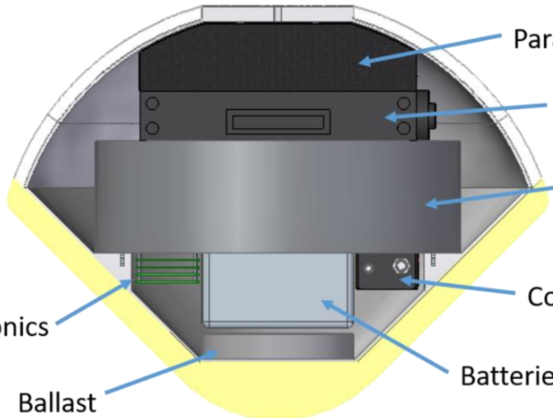
RED-4U cube payload configuration

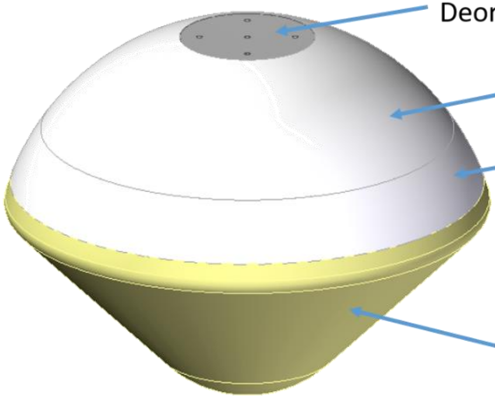
RED-4U EDU Open Configuration



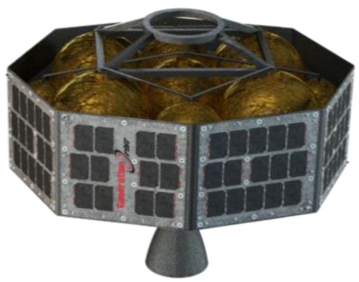
RED-4U annular payload configuration

RED-25 Small Sample Return Capsule (25 kg class)





Service Stage with Capabilities for Orbit Circ and On-demand Deorbit



Reconfigurable Payload Bay (with on-orbit loading option and thermal control systems)

RED-4U and RED-25 Guided Parafoil

RED-4U and RED-25 Technical Challenges (1 of 3)

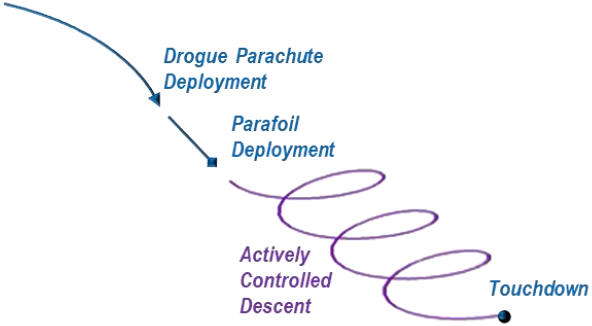
- Manufacturing low cost thermal protection system
  - Challenge – traditionally, the primary source of thermal protection materials has been government or large companies at a cost which is unattractive from a small company's point of view. Scaling up manufacturing from RED-Data2 size to RED-50 also a challenge
  - Solution – Learn to make low cost TPS. TVA has a Non-Reimbursable Space Act Agreement with NASA Ames to learn to manufacture and evaluate C-PICA, a conformal form of PICA.

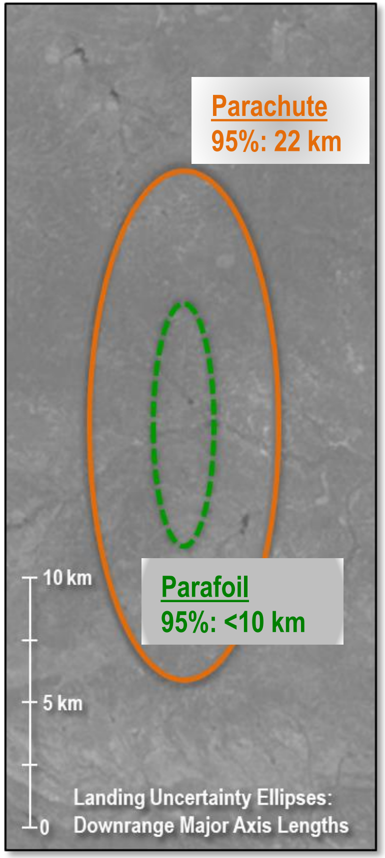
TVA produced C-PICA coupons

NASA Ames installed C-PICA and C-SIRCA on RED-Data2

RED-4U and RED-25 Technical Challenges (2 of 3)

- Rapid Sample Recovery
  - Challenge – reduce uncertainty in the landing footprint to ensure speedy sample recovery
  - Solution – Utilize a guided parafoil for terminal descent, goal is to reduce landing uncertainty, goal is < 10km
  - Solution – Robust service module with 600 m/s for deorbit maneuver.
    - Coordinate the deorbit burn according to day-of-flight wind data
    - Use deorbit stage attitude control system to account for off-nominal deorbit burns (correction maneuvers after main deorbit burn)





RED-4U and RED-25 Guided Parafoil (3 of 3)

- Remote Command and Data Handling
  - Challenge – for sample return missions which do not utilize ISS crew, vehicles need to be remotely commanded to open/close for sample loading, perform orbital maneuvers, etc. Robotic mechanism needed to load samples.
- Internal Thermal Control
  - Challenge – maintain samples at desired temperatures. Temperatures could vary based on mission/sample requirements. Active heating/cooling could represent significant % of power budget
  - Solution - ….. Still a work in progress

THANK YOU!

Terminal Velocity Aerospace, LLC

www.tvaero.com | info@tvaero.com

Atlanta: 1050 Crown Pointe Parkway, Suite 1400 | Atlanta, GA 30338 USA

404-991-2210 | 770.379-8001 (Fax)

Integrated Concept of Operations