Summary of Ultralightweight Ballute Technology Advances

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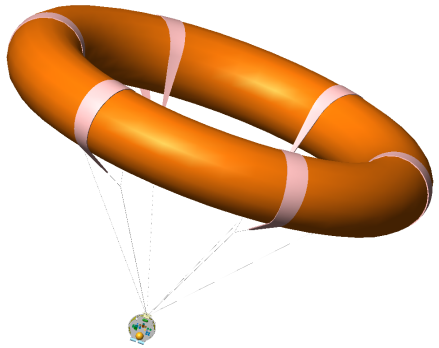
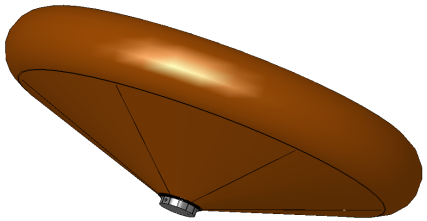
Ultralightweight Ballutes (ULWB)

- Balloon + Parachute = Ballute
  - Deployable, inflatable drag device
  - Can provide aerodynamic deceleration for aerocapture, entry, descent, landing
- Ultralightweight Ballute (ULWB): “Fly Higher, Fly Lighter, Fly Cooler”
  - Large drag area allows the spacecraft to decelerate at very low densities high in the atmosphere with relatively benign heating rates (comparable to that for aerobraking missions)
  - Lower heating rate experienced during atmospheric entry allows the use of light-weight construction techniques for the ballute, resulting in significant mass performance
  - Packaging benefit enables aeroassist to be used where constraints imposed by structurally fixed aeroshells are prohibitive
    - Spacecraft component packaging not constrained by aeroshell structural envelope
    - CG does not have to be strictly controlled to maintain aerodynamic stability (large CG envelope)
    - Decelerator does not interfere with communications, instrument pointing, and spacecraft thermal control during interplanetary cruise because it is only deployed during entry



Trailing Ballute



Attached Ballute

Ball Development Efforts and Partners

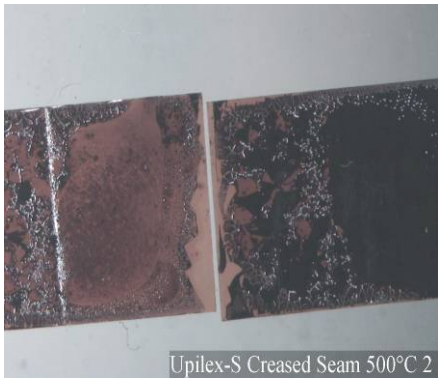
- Ballute Development Efforts
  - Mars Micromission (JPL) – Mars missions
  - Gossamer (JPL) – Mars missions
  - NASA In-Space Propulsion (ISP) Cycle 1 and Cycle 2 (MSFC) – Titan and Neptune missions
  - NASA ESR&T (Langley) – Return to Earth from the Moon

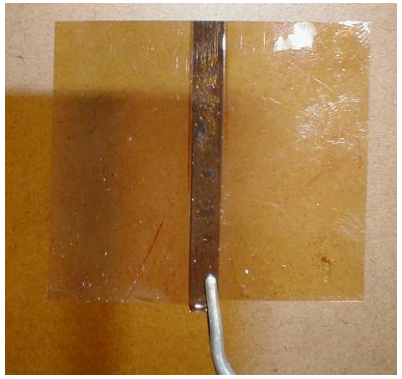
- Team Draws Expertise from Several Organizations with Applicable Experience
  - Ball Aerospace - Systems Engineering and Analyses
  - ILC Dover - Materials testing, inflatable design, and fabrication processes
  - Georgia Tech. - Aeroelastic modeling, integrated systems analysis tools
  - NASA Langley - Aerothermal analysis and test, aeroelastic analysis
  - NASA JSC - Guidance algorithm development
  - JPL - Mission and systems design, materials testing

- Technology Focus Areas:
  - Materials, Seaming, Construction
  - Flow Stability
  - Aeroelastic Modeling
  - Trajectory Control
  - Integrated Systems Analysis and Design

Materials Technology and Manufacturing

- Broad variety of lightweight films have been tested to develop properties at relevant temperatures
  - Testing of pristine & creased material samples at room and elevated temperatures
  - Key parameters include strength, flexibility, manufacturability, and mass
- An array of seaming adhesives and materials combinations have been evaluated
  - Testing of pristine & creased seamed samples at room and elevated temperatures
  - Flexibility, manufacturability, tear strength and tensile strength
  - Identified two combinations that meet goals
- Results
  - High strength solutions have been identified using Upilex and PBO films
  - Test results factored into nonlinear FEM and ballute structural design / sizing



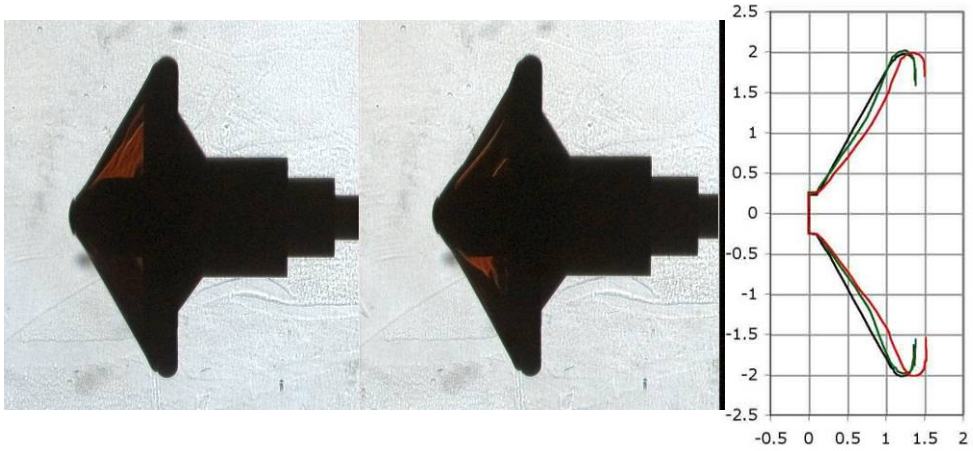


Flow Stability Validation in the Continuum Regime

- Wind tunnel models developed to capture response to hypersonic flow and heating
  - "Flight-like" film materials
  - Rotational and translational degrees of freedom
- Critical geometry evaluated parametrically to establish design limits
- Flow/ballute interaction captured for model validation

Flexible clamped ballute wind tunnel model

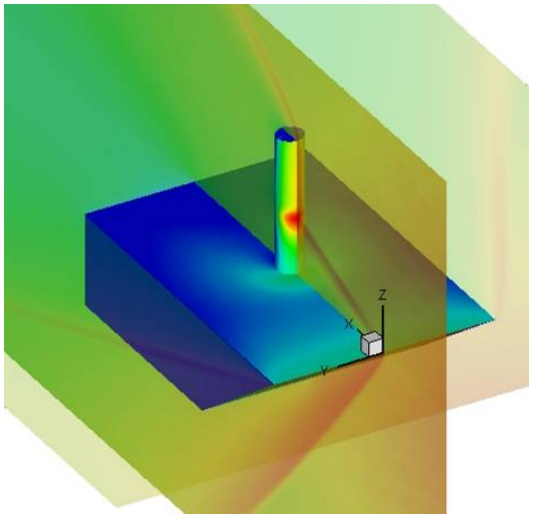
Several ballute wind tunnel models of various configurations were constructed and tested at NASA Langley.

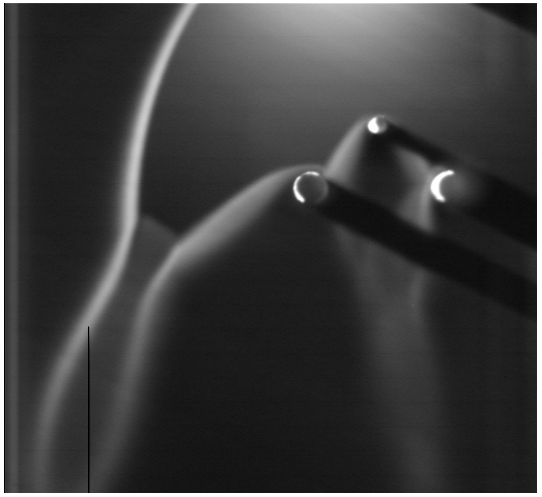


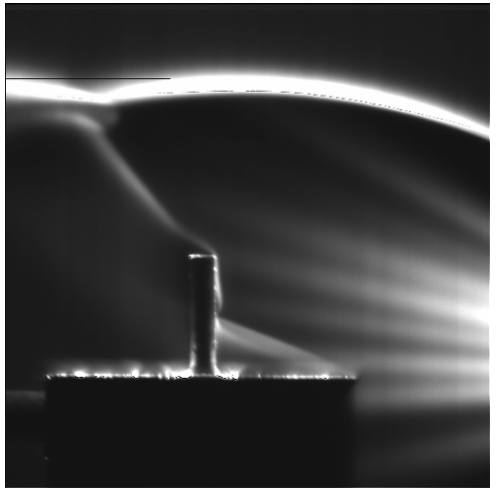
Aeroelastic deformation measured in hypersonic wind tunnel test

Flow Stability Validation in the Rarefied Regime

- Tests conducted at low density facility at University of Virginia provide good match for design Knudsen and Mach numbers
- Tests provide model validation on key facets of ballute design, including:
  - Validation cases with cylinder in cross flow,
  - Tether attachment point cases
  - Two body interaction cases

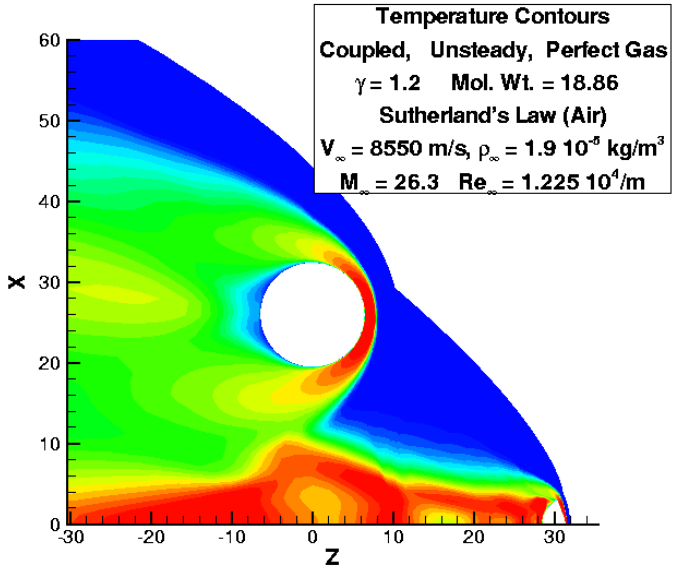




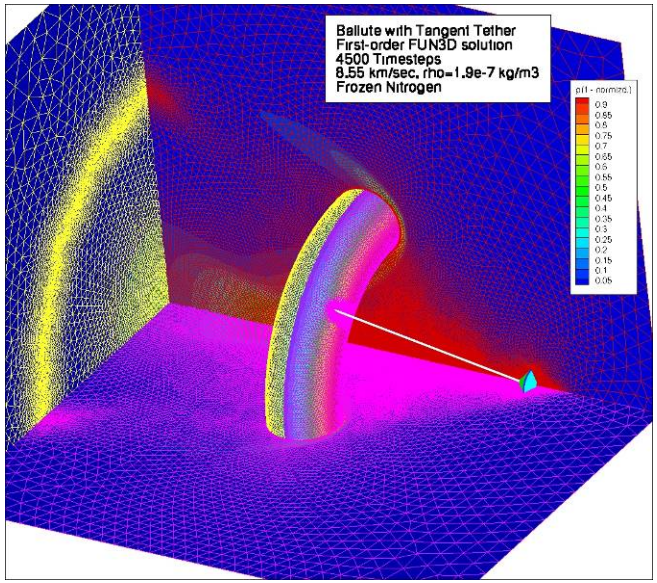


Hypersonic Analysis of Ballute Aerocapture

- CFD (LAURA and FUN3D) are used to compute drag efficiency, aerodynamic loads, aeroheating, and flow stability for candidate ballute configurations.
- Progress includes:
  - Confirmation that CFD tools can be used to predict steady or unsteady flow for the trailing ballute configuration through comparison with hypersonic test results
  - Unstructured grid used to accurately model widely variant feature sizes associated with ballute systems



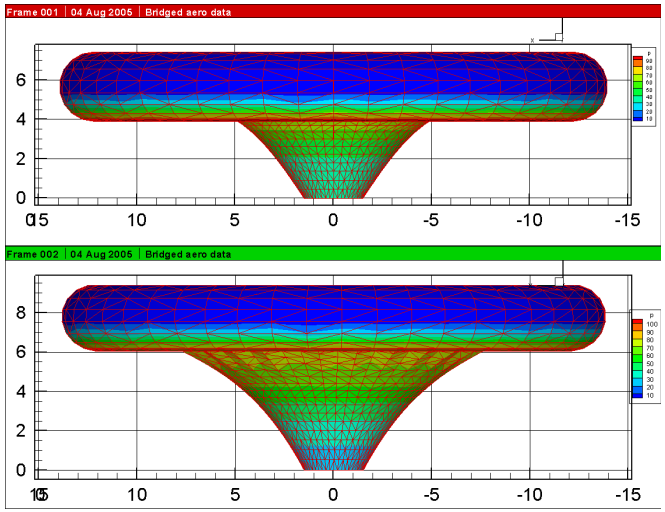
Single frame from unsteady simulation showing temperature contours in which relatively high temperature gases have pushed up to the base of the towing spacecraft through its wake



Simulation of spacecraft-tether-ballute interaction using unstructured flow solver FUN3D with hypersonic option

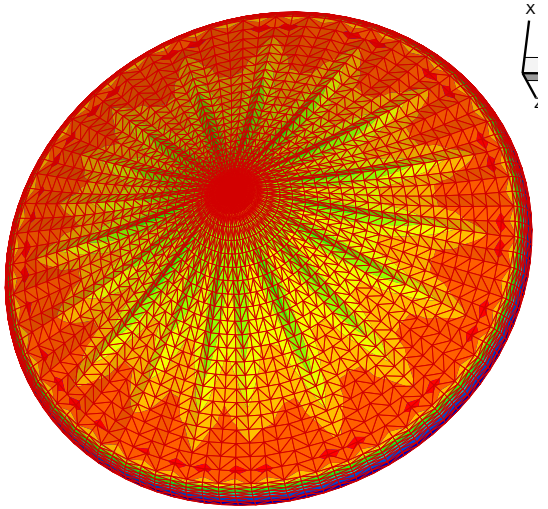
Aeroelastic Modeling and Analysis

- Coupled aeroelastic response with non-linear structures in rarefied hypersonic conditions never modeled before
- Approach: Couple together validated tools for individual disciplines
  - Including aerothermal (NASA DSMC analysis code/ NASCART-GT), structural (LS-DYNA) and thermal (SINDA/G) response
- Results:
  - Coupled analysis tools able to obtain solutions.
  - Comparison with test data shows good agreement



Undeformed clamped ballute (top) and static aeroelastic solution at (bottom)

Hypersonic Thin Film Test Model

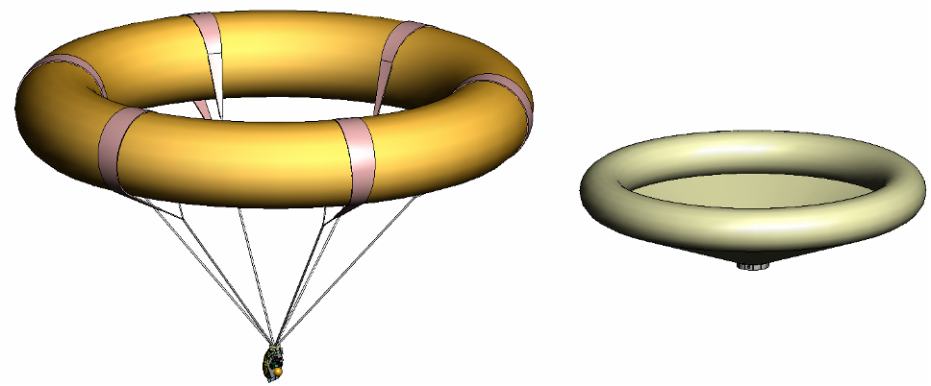


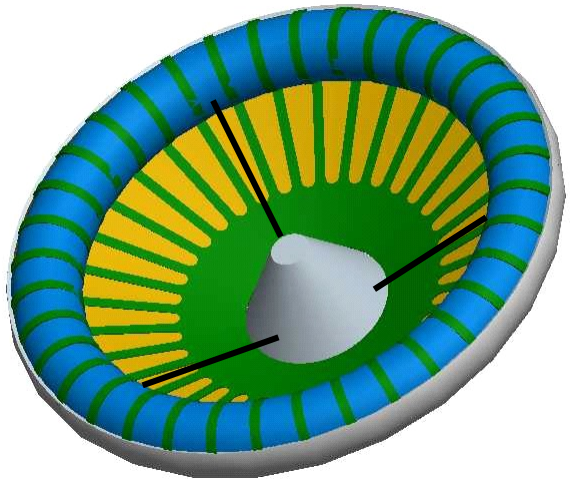
Simulation Results

Aeroelastic simulation accurately models wrinkles induced by hypersonic flow field

Ultralightweight Ballute Concepts

- Trajectory, aerothermal, structural, thermal analyses used to develop ballute system concepts for robotic and human missions
- Analysis tools and models incorporate results from test data as available to increase fidelity of analyses and design concepts
- Concepts developed through integrated systems analysis verifies excellent ULWB performance for robotic and human class missions.





- Aerocapture of 1000 kg at Titan
- Thin-film construction, local fabric reinforcement
- Ballute system mass fraction: 10%

- CEV return to Earth from the Moon
- Film/fabric laminate with local fiber reinforcement
- Ballute system mass fraction: ~8%

Summary

- Ultralightweight ballutes offer revolutionary performance benefit compared to other entry or orbit insertion technologies
  - Ballute mass fraction 8 - 10% vs. traditional aeroshell of 20% - 40%
  - General purpose, lightweight decelerator applicable to human and robotic missions at many destinations
  - Packaging benefit enables aeroassist to be used where constraints imposed by structural aeroshells are prohibitive
- Future work planned to refine and validate aero/aeroelastic tools, and to further develop materials and manufacturing processes
- System design fidelity will continue to increase as results from higher fidelity analyses and test are incorporated
- Flight validation testing is the most critical step to applying this technology

For Further Information

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