Large Supersonic Ballutes: Testing and Applications
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Overview

• Ballute history
• Parachute deployment device
• Ballutes as SIADs
• Use with high-beta entry vehicles
• Future work
Trailing Decelerator Development

- Beginning in 1960’s, NASA and the Air Force began researching and developing trailing decelerators for launch vehicle and entry vehicle recovery.

- Initial concepts focused on simple geometries like cones and spheres and quantifying their aerodynamic performance.

- Later geometries evolved to consider a more structurally optimal shape.
Isotensoid Theory

• An engineer at Goodyear (Houtz) developed a more structurally optimal geometry => Isotensoid
  – Allows for use of thinner gage, and lighter, materials

• Ideally, isotensoid theory creates a stress state that is equal in both radial and circumferential directions
  – Actual implementation has concentrations due to drag and presence of a burble fence that creates a load concentration
  – Resulting geometry is still relatively low-stress though

• This trailing isotensoid concept was termed a “ballute” by Goodyear aerospace corporation

Ref: Goodyear Aerospace Corp
Goodyear Ballute Development

• Goodyear continued to mature the ballute concept through the decade, largely through Air Force sponsorship
  – Aerodynamic Deployable Decelerator Performance Evaluation Program (ADDPEP)

• Program covered significant analysis, maturation of materials, supersonic wind tunnel testing, and multiple sounding rocket flights of 5-ft diameter test articles

• Overall very successful program that matured the concept significantly

Aerodynamics

- Compilation of performance data shows rather consistent performance, though much of it behind slender bodies.
- Qualitative assessment of stability always very favorable
  - Very little motion of the ballute in the wake of a vehicle.


Ref: Goodyear Aerospace Corp

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Inflation & Deployment

- Closed, isotensoid design is amenable to pressurization via ram-air
- Most designs incorporated a number of inlets on the periphery of the ballute for this purpose
  - Early versions were raised to get out of the boundary layer and get higher total pressure air, more recent concepts utilized surface mounted inlets for simplicity
- Most flight tests also incorporated some sort of inflation aid to provide initial pressurization
  - Exception was a 5.5 m ballute tested by NASA which failed to inflate successfully

Additional Usage Examples

- After initial development, the ballute saw numerous applications as a supersonic decelerator or stabilization device

Examples
- Gemini ejection seat stabilization
- Meteorological Sounding Rocket Decelerator
- Proposed as pilot for Mars Viking Mission by Martin Marietta

Ref: Goodyear Aerospace Corp
Recent Experience: NASA LDSD ballute

- Developed as a parachute deployment pilot device
- Flown at Mach 2.7, 500 Pa in a blunt-body wake
- Specs:
  - Silicone-coated Kevlar broadcloth
  - Pyrotechnic-initiated methanol inflation aid
  - Mortar-deployed
  - 18 kg mass
  - 8000 N drag force
- Heavily relied on analysis, with minimal testing prior to supersonic flight
LDSD Supersonic Flight Dynamics Test Overview

- Powered Flight Segment
- Float Segment
- TV DROP
- Balloon Drop & Recovery
- Spin-Up and Ignition
- Despin
- Burn out
- SIAD Deploy
- PDD Deploy
- PDD Release
- SSRS Deploy
- SSRS Deploy + 180 sec

SSRS: Supersonic Ringsail
PDD: Parachute Deployment Device

Launch

40-150 Nautical Miles

Distance

Nominal Flight: ~25-75 nautical miles

Ocean Impact & Recovery
Recent Experience: NASA LDSD Supersonic Test:
After success of LDSD ballute, how can this be infused into a Mars mission?

1. Parachute deployment (same use as LDSD)
2. Supersonic decelerator
   - On a heavy robotic mission (4.4m trailing ballute against 6 m attached toroid)
   - Aerodynamic decelerator assisting supersonic retropropulsion (human-scale)
Ballutes as Parachute Deployment Devices

Preliminary ballute sizing for parachute deployment:

\[ D_{\downarrow 0} = 2\sqrt{m_{\downarrow \text{deploy}}/\pi C_D} \left( \frac{V_{\downarrow \text{LS}}^2}{2q_x\downarrow \text{LS}} + \frac{1}{\beta \downarrow V} \right) \]

Assumptions:
- Constant deployment mass
- Constant \( C_D \)
- Constant \( q \)

Nominal inputs represent typical Mars conditions
- Mach 1.7, 400 Pa parachute deployment
- 200 kg/m\(^2\) vehicle ballistic coefficient
- 38 m/s parachute line stretch velocity
Parachute Deployment Device (PDD): Mass Comparison

In order to compare mortars to pilot deployment, we consider the following:
- Parachute mass model, \( f(D_0) \)
- Ballute mass model, \( f(D_0) \)
- Mortar mass model, \( f(m_{\text{eject}}) \)
- Pilot ballute model, (previous chart)

Conclusions:
- Ballute PDD offers mass savings over parachute mortar
- Parachute mortar has advantage of single stage system

Trade simplicity with mass
SIADS: Trailing Ballute vs Attached Toroid

- Future Mars landing mission with a ballistic coefficient of 230 kg/m² and low L/D
  - The trajectory never achieves deployment conditions of the current technology parachutes

- Need for a supplementary decelerator. We considered “Off the Shelf” tech SIADS on a 4.7 m diameter aeroshell:
  - Trailing ballute (4.4 m LDSD)
  - Attached toroid (6 m LDSD)

- Both SIADS deployed at Mach 3 for a direct comparison
SIADS: Trailing Ballute vs Attached Toroid

Attached Toroid
- **106 kg** (6 m diameter + gas generators, no cover panels)
- More complicated mechanical interface
- Uses relatively empty real estate on back shell
- Requires thermal protection during hypersonic phase

Trailing Ballute
- **33 kg** (4.4 m diameter + mortar)
- Relatively simple mechanical interface
- Must share aft section of entry vehicle with parachute
Ballutes for High Ballistic Coefficient Vehicles

- Without new designs and qualifications, parachutes can’t be used with high (>= 500 kg/m²) ballistic coefficient vehicles
  - Terminal velocity exceeds Mach number limits for parachutes
  - Dynamic pressure is 10x typical

- This defines what environments the ballute needs to survive
  - Desire capability at Mach 4 and 5 kPa
Ballute-Assisted Supersonic Retropropulsion

Calculated deceleration mass as a function of ballute diameter.

Inputs:

- 9 metric ton entry mass, single stage entry, 4 m diameter aeroshell
- Low L/D (0.24)
- No parachute, fully propulsive descent
- Ballute is deployed at Mach 3.5

9.3 m ballute minimizes decelerations mass (50% less decel mass)

4.5 m ballute provides 25% less deceleration mass
Technology Development

• Heating
  – Drives deployment Mach number
  – Current deployment limits from conservative CFD + thermal model
  – Temperature measurements are needed to validate models

• Fabric Development
  – Past ballutes have used lightweight high-temperature fabrics
  – LDSD ballute used the lightest Kevlar fabric that was available within schedule and budget constraints
  – LDSD fabric had more than enough strength, but suffered from low seam efficiencies due to the characteristics of the fabric

• Ballute Accomodation
  – Mechanical configurations should be studied to determine how to package a ballute and parachute into the aft of the aeroshell
Summary

- Ballutes have a lengthy history of providing drag and stability at supersonic conditions

- LDSD ballute was flown twice successfully
  - 4.4 m diameter was particularly large for the parachute deployment

- Ballutes can offer mass savings when used as a parachute deployment device

- Ballutes can also be used as supersonic decelerators
  - Prior to parachute deployment
  - Prior to retropropulsion
Additional References


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