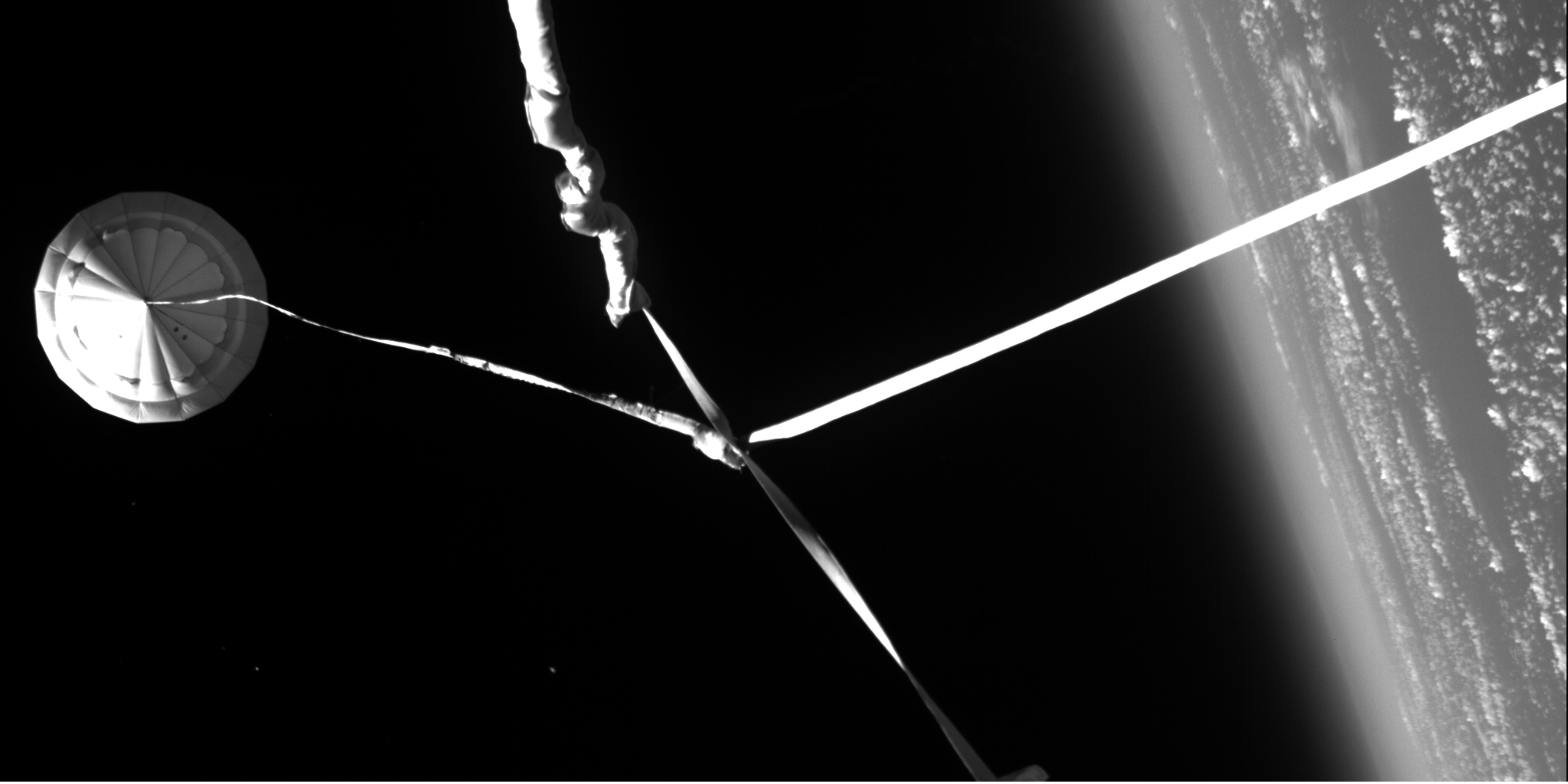

Large Supersonic Ballutes: Testing and Applications

FISO Telecon 06-29-2016

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Overview

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

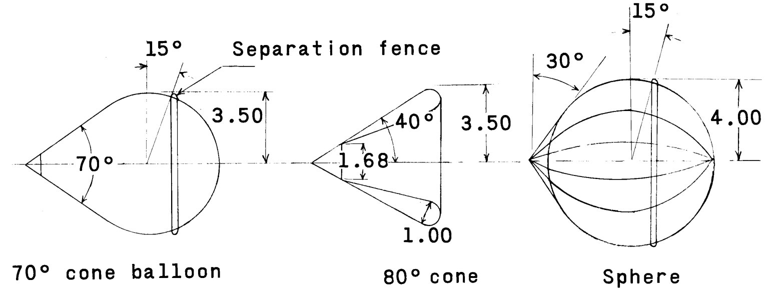
Trailing Decelerator Development

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

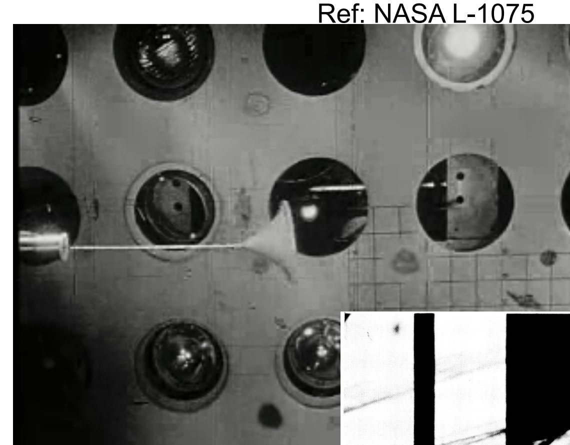
- Initial concepts focused on simple geometries like cones and spheres and quantifying their aerodynamic performance

- Later geometries evolved to consider a more structurally optimal shape

Ref: NASA TN D-1601



Ref: NASA L-1075



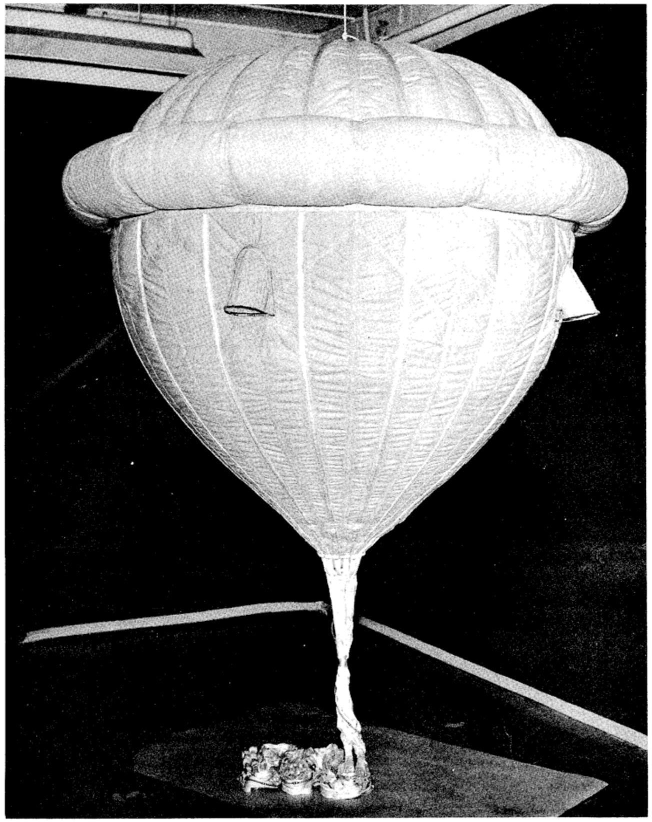
Ref: NASA TN D-1601

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



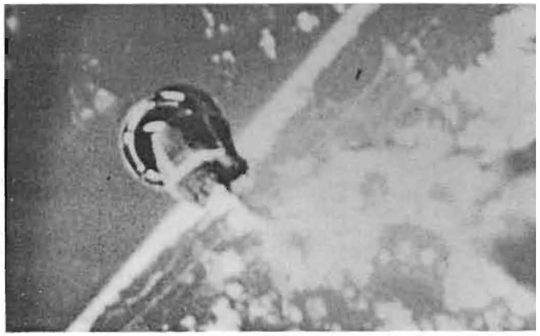
Ref: Goodyear Aerospace Corp

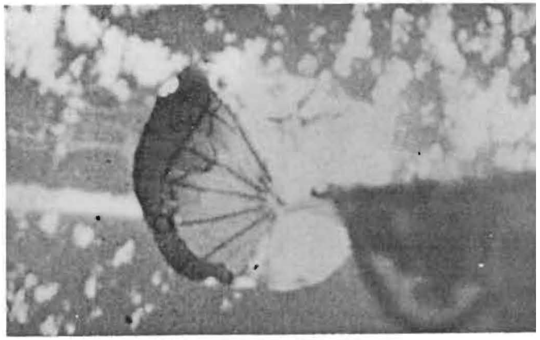
Goodyear Ballute Development

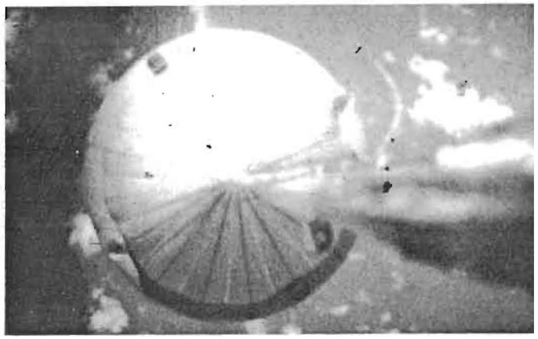
- Goodyear continued to mature the ballute concept through the decade, largely through Air Force sponsorship
  - Aerodynamic Deployable Decelerator Performance Evaluation Program (ADDPEP)

- 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







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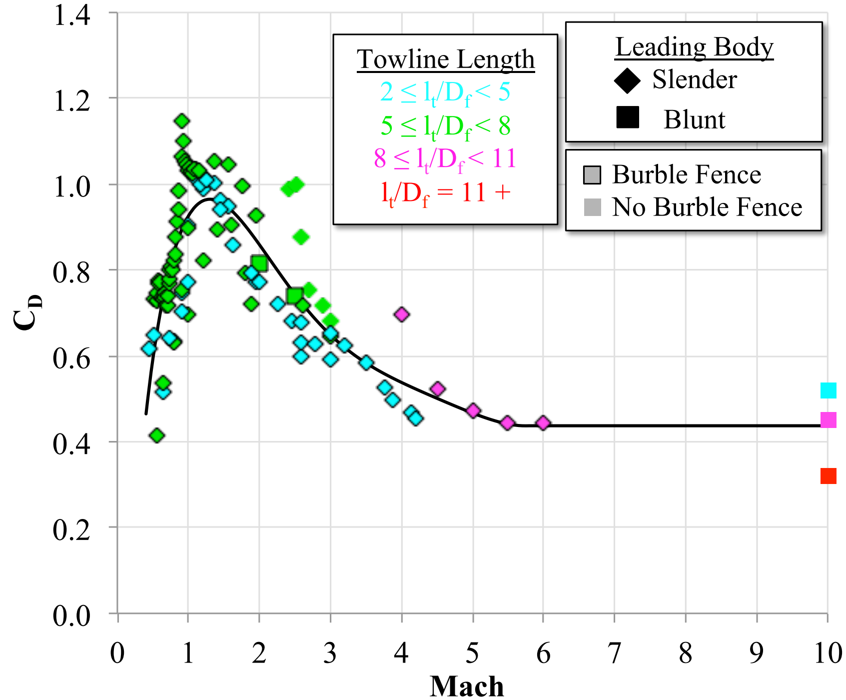
Aerodynamics

- 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



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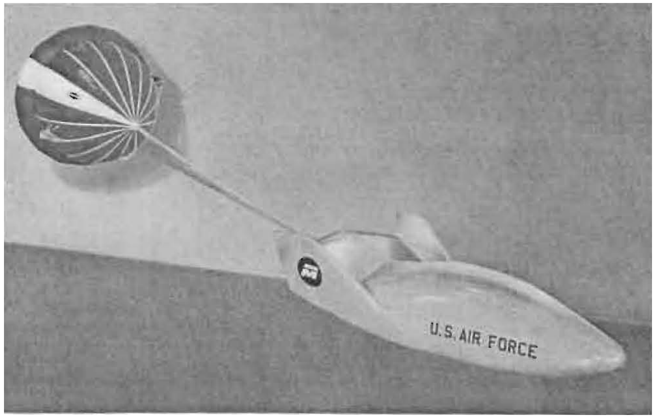
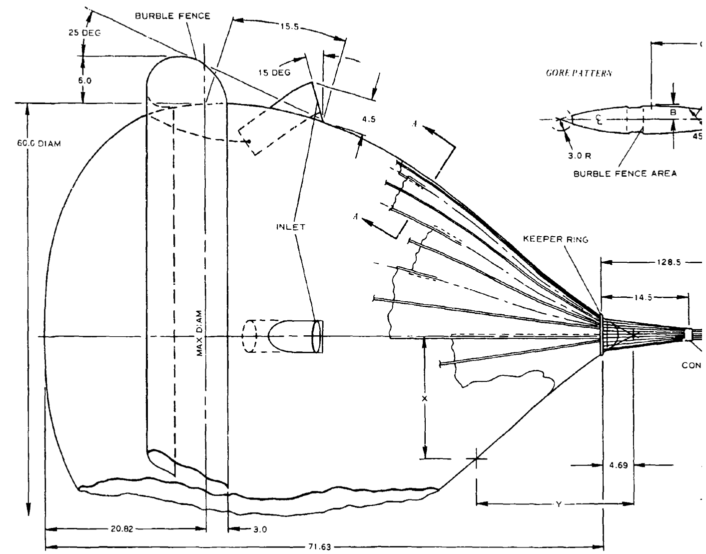


Ref: Goodyear Aerospace Corp

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



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- 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

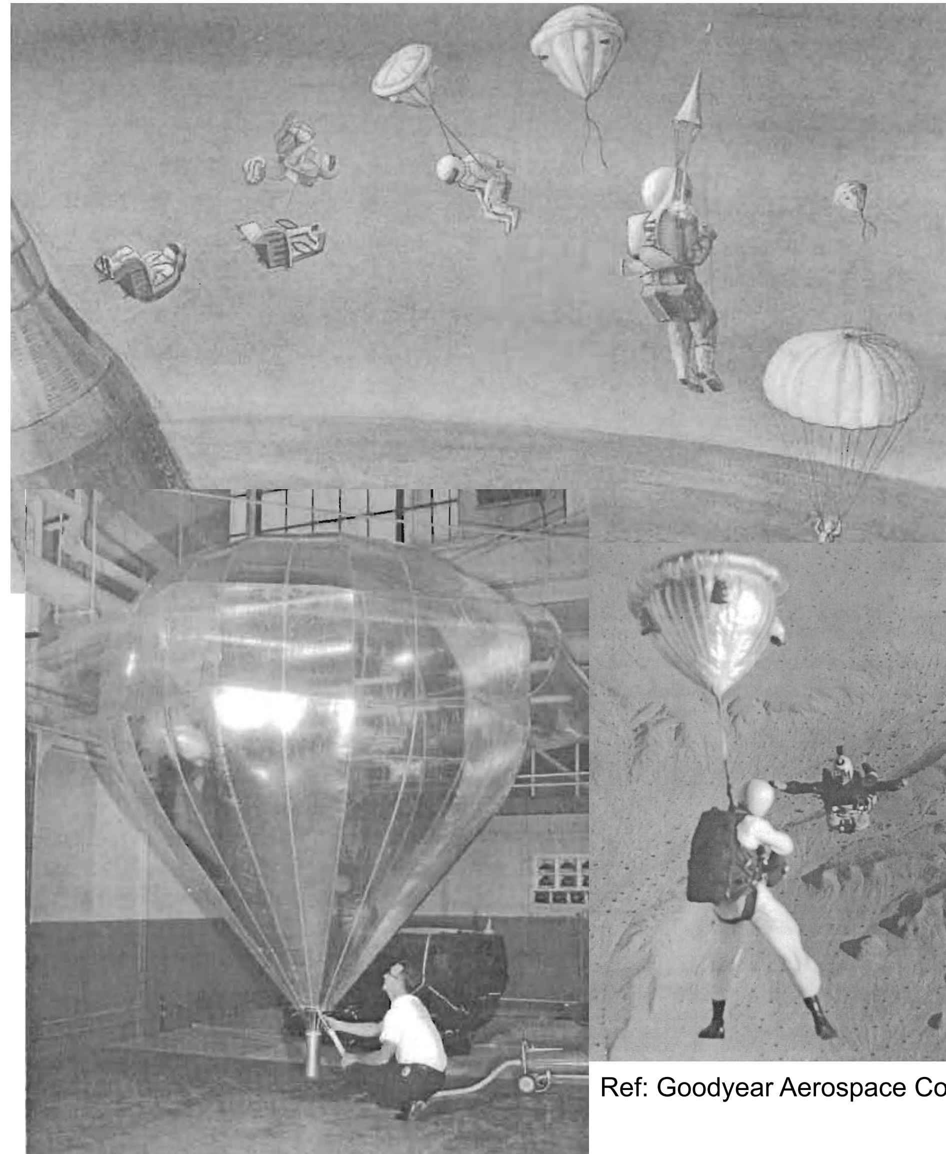
Additional Usage Examples

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

<u>Examples</u>

- Gemini ejection seat stabilization
- Meteorological Sounding Rocket Decelerator

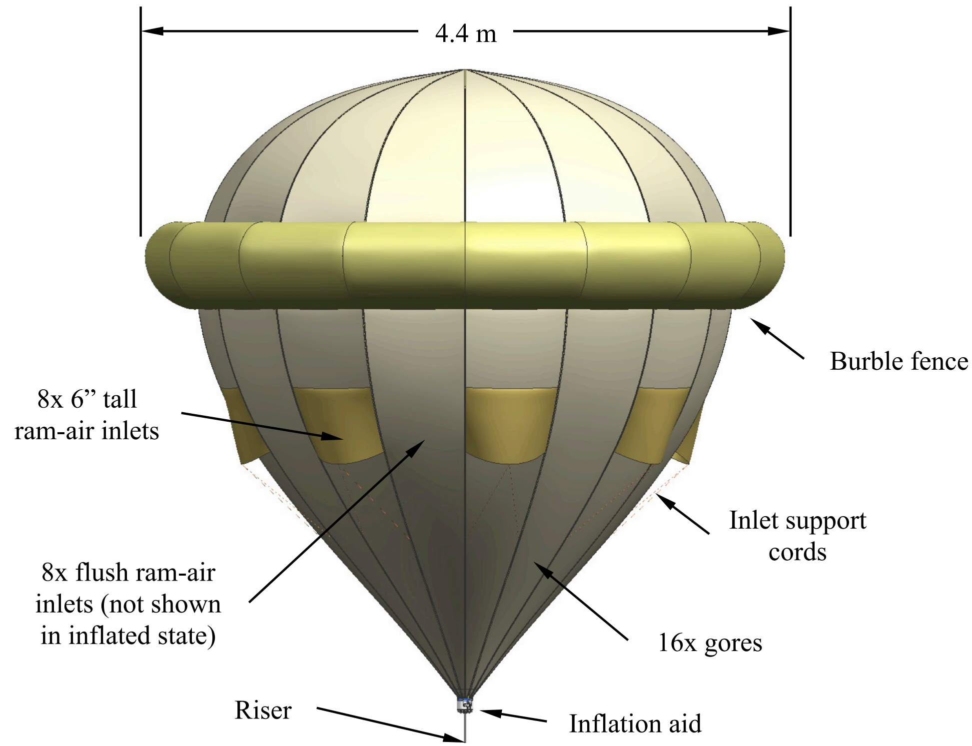
- Proposed as pilot for Mars Viking Mission by Martin Marietta



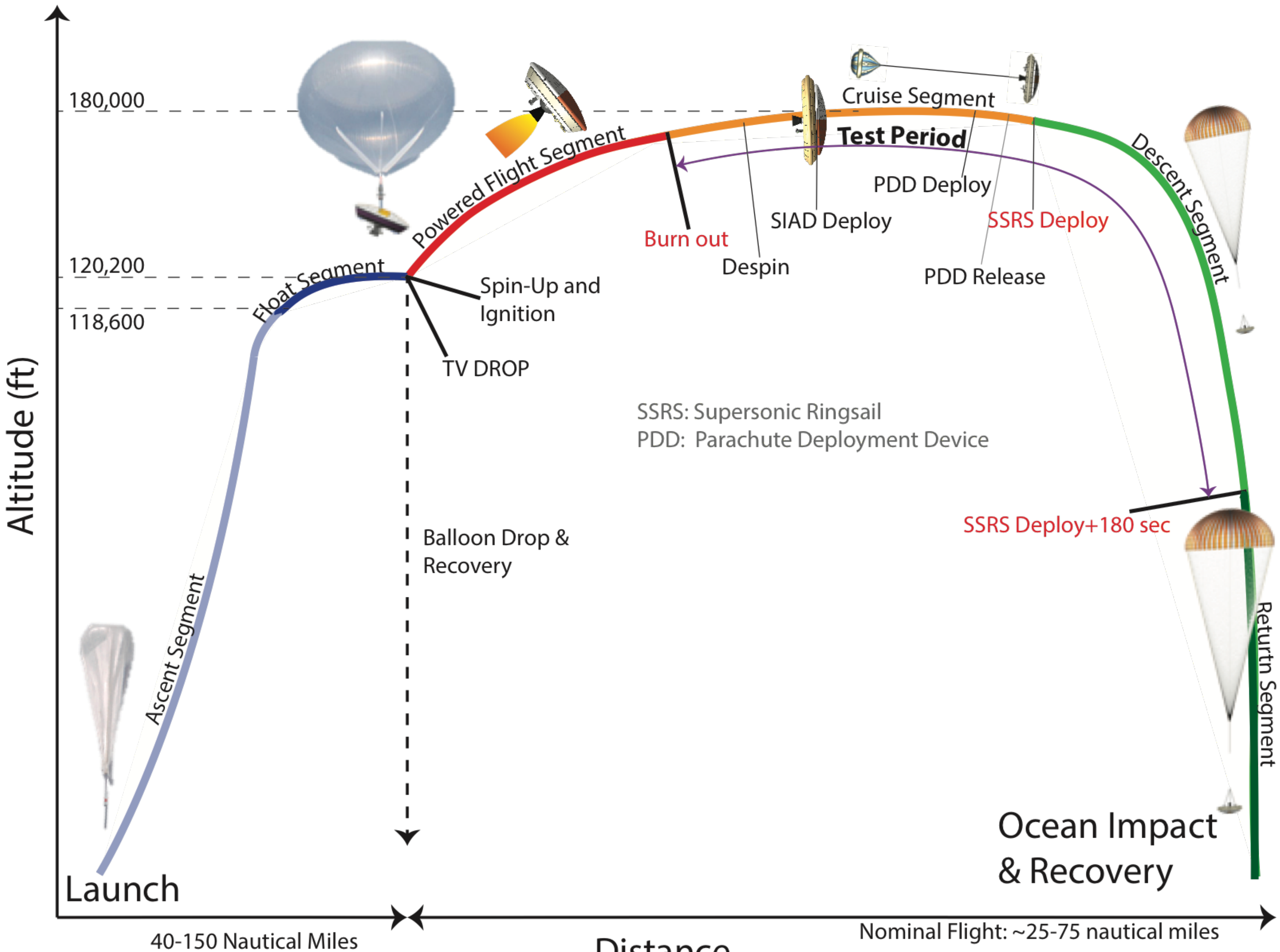
Ref: Goodyear Aerospace Corp

Recent Experience: NASA LDSD ballute

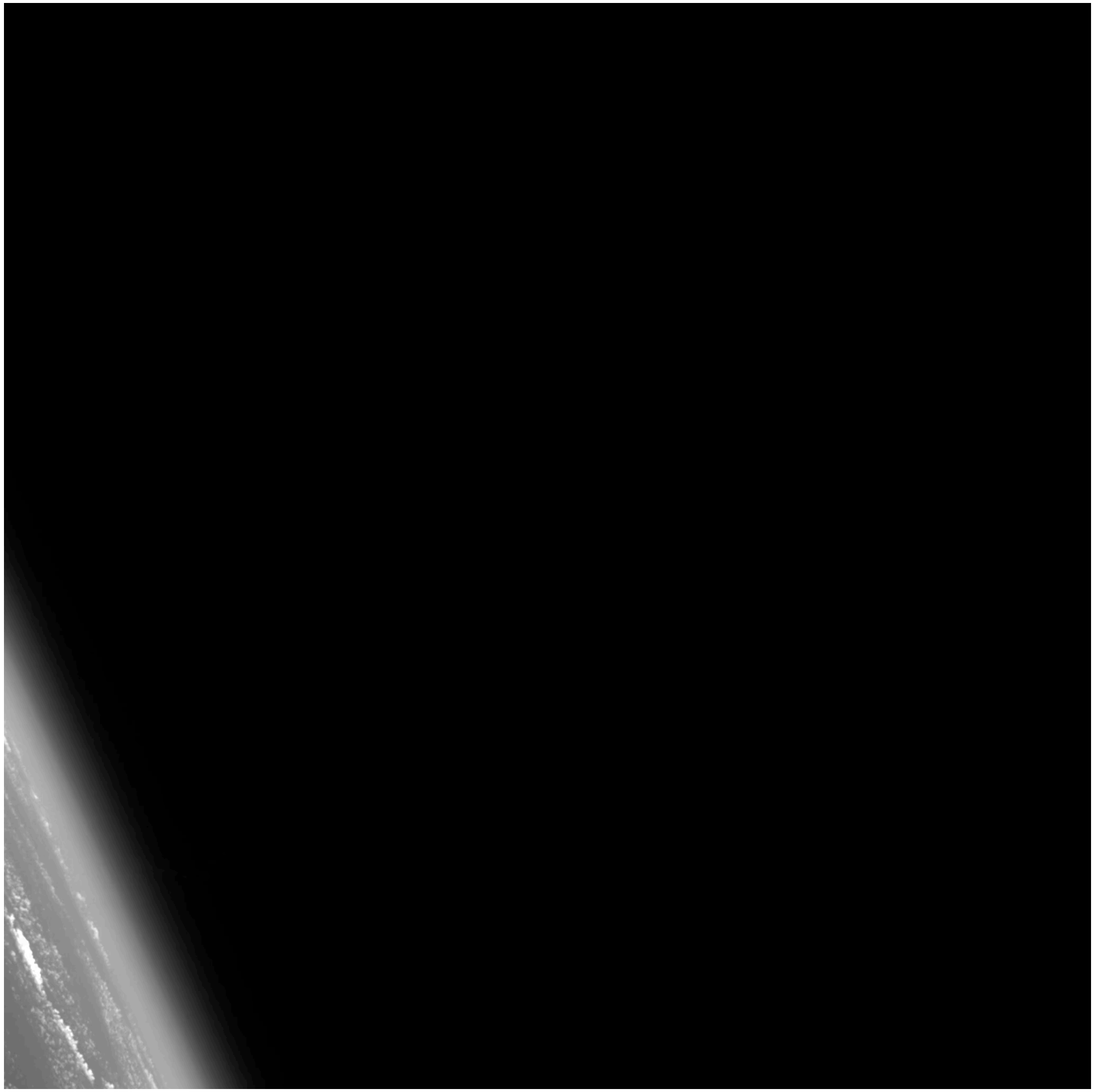
- Developed as a parachute deployment pilot device
- Flown at Mach 2.7, 500 Pa in a blunt-body wake
- Specs:
    - Silicone-coated Kevlar broadcloth
    - Pyrotechnic-initiated methanol inflation aid
    - Mortar-deployed
    - 18 kg mass
    - 8000 N drag force
- Heavily relied on analysis, with minimal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



LDSD Supersonic Flight Dynamics Test Overview



Recent Experience: NASA LDSD Supersonic Test:



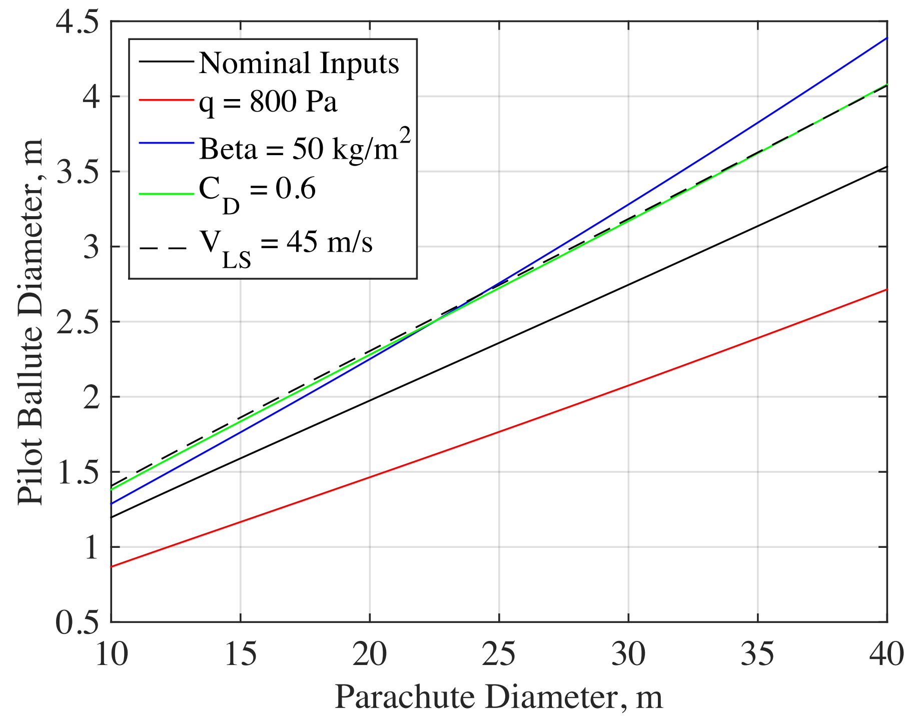
After success of LDSD ballute, how can this be infused into a Mars mission?

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:

$$D_0 = 2\sqrt{\frac{m_{deploy}}{\pi C_D}\left(\frac{V_{LS}^2}{2 q x_{LS}} + \frac{1}{\beta_V}\right)}$$



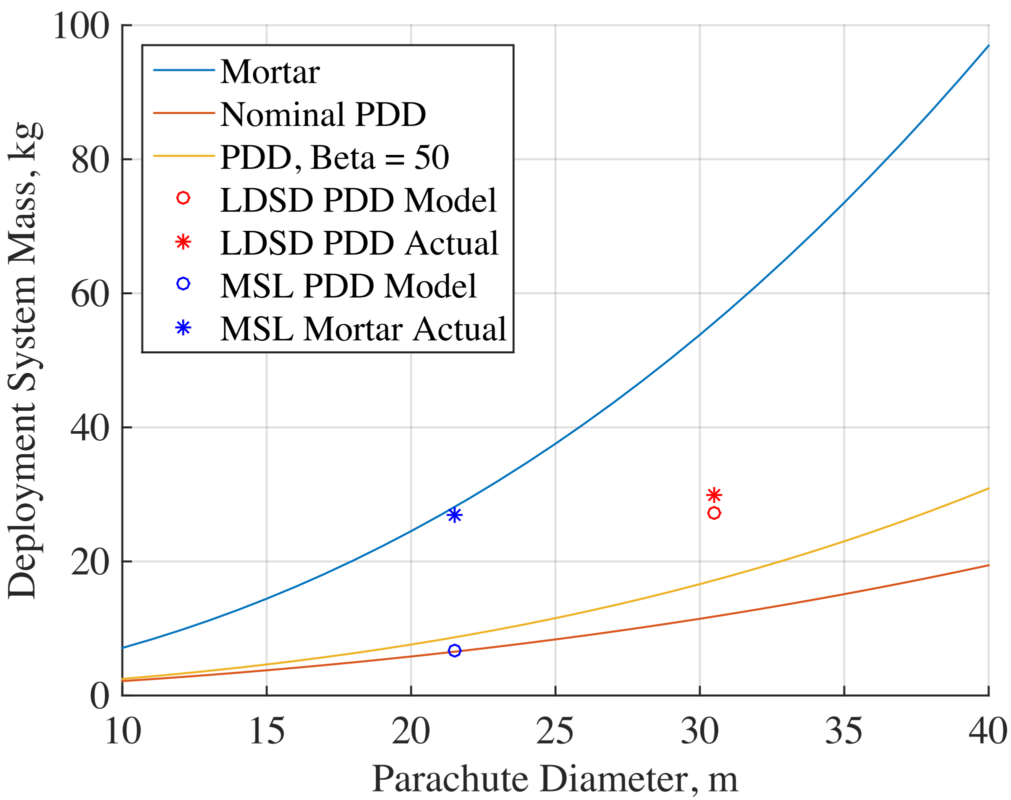
Assumptions:

- Constant deployment mass
- Constant Cd
- 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:

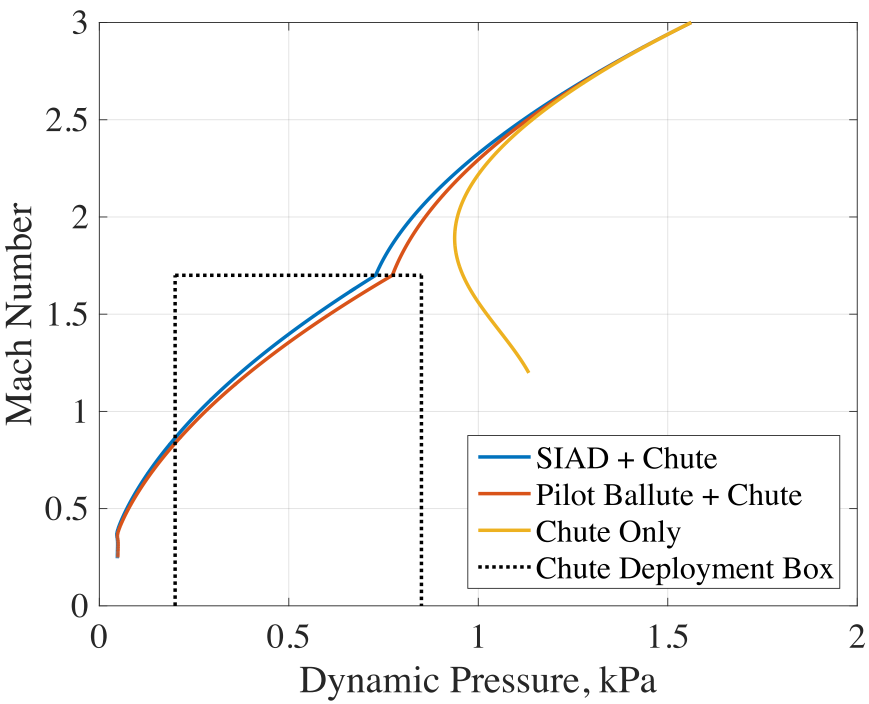
- Parachute mass model, f(D_0)
- Ballute mass model, f(D_0)
- Mortar mass model, f(m_{eject})
- Pilot ballute model, (previous chart)

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/m^2 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

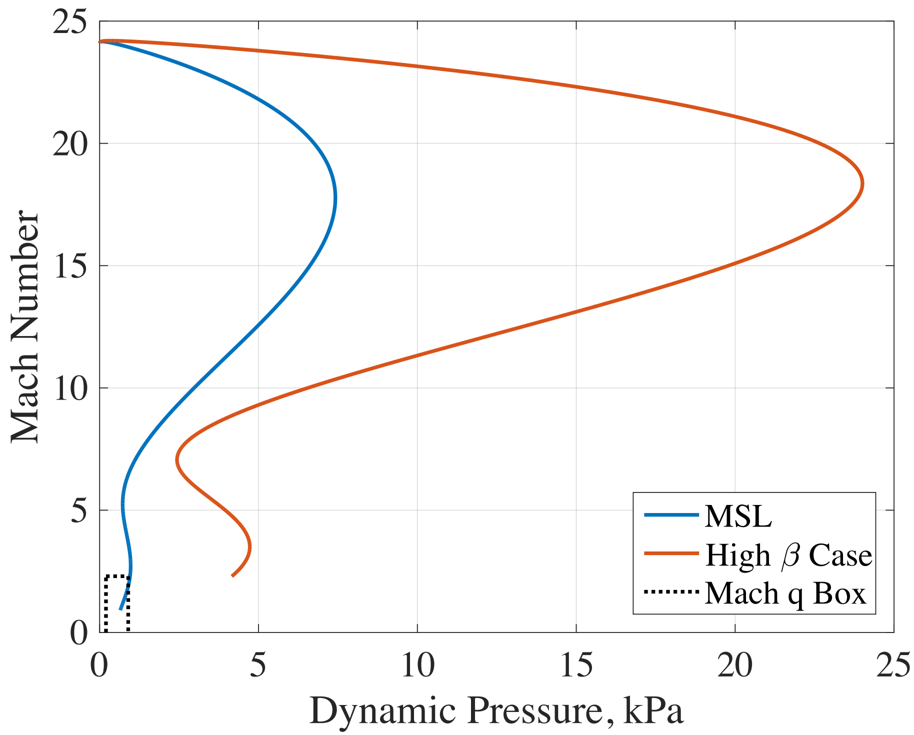
Attached Toroid

- **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

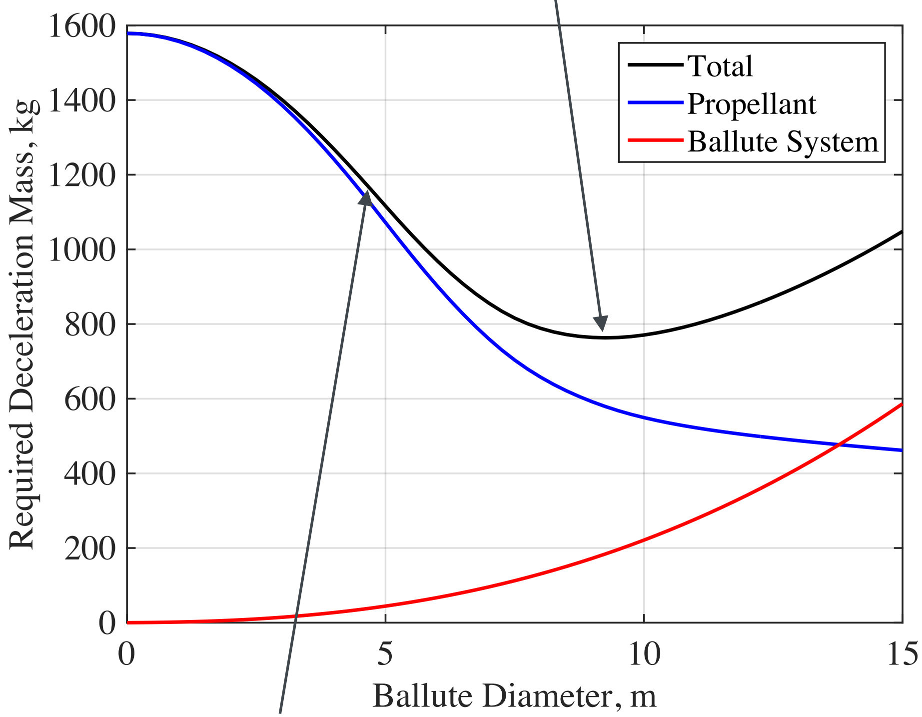
Ballutes for High Ballistic Coefficient Vehicles



- Without new designs and qualifications, parachutes can't be used with high (>= 500 kg/m^2) 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

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



4.5 m ballute provides 25% less deceleration mass

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

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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