3rd International Planetary Probe Workshop

Parachute System Design Case Study - Huygens

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Case Study - Huygens

- Destination
  - Titan
- Type
  - Atmospheric Probe
- Parachute Requirements
  - Remove protective aeroshell
  - Stabilise transonic deceleration
  - Control descent time
  - No interference with probe spin

Challenges

- Environment
  - -210 to +25°C
  - 10^5 rads
- Cleanliness
- Reliability
  - 0.99 at 60% confidence level
    - Single Point Failures
- Testing
  - Conditions not similar to Earth
- Life
  - 7 Years in hard vacuum

Operation Sequence (Option 1)

- Release rear aeroshell
  - Includes annulus of front shield
- Deploys main parachute
- Release nose cap

Operation Sequence (Option 2)

- Mortar-deploy pilot chute
- Release back cover
  - Removed by pilot chute
    - Deploys main parachute(s)
- Release front shield
- Reduce drag area to meet descent time
  - Cut away all but one of a cluster of main parachutes
  - Post-reef main parachute
  - Use main parachute to deploy smaller parachute
  - Release main parachute and free-fall to surface

Sequence Tradeoff

- Option 1
  - Only one parachute
  - Lack of heritage
  - Complicated aeroshell release
  - Release plane in front aeroshell
- Option 2
  - Two / three parachutes
  - Galileo heritage
  - Simple sequence
  - Release plane is on rear of aeroshell
- BASELINE

Descent time modulation choice

- Cut away all but one of a cluster of main parachutes
  - Complicated
- Post-reef main paracute
  - Incompatible with swivel
- Use main parachute to deploy smaller parachute
  - Baseline
- Release main parachute and free-fall to surface
  - Probe is unstable

Sequence Choice

- When do we release the back cover?
  - Supersonic sequence
    - Release the back cover immediately pilot chute inflated
    - Main parachute decelerates through Mach 1
  - Subsonic sequence
    - Retain back cover until Mach 0.6
    - Pilot chute decelerates through Mach 1

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Subsonic vs Supersonic sequence

- Supersonic
  - Main parachute better for transonic stabilisation
  - Large bridle required for stability
- Baseline

- Subsonic
  - Main parachute loads lower
    - Lighter
  - Main parachute inflates subsonically
    - Better inflation
  - Potential for single BC/FS release

Final Sequence

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Parachute Materials

- Requirements
  - Good cryogenic strength
  - Compatibility with high temperature bake-out
  - Ability to join without significant strength loss
  - Ability to weave (for broadloom fabrics)
  - Availability
    - At required yarn density
- Candidates
  - Polyester, Nylon, Kevlar, Spectra, PTFE

Parachute Materials

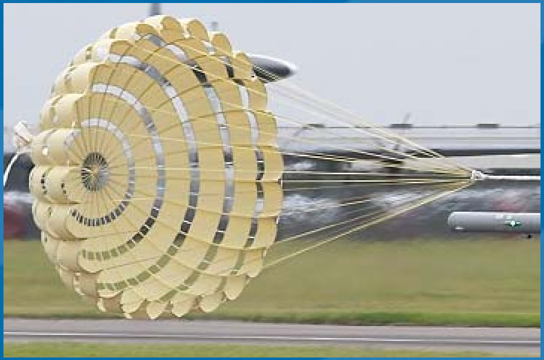
- Polyester
  - Pioneer Venus, Viking, Galileo heritage
  - Unable to weave lightweight fabric
- Kevlar
  - Good strength properties
  - Good for tapes / cords
  - Poor for broadloom fabric
- Nylon
  - Good temperature resistance
  - High moisture gain
- Spectra
  - High strength
  - Poor high temperature performance
  - Lack of heritage
- PTFE
  - Poor strength

Materials Choice

- Broadloom fabric
  - Nylon
  - Much improved since Polyester chosen for Pioneer Venus
  - Water absorption required TML waiver
- Tapes and lines
  - Kevlar
  - Excellent strength and high temperature performance
- Threads
  - Polyester / Kevlar

Pilot Chute Type

- Requirements
  - Inflation
    - Supersonic
    - Low dynamic pressure
  - Stable
- Options
  - Disk-Gap-Band
    - Good supersonic, low dynamic pressure inflation
    - Easy to build small scale models
  - Variable Porosity Conical Ribbon
    - Excellent supersonic inflation
    - Very difficult to build scale models



Pilot Chute Size

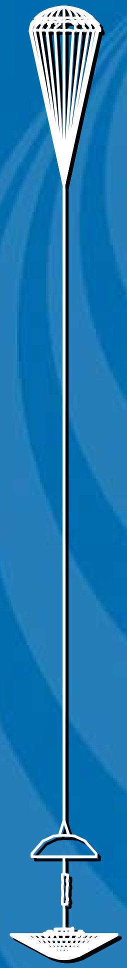
- Must separate back cover from probe
  - Ballistic coefficient ratio better than 0.7

$$\beta_i = \frac{\sum_j m_{ij}}{\sum_j (C_d S)_{ij}}$$

- Must use worst case
  - Mass
    - Including all design margin
  - Drag coefficient
    - At worst Mach number

Pilot Chute Size

- Released assembly
  - Pilot chute
  - Back cover
  - MAIN PARACHUTE
- Masses
  - Maximum mass
- Aerodynamics
  - Minimum drag coefficients
  - Include wake recirculation



- Probe
  - Remainder
- Masses
  - Minimum mass
- Aerodynamics
  - Maximum drag coefficient

Pilot Chute Size (minimum)

$$\beta_{probe} = \frac{m_{\min}}{C_{d\max} S} = \frac{276.967}{1.510 \times 5.726} = 32.03\, kg/m^2$$

$$\beta_{released} = 0.7\beta_{probe}$$

$$\beta_{probe} = \frac{m_{BC_{\max}} + m_{PC_{\max}} + m_{MP_{\max}}}{C_{d_{PC.\min}} S_{PC} - C_{d_{BC.\max}} S_{BC} \chi} = \frac{21.358 + 0.568 + 5.421}{0.38 S_{PC} - 0.38 \times 2.38 \times 0.42}$$

$$S_{PC} = 4.21 m^2$$

N.B. All units are SI (kg, m, s)

Pilot Chute Design

- Size
  - $S0=5.29\ m^2$
  - $D0=2.59$ m
  - Lines: 12
  - Line length: $2 \times D_0$
  - Larger than minimum
- Type
  - Disk-Gap-Band (13.1% geometric porosity)
  - Taschengurts to stabilise band
- Materials
  - Nylon broadloom fabric
  - Kevlar lines and webbing

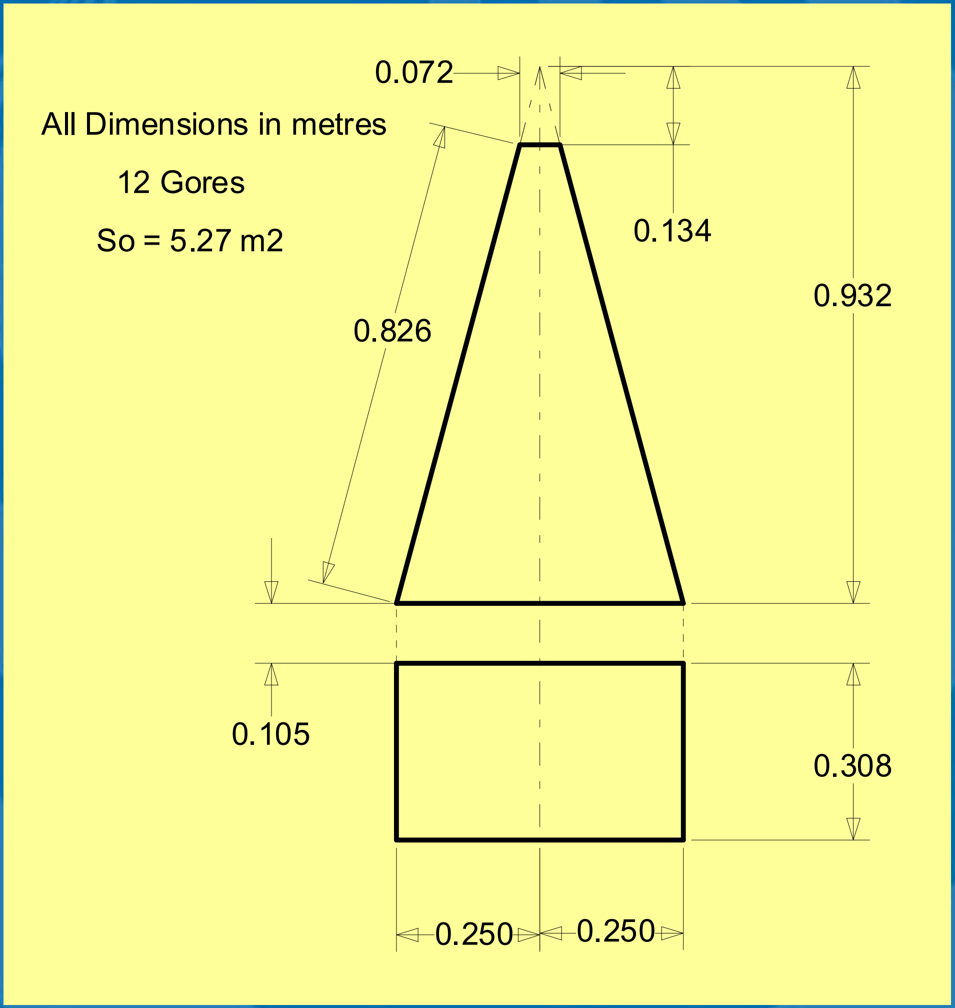
Pilot Chute Design Loads

- Inflation load
  - Maximum load was 1.8 kN
    - Failure case – fire on arm
- Component design loads

Component	Load
Canopy fabric	0.89 N/m
Lines (12)	150 N
Bridle legs (3)	1800 N

Pilot Chute Design

- 12 Gores
- Taschengurts
- 12,2xD_0 Lines
  - 5.18 m
- 21.1 m riser
  - 27 m trailing dist
- 0.53 m bridle



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Pilot Chute Testing

- Joint Tests
- Wind Tunnel Tests
- Environmental Tests
  - Temperature
  - Vibration
- Deployment Tests
  - Bench
  - Rapid
- Drop Tests
- System Test

Mortar Type

- Requirements
  - Deploy pilot chute through probe wake
    - Minimum 24 m/s required
  - Minimise reaction load
  - Prevent contamination of payload
- Options
  - Closed mortar
    - Piston deploys parachute
    - Gasses retained within mortar
  - Open mortar
    - Sabot deploys parachute
    - Sabot released allowing gasses to exit

Mortar Type

- Open
  - Long stroke
    - Low reaction loads
  - Combustion products released
    - May contaminate instruments
  - Sabot and cap released
  - BASELINE
- Closed
  - Short stroke
    - High reaction loads
  - Combustion products retained
    - Could leak during science mission
  - All components retained
    - However, breakout patch in back cover released

Mortar Design

- Open design
- Choked cartridge
- Twin NSI initiation
- Stowage for PC bridle
- Reaction load
  - 8.5 kN
- Velocity
  - 33 m/s
- Packing Density: 600 kg/m^3

Mortar Testing

- Environmental Tests
  - Temperature
  - Vibration
- Functional Tests
  - Ambient
  - Temperature Conditioned
- System Test

Main Parachute Type

- Requirements
  - Good supersonic inflation
  - Good low dynamic pressure inflation
  - Good stability
- Options
  - Disk-Gap-Band
  - Variable Porosity Conical Ribbon
  - Ringsail
  - Ringslot
  - Cruciform

Main Parachute Type

- Disk-Gap-Band
  - Proven design
  - Comonality with pilot Chute
- VPCR
  - Difficult to test at small scale
- Ringsail, Ringslot, Cruciform
  - Unproven or poor supersonic performance

- DGB chosen

Main Parachute Size

- Requirements
  - Transonic Stability
    - Simulations
  - Separation of probe from front aeroshell
    - Ballistic coefficient ratio better than 0.7

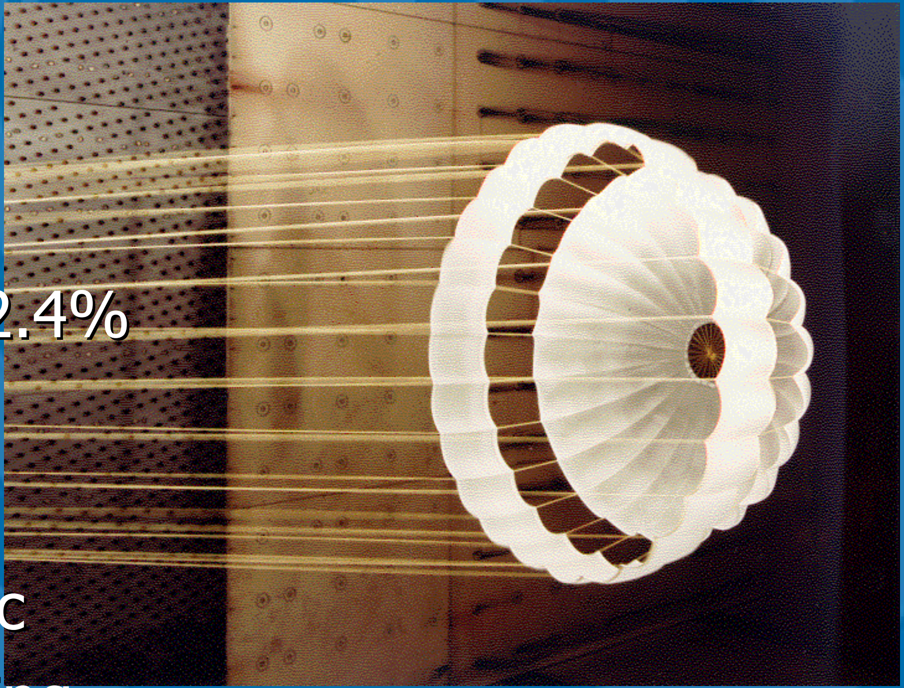
$$\beta_{FS} = \frac{m_{FS_{\min}}}{C_{d_{FS.\max}} S_{FS}} = \frac{71.491}{0.982 \times 5.726} = 12.71\, kg/m^2$$

$$\beta_{probe} = 0.7\beta_{FS} = \frac{m_{probe_{\max}}}{C_{d_{MP.\min}} S_{MP}} = \frac{205.863}{0.489 \times S_{MP}}$$

- Reference area at least 47.3 m^2

Main Parachute Design

- Disk-Gap-Band
  - D_0=8.3 m
  - S_0=54.1 m^2
  - Geometric porosity: 22.4%
  - Lines: 24
- Materials
  - Nylon broadloom fabric
  - Kevlar lines and webbing



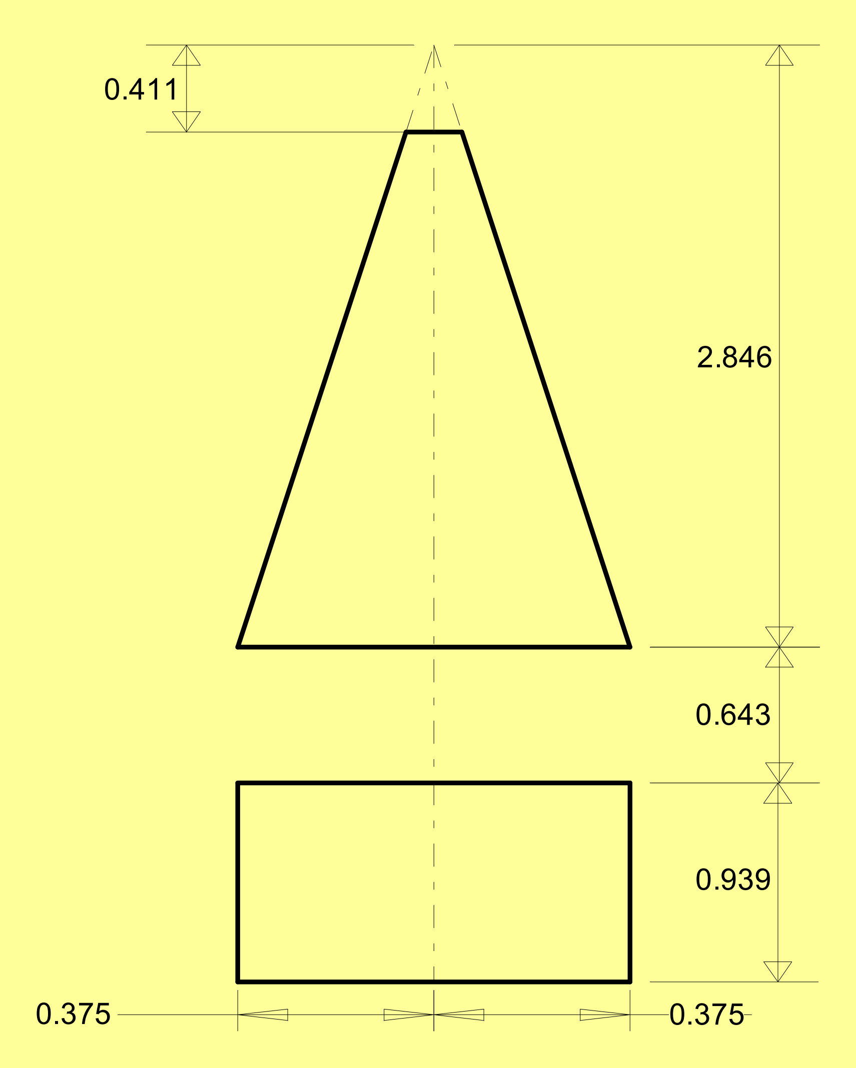
Main Parachute Design Load

- Inflation load
  - Maximum load was 14.7 kN
    - Failure case – fire on arm
- Component design loads

Component	Load
Canopy fabric	2.27 N/m
Lines (12)	613 N
Bridle legs (3)	14700 N

Main Parachute Design

- 24 Gores
- 24,2xD_0 Lines
  - 16.6 m
- 6.0 m riser
  - 27 m trailing dist
- 3.9 m bridle
  - Optimised for stability
- Swivel



Main Parachute Testing

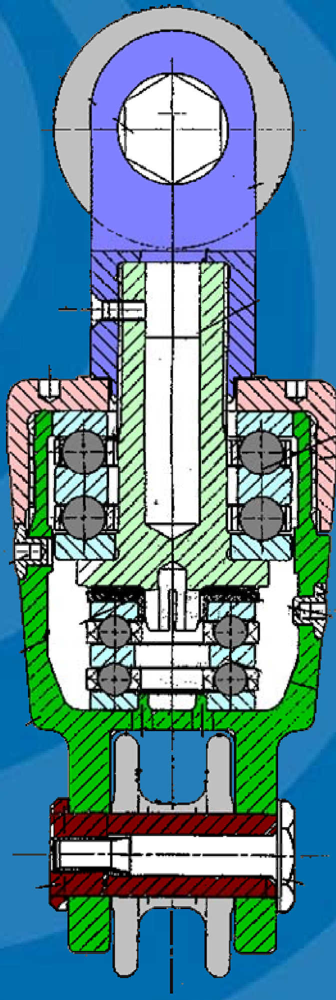
- Joint Tests
- Wind Tunnel Tests
- Environmental Tests
  - Temperature
  - Vibration
- Deployment Tests
  - Bench
  - Rapid
- Drop Tests
- System Test

Swivel Requirements

- Requirements
  - Decouple probe rotation from parachute
    - Maximum allowable torque
      - 0.01 Nm (F<245 N)
      - 7.6×10^{-5} F Nm (F>245N)
  - Withstand Main Parachute opening load
    - 14.7 kN
  - Environment
    - Cryogenic
  - Compatibility with outgassing

Swivel Design

- Thrust Ball Bearings
  - Redundant main bearings
- Compliant preload
  - Redundant preload bearings
- Tribology
  - MoS_2 coating on races
  - TiC & MoS_2 coating on balls



Parachute Release Mechanism

- Requirements
  - Withstand main parachute opening load
  - Release all three parachute attachments simultaneously
  - Low or zero force required for separation
  - High reliability
  - Environment
    - Cryogenic temperatures

PRM Trades

- Location
  - At bridle confluence
    - Single Unit
    - Bridle remains attached to probe
  - Three locations on upper platform
    - Ease of integration
  - Three locations beneath upper platform
    - Benign environment

PRM Trades

- Mechanism
  - Release nut below platform
    - Galileo, Pioneer Venus
    - Not fully redundant
  - Gas locks with dual cartridges and gas distribution
    - Used on ejection seats
    - Good simultaneity
      - Single gas source
    - Heavy
  - Pyrotechnic rod cutters
    - Commonality with SEPS

PRM Design

- Three mechanisms
  - One for each bridle leg
- Fully redundant rod cutters
- Twin ESI initiation
- No sharp corners

Stabilising Drogue Type

- Requirements
  - Good low dynamic pressure inflation
    - 10 Pa
  - Good stability during descent
  - Set overall descent time
- Options
  - Cruciform
  - Guide surface
  - Disk-Gap-Band

Stabilising Drogue Type

- Cruciform
  - Excellent stability from literature
  - Poor stability in wind tunnel models
- Guide surface
  - Good stability
  - Unproven low dynamic pressure inflation
- Disk-Gap-Band
  - Commonality with other parachutes
  - Excellent stability in wind tunnel tests

Stabilising Drogue Size

- Size determined by system descent time
- 3 dof trajectory code used to determine size
  - Nominal descent time: 2.25 hours

Stabilising Drogue Design

- Disk-Gap-Band
  - D_0=3.03 m
  - S_0=7.23 m^2
  - Geometric porosity: 22.4%
  - Lines: 24
- Materials
  - Nylon broadloom fabric
  - Kevlar lines and webbing

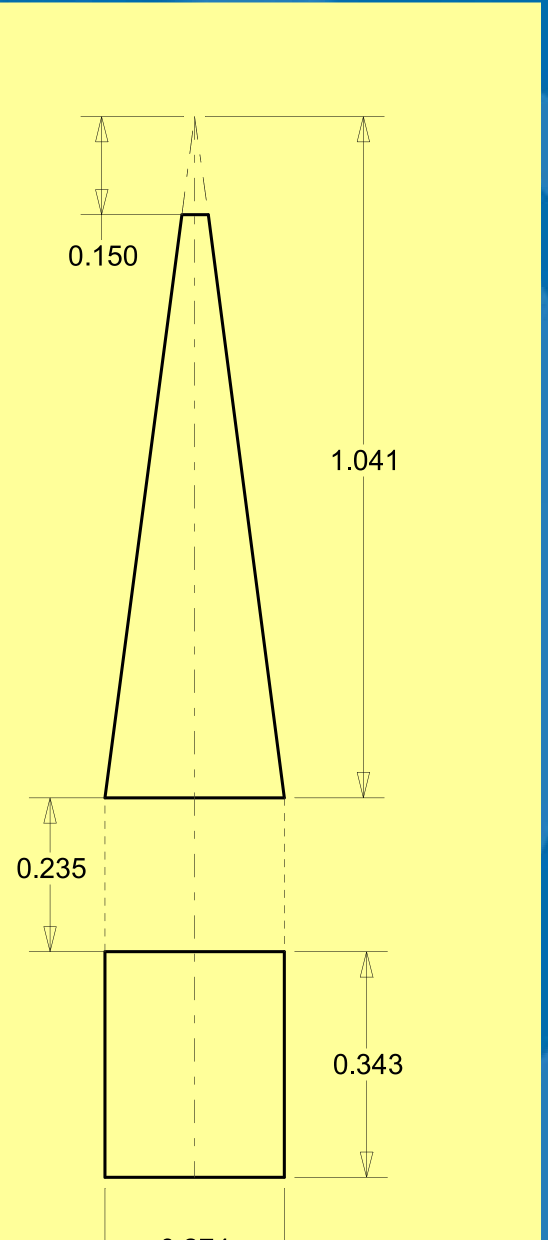
Stabilising Drogue Design Load

- Canopy and upper strop
  - Steady-state descent: 300 N
- Lower strop and bridle
  - Deployment snatch load: 1.8 kN
    - Due to rapid deployment

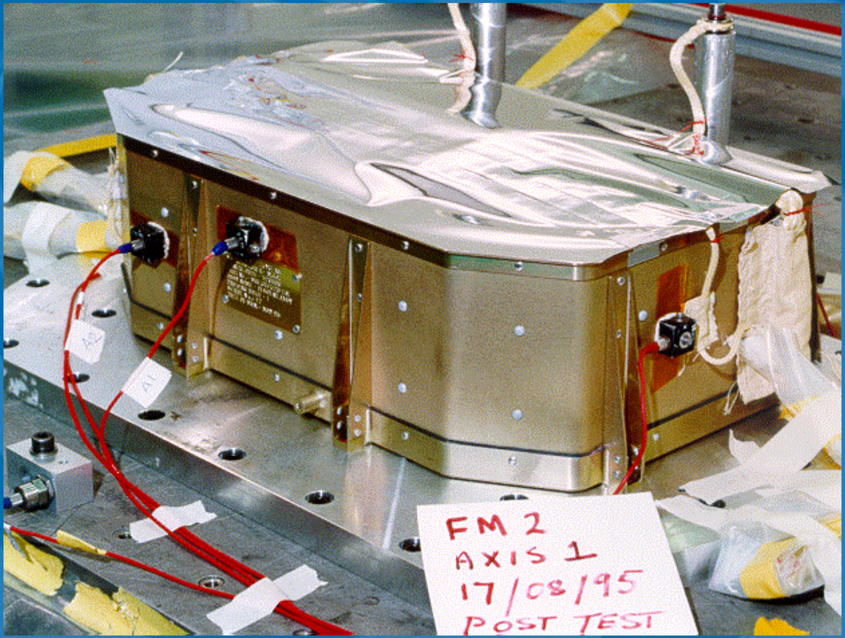
Component	Load
Canopy fabric	0.13 N/m
Lines (24)	13 N
Bridle legs (3)	1800 N

Stabilising Drogue Design

- 24 Gores
- 24,2xD_0 Lines
  - 6.06 m
- 1.0 m riser
  - 12 m trailing dist
- 3.9 m bridle
  - Optimised for stability
- Swivel



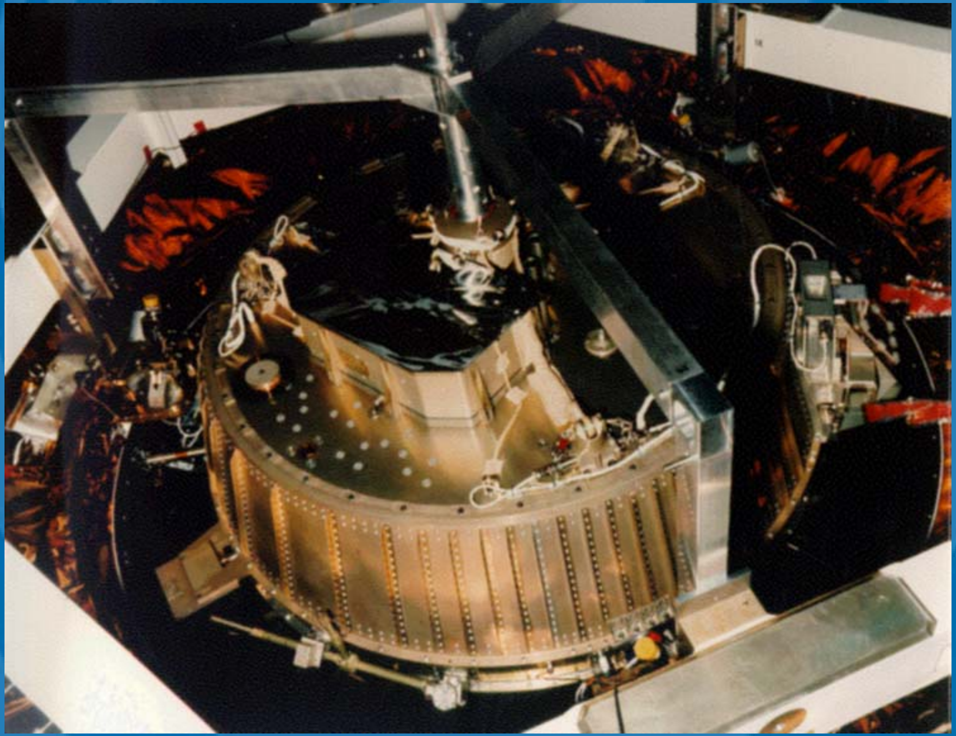
Container



- Requirements
  - Storage
    - Main Parachute
    - Stabilising Drogue
  - Thermal protection
  - Restrain parachutes
    - CG position must not change
    - Must not resonate
- Design
  - Aluminium structure
  - Packing Density: 300 kg/m^3

Integration

- Attached to upper platform
- Parachute bridles
  - Avoid fragile items
    - Antennae
  - Velcro attachment
- Exposed fabric
  - Kevlar only
  - High temperatures



Reliability

- Single Point Failures
  - Unavoidable in parachute systems
    - PDD Cartridge
    - PDD Body
    - Pilot Chute
    - Extraction lanyards (2)
    - Container
    - Main Parachute
    - Swivels
    - PJM (3)
    - Stabilising Drogue

Mass Breakdown

EQUIPMENT	Min Mass (kg)	Nom Mass (kg)	Max Mass (kg)
Pilot Chute	0.638	0.645	0.651
Main Parachute	4.527	4.573	4.751
SDA	0.751	0.758	0.787
Swivel Assemblies	0.814	0.823	0.831
PDD Assembly	1.257	1.269	1.282
PJM Assembly	2.123	2.145	2.166
Container Assembly	1.685	1.702	1.719
BoP Assembly	0.213	0.218	0.222
TOTAL	12.008	12.132	12.408

Conclusion

- 7 year development
- 7 year delivery
- 2.5 hour mission
- 24 Papers at this conference
- 6 Posters

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