Sub-scale, High-altitude testing of parachutes

A low-cost methodology for the characterisation of parachutes for planetary entry

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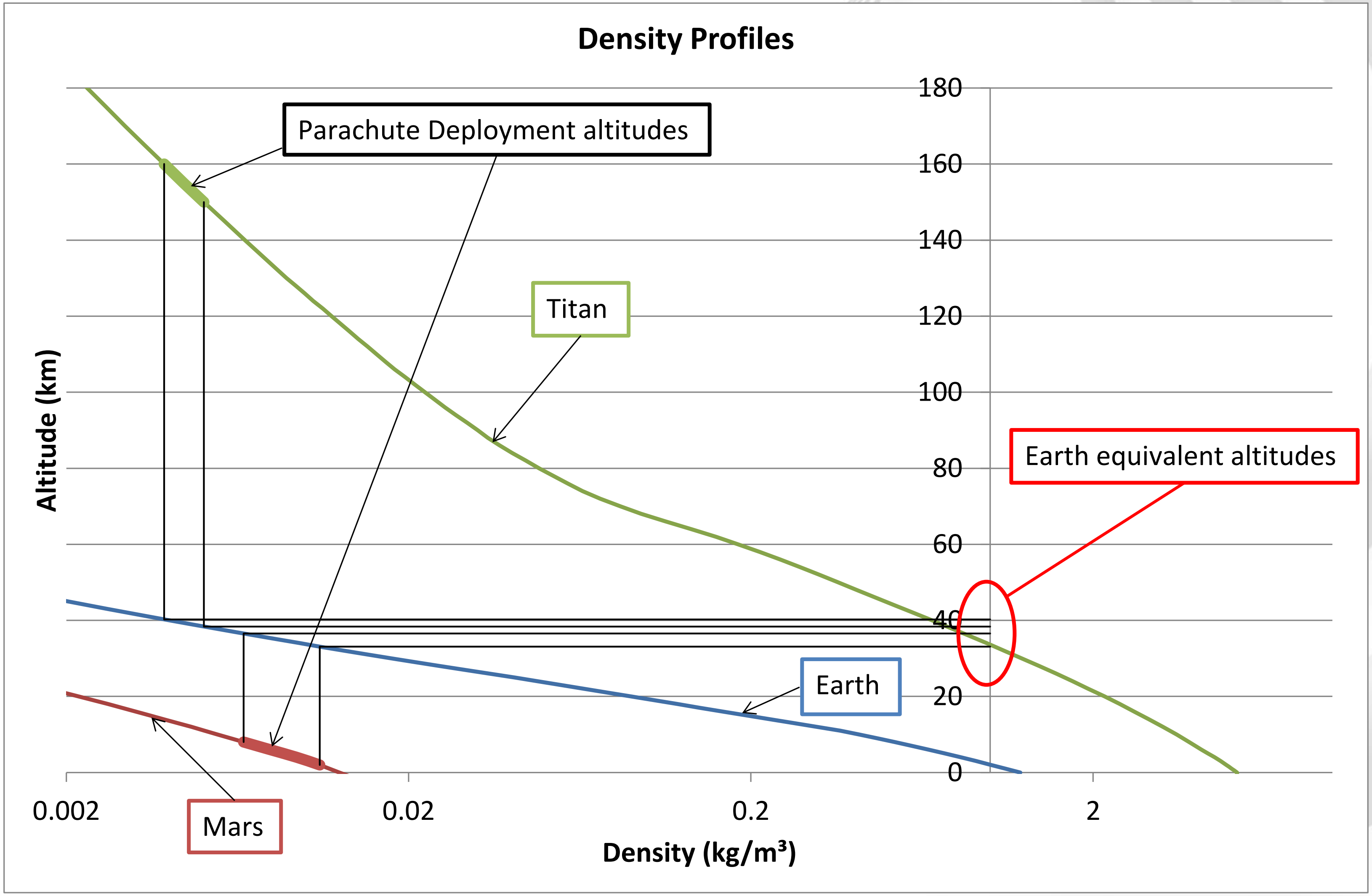
Why test at high altitude?



Why test at high altitude? - Inflation

- Full scale
  - Equivalent density and velocity gives similar load & stress
- Sub-scale
  - Need to match Mach number
  - Low density allows tests on lightweight models
  - Stiff materials affect inflation characteristics
  -

	Earth sea level	Mars @ 8km
Mach 0.5	17,700 Pa	48 Pa
Mach 2.5	443,000 Pa	1200 Pa

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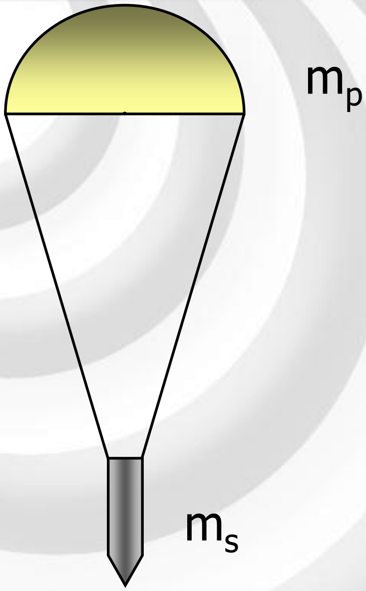
Why test at high altitude? - Dynamics

- Parachute
  - Moves through atmosphere
  - Atmosphere entrained
  - Effective mass increased
  - “Added mass”
- System CG moves
  - Earth low level
    - CG close to parachute
  - Mars
    - CG close to payload
- Stable parachute: No change
- Unstable parachute: Problems

Added mass

$$a_{11} = 2.136\rho \frac{\pi D_p{}^3}{12}$$



Do (m)	Earth (kg)	Mars (kg)
1	0.22	0.00
3	5.82	0.04
10	215.39	1.58
30	5815.63	42.73

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Historic Testing

- PEPP / SPADE / BLDT
  - NASA
  - 1960’s
- Huygens SM2
  - ESA
  - 1995
- MSL
  - NASA
  - 2004

PEPP / SPED / SHAPE / BLDT

- Planetary Entry Parachute Programme
- Supersonic Planetary Entry Decelerator programme
- Supersonic High Altitude Parachute Experiment
- Balloon Launched Decelerator Tests

- Precursors for Viking mission
  - 20 Tests in total
  - Parachutes 7.7m to 26m diameter
  - Payload mass 100 to 250 kg (+ one of 1200 kg)
  - Rocket launch or balloon / rocket launch
  - Expensive!

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Huygens SM2

- End to end test of ESA Huygens parachute system
  - 300 kg test vehicle
  - 37.5 km
  - Free-fall to Mach 0.8
  - Four-parachute test
  - Pilot Chute
    - Mach 0.8
  - Main Parachute
    - Mach 0.8
  - Stabilising Drogue
    - Mach 0.1
  - Recovery parachute

MSL

- Testing of 33.5 m ringsail parachute originally proposed for MSL second stage
  - 0.34 million m^3 He balloon hoisted payload to 36 km
  - deployment after 21s freefall at Mach 0.54 and 148 Pa
  - Payload mass at release 980 kg including the parachute system
  - 4 tests conducted only one fully successful: 2 parachute failures due to inadequate deployment control, one balloon failure
  - On successful test high altitude instability of the low porosity ringsail parachute was evident

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Common features

- Size
  - Full-scale
    - ~10 m parachutes
    - 100 kg+ payloads
- Free-fall tests
  - Cost: € x,000,000
  - Complexity: High
    - Dedicated test vehicle + avionics
    - High reliability due to cost of test
- Boosted tests
  - Cost: € x0,000,000
  - Complexity: Very high
    - Additional rocket + GNC requirements

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Cost drivers

- Payload
  - Heavy
    - Transport & Recovery
  - High loads
    - Challenging mechanical design
- Balloon
  - Large, zero-pressure balloon required
    - ~1,000,000 m^3
    - Helium: ~€2/m^3 @STP
- Complexity
  - Radar transponders + beacons
  - Redundant cut-down systems

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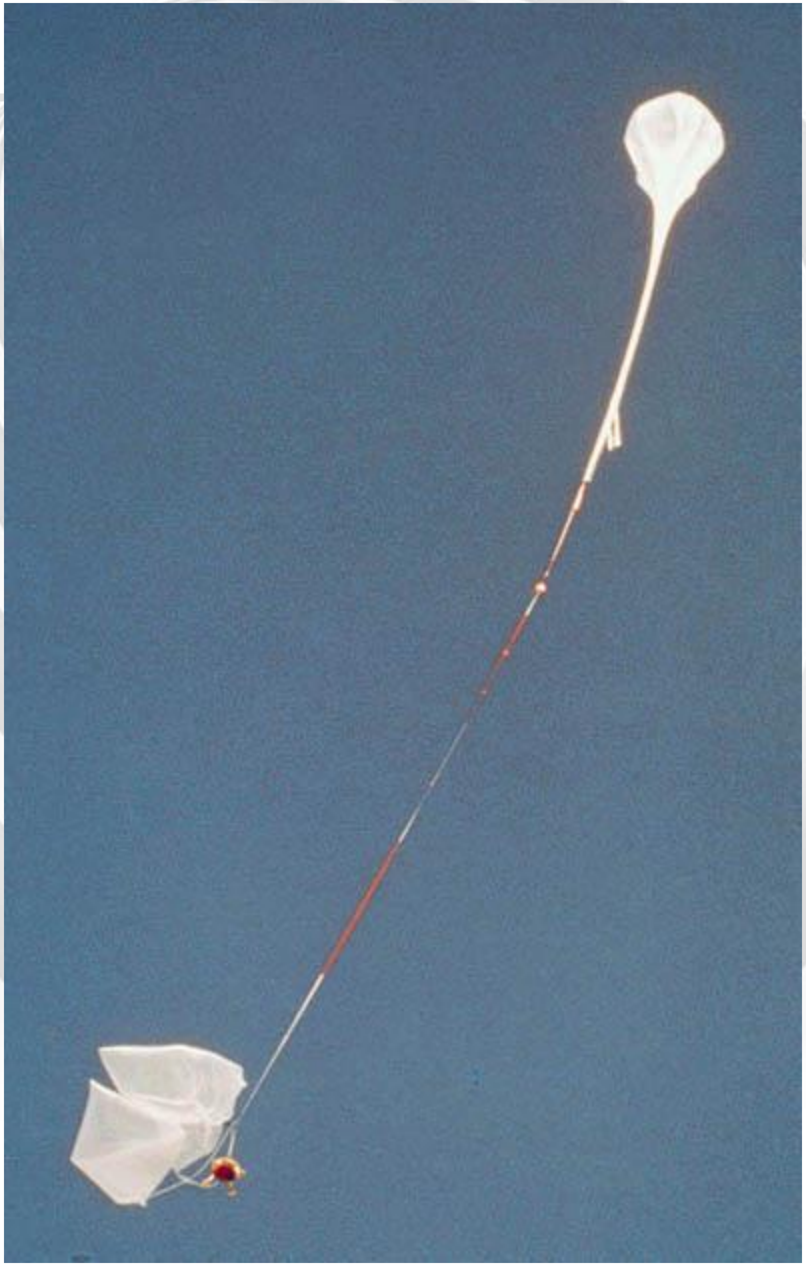
Balloon technology

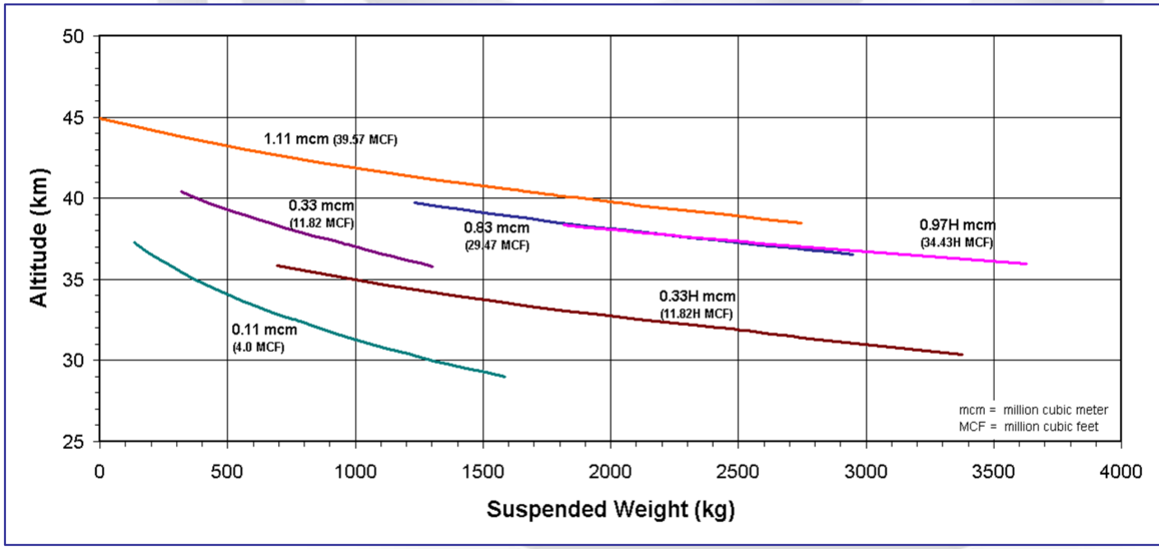
- Zero pressure
  - Used for all full-scale parachute tests
- Latex
  - Meteorological balloons



Zero pressure balloons

- Operation
  - Polythene envelope
  - Open at bottom
  - Gas expands during ascent
  - Gas vents from bottom at cruise altitude
- Capabilities
  - Masses up to 3500 kg
  - Altitude up to 45 km
- Disadvantages
  - Expensive
  - Redundant cut-downs

ANTARCTIC BALLOON LAUNCH (NASA)



Latex Balloons

- Operation
  - Latex envelope
  - Sealed
  - Gas and balloon expand during ascent
  - Balloon bursts at mechanical limit
    - No cut-down required
- Capability
  - Masses up to 15 kg
  - Altitude up to 40 km
- Disadvantages
  - Small payload

Comparison

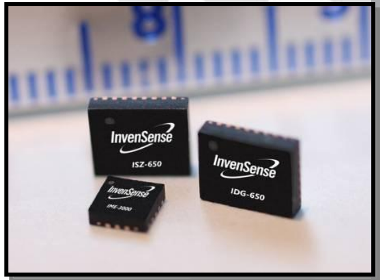
Launch Site

GSE

Gas

Payload

- Structure
- Test Parachute (up to 2.5m)
- Deployment mechanism
  - Spring drogue
  - Pyrotechnic release mechanism
- Instrumentation
  - Accelerometers (3 axis)
  - Rate gyros
  - Magnetometer
  - GPS
  - Pitot & Static pressures
  - Data recorder
  - Camera (300 fps)



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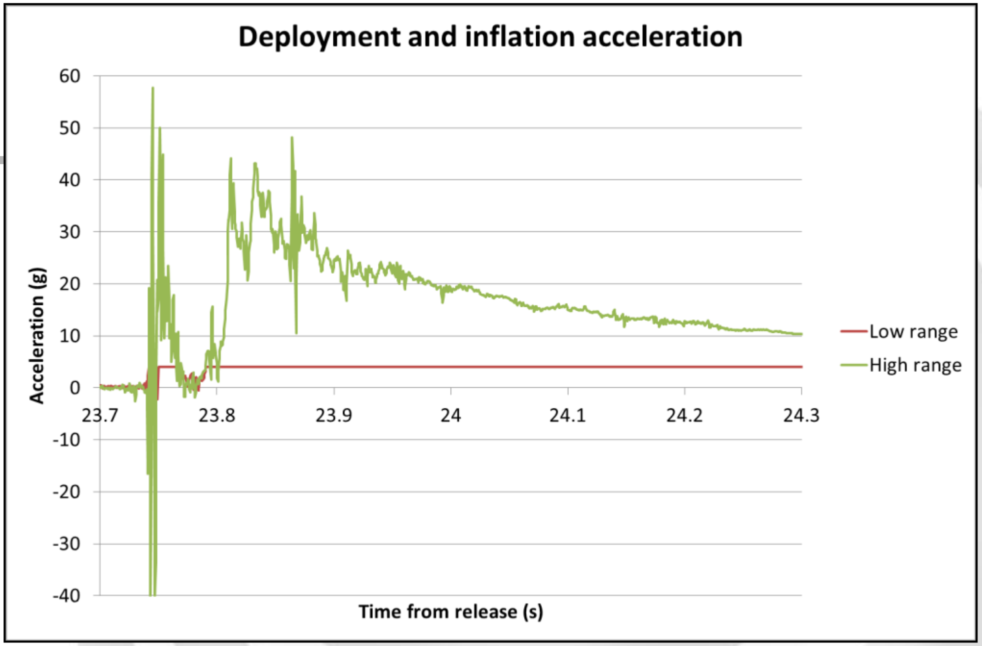
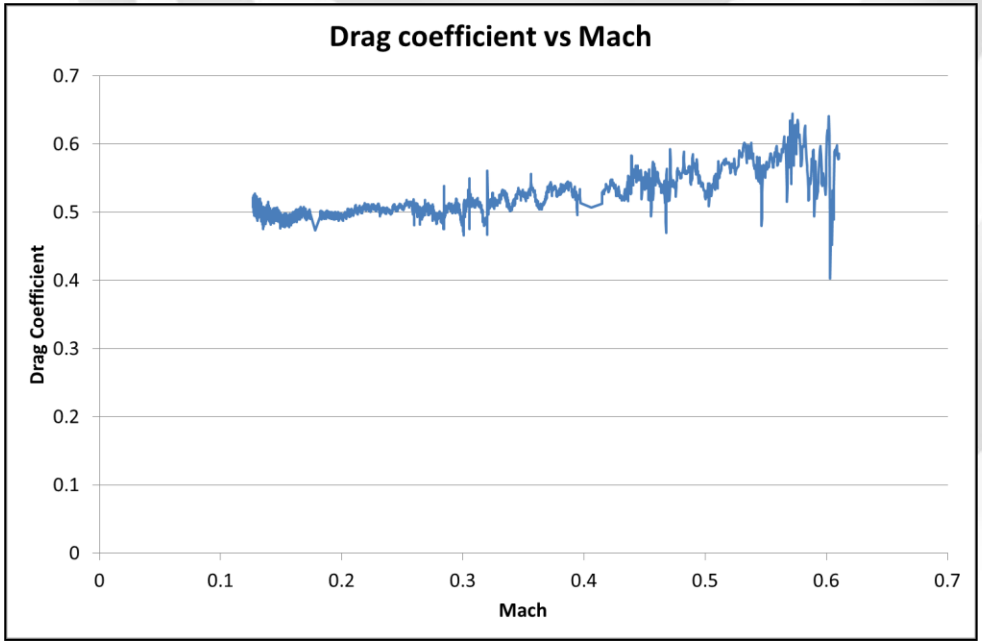
Low-speed, high altitude test

Low-speed, high altitude test

Mach 0.7 flight

- High subsonic speed
- All data measured
- Inflation profile deduced
- Cd(Mach) calculated
- All hardware recovered
- Video needs work





Mach 0.7 flight video

Mach 0.7 flight video (slow)

Lessons learned

- High altitude, sub-scale tests are feasible
- COTS components are compatible with environment
- COTS cameras not qualified for 100g acceleration

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Future Plans

- High altitude static-line deployed tests in progress
- Campaign of six tests at Mach 0.8 planned for spring 2013

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Questions