3rd International Planetary Probe Workshop

Parachute Testing 1

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Testing 1

- Test condition matching
- Wind tunnel testing
- System testing

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Matching

- Why?
  - Parachute performance depends on conditions
    - Mach, dynamic pressure, Reynolds number, velocity, forebody wake, suspended mass, gravity, …
- Why is it a problem for us?
  - Terrestrial system
    - Test in actual conditions
  - Extra-terrestrial system
    - Actual conditions may not exist on Earth
- Solution
  - Can match some conditions
  - Need to decide what is important

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What do we want to investigate?

- Deployment
  - Dynamics
    - Strength
- Inflation
  - Inflation force
    - Structural margin
  - Inflation process
    - Robustness of opening
  - Initial flight
    - Wake recontact
- Steady-state descent
  - Drag area
  - System dynamics
- Full system sequence

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Matching - Deployment

- Deployment dynamics
  - Velocity profile
    - Dynamic pressure
    - Gravity
    - System masses
- Alternative
  - Pulley system / Steam catapult
  - Match velocities to simulation

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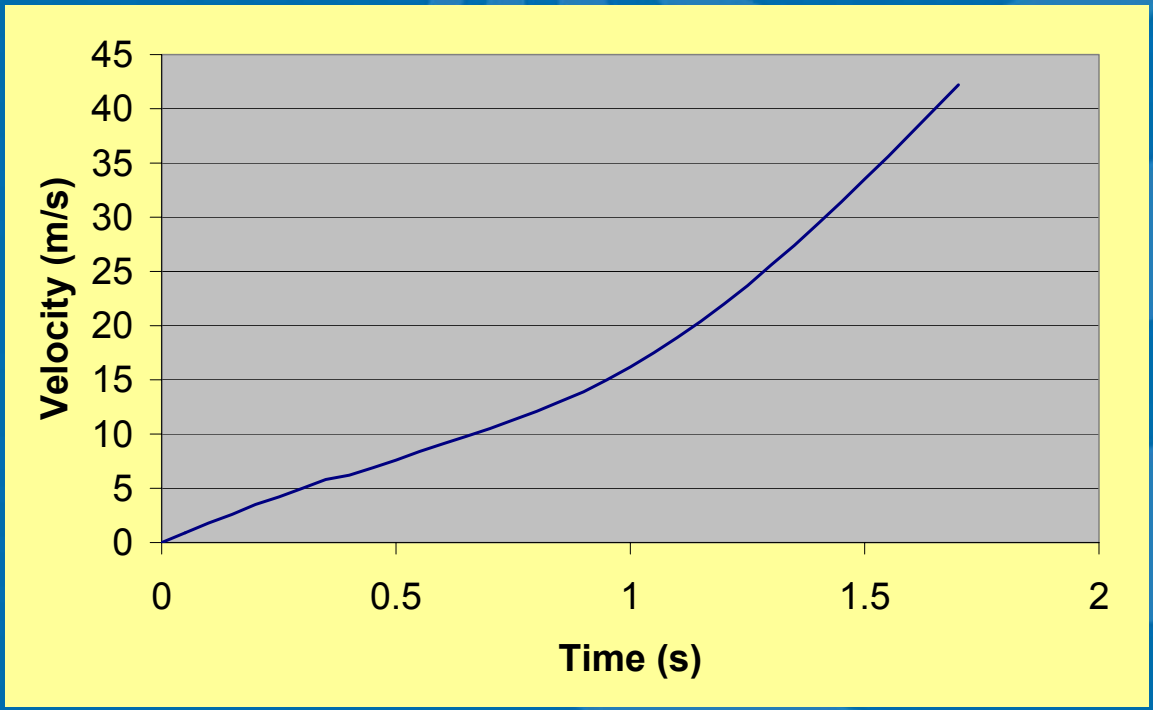
Example – Huygens Main Parachute

- Huygens Main Parachute Extraction
  - Deployment time: 1.7 s
  - Velocity at lines-taut: 42 m/s



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Example – Huygens Main Parachute

- Solution
  - Pulley system
  - 6:1 ratio
    - 40 m/s^2 acceleration
  - 300 kg mass

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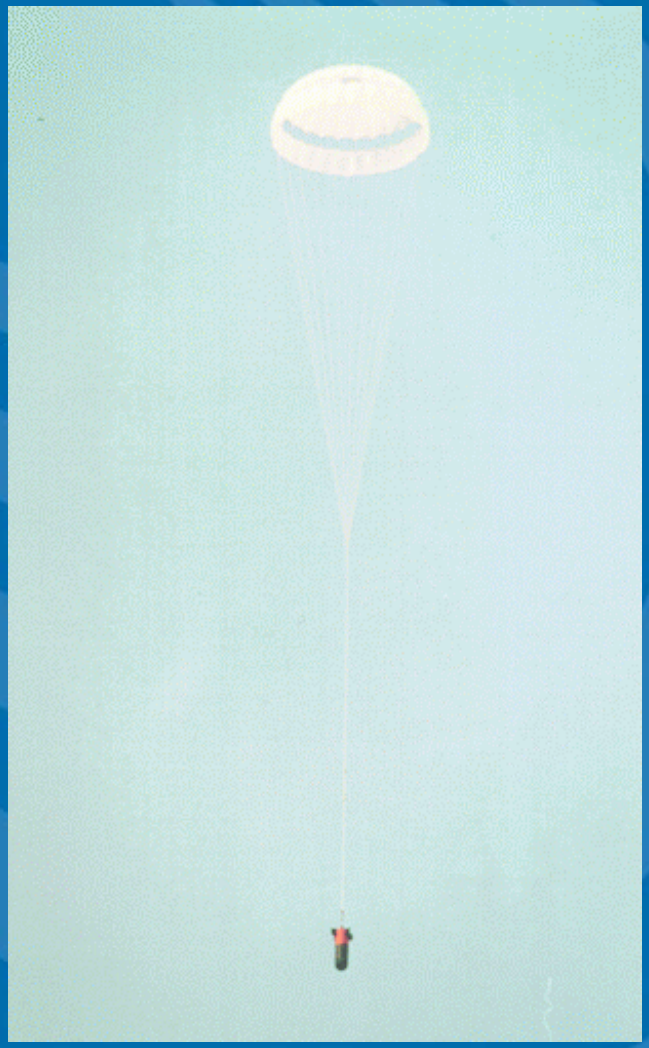
Matching – Inflation

- Inflation force
  - Easy to match peak force
  - BUT need to match dynamics
    - Stress distribution
- Inflation dynamics
  - Dynamic pressure
  - Velocity
  - Mass ratio
  - Mach number
- Wake recontact
  - Mass ratio
  - Velocity
  - Added mass



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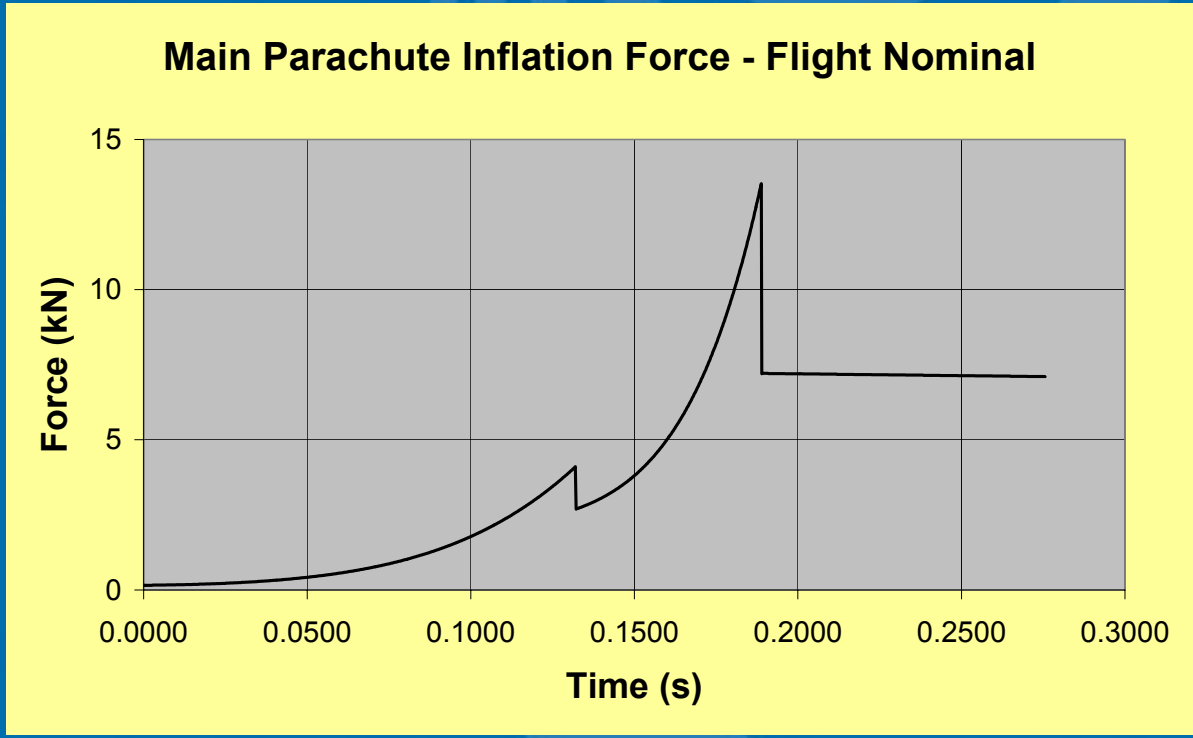
Inflation examples – Huygens Main

- Design opening condition
  - Mach=1.43, q=287 Pa, V=381 m/s, F=13.2 kN



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Inflation examples – Huygens Main

- Design opening condition
  - Mach=1.43, q=287 Pa, V=381 m/s, F=13.2 kN
    - ρ=0.0044 kg/m^3, mass=289 kg
- Test – Match opening force (low level)
  - Mach=0.22, q=3119 Pa, V=72 m/s, F=13.2 kN
    - ρ=1.22 kg/m^3, mass=100 kg
- Differences
  - Test vehicle lighter
    - Helicopter limit
    - Mass ratio smaller
  - Initial velocity lower
    - q falls more quickly for given acceleration

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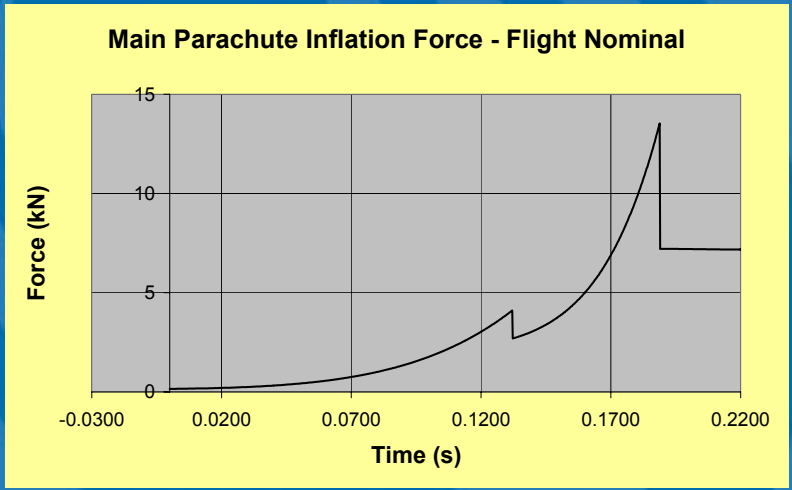
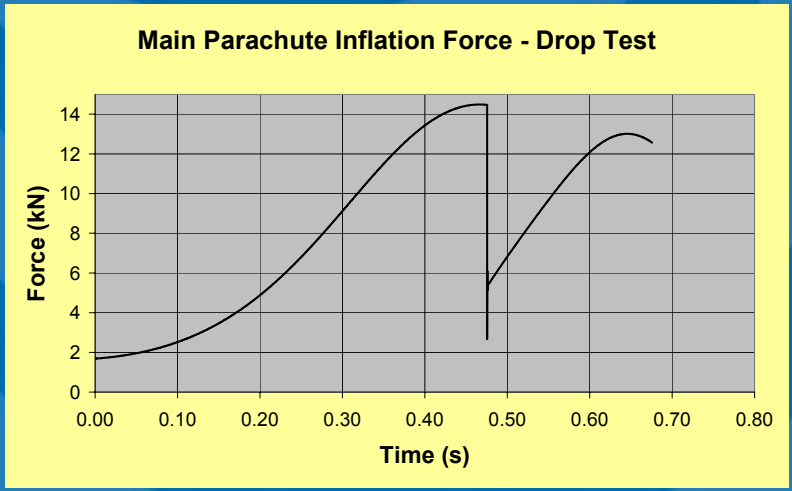
Inflation examples – Huygens Main

- Inflation load matched
- BUT
  - Load occurs earlier
  - Stress distribution different
- Solution
  - High altitude drop
    - Density lower
      - Velocity higher
    - Heavier test vehicle
  - €€€€€€€





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Matching – Steady-State – Drag Area

- Mach number
  - $M=f(V, c)$
- Reynolds number
  - $Re=f(D, \rho, \mu, V)$
- Wake
  - Need representative forebody
- Atmospheric conditions
  - Thermal activity
- Material flexibility
  - Wind tunnel models may not be representative
- "Steady state" never achieved

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Matching – Steady-State – System Dynamics

- Payload Inertia
- Parachute Inertia
  - Including added mass (i.e. density)
- Mass
- Weight
  - gravity
- Dynamic pressure
- Strouhal number
- Usually impossible to match all
  - Decide what is important
  - Depends on phenomenon being investigated

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Wind tunnel testing

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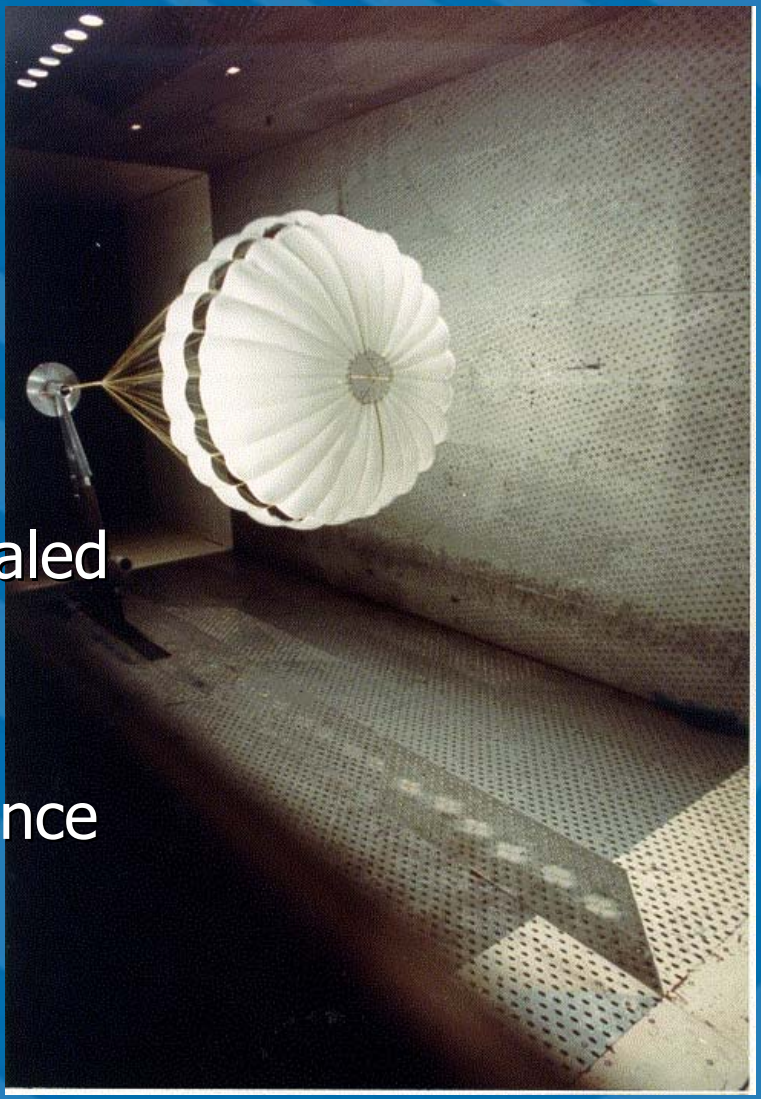
Wind tunnel testing

- Advantages
  - Clean flow
  - Easy to instrument
- Disadvantages
  - Test parachutes usually scaled
    - Blockage
  - Model stiffness
  - Support structure interference



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Wind Tunnel Facilities

- Examples
  - Subsonic
    - NASA Ames (USA) – 24 x 37 m, 12 x 24 m
    - DNW LLF (Holland) – 9.5 x 9.5m
    - TsAGI T101 (Russia) – 24 x 14 m
  - Transonic
    - AEDC 16T (USA) – 4.9 x 4.9 m
    - DERA (UK) – 2.5 x 2.5m
  - Supersonic
    - AEDC 16S (USA) – 4.9 x 4.9 m
    - Onera S2Ma (France) – 1.75 x 1.93 m
- Google

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Blockage

- Wind tunnels designed for <5% blockage
  - Wall effects
  - Can stall supersonic tunnels
- Correction factors for Cd
  - e.g. Maskell (Subsonic, solid wall tunnel)

$$\frac{q_{corr}}{q_{FS}} = 1 + 1.85 \frac{(C_d S_0)_{FS}}{S_t}$$

- Correction much smaller for perforated wall tunnels

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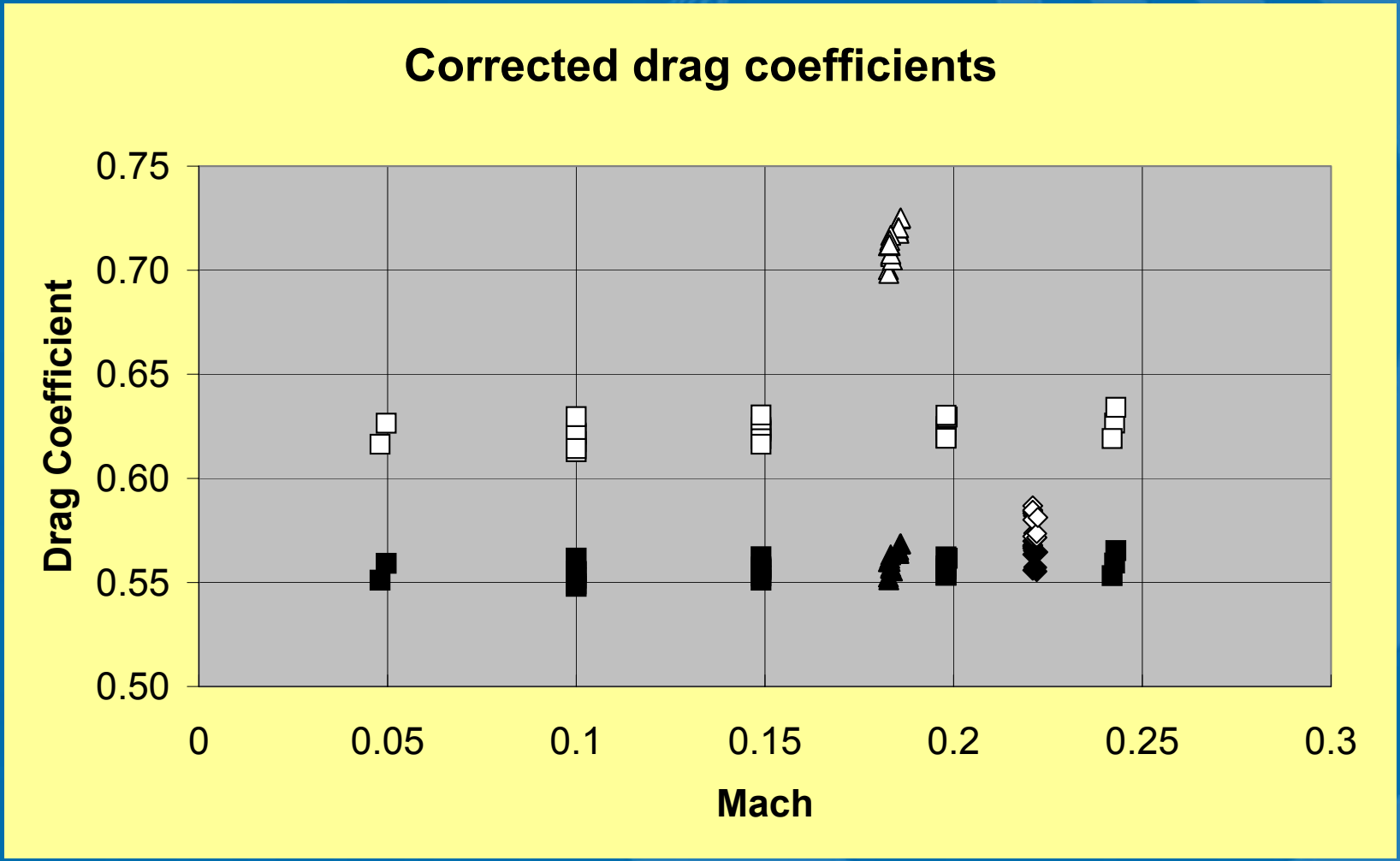
Blockage Correction



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Models

- Small
  - Except for low speed testing at NASA Ames
- Stiffness representative
  - Reduced size implies reduced stiffness
- Robust
  - Supersonic deceleration parachute
    - Inflation to subsonic in <10 seconds
  - Supersonic wind tunnel test
    - 10's of minutes on condition

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Instrumentation

- Standard wind tunnel
  - Flow conditions
  - Force on support structure
- Additional
  - Parachute force (force transducer on model)
  - Pitot-static sensor
    - Confirm blockage calculations
  - Wall static pressures
    - Variability of flow conditions by tunnel station
  - Video
    - Document model damage
    - Assessment of stability
  - High speed video
    - Inflations

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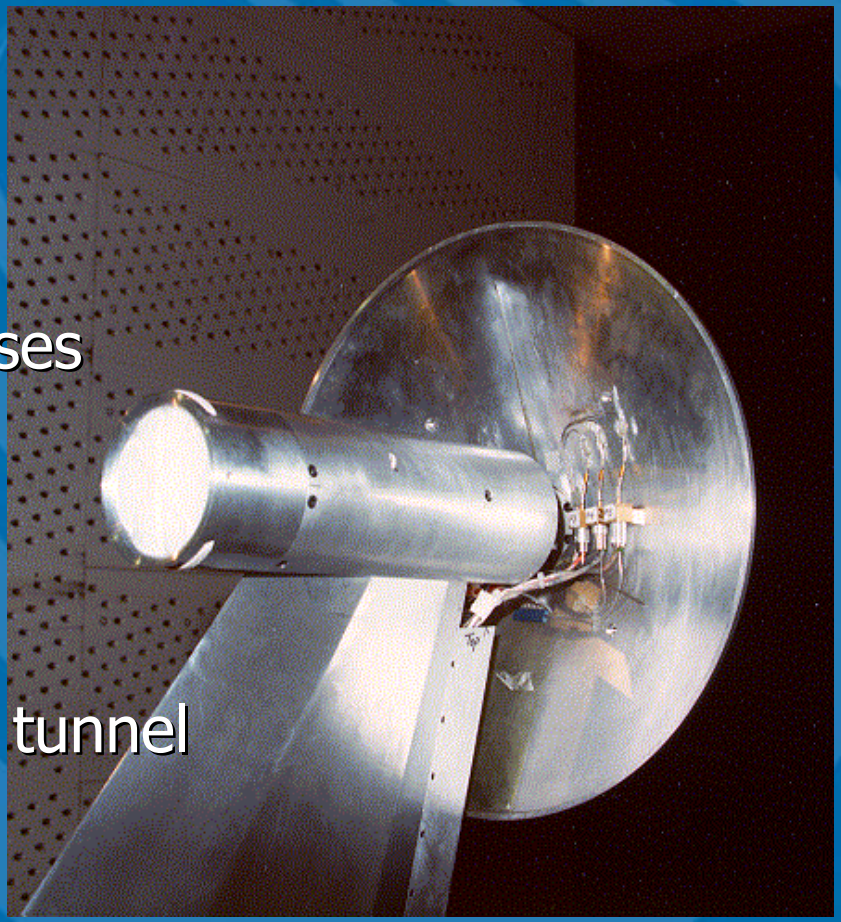
Techniques – Deployment

- Low speed
  - Lay parachute on floor
  - Deploy as airflow increases
- High speed
  - Mortar deploy
  - Limits damage duration
  - Limits startup power for tunnel



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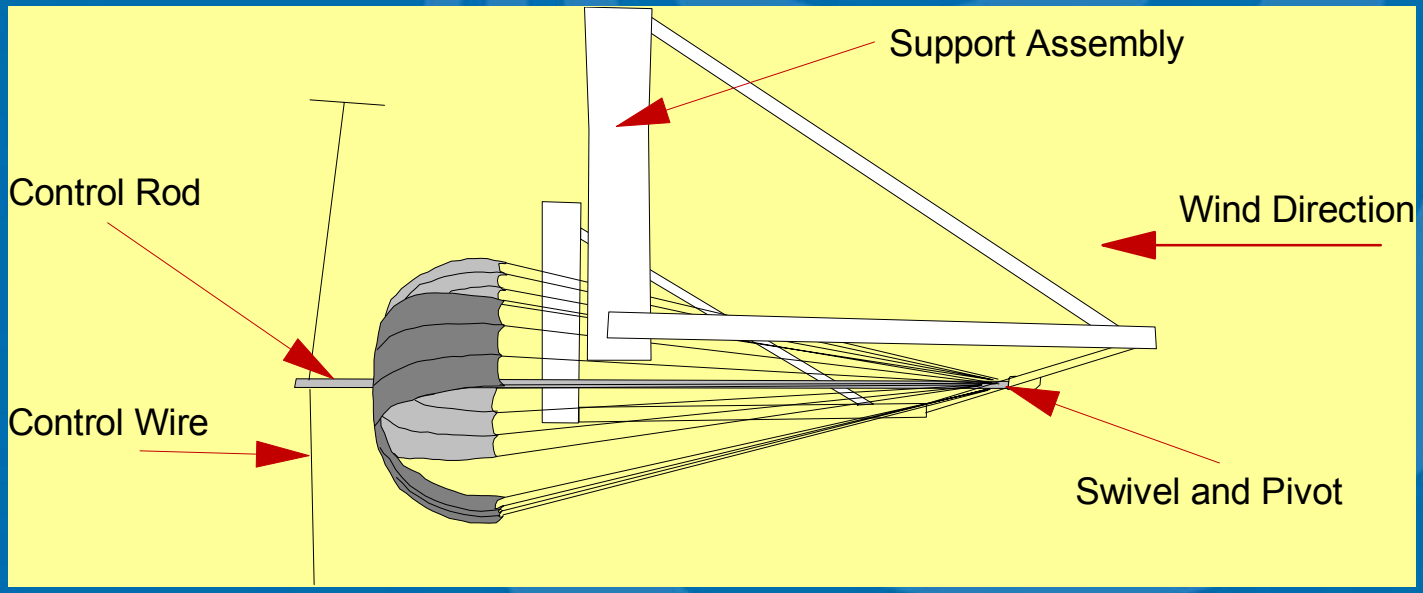
Techniques – Non-zero incidence

- Can force parachute incidence
- Treat results with caution



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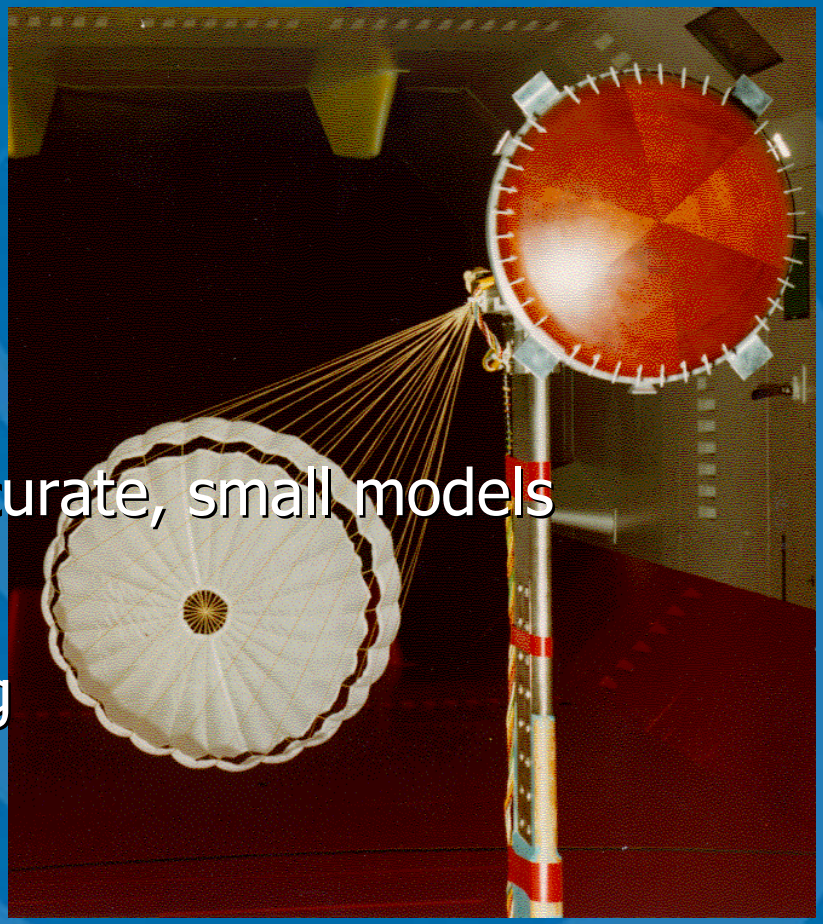
Consider

- Gravity
- Model fidelity
  - Very difficult to build accurate, small models
- Spares
  - You will break something
- Flexibility in plans



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System Testing

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System Test Philosophy

- Test every component to full design load
  - + margin
  - Under extreme environments
- Test every deployment sequence
  - Extreme conditions (e.g. velocity / temperature)
- Test interaction between components

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System Test Method

- Joint Tests
  - All candidate joints
    - Worst case environments
- Aerodynamic tests
  - Wind tunnel tests
- Full scale tests
  - Deployment, inflation and flight
- System Test
  - Full end-to-end test

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System testing

- Why?
  - Test full sequence
    - Identify interactions between elements
- Ideal
  - Single end to end test
- Realistic
  - Split into small number of overlapping sub-tests
  - Modify system for test

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Example – Huygens System Test

- Flight Sequence

Event	Time (s)	Mach	q (Pa)	Vel (m/s)	Force (N)
Mortar Firing	0.0	1.54	336	409	
Pilot Chute Inflation	0.8	1.52	317	405	1.55
Back cover release	2.0	1.47	299	391	
Main parachute inflation	3.4	1.43	287	381	13.2
Front shield release	30	0.44	30.7	118	
Main parachute release	900	0.14	9.4	36	
Stabilising drogue terminal		0.03	68	5	

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Huygens System Test – Pilot Chute

- Pilot Chute inflation
  - Mach 1.52, q=317 Pa, V=405 m/s
  - ρ=0.00387 kg/m^3
  - Altitude is 40.24 km
- Mach only 1.25
- Cannot achieve by freefall alone
  - Requires booster
- Probe unstable through Mach 1
- Compromise
  - Balloon drop from 37.5 km
  - Mach 0.78, q=325 Pa, V=242 m/s

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Huygens System Test – Main Parachute

- Huygens conditions
  - Mach 1.43, q=287 Pa, V=381 m/s
- Test conditions
  - Mach 0.79, q=384 Pa, V=247 m/s
- Dependent on pilot chute conditions
  - Titan: $q_{Pilot} > q_{Main}$
  - Earth: $q_{Pilot} < q_{Main}$
  - Cause: Gravity
- Main parachute inflation force too high
  - Within capability of parachute

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Huygens System Test – Front Shield release

- Huygens conditions
  - Mach 0.44, q=31 Pa, V=118 m/s
- Test conditions
  - Mach 0.33, q=106 Pa, V=99 m/s
- Dynamic pressure higher
- Separation dynamics will be different

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Huygens System Test – Stabilising drogue deployment

- Huygens conditions
  - Mach 0.14, q=9.4 Pa, V=36 m/s
- Test conditions
  - Mach 0.09, q=78 Pa, V=34 m/s
- Dynamic pressure higher
  - Deployment much faster
    - Snatch force higher: 4.2 kN
  - Steady-state force much higher (1.6 kN vs 300N)
- Margins
  - Aerodynamic loads – OK
  - Snatch loads - No
    - Required tear-webbing to attenuate load

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Huygens System Test – Stabilising drogue flight

- Huygens terminal conditions
  - Mach 0.03, q=68 Pa, V=5 m/s
- Test conditions
  - Mach 0.08, q=411 Pa, V=25 m/s
- Recovery Chute Necessary
  - Requires additional parachute release mechanism

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Huygens System Test – Summary

- Whole parachute sequence
- Inflation forces at least equal to flight
- Transonic & supersonic regime not tested
  - However covered wind tunnel trials
- Minor modifications to stabilising drogue
- Additional release mechanism and parachute

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Example – Mars lander with retro-rockets

- Terminal velocity on Earth lower than Mars

$$\frac{V_E}{V_M} = \sqrt{\frac{g_E}{g_M}\frac{\rho_M}{\rho_E}} \approx 0.15$$

- δV from retro rocket is the same
- Cannot test flight parachute and rockets together

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Conclusions

- Full system test with actual conditions
  - Rarely possible
- System test with off-nominal conditions
  - Can frequently be achieved
  - Consider designing for test from start
- Some systems require two or more sequential tests
  - Ensure adequate overlap between tests

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