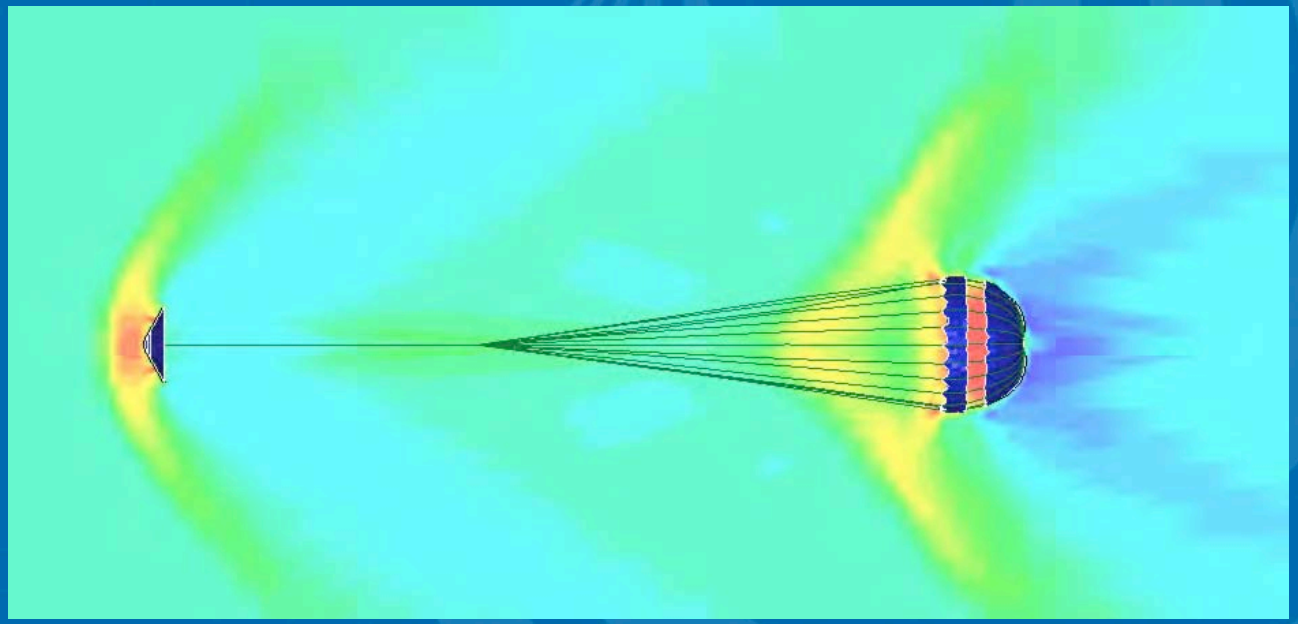
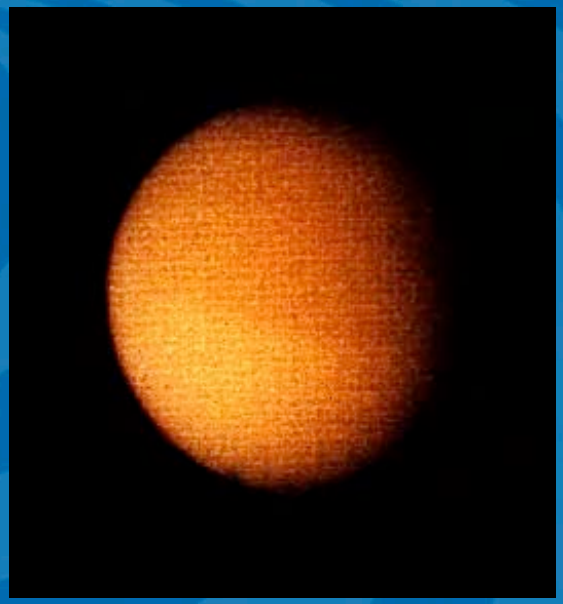
Huygens Performance Reconstruction



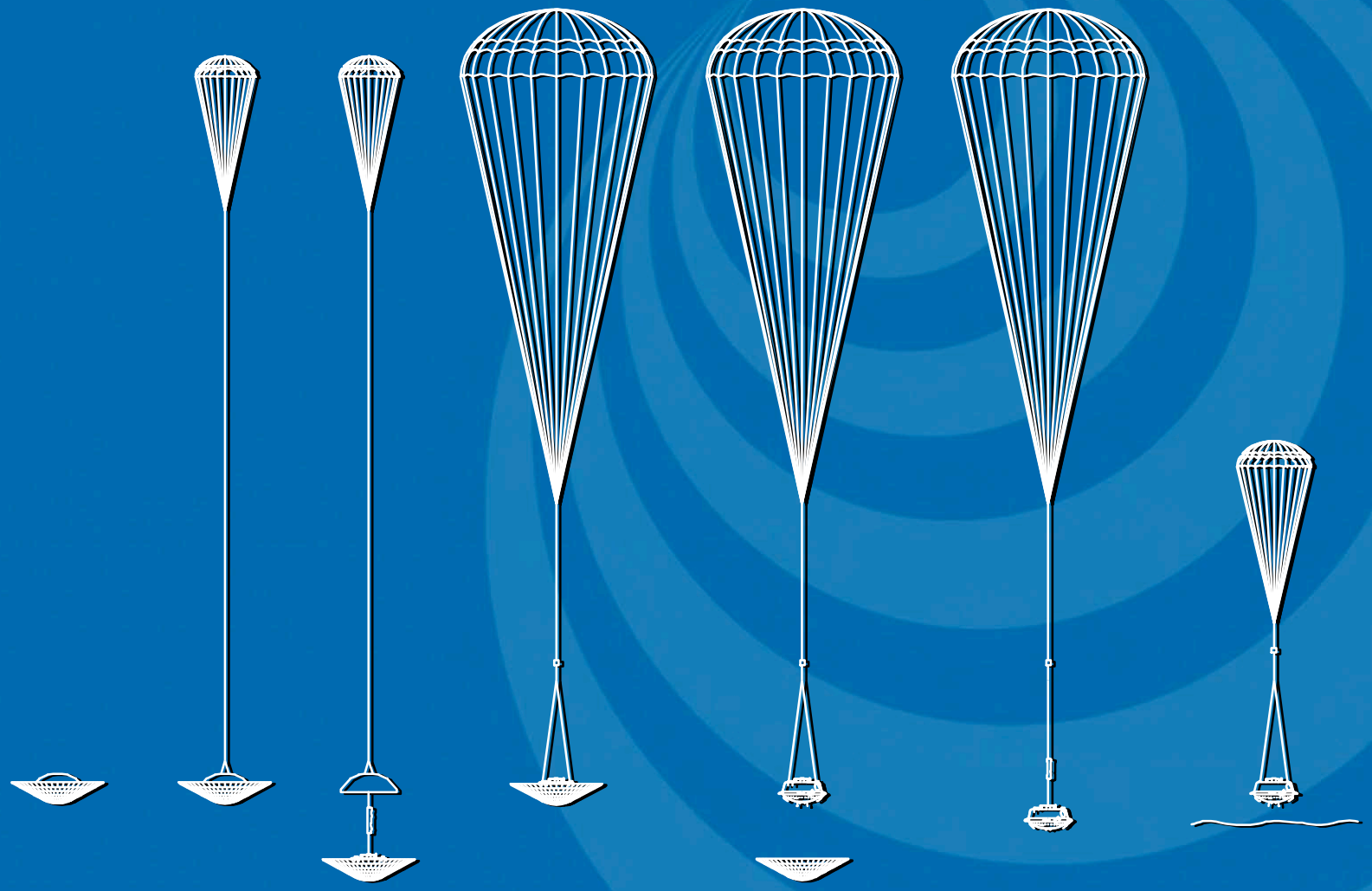
John Underwood
Vorticity Ltd

History



- Developed in early 1990's
- Titan knowledge
  - Voyager
  - Stellar occultations
- Since launch
  - Improvement in Titan knowledge
  - Additional parachute data
    - e.g. Mars Pathfinder and MER
  - Huygens baseline mission change
- Revalidation in 2003
  - Compliant with new conditions
  - Large margin in original design

Sequence



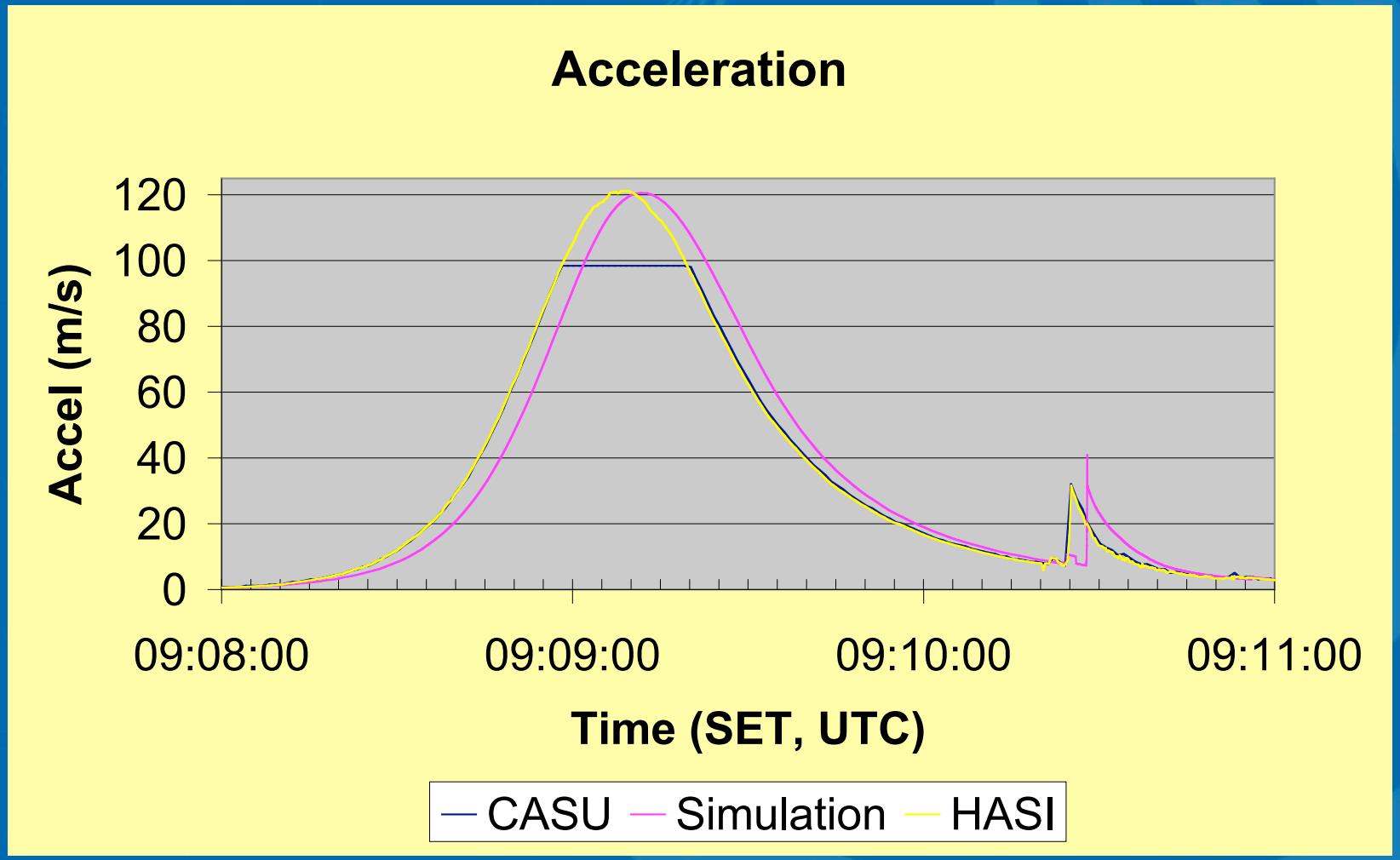
Timeline

Event	Time (s)	Altitude (km)	Velocity (m/s)	FPA (deg)	Mach	q (Pa)
Entry	0 (T_e)	1270	6031	-65.55	24.6	0
PDD Fire	271.25 (T_0)	156.3	386	-59.0	1.49	317
Back cover release	T_0+2.5	155.5	289	-59.3	1.41	289
Front shield release	T_0+32.5	150.6	104	-65.7	0.40	27
Main parachute release	T_0+900	110.3	34.8	-89.3	0.14	10
Landing	T_0+8846	0	4.9	-90	0.025	64

Time offset

- Initial state supplied by JPL
- Atmosphere model from Ta flyby data
- Probe model used during revalidation

Time offset


Acceleration
Accel (m/s)
120
100
80
60
40
20
0
09:08:00
09:09:00
09:10:00
09:11:00
Time (SET, UTC)
CASU
Simulation
HASI

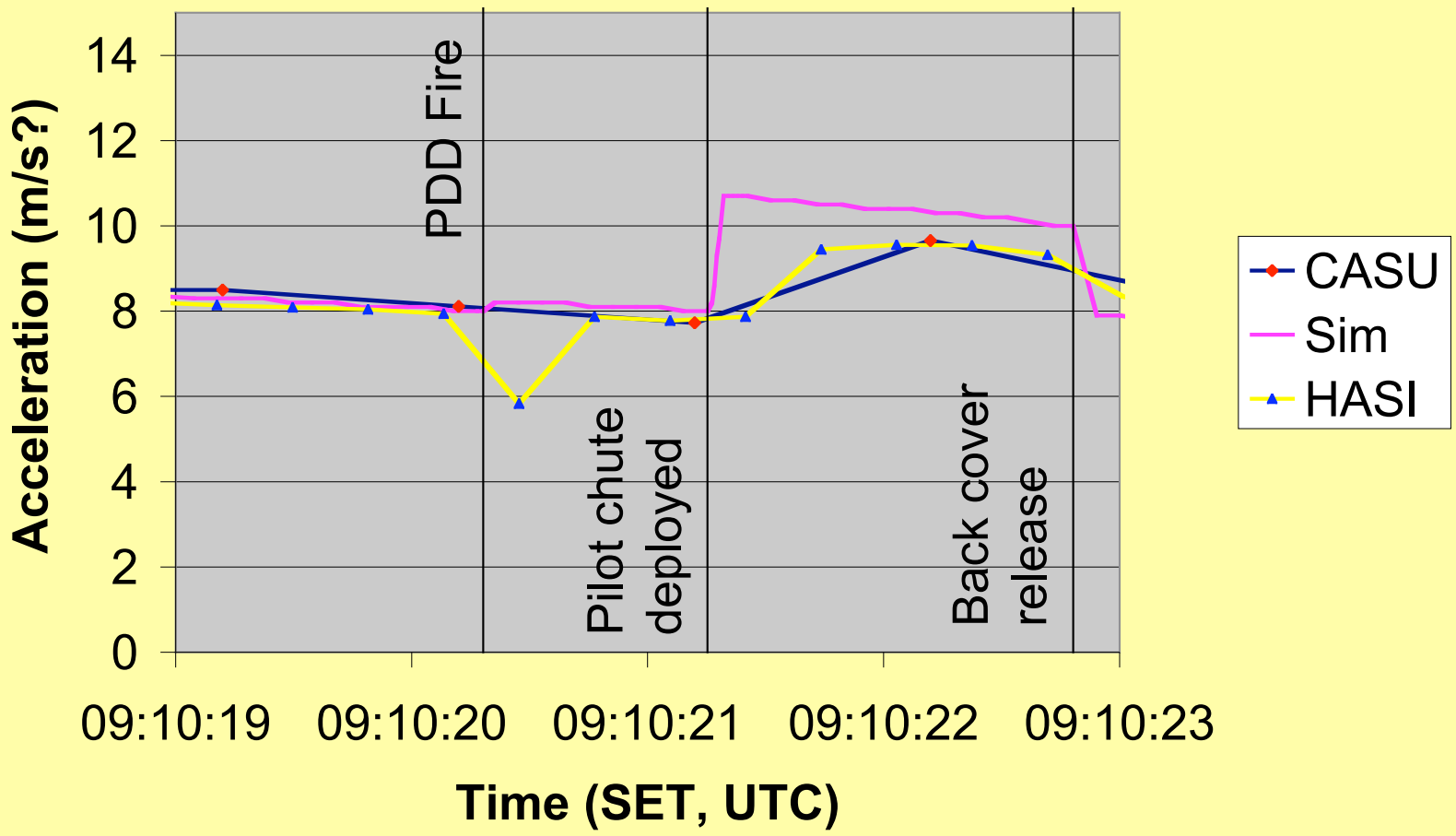
Time offset

- Offset is 3.2 seconds
  - Huygens reached atmosphere earlier than expected

Sequence timings

- T_0 (PDD fire)
  - Detected by housekeeping accelerometers
  - Very close to nominal value
- Subsequent events
  - Timeline

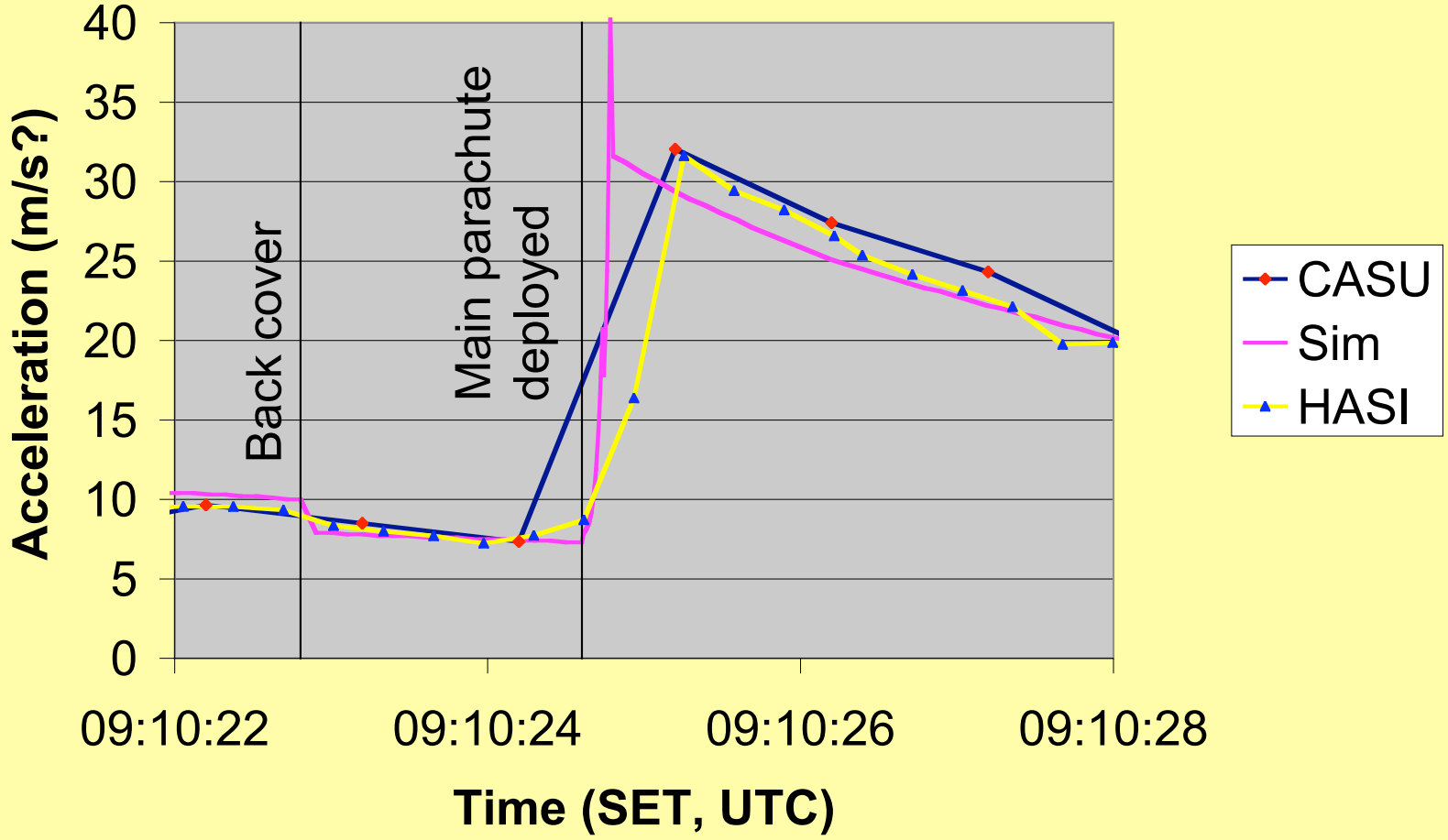
Pilot Chute deployment and inflation



Pilot Chute deployment and inflation

- PDD reaction load observed on HASI acc?
- Slightly slow deployment?
  - Reduced PDD velocity
  - Increased friction
  - Wake not as predicted
- Drag appears lower than expected
  - Equivalent to 30% reduction in pilot chute drag
    - Not reached steady flight?
    - Wake effects greater than expected?

Main Parachute Deployment and Inflation



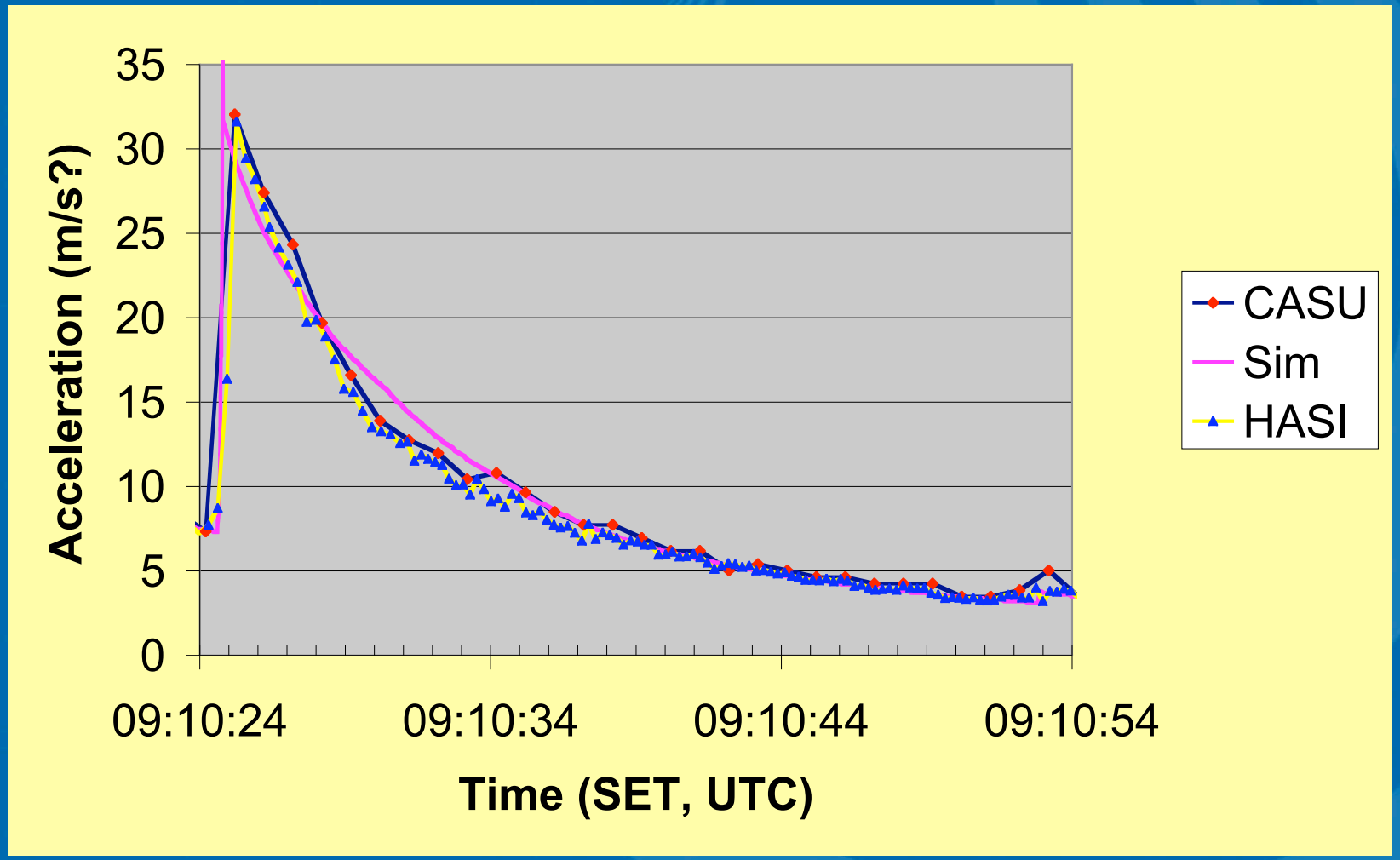
Main Parachute Deployment and Inflation

- Deployment time
  - Predicted: 1.8 s
  - Actual: between 1.9 and 2.1 seconds
  - 30% reduced pilot chute drag: 2.35 seconds
  - PC drag recovered during MP deployment
- Inflation peak not observed
  - Inflation predicted to take 0.22 s

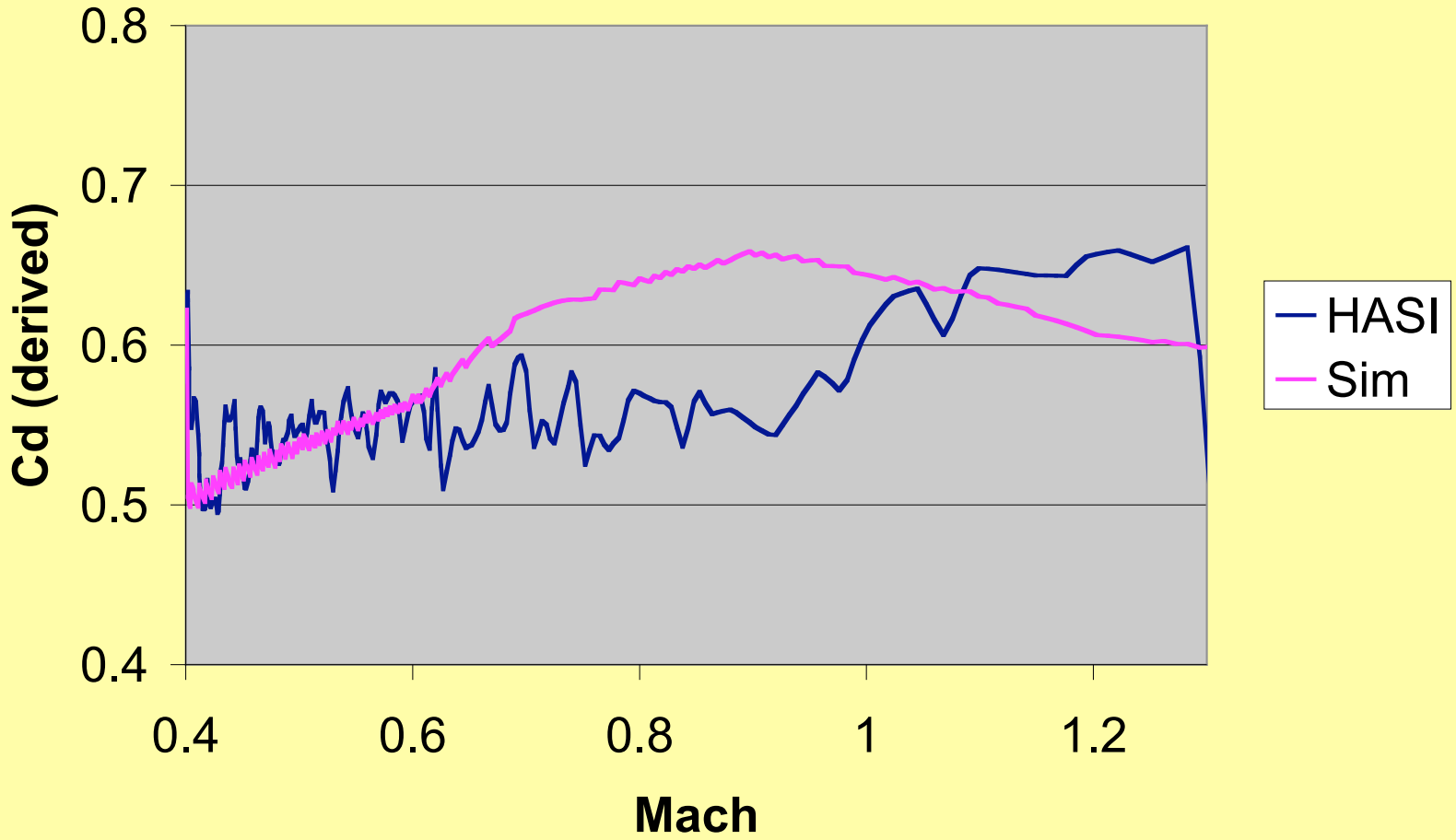
System Drag Coefficients

- Impossible to derive in steady-state descent
  - Descent velocity
    - Can only measure at low level
    - Depends on atmospheric density AND Cd
- Can derive during initial deceleration
  - Initial dynamic pressure known
    - Sequence triggered on dynamic pressure
  - Density changes are small during deceleration

Main Parachute deceleration

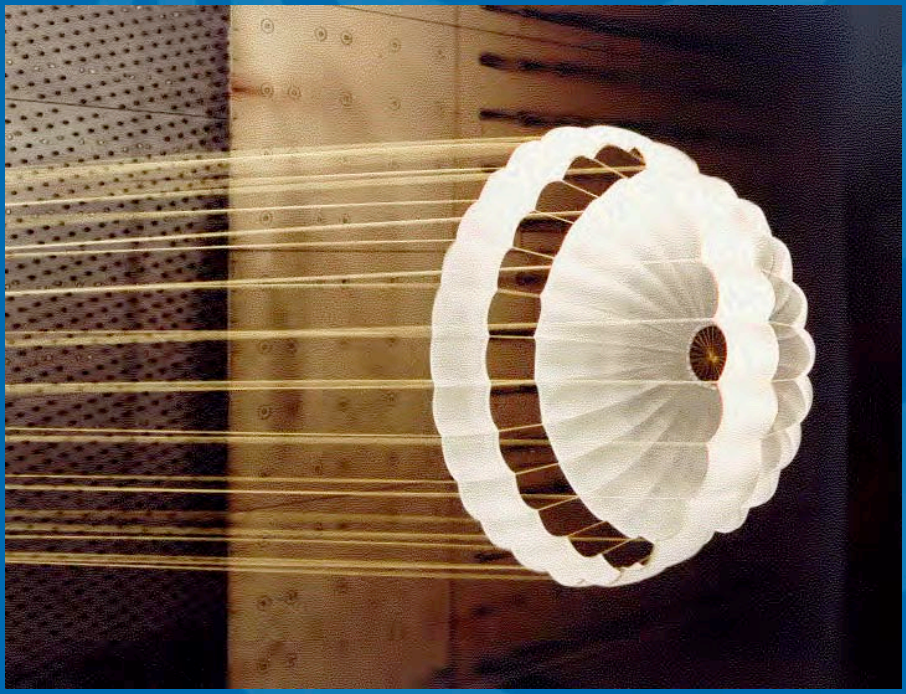


Drag Area under Main Parachute



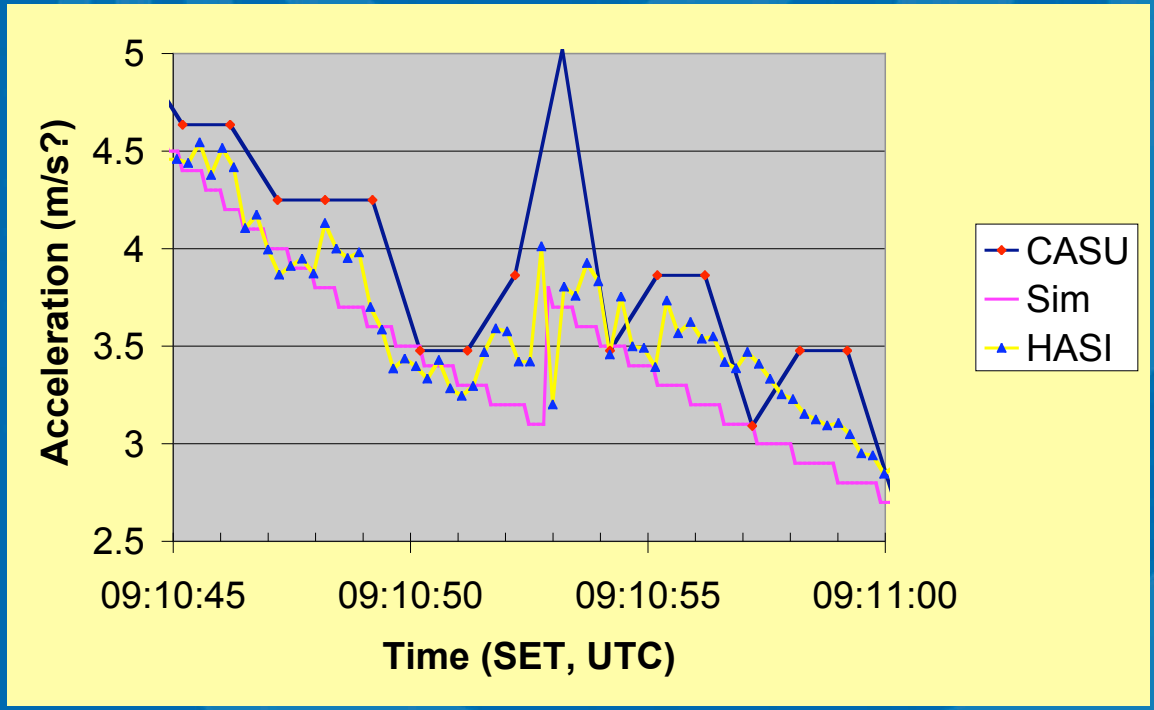
Drag Area under Main Parachute

- Drag area lower than expected
  - Mach 0.6 to 1.0
- Not critical for system performance



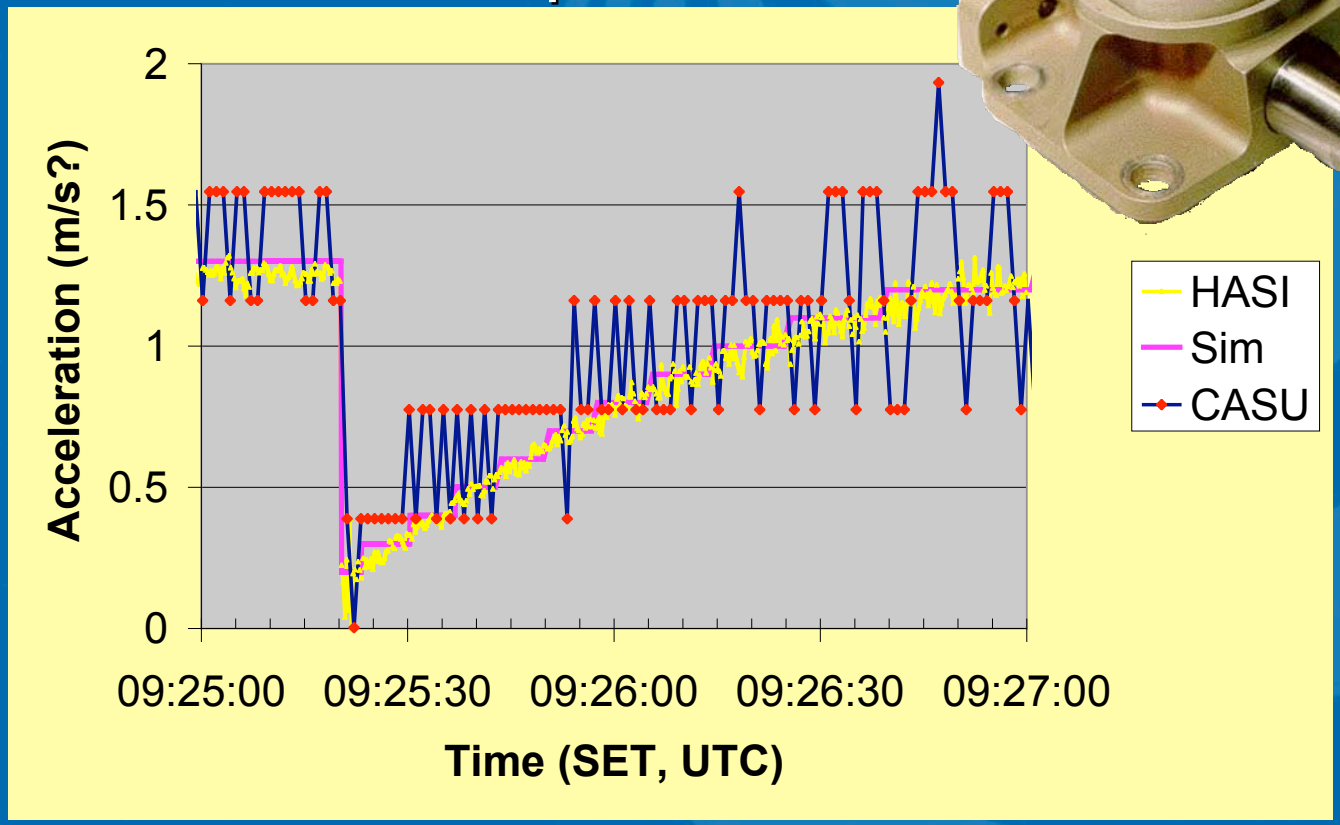
Front Shield Release

- Release visible on accelerometers
- Change in ballistic coefficient of system larger than expected



Stabilising Drogue Deployment

- Clear release
- Acceleration as predicted

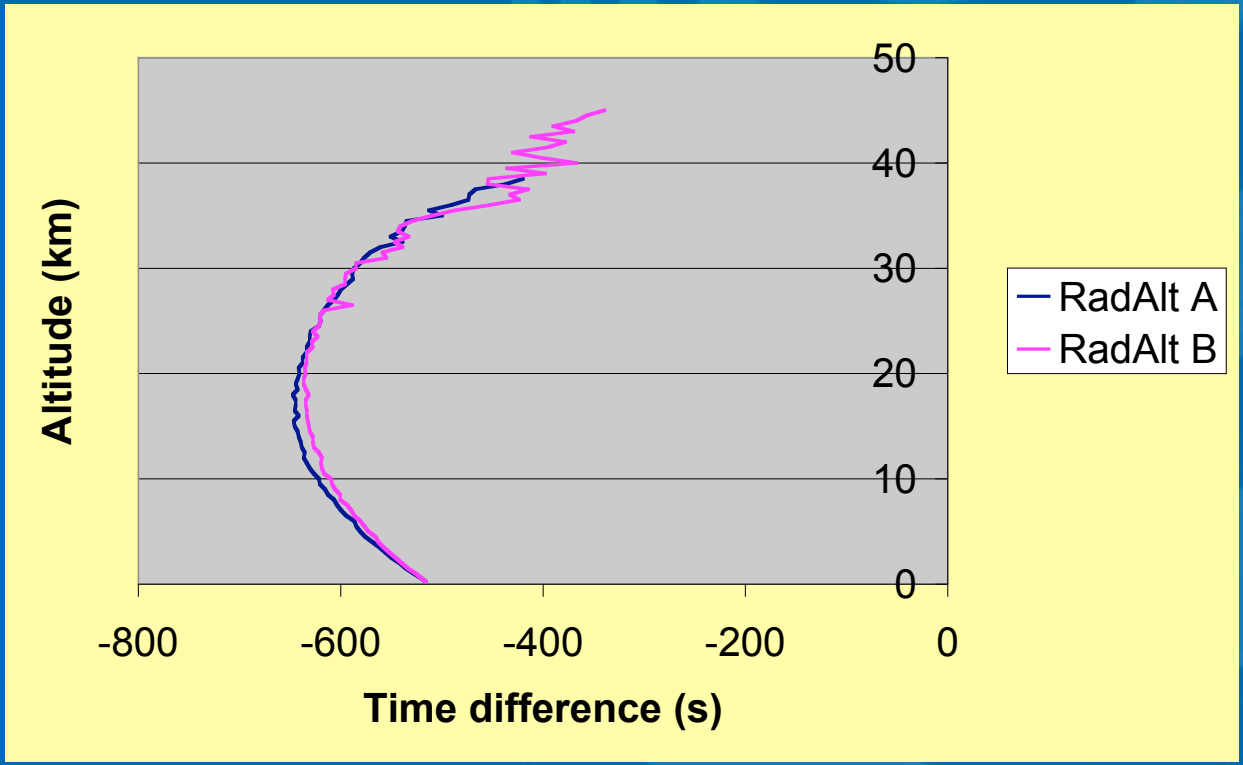


System Drag Area

- Descent velocity depends on
  - System drag area
  - Mass (known)
  - Gravity (known)
  - Density
- Density not known
- Overall descent time greater than predicted
  - Nominal prediction: 11:29:40
  - Actual: 11:38:12
  - 2.7_

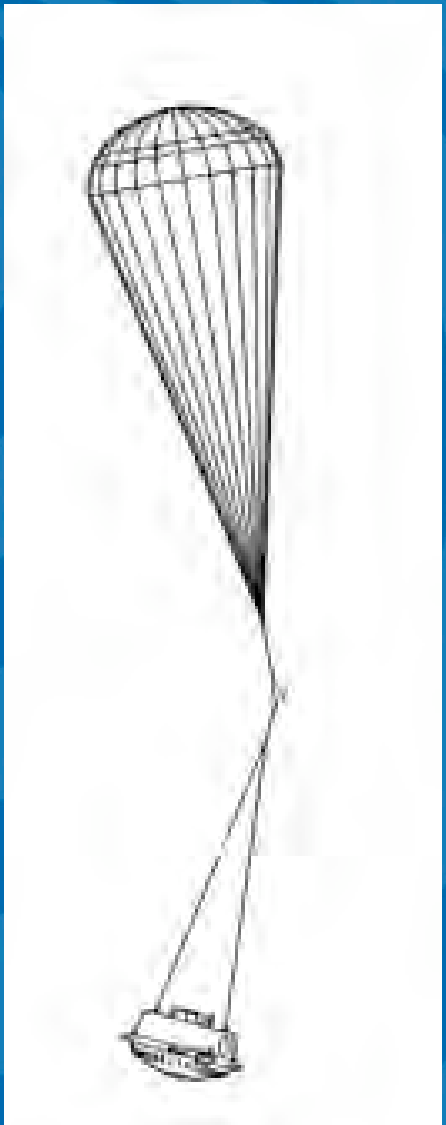
System Drag Area

- Time offset did not follow monotonic trend
- Unlikely to be parachute effect



System Stability

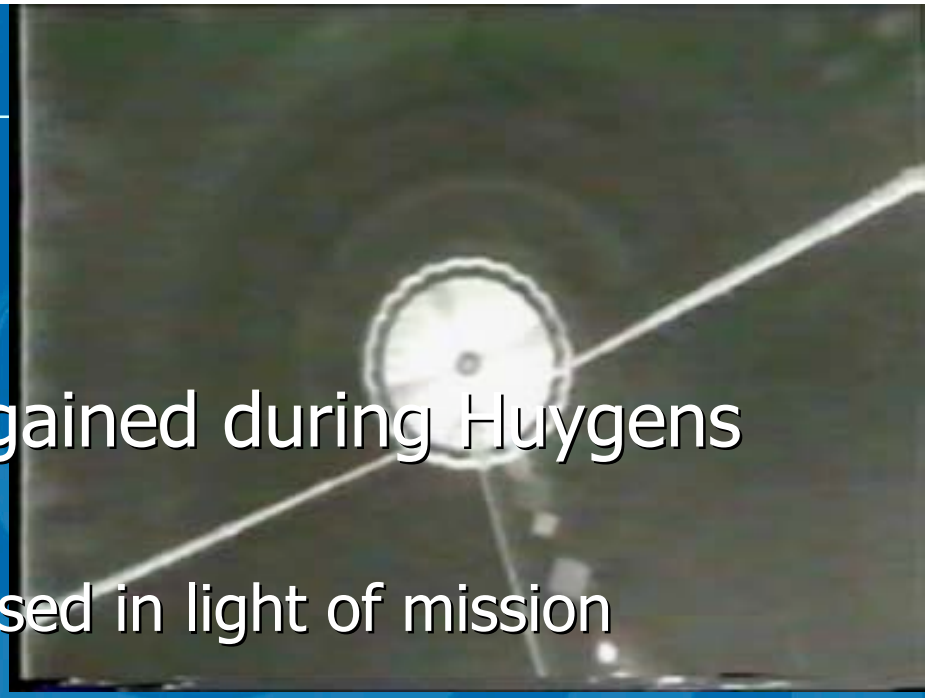
- 0.8 Hz oscillation on main parachute
- 1.0 Hz oscillation on stabilising drogue
- Simple Harmonic Motion about C of G
- Stimulus?
  - Vortex shedding?



Lessons Learned

- Tests
  - Test thoroughly
  - Replicate flight conditions as far as possible
- Margins
  - Resist temptation to minimise
  - Large margins enabled mission success when mission changed
    - Parachute strength
    - Heat shield thickness
    - Battery life

Future missions



- Significant knowledge gained during Huygens development
  - Tests should be reassessed in light of mission
- New technologies
  - Fluid / structure interaction for wake / parachute modelling
  - DGPS / Galileo for high-accuracy testing
- Flight instrumentation
  - High freq accels during deployment & inflation
  - Up-looking camera!!!