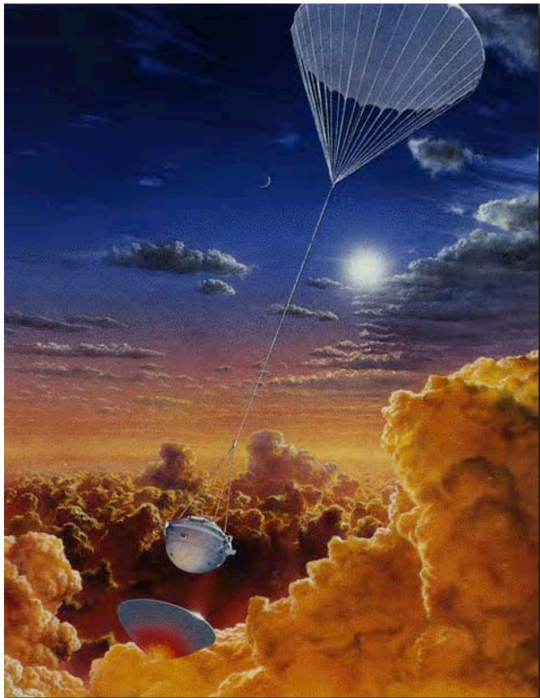

Jupiter Deep Probe Design - Entry/Descent System Challenges and Trades

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Background and Motivation Presentation

Jupiter Deep Probe Study presentation (Dr. Tibor Balint) focused on the overall mission architecture/design and technology challenges.

This presentation is the last part of the 3-part harmony focusing on the Entry and Descent part of the mission.

Objective for this work:

Focus is on **probe design** challenges and trades in support of JDP

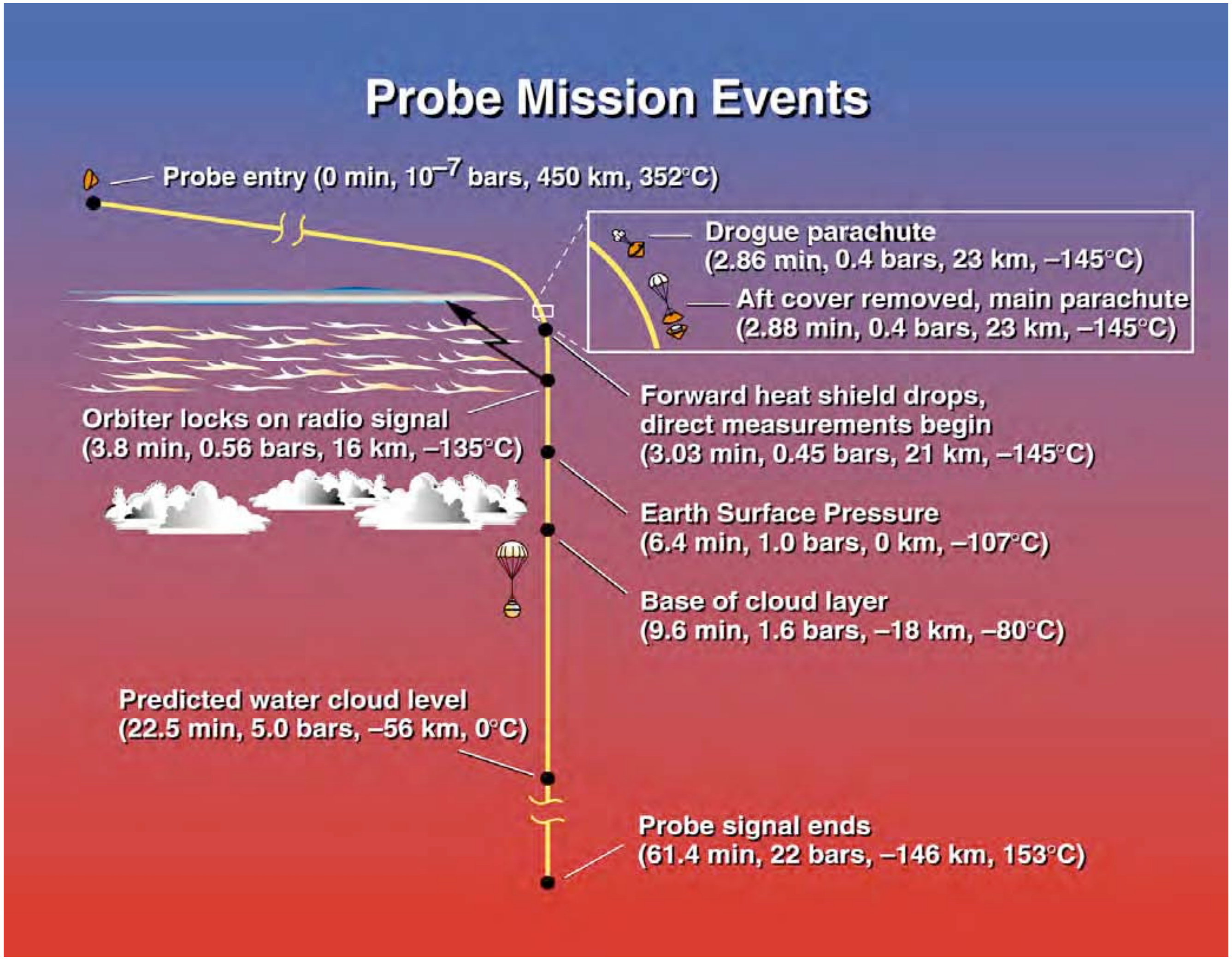
- Trade elements
  - Probe mass, size and number
  - Descent depth/mode
- Galileo probe is anchor (reference) for trade studies
- Key issues
  - TPS mass fraction
  - Scalability
  - Descent time (science, communication, thermal mgmt)

Jupiter Deep Probe Study
Architecture Trade Space

Trade Element ***(decision driver)***	Options
Launch vehicle *(lower cost)*	Delta IV-H (4050H-19); **Atlas V 521**
Trajectory *(target mission timeframe)*	High thrust direct; **HT Gravity Assist**; Low thrust direct; LT GA
Launch opportunity *(mission timeframe)*	2013 Direct; 2014 Direct; 2012 EGA; **2015 EGA**; 2013 EGA; 2014 EGA
Architecture *(lower cost)*	Orbiter with Probe(s); **Flyby with Probe(s)**
Approach *(comm, TPS)*	Polar approach; **Equatorial approach**
Number of probes *(science)*	One; Two; **Three**; Four or more
Probe size *(heritage)*	Half size (dimensions); **Galileo class**; Half size (mass)
Descent module(s) *(simplicity)*	**Single descent**; Two or multiple descents
Descent depth *(science)*	20 bars; **100 bars**; 200 bars
Descent mode *(visibility, comm, extr.env)*	Parachute only; **Chute 20bars+freefall 100 bars**; Chute 20 bars+freefall to 200 bar
Telecom Architecture *(physics)*	**Orbiter/Flyby Store and Dump Relay Telecom**; Direct-to-Earth Telecom

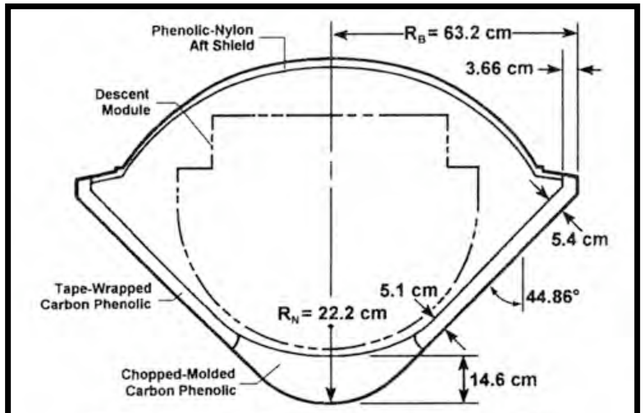
Subsystem Focus Presented in this Study

Galileo Mission: Entry and Descent Events

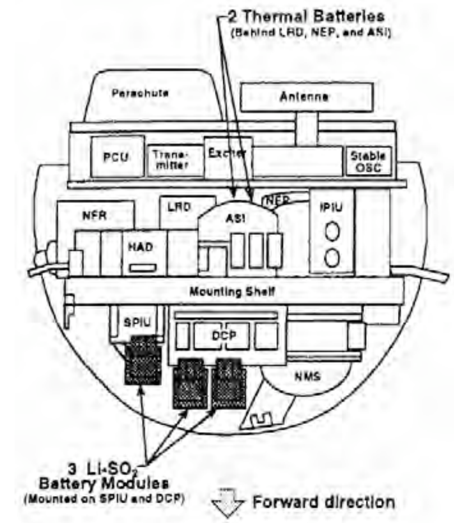


Galileo Probe Physical Properties and Key Scalability Challenges

Item / Subsystem	Mass (kg)	Mass Subtotals (kg)
Deceleration Module		221.8
Forebody heat shield	152.1	
Afterbody heat shield	16.7	
Structure	29.2	
Parachute	8.2	
Separation hardware	6.9	
Harness	4.3	
Thermal control	4.4	
Descent module		117.1
Communications subsystem	13.0	
C&DH subsystem	18.4	
Power subsystem	13.5	
Structure	30.0	
Harness	9.1	
Thermal control	4.3	
Science instruments	28.0	
Separation hardware	0.8	
Probe Total		**338.9**



Cross section of Galileo Probe deceleration module.



- Overall Challenge: What is the probe mass allocation amongst subsystems as we scale the probe?
  - Deceleration Module
    - TPS
  - Descent Module
    - Pressure Vessel mass - different than Galileo
    - Other subsystems mass allocations are made but need to be validated with future refinement

Ref: Galileo Probe Deceleration Module Final Report, Doc No. 84SDS2020, General Electric Re-entry Systems Operations, 1984
AIAA, "Project Galileo Mission and Spacecraft Design", Proc. 21st Aerospace Science Meeting, Reno, NV, January 10-13, 1983

Galileo Entry Probe - TPS Design Challenges and Lessons Learned

- **Design Codes of 1970 vintage used to design Galileo TPS**
  - Over estimated nose heating rates and surface recession
  - Underestimated cone frustum heating rates and surface recession.
  - Recessions calculated:
    - GE(now L-M) TOPIC Code: 96% too high at stag. pt., 18% too low on cone.
    - COLTS (LaRC) code: 31% too high at stag. pt., 43% too low on the cone, spallation mass prediction 3.5 Kg.

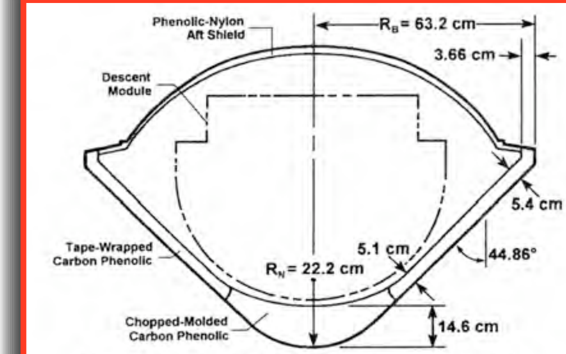


Fig. 1 Cross section of Galileo Probe deceleration module.

- **Lessons Learned**
  - Codes need modernizing to include better physics and better coupling of heating modes, especially radiation and turbulence.
    - Effect of shape change on heating and drag and effects of mass-loss on trajectory is important and the design codes must predict this reasonably accurately.
    - After-body heating and TPS response modeling need major improvements.

- **JAE (ARC) code (97-98) developed using higher fidelity methods and Galileo recession data**

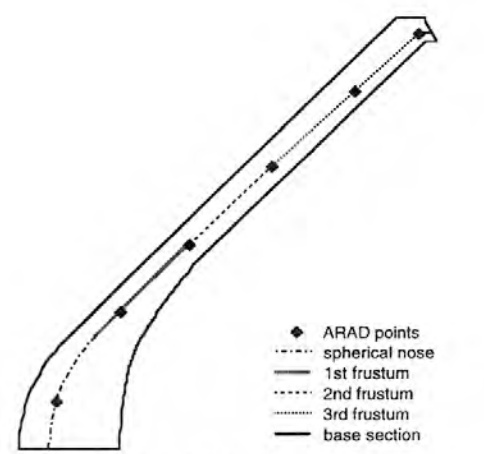


Fig. 9 Heat shield shape reconstruction.

Ref: M. Tauber, P. Wercinski, L. Yang and YK Chen," A Fast Code for Jupiter Atmospheric Entry Analysis," NASA TM 209796, 1999.

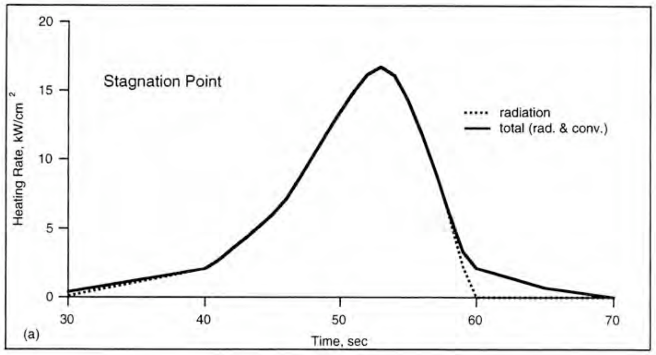
Jupiter Atmospheric Entry (JAE) Analysis Code

- JAE code, **a fast preliminary TPS design tool**, was developed at Ames during 97-98 time frame by M.Tauber, P. Wercinski, L. Yang and Y.K. Chen based on M. Tauber's (69-71) Jupiter Entry Code.
- **Fully coupled engineering analysis:** High-speed Trajectory, Flow Field, Heating Environment, and Ablation and Material Response analysis are integrated together to determine the fore-body heating rate,shape change, ablated mass, spallation and an approximate insulation mass (without margins for guidance and atmospheric uncertainties).
- Based on reconstructed Jovian Atmosphere
- Verified with Galileo Entry Probe data.
- Limited to Carbon-Phenolic and ballistic (L/D = 0) entry.
- Fast (3 cpu seconds of run time) and flexible (can vary ballistic coefficient, entry shape, entry velocity, entry latitude)
- Accounts for change in ballistic coefficient due to mass loss (Galileo heatshield mass loss ~ 50%)

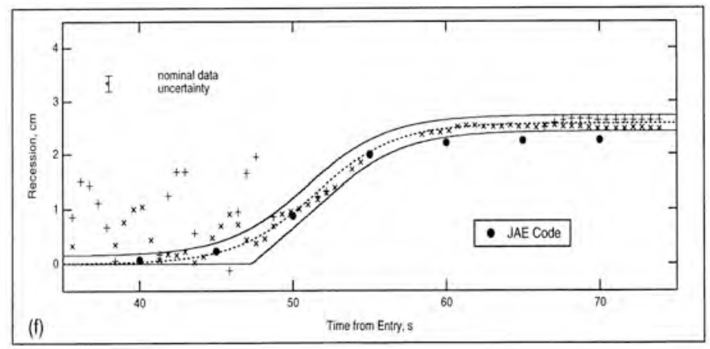
M. Tauber, P. Wercinski, L. Yang and YK Chen," A Fast Code for Jupiter Atmospheric Entry Analysis," NASA TM 209796, 1999.

Jupiter Atmospheric Entry (JAE) Analysis Code

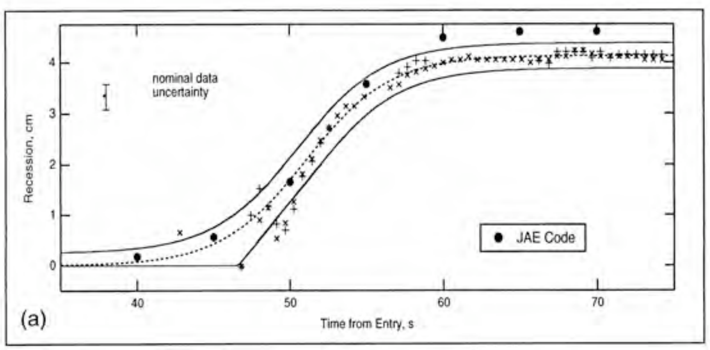
- **Verification of JAE Code with Galileo Entry Probe Measurements**



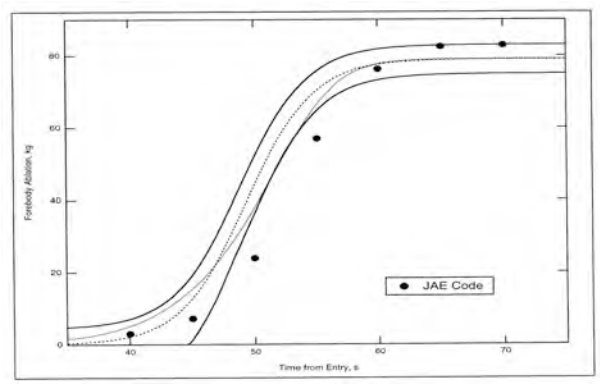
Heat flux prediction (blocked) during entry



Surface Recession Comparison near Shoulder Region



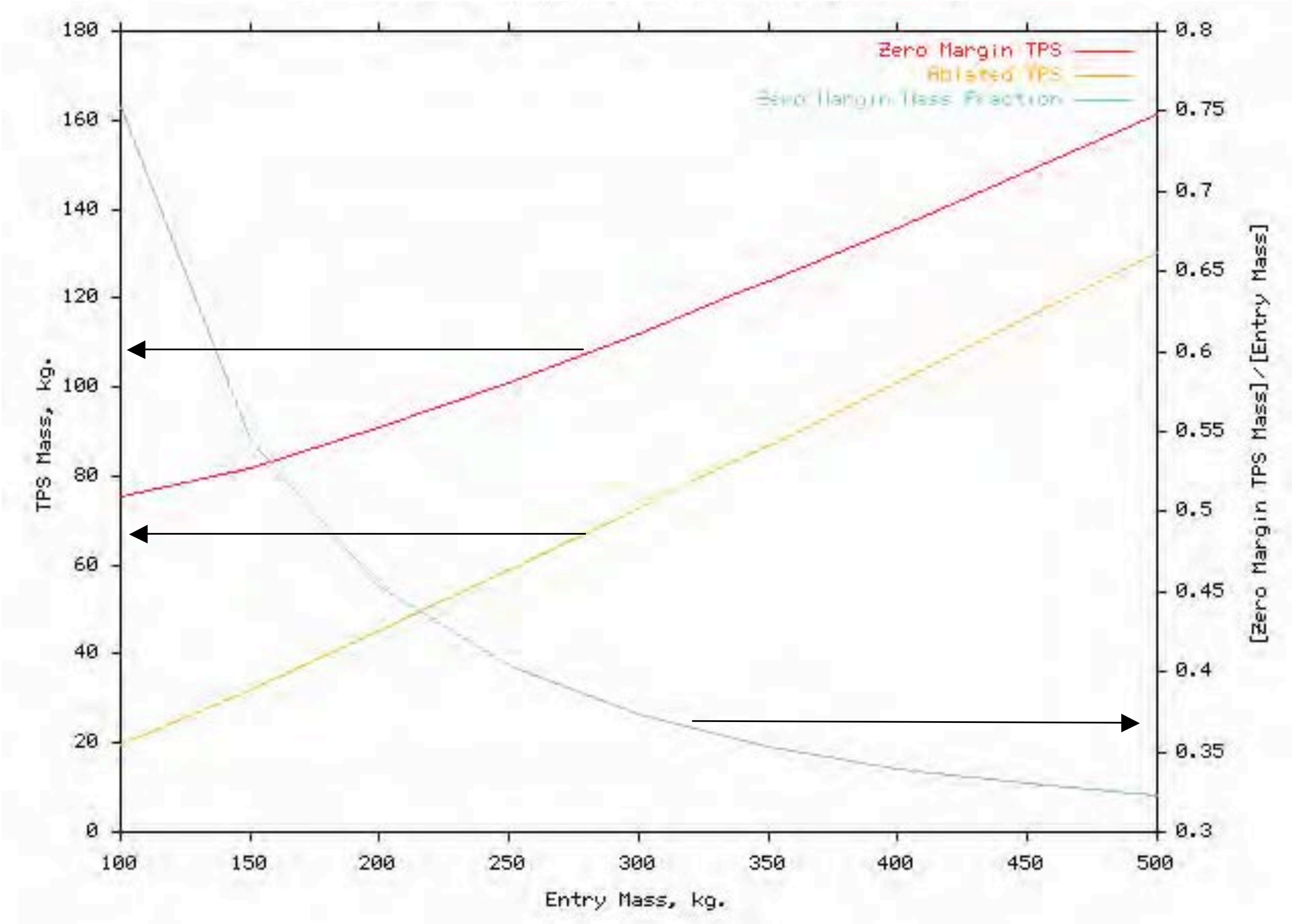
Surface Recession Comparison near Stagnation Region



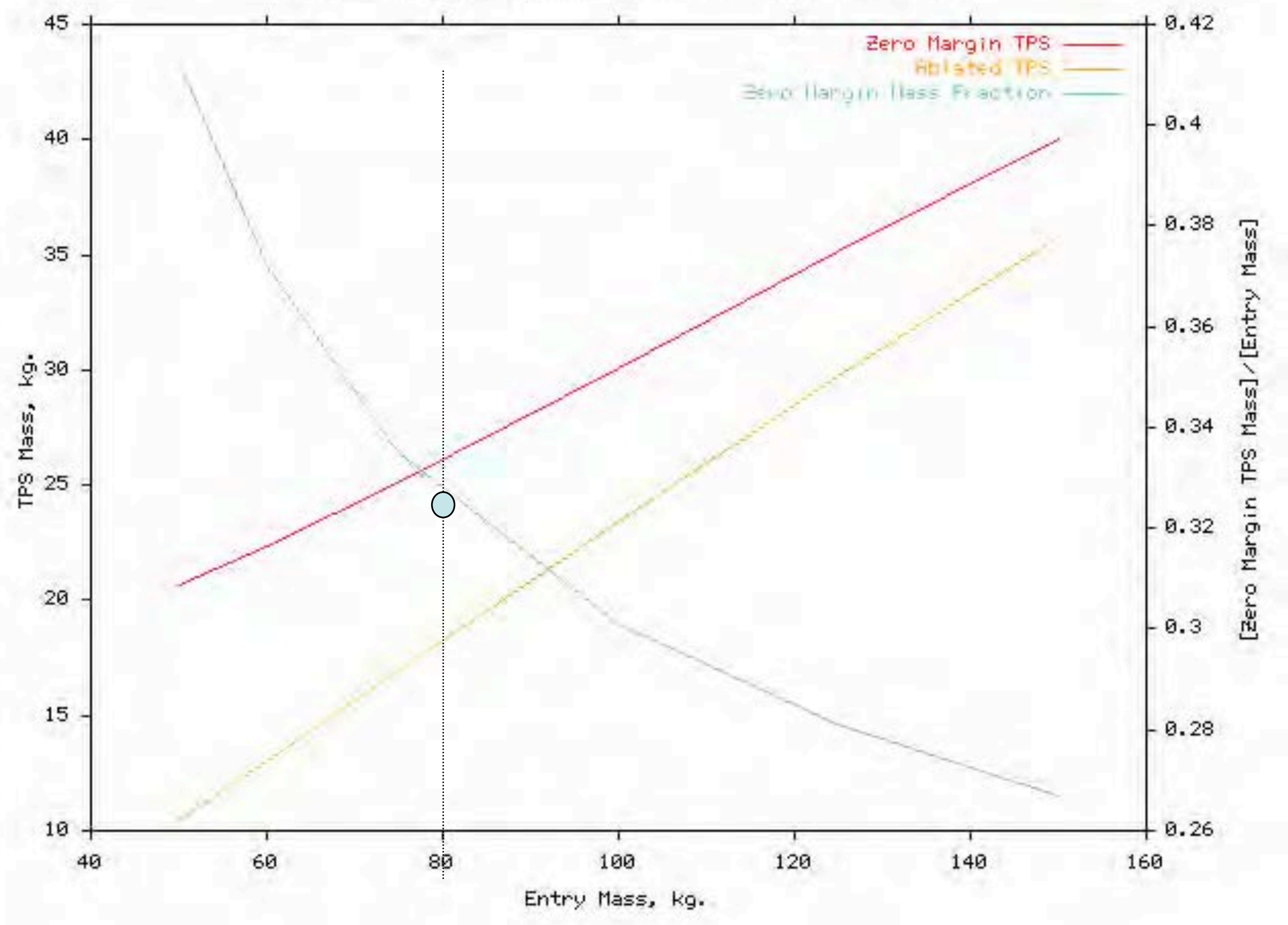
Forebody Mass Loss Comparison

- JAE Code, a fast preliminary engineering design code,is currently the best tool available and provides the best estimates for TPS mass fraction for speeds up to 60 km/s.

JAE Results: Galileo Entry Conditions at Full Scale



JAE Results: Galileo Entry Conditions at Half Scale (1/8 volume of full size Galileo Probe)



Mass allocation for 1/2 size Galileo Probe

Full Size

Item / Subsystem	Mass (kg)	Mass Subtotals (kg)
Deceleration Module		221.8
Forebody heat shield	152.1	
Afterbody heat shield	16.7	
Structure	29.2	
Parachute	8.2	
Separation hardware	6.9	
Harness	4.3	
Thermal control	4.4	
Descent module		117.1
Probe Total		**338.9**

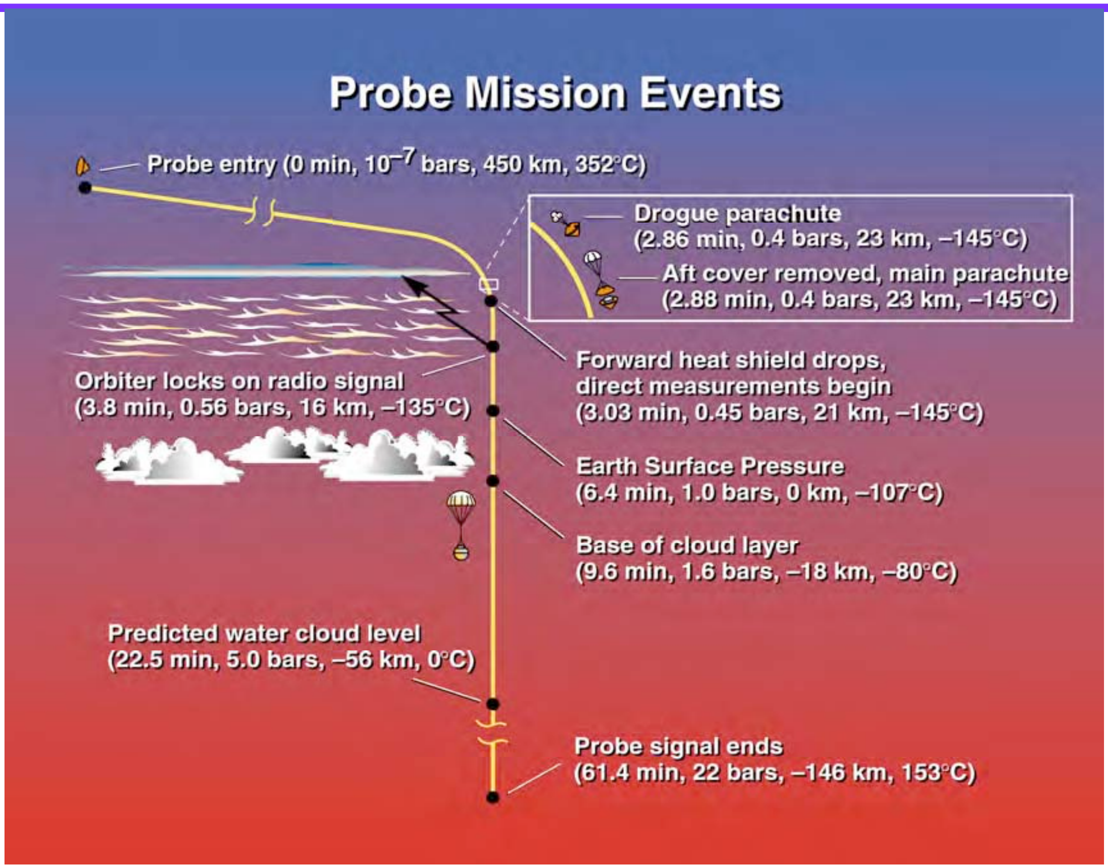
Half Size

Item / Subsystem	Mass (kg)	Mass Subtotals (kg)
Deceleration Module		49
Forebody heat shield	34	
Afterbody heat shield	4	
Structure	6.5	
Parachute	2.5	
Other	2.0	
Descent module		31
Probe Total		**80.0**

Descent module density for Galileo: 0.458 g /cc
Pioneeer-Venus: 0.763

- The mass estimate for half size probe (80 kg total entry mass) allows a bigger percentage of descent module mass as compared to Galileo Probe.
- Need detailed point-design to evaluate packaging and mass allocation issues. Increased communication, power, pressure vessel mass and size of components will be more challenging for half size probe as compared to Galileo size probe.

Galileo Mission: Descent Simulations



- Galileo reached 22 bars
- JDEP study goal is to reach 100 bars
- Goal is to configure descent segment so that data collection (science goals) and data transmission (fly-by up-link) are accomplished

TRAJ Background for Descent Simulations

*Traj** is a software package intended as a design tool for spacecraft thermal protection systems.

It combines a conventional three-degrees-of-freedom trajectory simulation module, an equilibrium thermodynamics module, a stagnation point convective and radiative heating module, and a one-dimensional material thermal response module into a single framework.

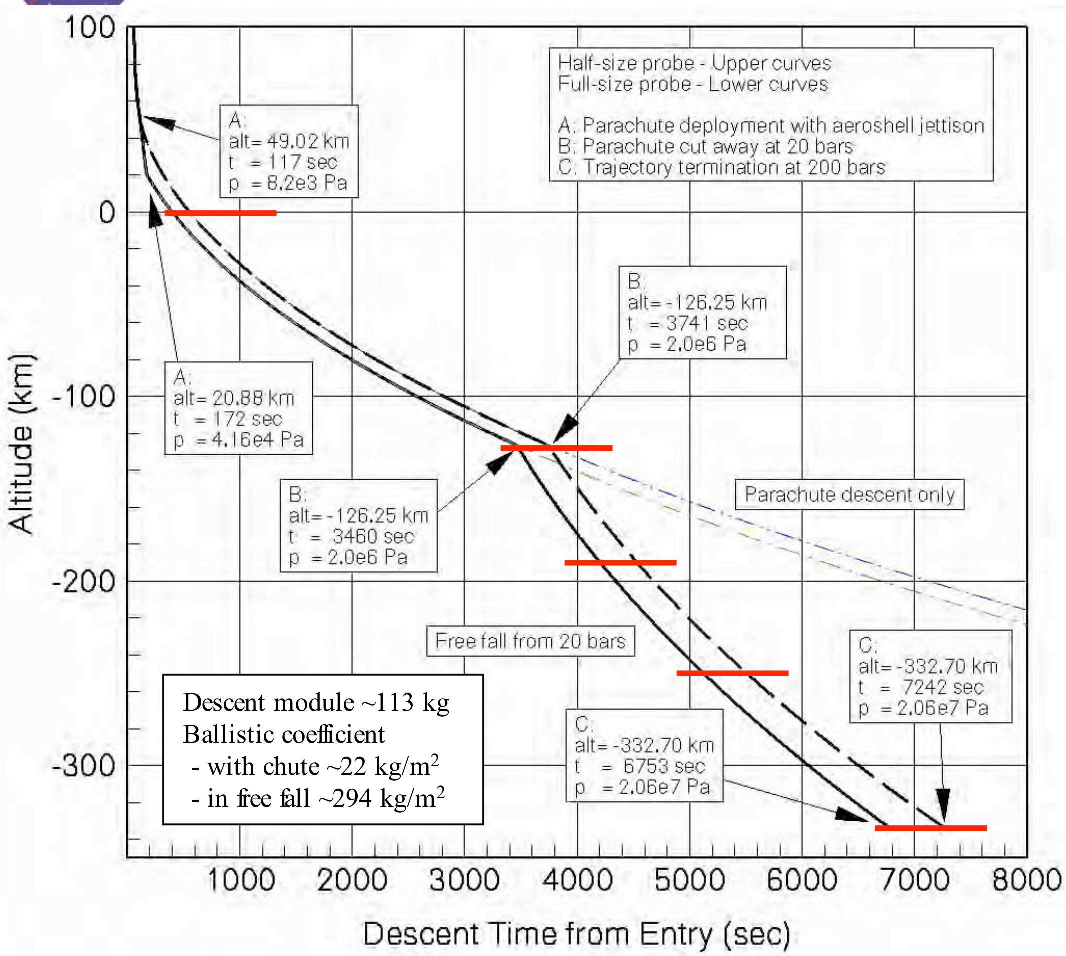
Traj can be used to calculate entry trajectories, aerothermal heating, and thermal protection system thickness and mass for both direct atmospheric entry and aerocapture simulations.

Numerous generic shapes and actual planetary probes are supported along with arbitrary geometries defined by external aerodynamic databases for entries at Venus, Earth, Mars, Titan, and Pluto.

Trajectory and thermal response solutions of *Traj* have been validated against flight data for several atmospheric entry vehicles.

* Gary A. Allen, Jr., Michael J. Wright, and Peter Gage“The Trajectory Program (*Traj*): Reference Manual and User’s Guide”, NASA TM-2005-212847, 2005.

Probe Descent – On Parachute to 20 bars & Free fall to 200 bars



Probe size	Full size	Half size	*Delta*
Deploy parachute	172 sec	117 sec	*-31.98%*
1 bar (0 km)	408 sec	562 sec	*37.75%*
20 bars (-125.7 km)	3460 sec	3720 sec	7.51%
50 bars (-191.8 km)	4229 sec	4558 sec	7.78%
100 bars (-252.4 km)	**5164 sec**	**5552 sec**	**7.51%**
200 bars (-328.9 km)	6753 sec	7175 sec	6.25%

- Descent of a half size probe is only about 6-7 minutes slower over a 1.5 hour descent to 100 bars
- This does not have a significant impact on telecom, pressure vessel or thermal designs
- Note: the thermal calculations were performed for a 2.5 hours descent scenario for a full size probe, which is bounding

Concluding Remarks

- Galileo design is a good baseline
  - Successful mission
  - Variation of probe design require a thorough understanding of Galileo Probe design and the current SOA of the technology
- Entry and Descent analysis for full and half-scaled Galileo probe
  - TPS mass fraction is comparable to that of Galileo with C-P heatshield
  - Mass allocation for the descent module needs further analysis
    - Packaging within the pressure vessel to reach 100 bar - needs additional work and focus
- Entry Segment: Probe Design Scaling Design
  - TPS mass is the highest and major contributor to the entry mass
    - Scaling from Galileo requires estimate of size and ballistic coefficient which drives Aerothermal environment / TPS mass
    - At this point in time engineering code such as JAE is the SOA and is required to estimate trajectory, TPS mass and ballistic coefficient
- Descent Segment:
  - Balancing between on-chute and freefall time to achieve 100 bar to meet science goals and allow for communication link-up
    - Able to meet both science goal and communication link-up time by staying
  - Descent time to 100 bar pressure level meets com. requirements.