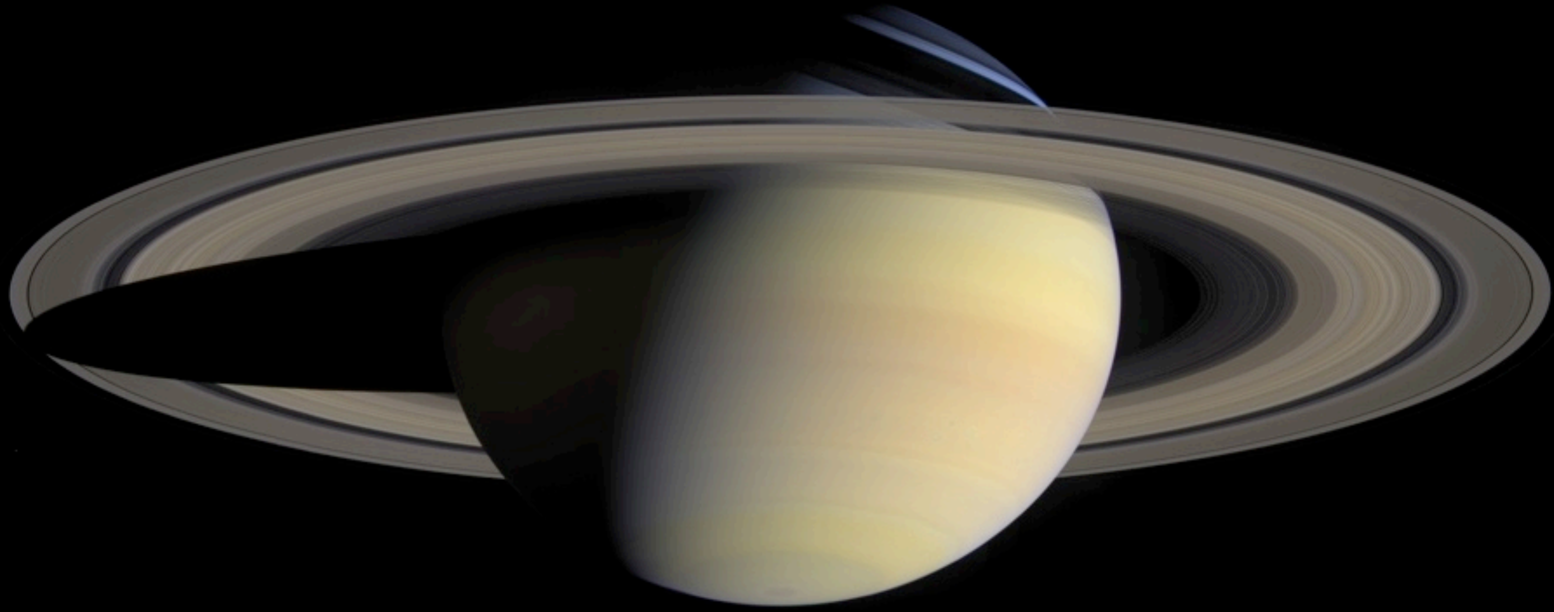
Saturn Atmospheric Structure Investigation: Challenges and Recommendations for Extending the Galileo Approach to Future Probe Missions

E. Venkatapathy[1], D. Prabhu[2], D. Ellerby[1] and E. Martinez[1]
[1]NASA Ames Research Center, Moffett Field, CA 94035
[2]ERC, Inc./NASA Ames Research Center Moffett Field, CA 94035



International Workshop on Instrumentation for Planetary Missions
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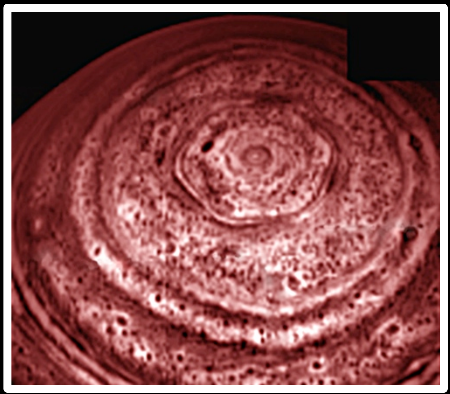
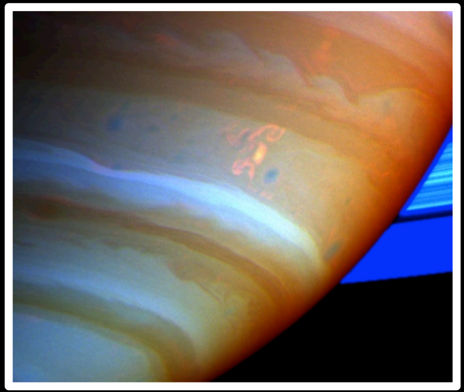
Outline

North Pole

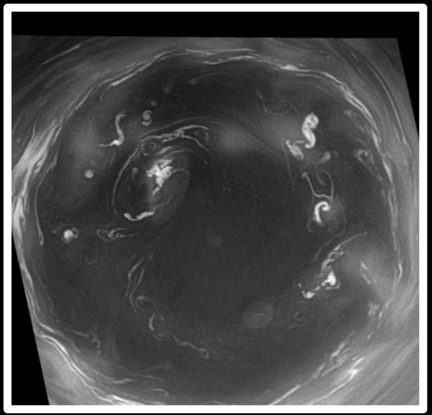


North Hemisphere

- Atmospheric Structure Instrument
- Destinations and ASI Approaches
  - Huygens vs Galileo
- In-depth look at Galileo Entry ASI
- Challenges for Saturn Probe Mission
  - Entry Conditions, TPS Choice and Implication to ASI
  - Challenges & Recent Developments
- Recommendations for Future Probe Missions



Southern Hemisphere



South Pole

Atmospheric Structure Instrumentation

Objective:

- Direct and indirect measurements of the physical quantities for characterizing the atmospheric structure of the planet.
    - Pressure, temperature, density, velocity, electrical and acoustic disturbances, etc.

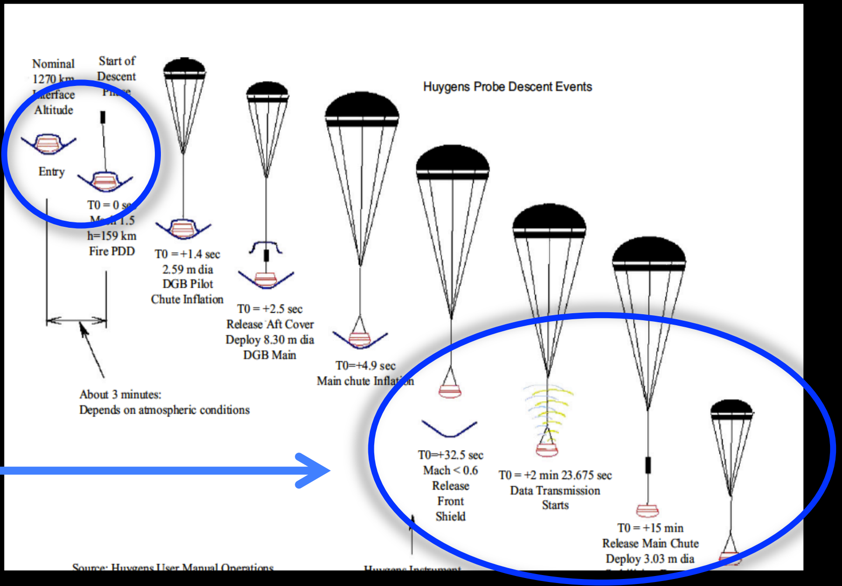
Instruments:

Entry Phase Science

- Direct measurement of quantities of interest not possible due to extreme heating
- Indirect measurement instruments includes:
    - Accelerometers & Recession sensors.

Descent Phase Science

- Direct measurement using pressure transducers, temperature sensors, electrodes and microphones, etc.

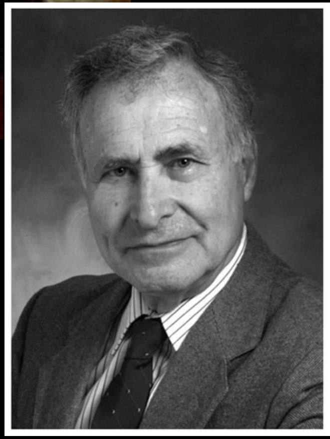


Huygen's Entry, Descent and Landing

- **The focus of this presentation limited to Entry Science**

Entry Phase
From Newton to Al Seiff

Constructing the density profile:



- **Al Seiff turned the entry problem into solution using Newton's law**

$F(t) = M(t) \times a(t)$ (Newton's Law)

$M(t) \times a(t) = 0.5 \times \rho(t) \times V^2(t) \times S \times C_D(t)$

$$\rho(t) = [\, 2.0 \times M(t) \times a(t) \,] / [V^2(t) \times S \times C_D(t)]$$

Where M = Mass
a = Acceleration
V = Velocity
C_D = Drag Coefficient
S = Reference Area
t = time

By measuring acceleration and by either measuring (or estimating) the mass and drag changes,

➢ Density as a function of time (or altitude) is determined

Entry Problem: Destinations and ASI Approaches

- Acceleration measured using accelerometers
  - Used for trajectory reconstruction and a standard instrument

- Mass Loss: Instrumented heat shield required
  - If the heat shield TPS is an ablator, then mass loss is due to
    - a) recession and b) pyrolysis
  - Recession can contribute to drag change
    - Drag coefficient due to shape change during entry phase

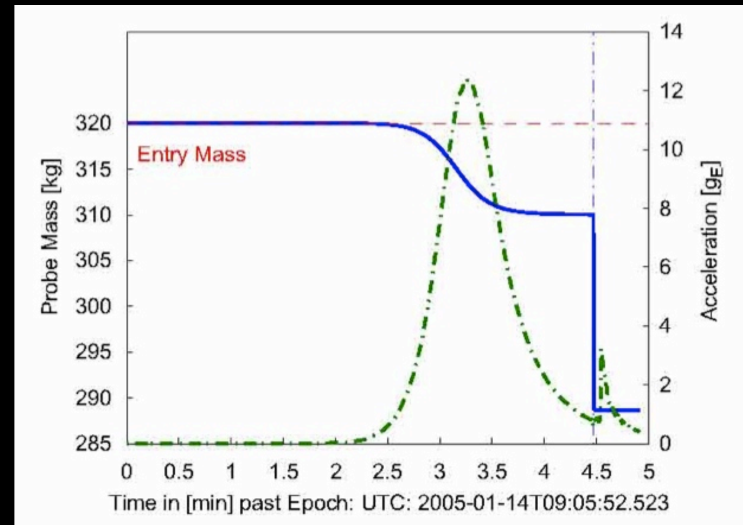
- Entry environment and the role of TPS
  - Benign environment with small mass loss: Huygens, Pathfinder
  - Extreme Entry with significance mass loss and shape change: Galileo

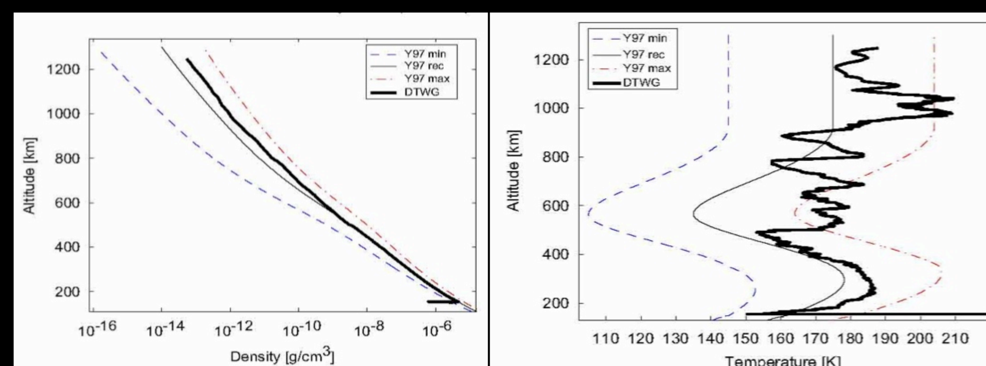
- Saturn? The focus of this presentation.
  - Uranus and Neptune have entries similar to Saturn.

  Ref: Spilker, T. R. and Atkinson, D. H., "Saturn Entry Probe Potential," 9th International Planetary Probe Workshop (IPPW9), Toulouse, France, June 2012

Huygens Entry: Mild Entry Environment

- Density profile is determined from:
  - Probe **velocity** reconstructed from aerodynamic deceleration;
  - Mass loss estimated from TPS material characterization
    - Huygens heat shield was not equipped with recession sensors on the TPS.
    - The ablation process could only be modeled taking into account the integrated mass loss estimated from preflight simulations.
  - C_D variation estimated as a function of altitude
    - assumes no shape change and only a function of regime (free molecular,





- Temperature profile determined from density and pressure.

" Huygens' Entry and Descent through Titan's atmosphere —Methodology and results of the trajectory reconstruction," B. Kazeminejad, D. H. Atkinson, M. Perez-Ayucar, J. Lebreton and C. Sollazzo, Planetary and Space Science 55 (2007) 1845–1876, Elsevier (www.elsevier.com/locate/pss).

Galileo: Extreme Entry Environment

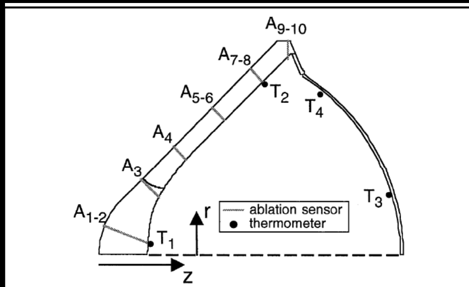
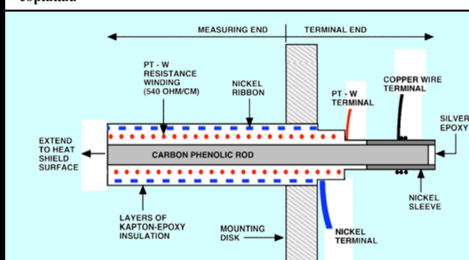
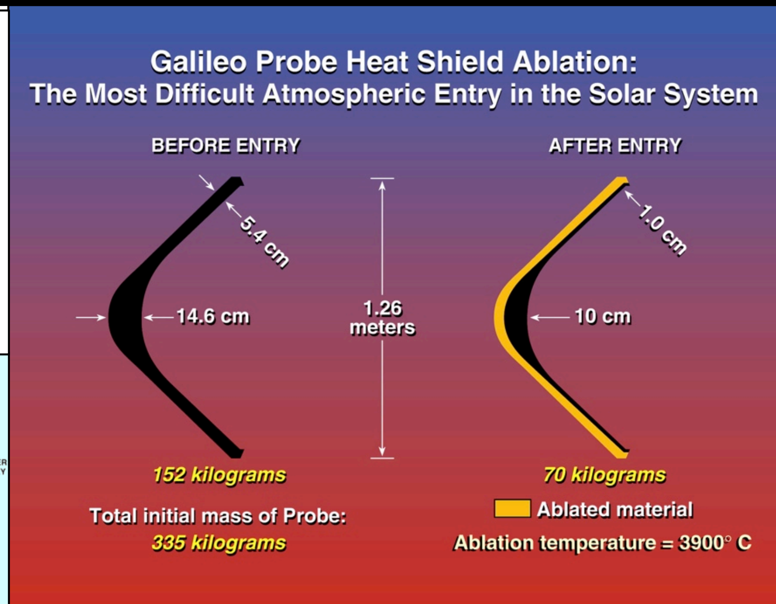
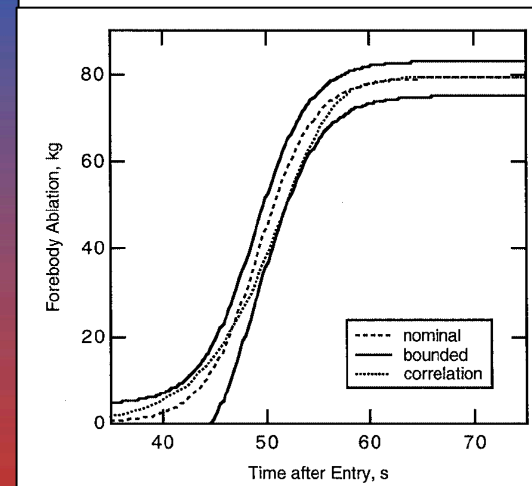


Fig. 2 Locations of 10 ablation sensors (A_1–A_{10}) in heatshield and four resistance thermometers (T_1–T_4) inside structure; sensors are not coplanar.







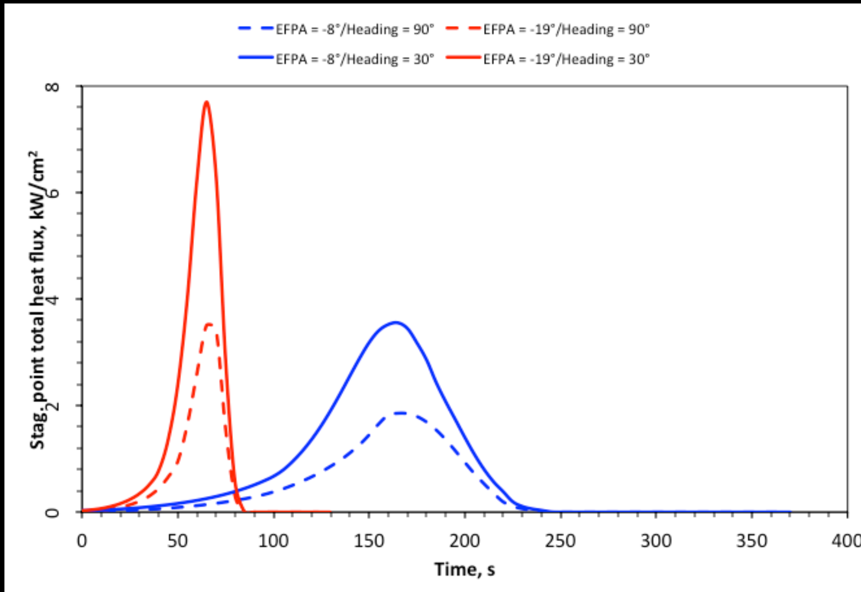
- Flight data from the analog resistance ablation detector (ARAD) allowed us to estimate the mass loss, shape change and the aerodynamic drag changes
- ARAD follows the an isotherm (pyrolysis front) and not recession.
  - For Galileo, the ablation process was fast enough that the recession front and the pyrolysis front tracked each other very well.

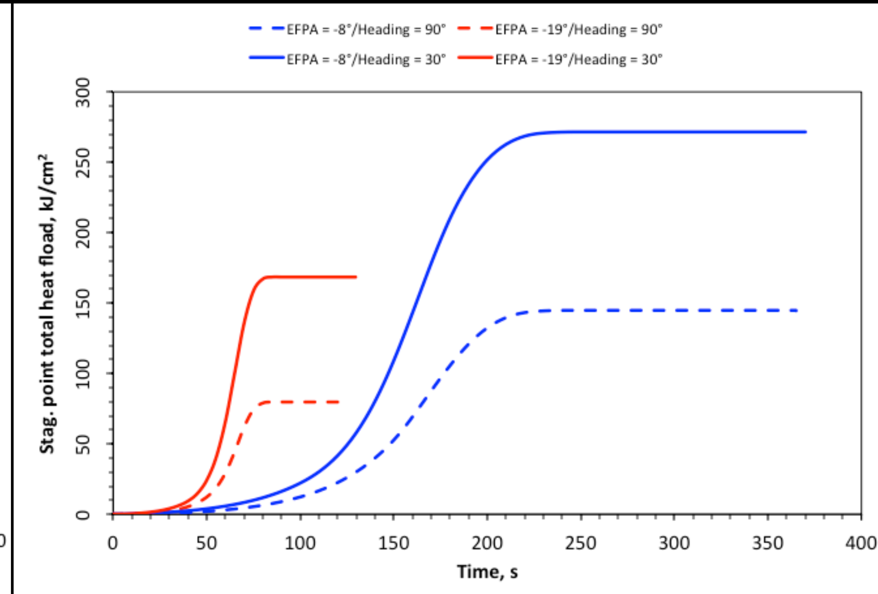
SATURN

- Multiple missions studies, in the recent past, have looked at Saturn Probe Mission Design
- Entry conditions vary widely for Saturn
  - Pro- or retro-grade, equatorial or higher latitude, and entry flight path angle selection.
- TPS:
  - Heritage Carbon Phenolic (HCP) no longer available
  - Alternate TPS may not behave the same way as HCP
    - NASA STP-Game Changing Program is funding Woven TPS – very promising TPS that allows tailoring of the TPS - behavior will be different that of HCP.
- Recession measurement:
  - HEAT (modernized ARAD) has flown on MSL and is being integrated with Orion/ MPCV

Can the upgraded ARAD/HEAT be used for Saturn?
Impact of an alternate TPS instead of heritage Carbon Phenolic?

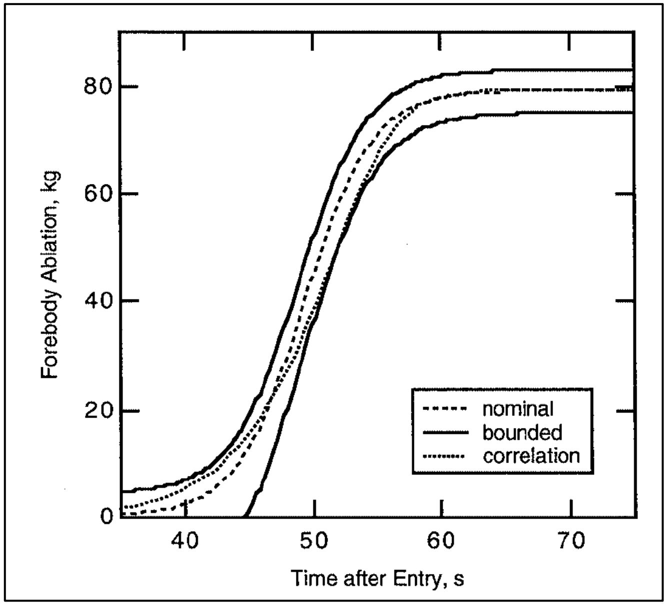
Saturn Entry Environment

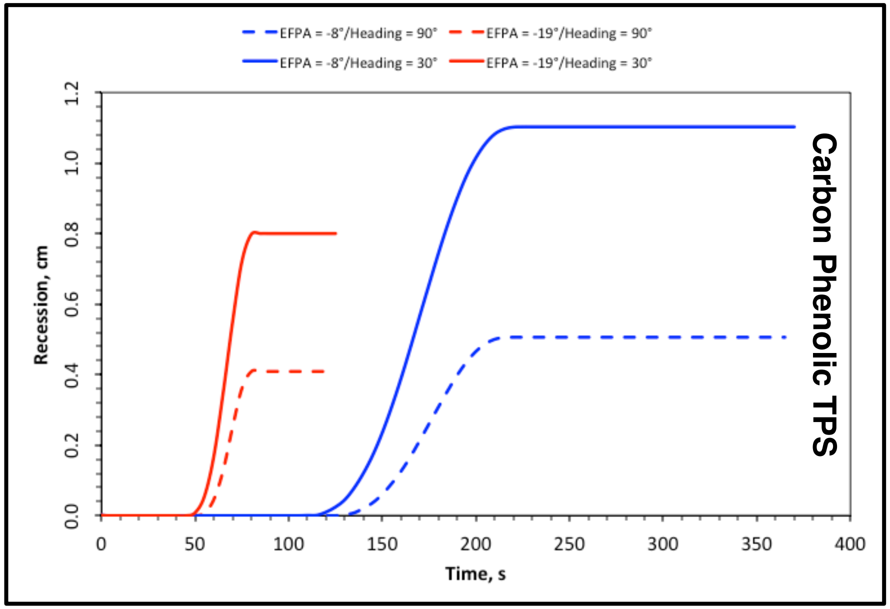




- Entry conditions - Pro-grade only *(Retro-grade results in heat-flux similar to Galileo)*
  - Bounding Cases: Equatorial and 60^0 latitude with shallow (-8^0) and steep (-19^0) EFPA
  - Equatorial entry is preferred from lower entry conditions and qualification of TPS
  - Science requirement may drive entry to higher latitude.
    - Current test facility limitation coupled with qualification/certification of newer forms of CP or Woven TPS as heritage is no longer available is the challenge
  - Higher latitude requirement coupled with mission assurance will drive the entry to a shallower entry flight path angle
    - Future test facility mods may accommodate higher latitude and flight path angle.

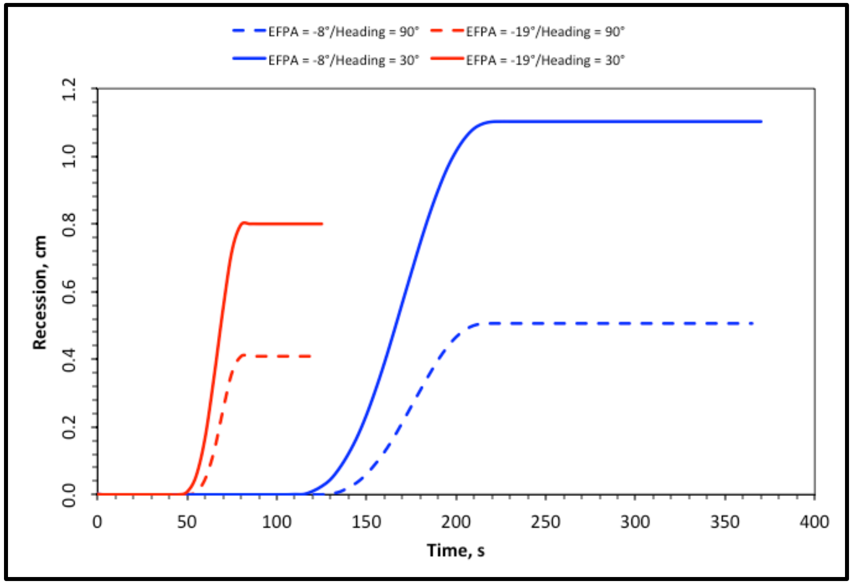
Galileo vs Saturn

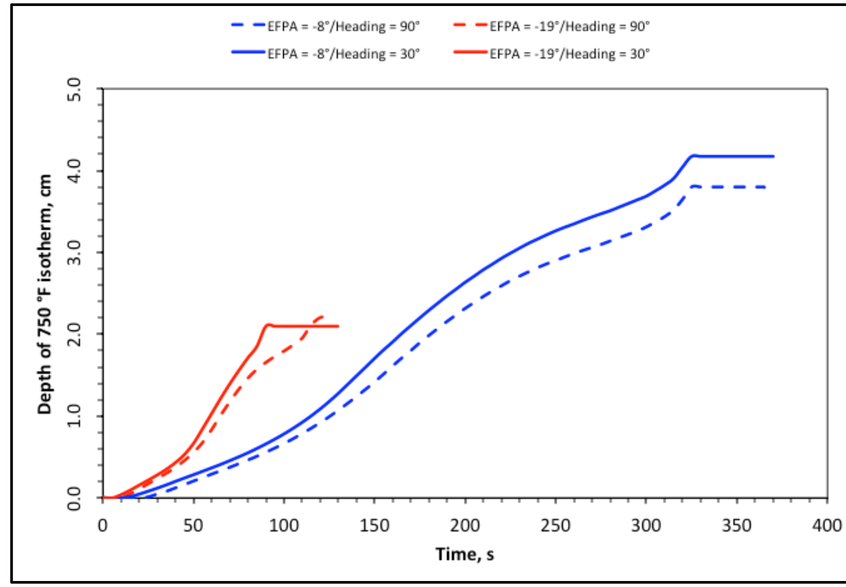




- In the case of Galileo, 90% of the heat shield recession occurred in less than 15 sec. (~50% change in mass of the heat shield in 15 sec)
  - Extreme heating profile (peak estimated at ~30,000 W/cm^2)
- Saturn mass loss will be significant enough to warrant recession measurement during entry (with HCP TPS mass loss fraction = 0.15 – 0.3)
- In the case of Saturn, recession takes much longer (35 – 100) sec.
- Recession could be significantly different than tCP estimates shown above.

Will HEAT sensor measure Recession? Recession vs (750 ^{0}F) Isotherm





- Computed recession is compared with that of a 750 F isotherm (HEAT or ARAD sensors track Isotherm)
- Recession and Isotherm do not correlate.

HEAT (ARAD) Sensor will not track, correlate or measure recession

What then?

- Direct measurement of recession is needed for determining the structure of upper atmospheric
- Non-intrusive, Ultrasonic instrumentation – very promising
  - Ultrasonic sensor does not present heat shield integration challenges
  - It can work with alternate to heritage carbon phenolic
    - See companion poster presentation: "A New, Non-Intrusive Ultrasonic TPS Recession Measurement Needed to Determine the Thermal Structure of the Upper Atmosphere of Venus, Saturn, Uranus or Neptune," Lloyd J.A., Stackpoole M., Venkatapathy E., and Yuhas D. E.
  - HEAT sensor (MSL heritage) coupled with ultrasonic measurement can provide more accurate mass loss and shape change
    - Mass loss due to recession as well as pyrolysis can be determine accurately.
- TPS sensors suite will serve multiple purposes
  - Science as well as engineering – Galileo is a great example

Concluding Remarks

- Saturn Entry is challenging and ASI is coupled to the entry system design and heat shield material selection .
  - Heritage Instrument (HEAT/ARAD) not recommended
  - Alternate means of measuring recession/char needed
- Integrated development of sensors with emerging TPS recommended
  - Heritage TPS (HCP) no longer available
  - Promising ultrasonic recession measurement integrated with new TPS, funded by the Space Technology Program (GCDP) and under development, can address these challenges.
- Scientists and TPS Technologists working closely can address this challenge
  - We have the time and opportunity to get ready for the next opportunity

Time to start is Now

Acknowledgement

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- Their timely support is greatly appreciated.

References

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