3rd International Planetary Probe Workshop
Session 2C

HUYGENS Entry & Descent Analyses Go-ahead for the Mission

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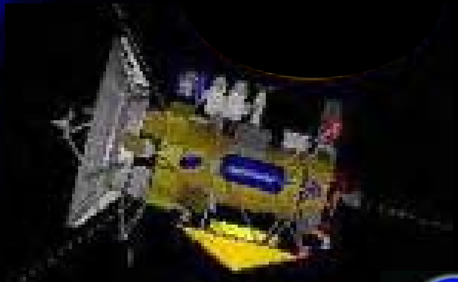
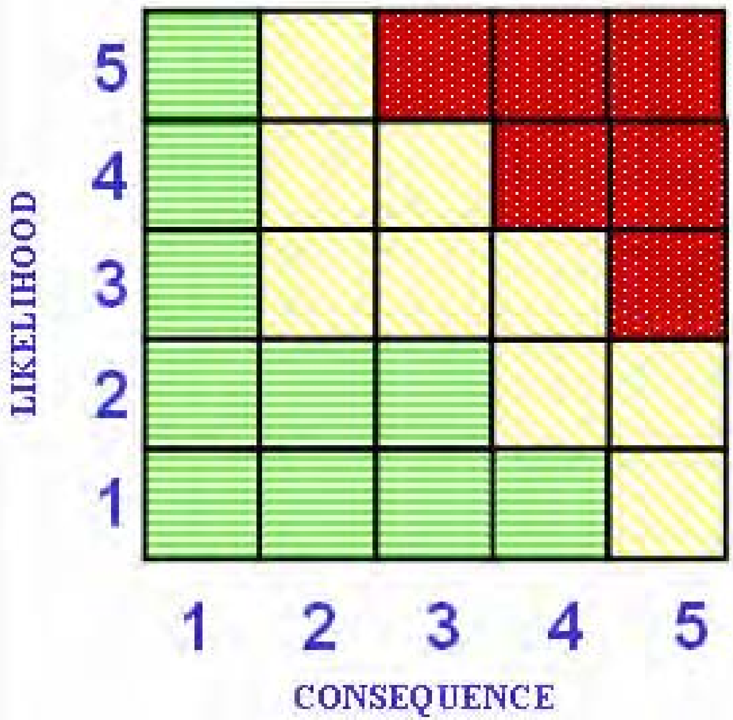
ESA-ESTEC, The Netherlands



Anavyssos, Greece, 28 July 2005

Criteria for Risk Assessment



Risk Type (either or both may apply to each risk)

☒ Mission Risk ☐ Implementation Risk

Consequence of Occurrence

Level	Mission Risk Level Defintions
5	Complete mission failure
4	Partial failure or significant reduction in mission return
3	Moderate reduction in mission return
2	Small reduction in mission return
1	Minimal (or no) impact to mission

Likelihood of Occurrence

Level	Likelihood
5	Very High
4	High
3	Moderate
2	Low
1	Very Low

Overall Huygens Residual Risk

LIKELIHOOD	1	2	3	4	5
5					
4			1		
3	2	1	2	6	
2	1	1		2	1
1	2	1	1	1	7

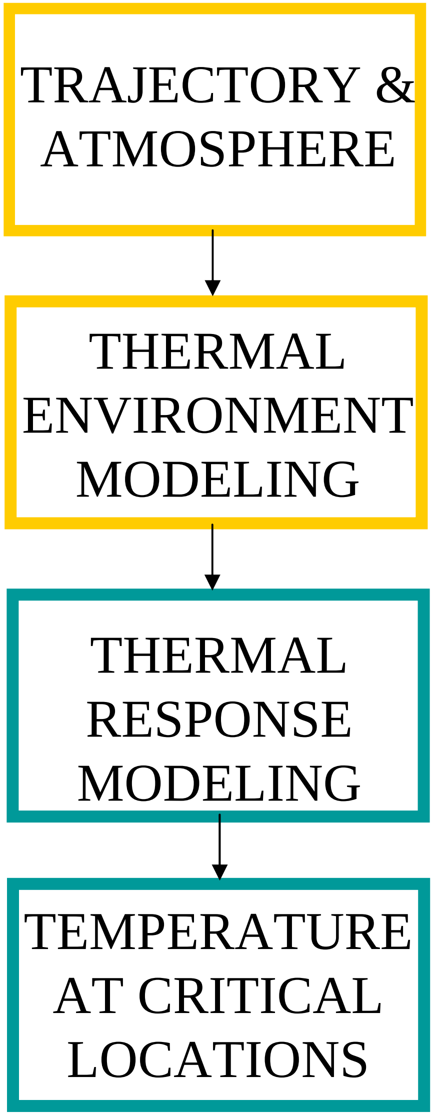
CONSEQUENCES

- **29 residual risks**
- **20 Yellow risks**
  - Forebody TPS performance not within specification
  - Aftbody TPS performance not within specification
  - Aftbody TPS thermal response not adequately characterized
  - Unexpected Angle of attack at peak heating
  - Probe does not reach ground in specified time
  - Atmospheric density & composition model uncertainty
  - Wind model uncertainty
- **9 Green** (Not including items from EDL panel in avionics, sensors, and algorithms area that were rated green due to high-level evaluation of methodology)

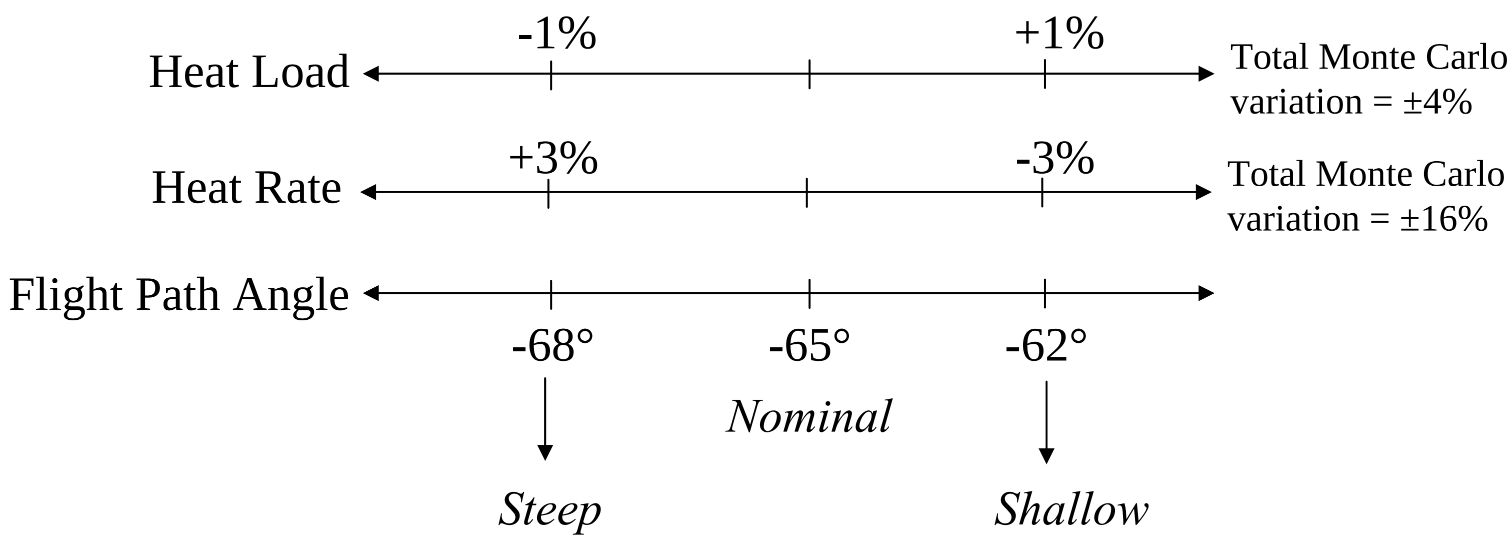
Residual Risk to the Probe Mission is Moderate

Aerothermal Analysis Flow

Aerothermal Analysis Flow Dominates High Risk Items

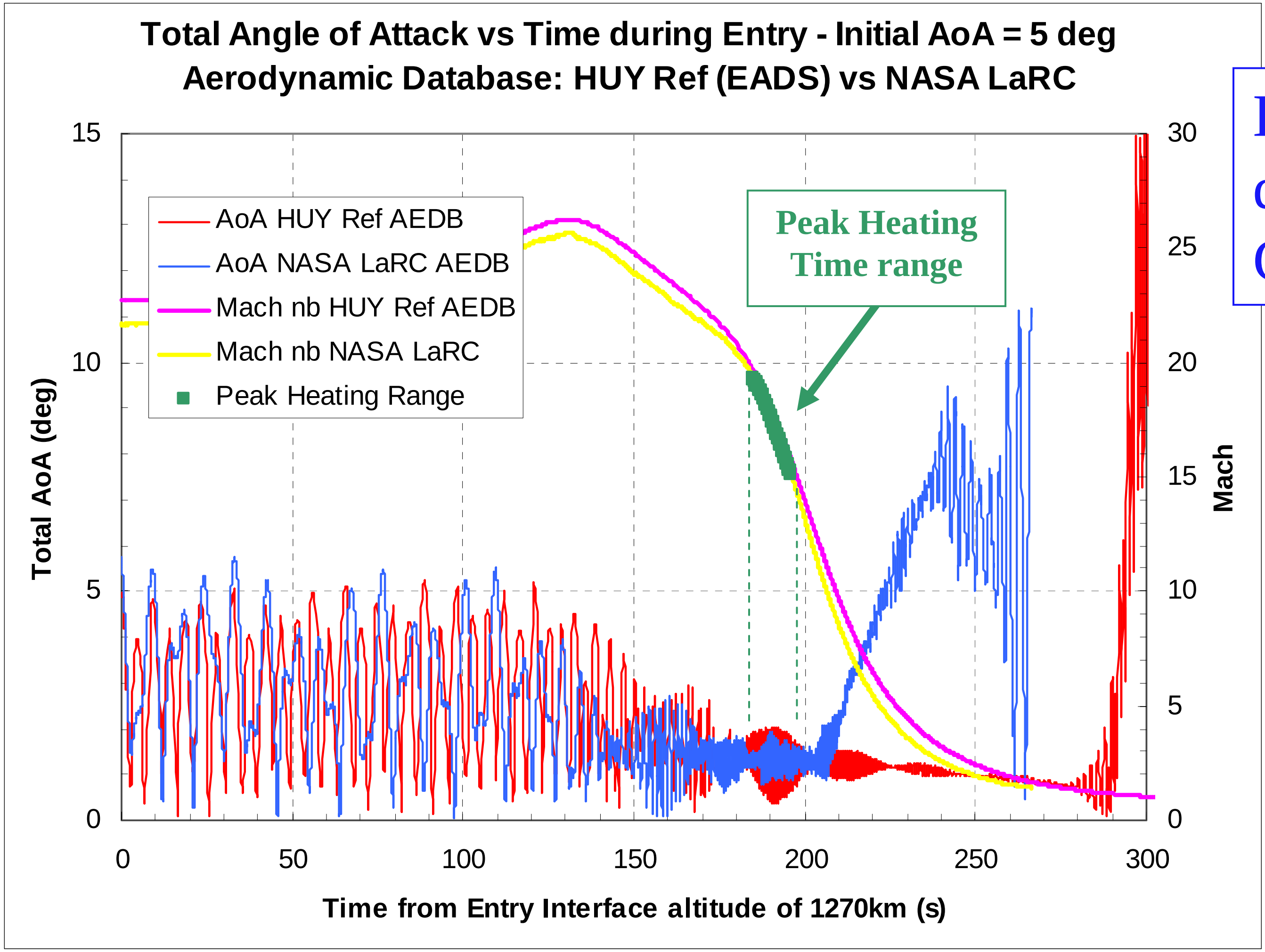


Flight Path Angle Effects



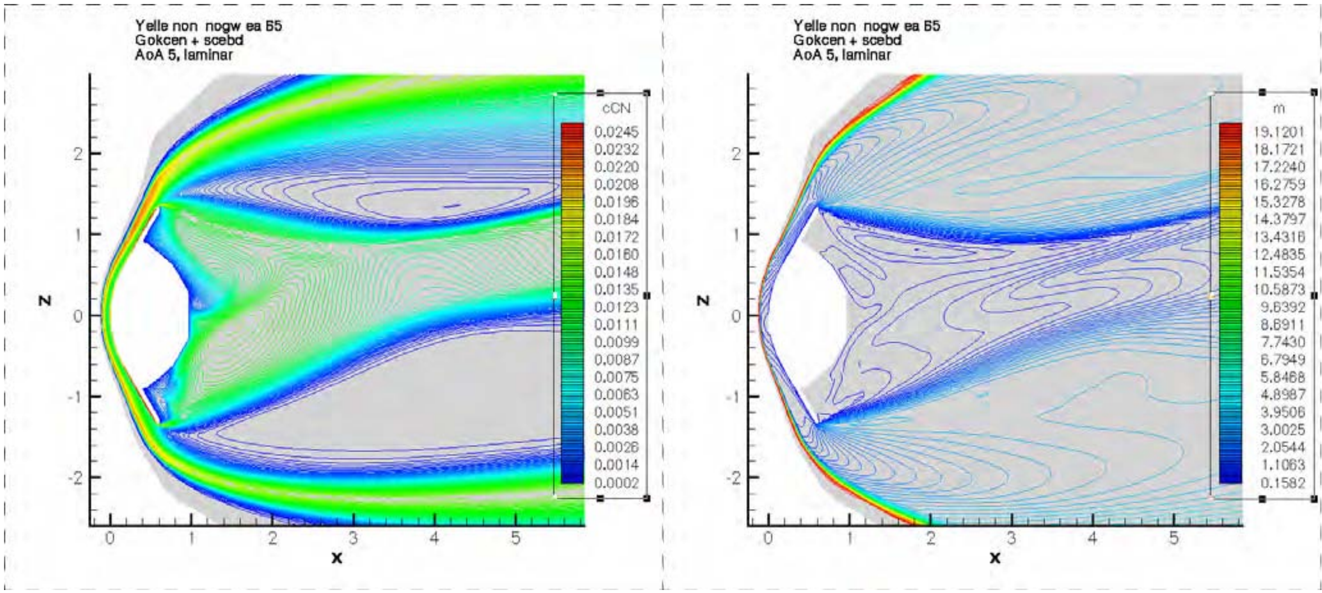
- *High heat rates can lead to material integrity issues such as TPS melting*
- *High heat loads can lead to structural temperatures higher than specification*
- *Most of the variation in performance is caused by the atmosphere*
- *Ability to mitigate heat rate or load concerns by varying flight path angle is extremely limited due to Titan's large atmospheric scale height*

Entry Stability & Angle of Attack Independent Aerodynamic Databases

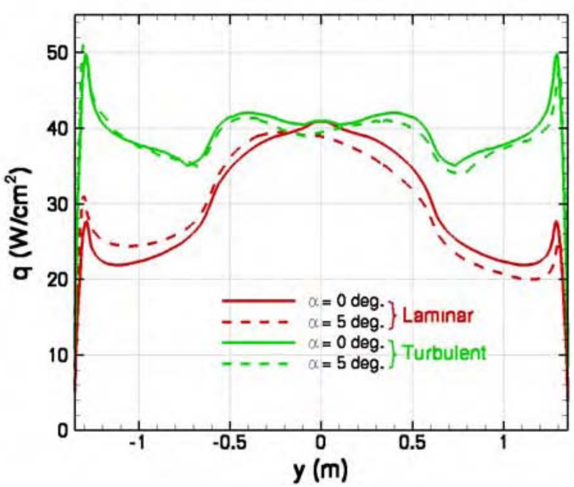


LaRC AEDB derived from Genesis

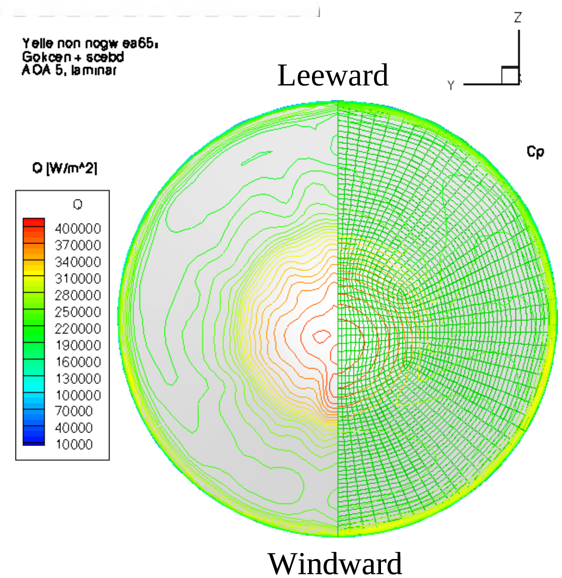
Worst case Angle of Attack (5deg) Impact on Aeroheating



Rnom_NoGW_Ea65, t =187 s



- **Laminar heating rate shows expected (small) bias toward windward side**
- **Minimal impact on turbulent heating rate**



Uncertainty Factors applied to Boltzmann Heat Flux predictions

- Full uncertainty factors:
  - Laminar Convective Flux: 15%
  - Turbulent Convective Flux: 40%
  - Radiative Flux: 60%

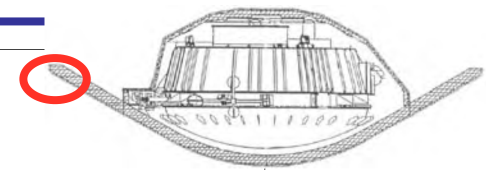
- Thermal model: 0%, 10%, 20%

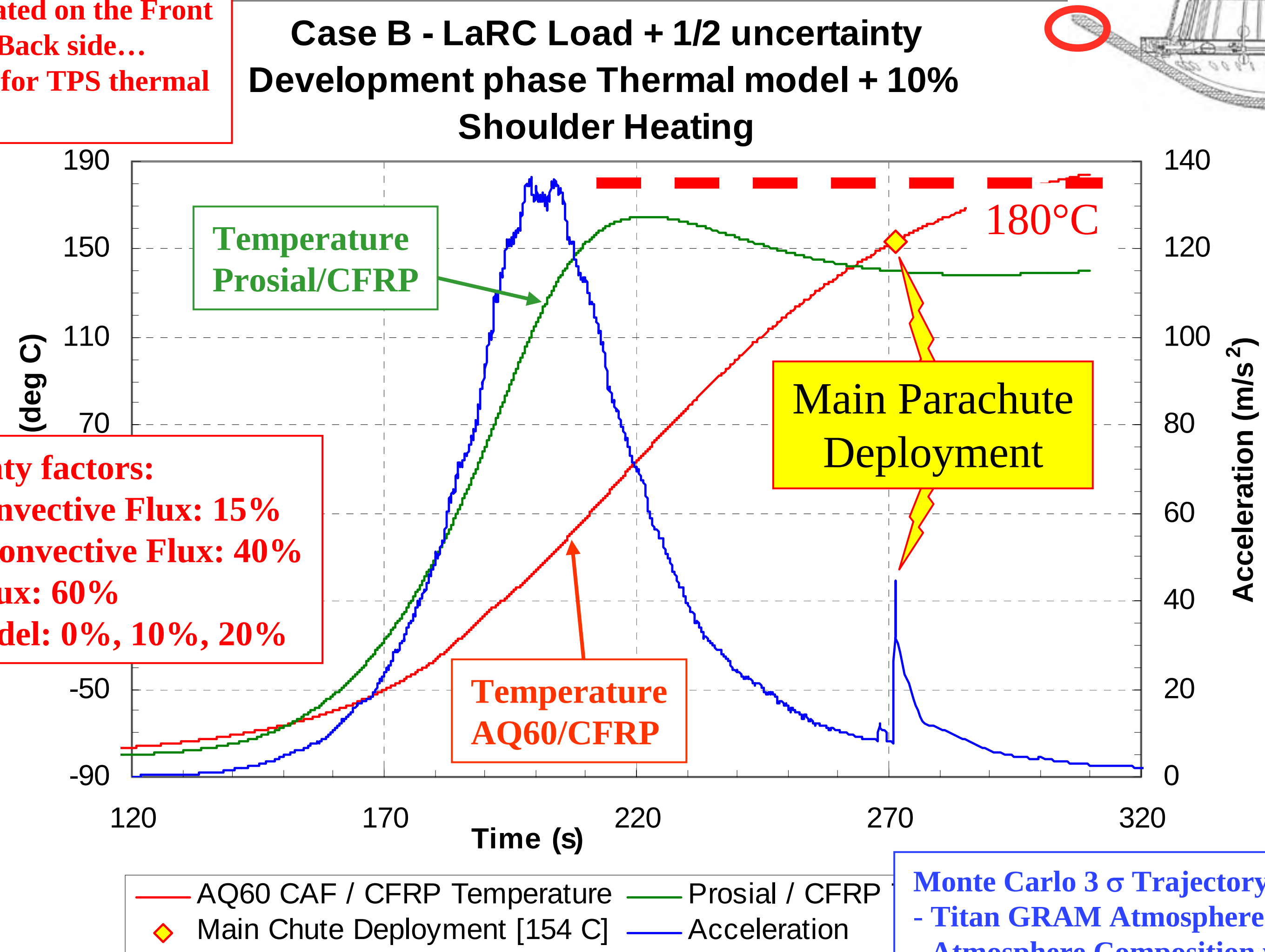
Such uncertainties were considered commensurate with understanding of the models and conservatism already applied…

Last Significant mechanical Load on Front Shield

Trajectory LaRC max Heat Load + ½ Uncertainty

Decelerator part of Front Shield (Shoulder) is heated on the Front Side and on the Back side…
➔ Most critical for TPS thermal Response.



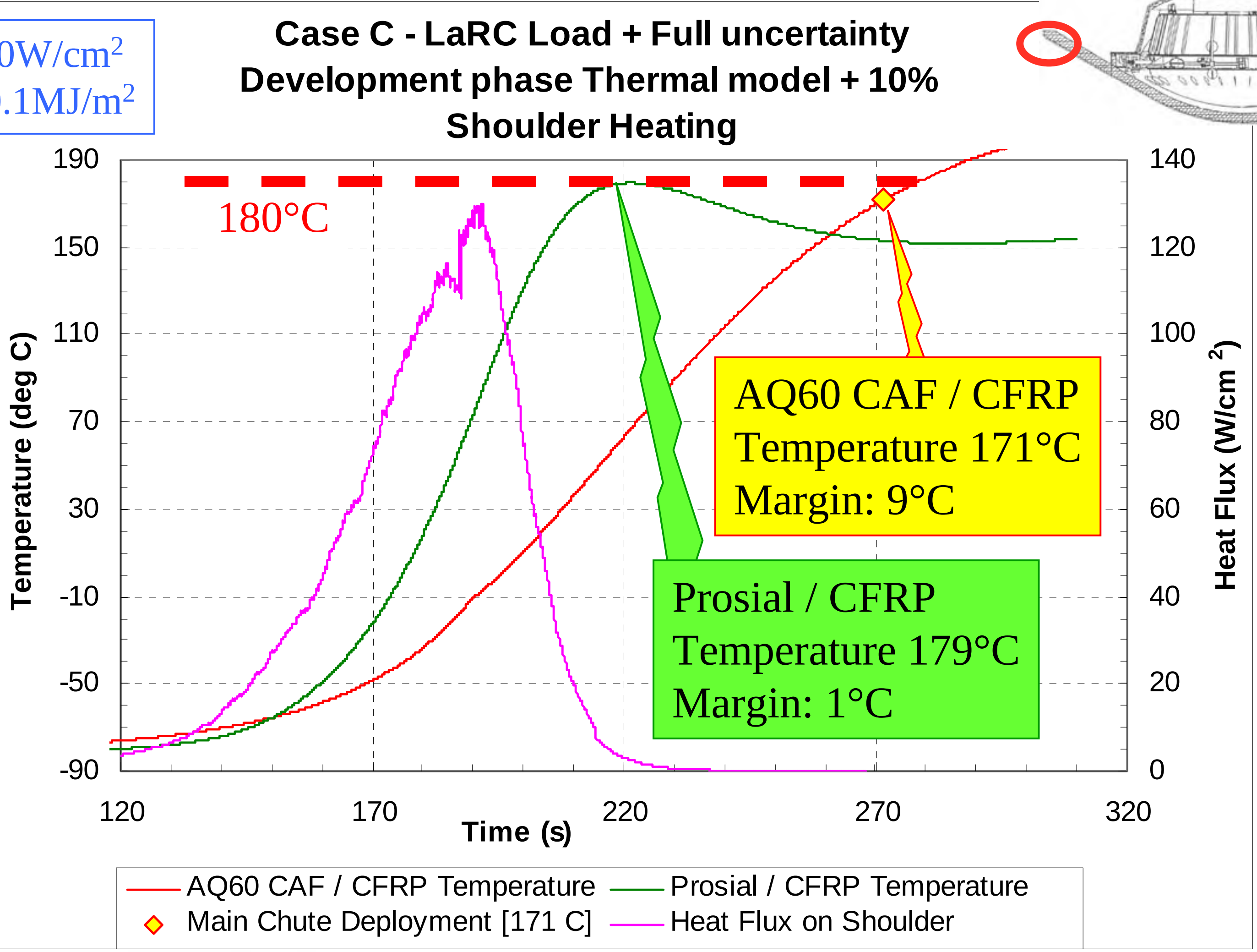


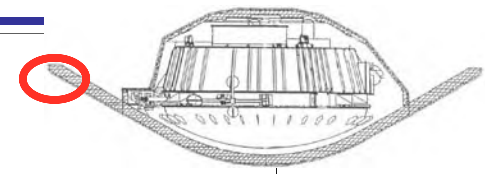
Full uncertainty factors:
- **Laminar Convective Flux: 15%**
- **Turbulent Convective Flux: 40%**
- **Radiative Flux: 60%**
- **Thermal model: 0%, 10%, 20%**

Monte Carlo 3 σ Trajectory data includes:
- **Titan GRAM Atmosphere Density dispersion**
- **Atmosphere Composition with 2.3%CH4**
- **Entry Velocity dispersion Wind included**
- **Flight Path Angle dispersion: +/- 3 deg**

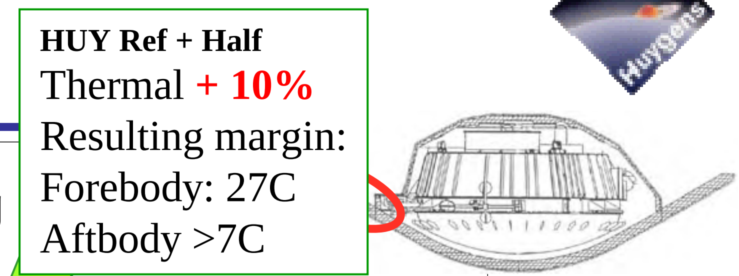
Case C 10%: LaRC max Heat Load + Full Uncertainty
Heat Shield TPS Thermal response to Heat Flux

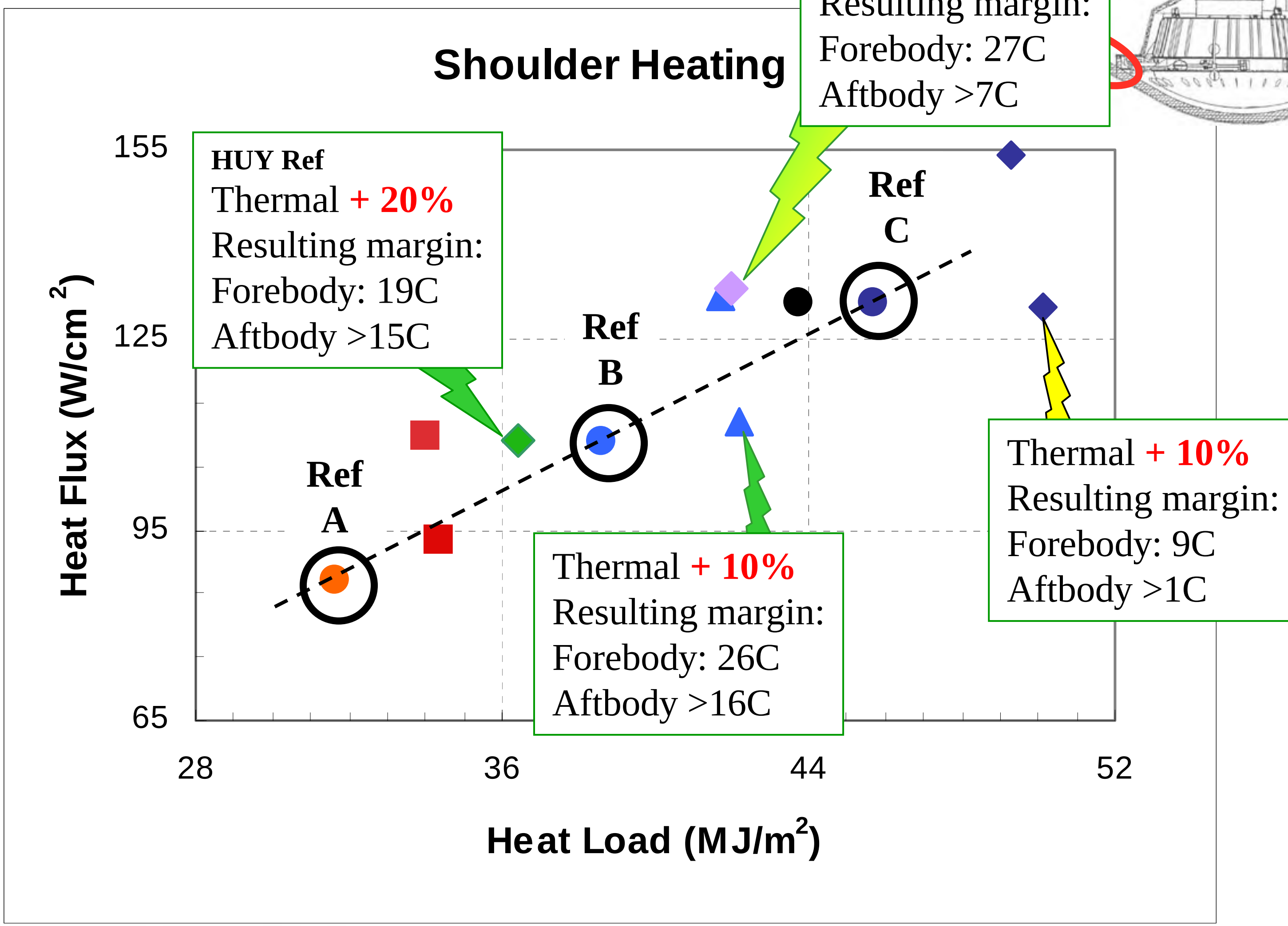
Peak Flux: 130W/cm²
Heat Load: 50.1MJ/m²

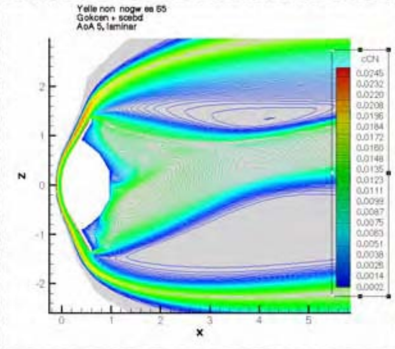




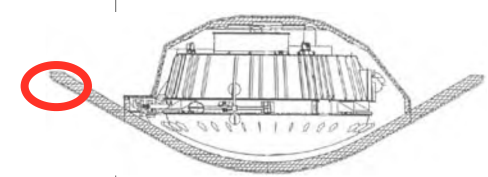
Aerothermal TPS Response
Sizing Cases



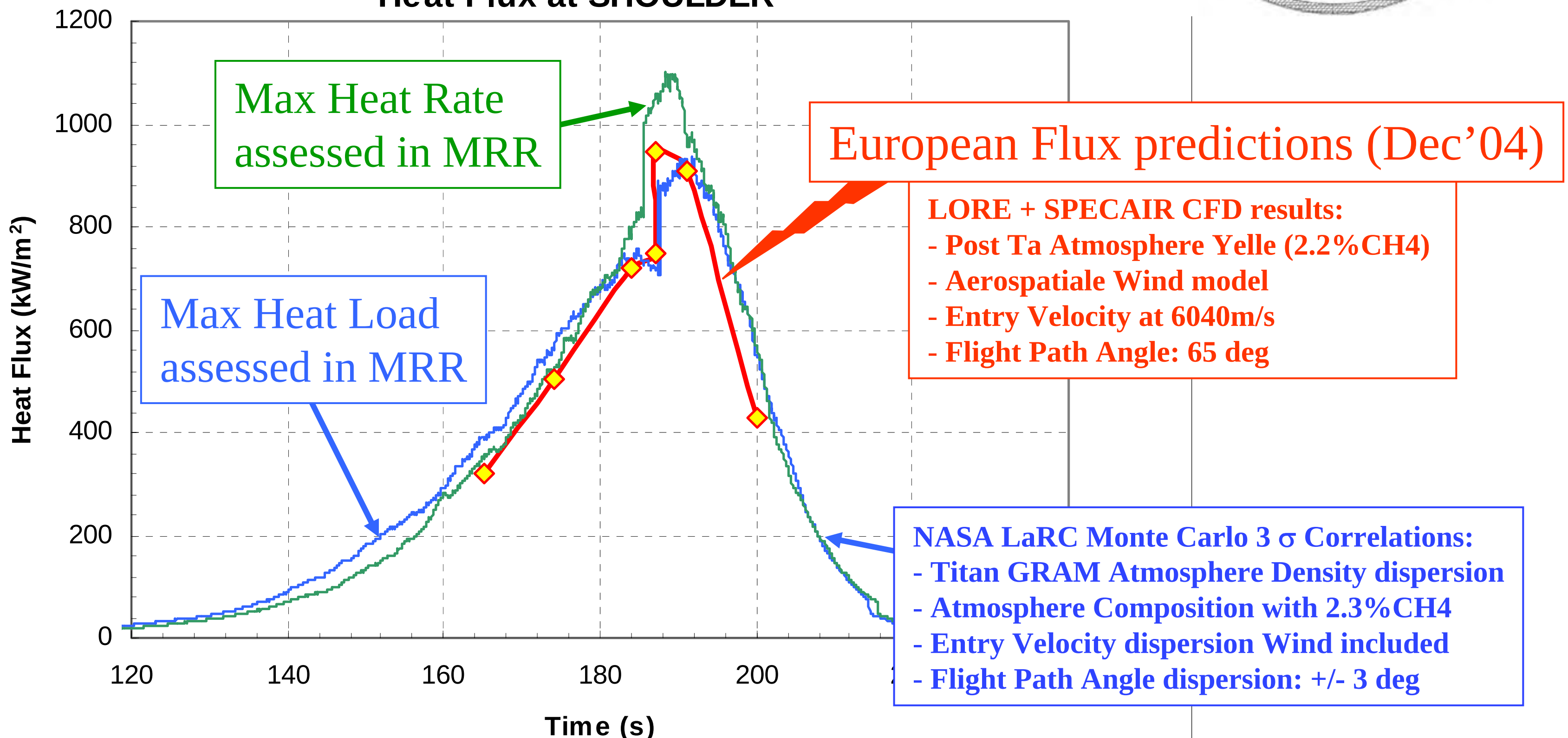




Heat Flux at Shoulder
Most critical element of Front Shield



Post Ta Atmosphere FPA 65 - LORE + SPECAIR
vs Monte Carlo 3 σ - NASA LaRC
Gokcen - Boltzmann 3D - Coupled Tauber
Heat Flux at SHOULDER



Margins Analysis Matrix

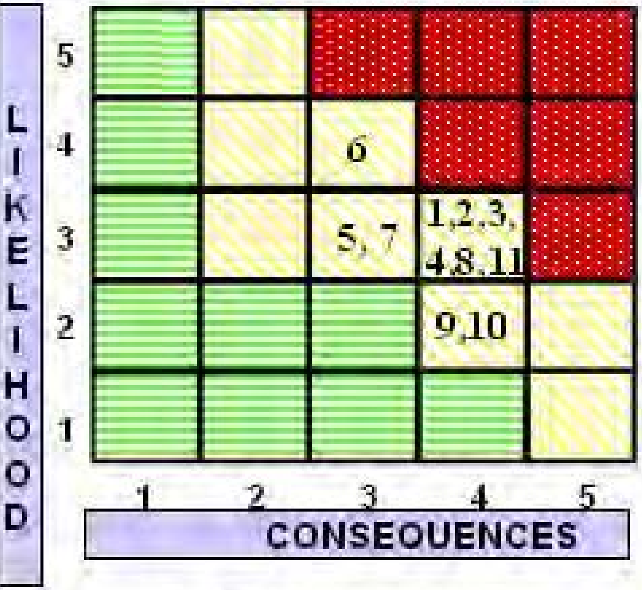
Cassini-Huygens MRR – EDL panel Final report

TPS Thermal Response Uncertainty	None	Half	Full
20%	**A20** - Margin* Forebody >19°C Aftbody >15°C	**B20** – Margin** Forebody >5°C Aftbody >7°C	**C20** – Margin 
10%	**A10** - Margin Comfortable Based on A20	**B10** - Margin Forebody: 26°C Aftbody >16°C	**C10** - Margin Forebody: 9°C Aftbody >1°C
0%	**A0** - Margin* Forebody >42°C Aftbody >34°C	**B0** - Margin Comfortable Based on B10	**C0** – Margin*** Forebody >20°C Aftbody >10°C

Aerothermal Environment Uncertainty

* Case "HUY Ref" + RSS [(λ1+λ2) & (ε1+ε2)]
** Derived from B10 results + Thermal model sensitivity
*** Derived from "HUY Ref + ½ uncertainty" + Thermal model sensitivity

EDL Panel Risk Assessment



NOTE: EDL panel has been tracking a number of "green" risks, primarily in the avionics, sensors, and algorithms area that were rated green due to high-level evaluation of methodology as opposed to deep penetration. Some of these include things that we are recently sensitive to such as g-switch orientation!

Risk#	ID	Risk	Risk Title
1	T3	High to Mod	Forebody TPS performance not within specification
2	T6	High	Aftbody TPS performance not within specification
4	T5	High	Aftbody TPS thermal response not adequately characterized
3	T2	Med	Forebody TPS thermal response not adequately characterized
5	S3	Med	Unacceptable angle of attack at peak heating increases aerothermal heating effects
6	S10	Med	Probe does not reach ground in specified time and as a result, scientific information may be lost
7	S5	Med	Atmospheric density and composition models and uncertainties do not reflect updated scientific knowledge
8	S6	Med	Wind model and its uncertainty does not reflect updated scientific knowledge
9	A4	Med	Parachute deployment algorithm may malfunction in the presence of atmospheric and/or dynamic transients
10	T1	Med	Forebody thermal environment may not be predicted correctly
11	T4	Med	Aftbody thermal environment may not be predicted correctly

Huygens Atmospheric Entry Validation

Entry validation work covered critical aspects:

- **Probe entry detection mechanism & Parachute deployment**
  - Probe entry acceleration profiles (80 m/s^2 < Peak Acc < 196 m/s^2)
  - Pyro Arming and Firing ranges (Ta = 9.48 m/s^2, T0 = 10 m/s^2 + 6.375 sec)
  - On-board computers Inter-Chain Delay (< 2 sec to cover failure modes)
  - Probe stability at parachute deployment (AoA < 20 deg at Pilot firing)
  - Pilot and Main Parachute deployment Loads (Mach & P_{DYN} dependant) (Pilot < 2100 N , Main < 17600 N)
- **Probe entry Aerothermal environment predictions**
  - Peak Heat Flux during entry (< 1500 kW/m^2)
  - Maximum Heat Load during entry (order of 40 to 45 MJ/m^2)
  - Probe TPS Thermal Response (Front-Shield inner structure < 180°C)

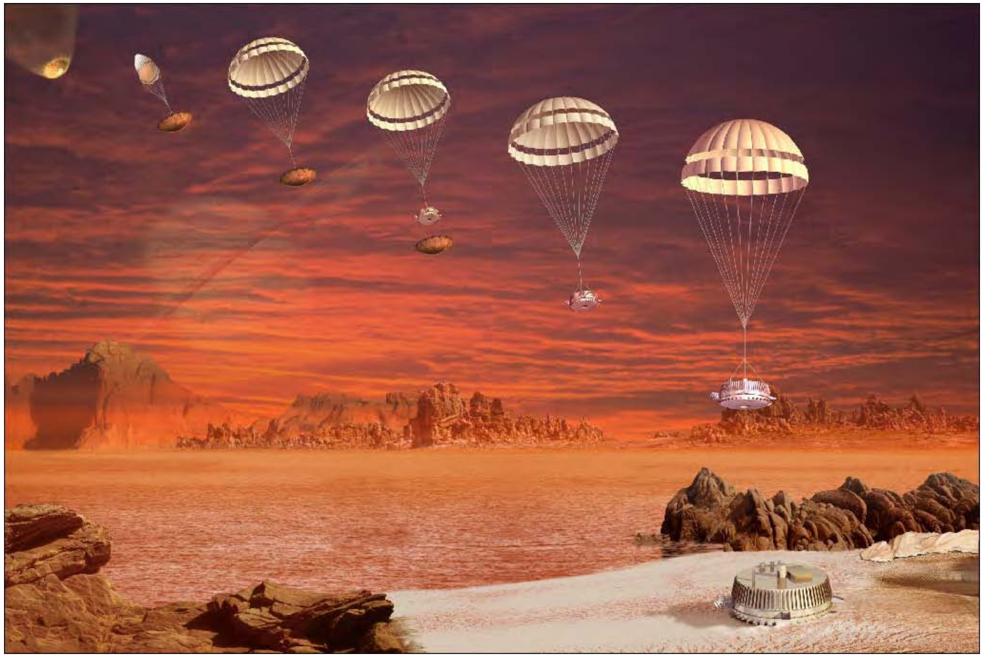
- Despite being scheduled late and concluded less than a month before nominal Cassini/Huygens Separation, the Mission Risk Review brought a useful independent assessment of EDL predicted performances.

- Amongst other issues, the possibility of a Probe longer descent time was raised…

- Time has been extremely busy in these last months before the mission… and very hot !...

- International cooperation has been most valuable both for ACWG and MRR work…

Final Go-ahead for a 25 December Separation was given on 16 December…!



Courtesy: SSP