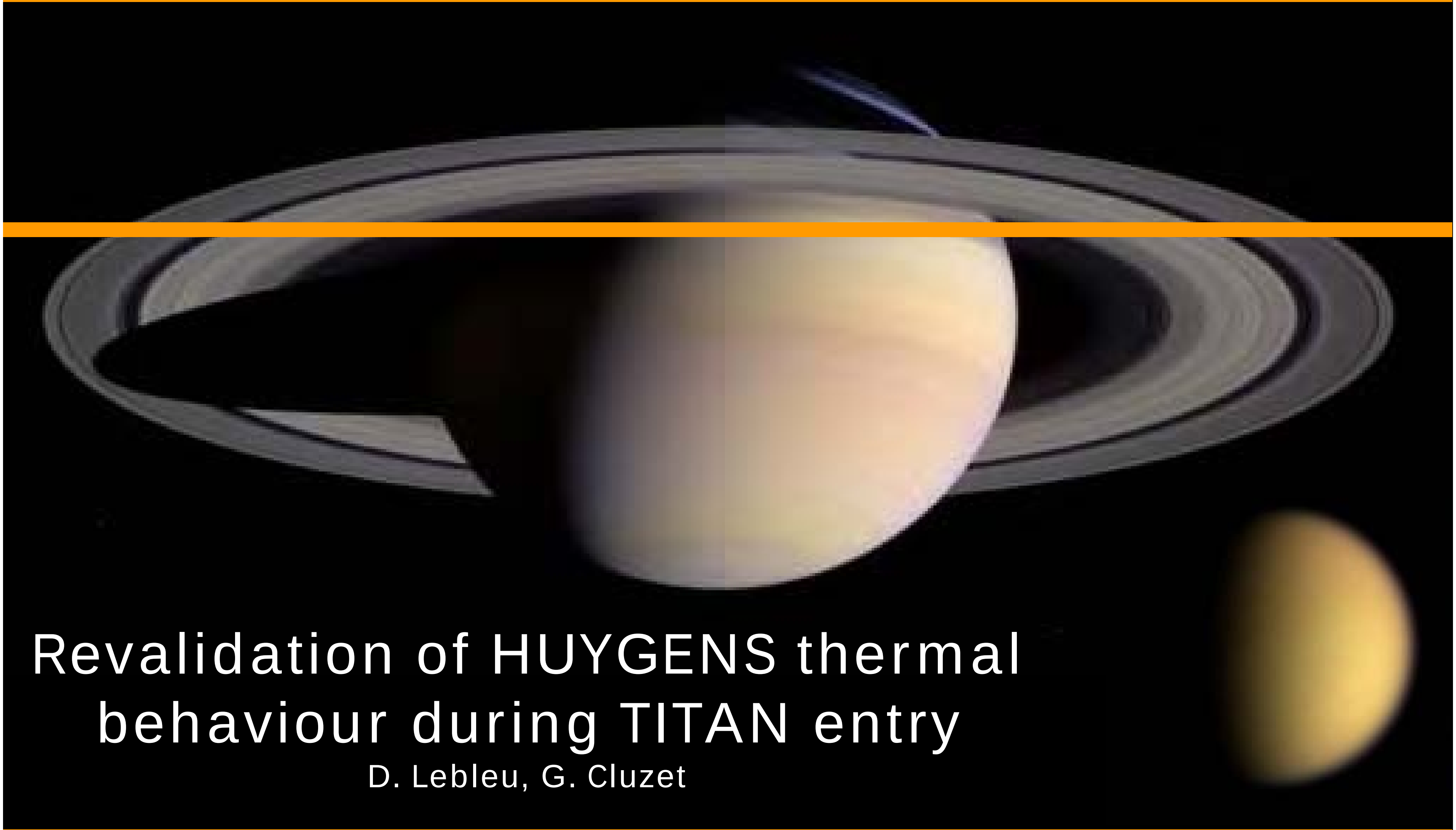

Revalidation of HUYGENS thermal behaviour during TITAN entry

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Forewords

- HUYGENS DELTA FAR (January 2004)
  - Confrontation in methodology for Entry radiative Heat flux evaluation
- The HUYGENS ESA project team has created a working group involving different partners to reconcile the different methodology
  - Agencies
  - Industry
  - Scientific community
- Aerothermal environment first iteration in June 2004 (6 month before probe release)
  - Exceed the environment considered for the probe sizing
- Necessity to evaluate the impact of such environment on the probe
  - In parallel to the radiative heat flux evaluation

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Management of probe thermal behaviour at system level

> Thermal Protection System modelling

- Extremely rapid variation of the environment
- TPS includes complex phenomenon
  - Conduction heat exchange
  - Chemical decomposition
  - Phase change
  - > Require important discretisation across the TPS thickness
    - 1D modelling (some 2D local modelling in high curvature areas)

> Probe overall thermal modelling

- Mandatory to be 3D

> The 2 modelling are not compatible

- Analysis split in 2 parts
  - > TPS
  - > Probe

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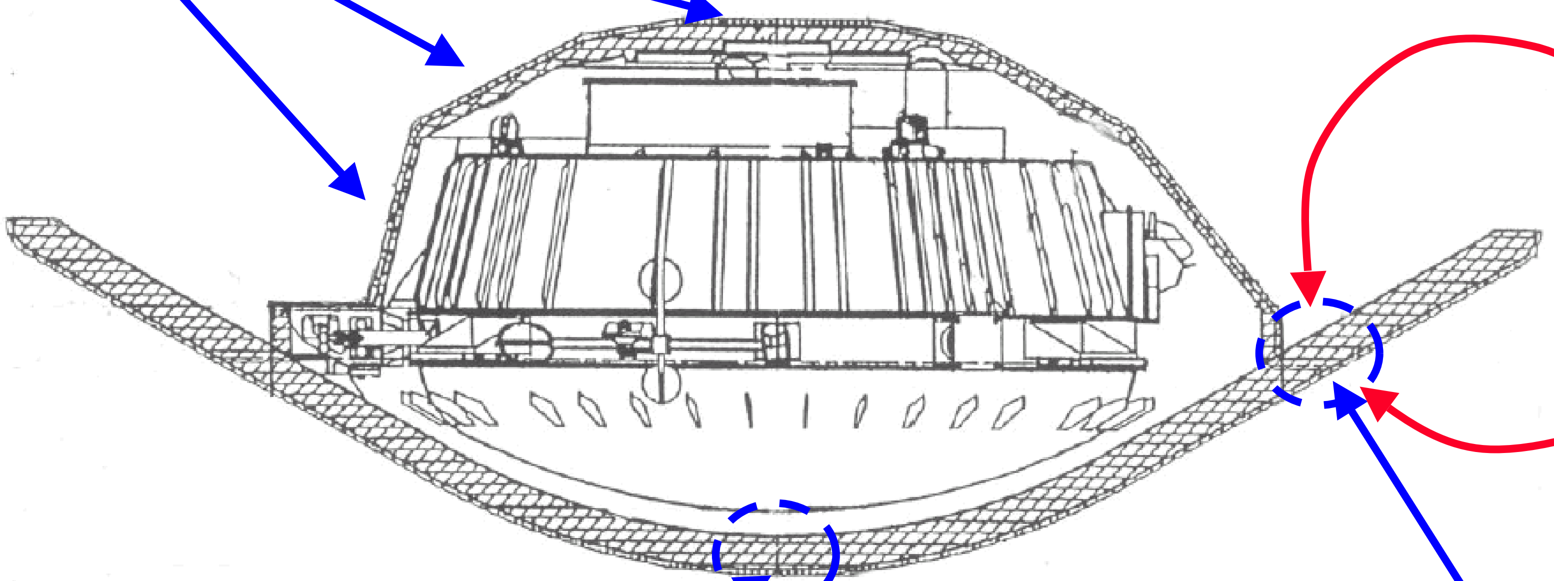
Aeroshell verification points

Back cover behaviour

- TPS
- Structure

Flux on both sides



Frontshield behaviour - Mid cone

- TPS
- Structure

Frontshield behaviour - Stag point

- TPS
- Structure

> TPS analysis will provide boundary conditions for Thermal analysis

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> Frontshield (same trend for the back cover)

Stagnation point

	Total HF kW/m²	Heat Loads MJ/m²
Shallow entry	1057	44
Steep entry	2046	40
Shallow entry Development phase	920	36

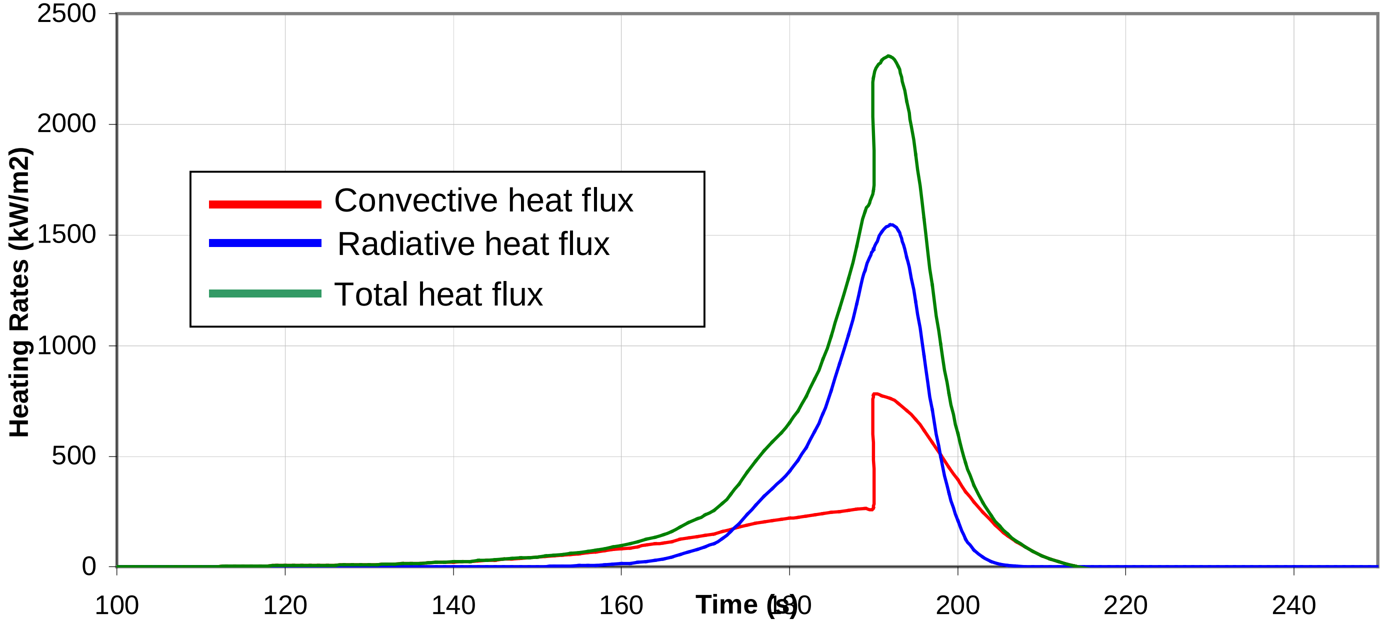
Shallow entry still sizing case

Increase > 20%

Mid cone

Heat Loads MJ/m²	Total HF kW/m²	
34	882	Shallow entry
37	2305	Steep entry
26	723	Shallow entry Development phase

FS Heat Flux (gamma=-68 deg. - Minimum density)
Mid cone - Laminar Turbulent Transition - Tw = 1500K



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Frontshield TPS analysis

> Frontshield structure maximum temperature

- Specified as
  - > +180°C : Upper level of available experience for CFRP
    - – Feared event: Carbon skin/honeycomb skin potential phase change (become liquid and loose all mechanical properties
  - > At Frontshield end of mission = Separation from the probe (30s after T0)

> TPS analysis for stagnation point (Conducted by EADS)

- Maximum 143°C ==> provides 37°C margins

OK

> TPS analysis for mid cone (Conducted by EADS)

- Maximum 196°C on the back face (computed)
  - > Negative margins of -16°C

Uncertainties should be added above computed level

Probe behaviour to be verified

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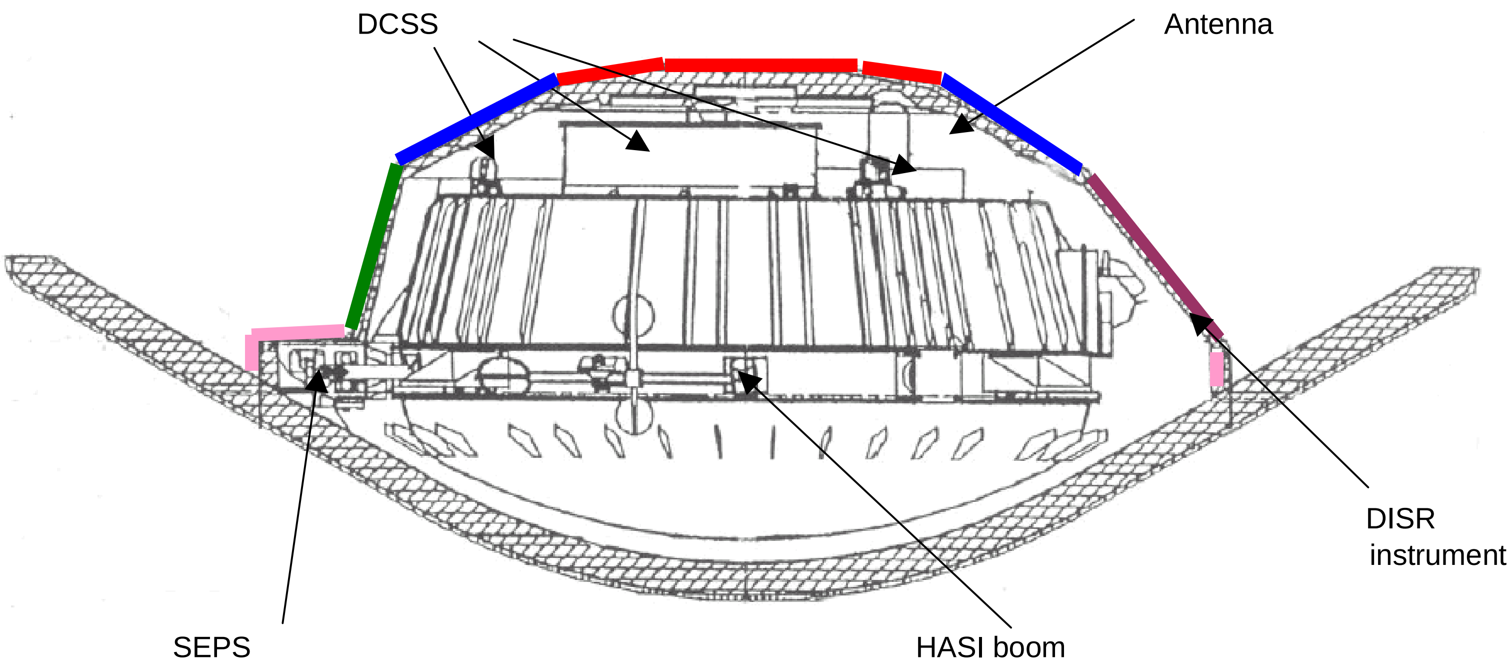
Back cover TPS analysis

> Several areas are defined on the back cover wrt the environment



> Maximum temperature defined at 250°C

> Sufficient margins on the different areas except back cover lateral sides

- Peak computed temperature of 255°C
  - Negative margin of -5°C, without uncertainties

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> In front of 3 difficulties

- At Frontshield equipment level
  - TPS qualification (AQ60 front face and PROSIAL back face)
  - Tile glue and inter-tiles joint
  - Frontshield structure

- At back cover equipment level
  - TPS qualification
  - Back cover structure

- At descent module level … as the Back cover interface temperature is now above the level considered for the probe sizing
  - Necessity to verify all Descent Module elements behaviour under these updated temperature

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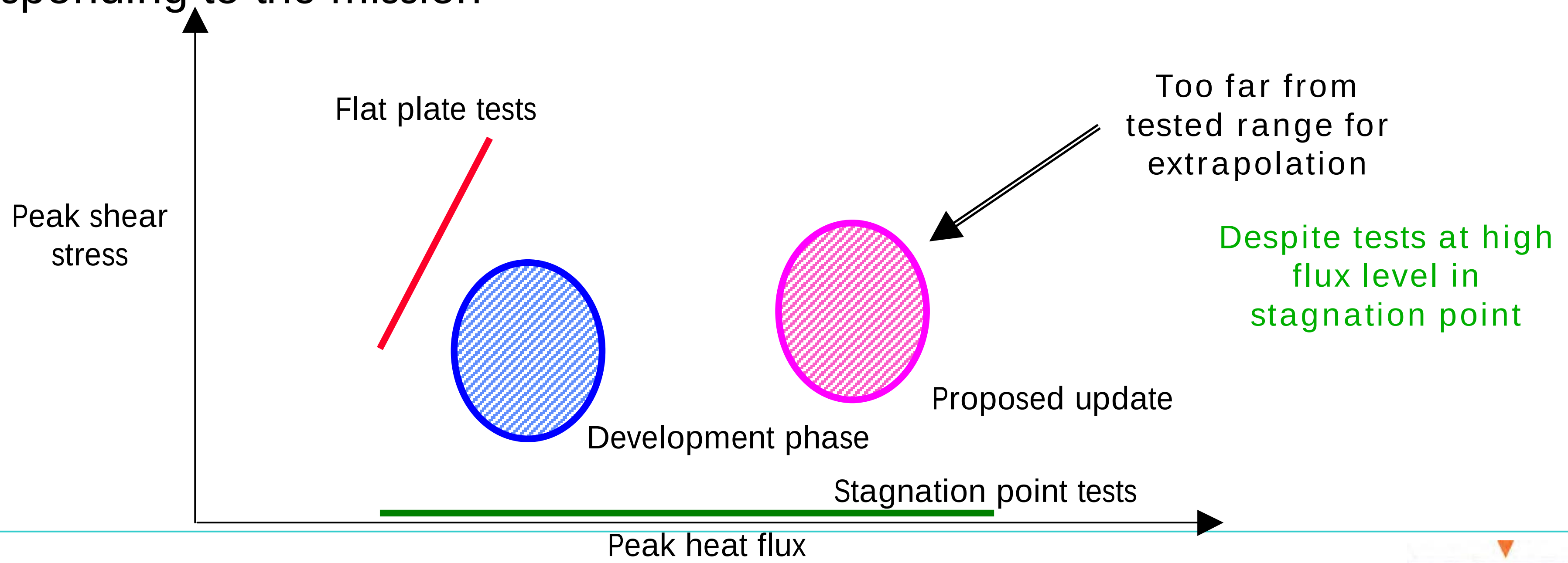
TPS behaviour

> TPS qualification level - The difficulty is on the Frontshield cone

- In this area, we have combination of
  - High heat flux
  - High heat load
- Feared event: Char layer removal by the boundary layer shear stress
  > Potential decrease of TPS insulation capabilities
- Classically, this is covered by TPS tests in range of heat flux / shear stress corresponding to the mission



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Frontshield structure behaviour

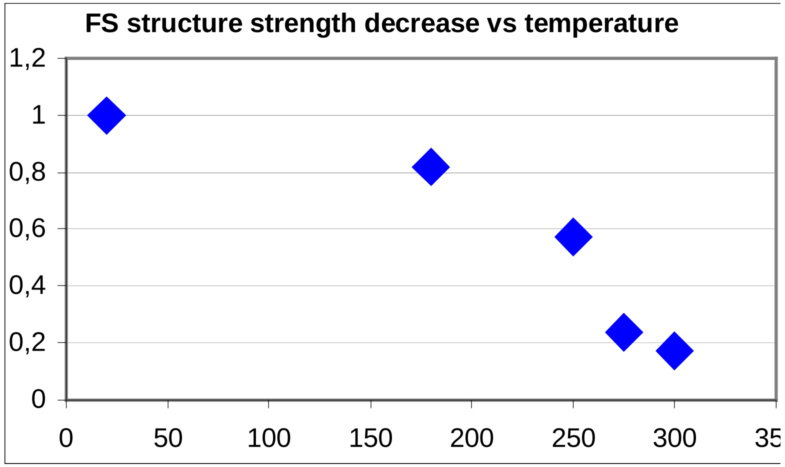
> Feared event with high temperature

- Phase change in glue between carbon skin & aluminium honeycomb

> Qualification done for 180°C max temperature

- Simulation indicate 196°C (end of FS mission)
- Negative margins

> Frontshield mission life



Events	Thermal environment	Mechanical environment
Entry Interface Point	Cold level (-80°C)	No loads
Peak deceleration	Moderate level (<100°C)	Peak pressure effect on the Structure (~13 kPa, ~58kN)
Pilot chute deployment	High temperature	Moderate load (~2kN)
Main chute deployment	High temperature	Moderate load (~15kN)
Frontshield separation (end of mission)	Maximum temperature	No loads (only weight)

- Last mechanical load is the significant event
  - > Temperature is now 175°C
- Margin of Safety > 3
  - > But data based on only 3 tests
  - > Not enough for qualification

= = > gives good confidence

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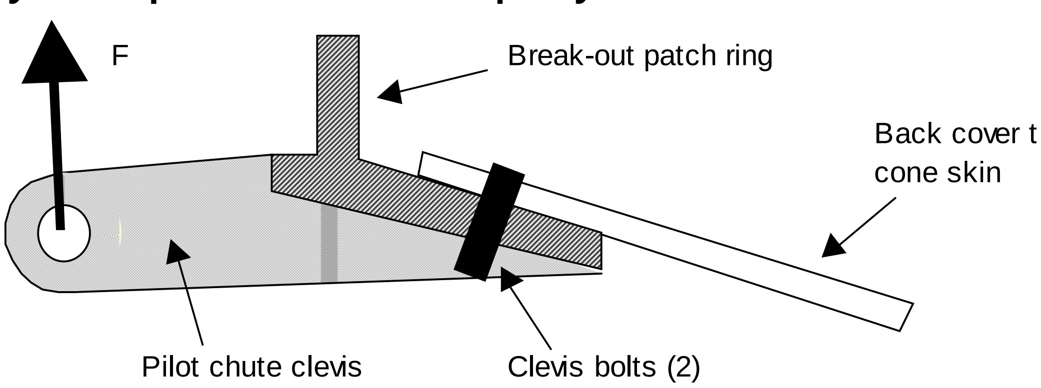
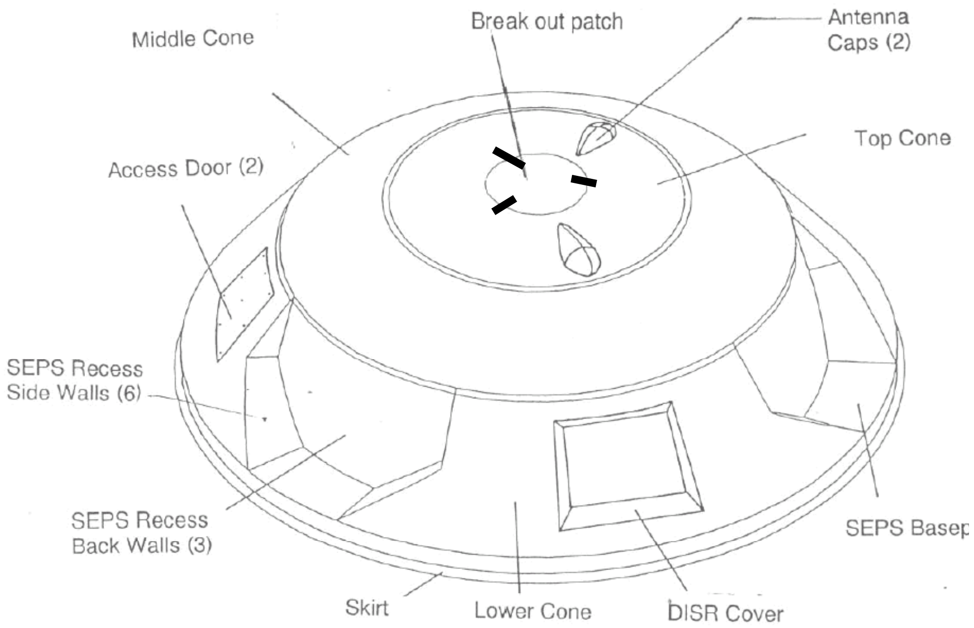
Back cover structure behaviour

> On Back cover, the sizing case is clearly the pilot chute deployment

- High temperature
- and sizing mechanical load





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Back cover structure behaviour

> Aluminium has reduced mechanical strength at high temperature

- Available data are from Aircraft experience
  - 1995 : -23% @ 250°C
  - 2004 : More refined analysis => -40%

New reference in 2004 as impossible to find the reference used 10 years ago ...

⇒ Negative margins

> But conservative hypotheses

- All deployment load on 1 clevis (probe AoA unknown at PC deployment)
- Static mechanical analysis
  - Material elastic behaviour (plastic deformation of the back cover will not be a concern)
  - No load redistribution, in particular no probe rotation under this load is considered

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Descent Module elements

- Necessity to verify all elements behaviour
  - Descent Module structure and internal equipment (including instruments)
    - Covered by thermal system analysis
  - Descent Module external elements
    - Descent subsystem (parachutes, bridles, mechanisms)
      - MBA/VORTICITY has performed an analysis which has presented a compliance with this environment
    - Antennas: Local thermal analysis has shown no criticality
    - Separation subsystem: It was verified again that Pyro critical parts (power auto-inflammation @ +110°C) are protected from entry environment by the SEPS and pyro structure thermal inertia

- No criticality on Descent Module

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Status at end of analysis

- Most of the probe elements can withstand higher flux but 3 major difficulties remains
  - TPS qualification — But engineering feeling remains good
  - Frontshield structure — But margins exist with regard to the last significant event
  - Back cover structure — But under conservative assumptions
- To improve the situation : Only 1 DoF ==> FPA
  - But TPS qualification corresponds to steep entry (max flux)
  - and Aeroshell structure limits corresponds to shallow entry (max temperature)

No solutions !

- As engineers from Industry who, as a person, have designed and build HUYGENS, we were in front of a dilemma :
  - As engineers we were confident on probe capabilities under such environment
    - GO for the mission
  - As Industry, our contractual obligation is to provide information to our customer
    - Probe not qualified for such environment

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Following activities

> This analysis was performed in parallel to heat flux analysis

- It was based on the first iteration

> The Effort was continued :

- to improve accuracy on aerothermal environment knowledge by all partners, Agencies, Industry, scientific laboratory
- Refinement on TPS analysis with real thickness

> This has results in a large improvement of the situation

- Go for the mission

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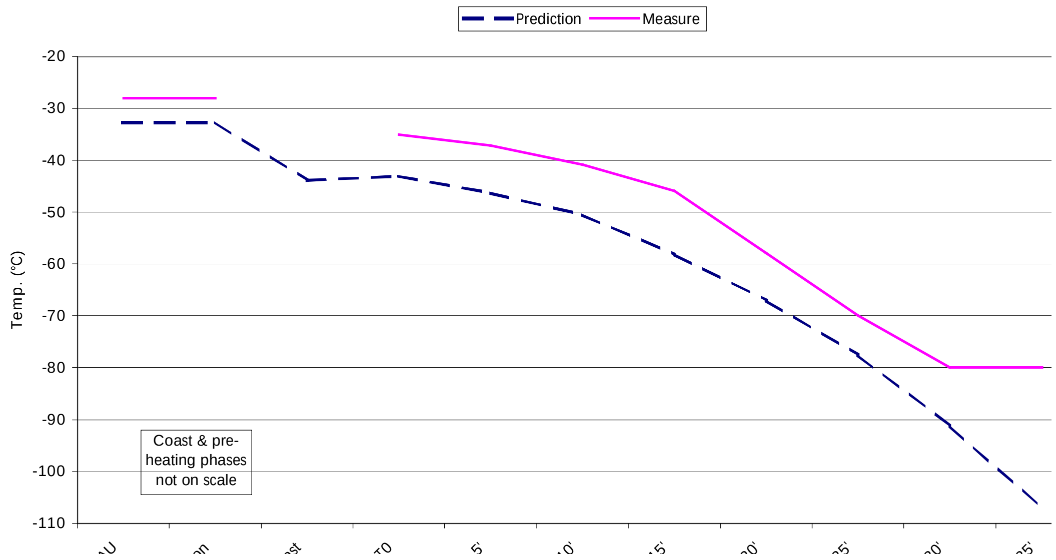
HUYGENS probe to TITAN

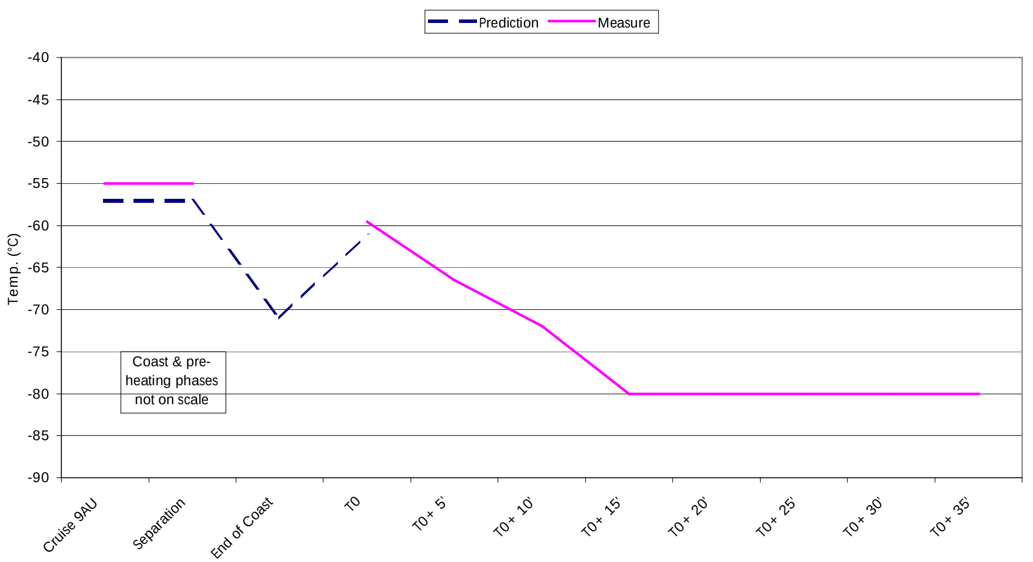
Flight

- No temperature sensors on the Aeroshell
- The impact of the <u>entry fluxes</u> on the temperature of external Descent Module elements is limited, and not higher than expected

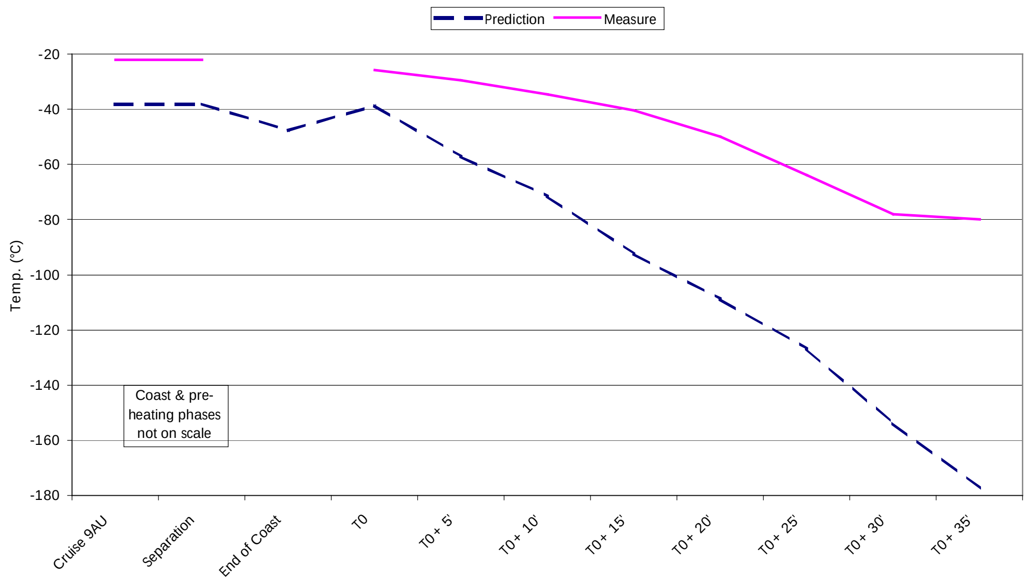
D5015T - PJM B - Node 712



D5013T - SEPS B - Node 442



D5024T - After Cone/Foam outside - Node 34



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HUYGENS probe to TITAN

European Space Agency/J. Mai