3rd International Planetary Probe Workshop

Session 2C

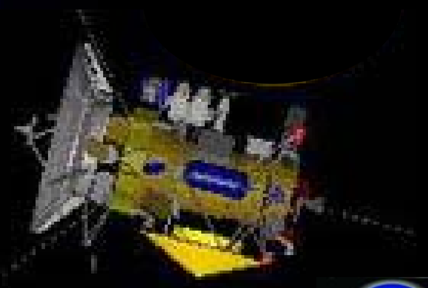
HUYGENS

From the Δ Flight Acceptance Review To the Mission Risk Review

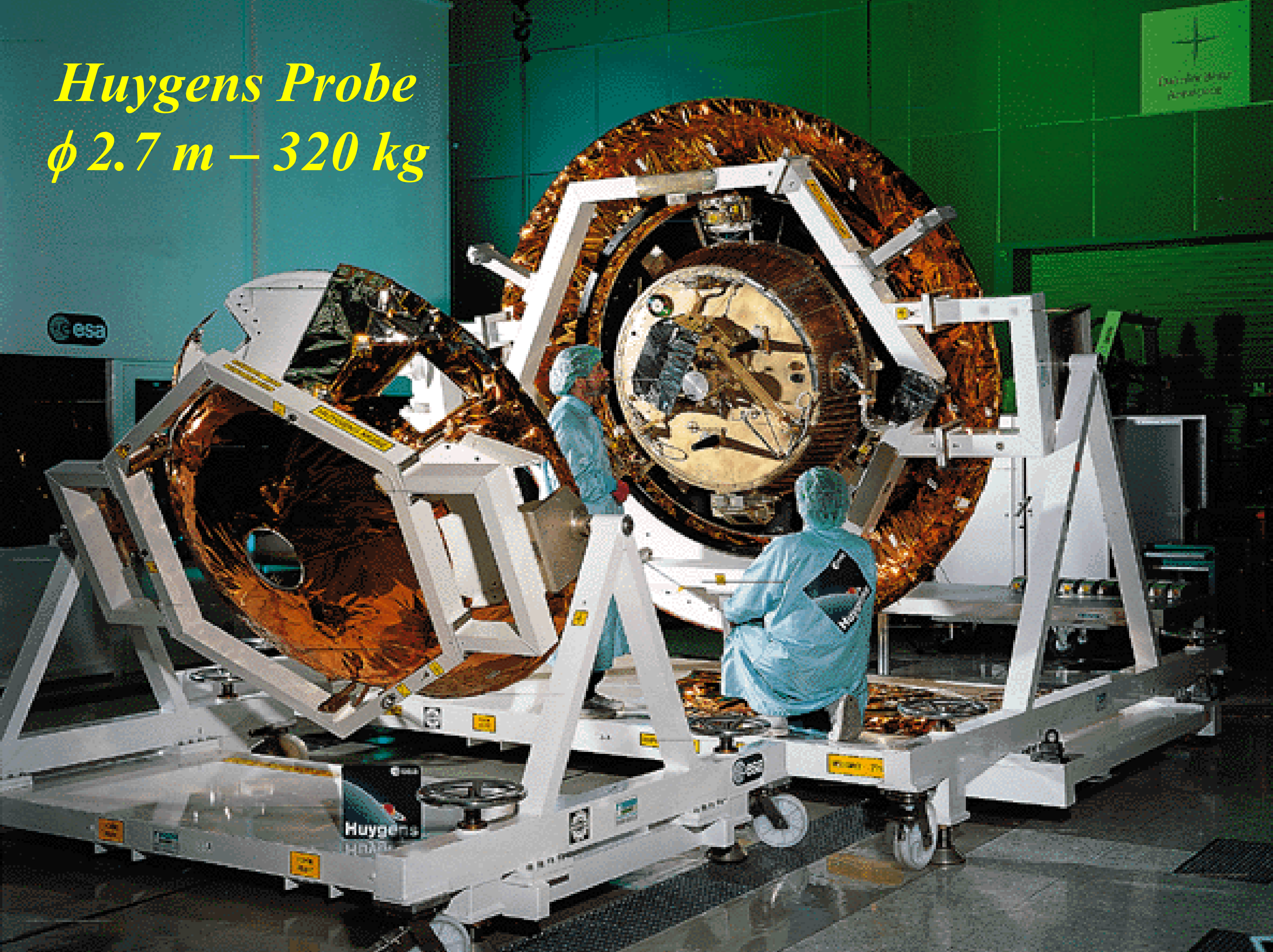
Thierry Blancquaert

ESA-ESTEC, The Netherlands

Thierry.blancquaert@esa.int



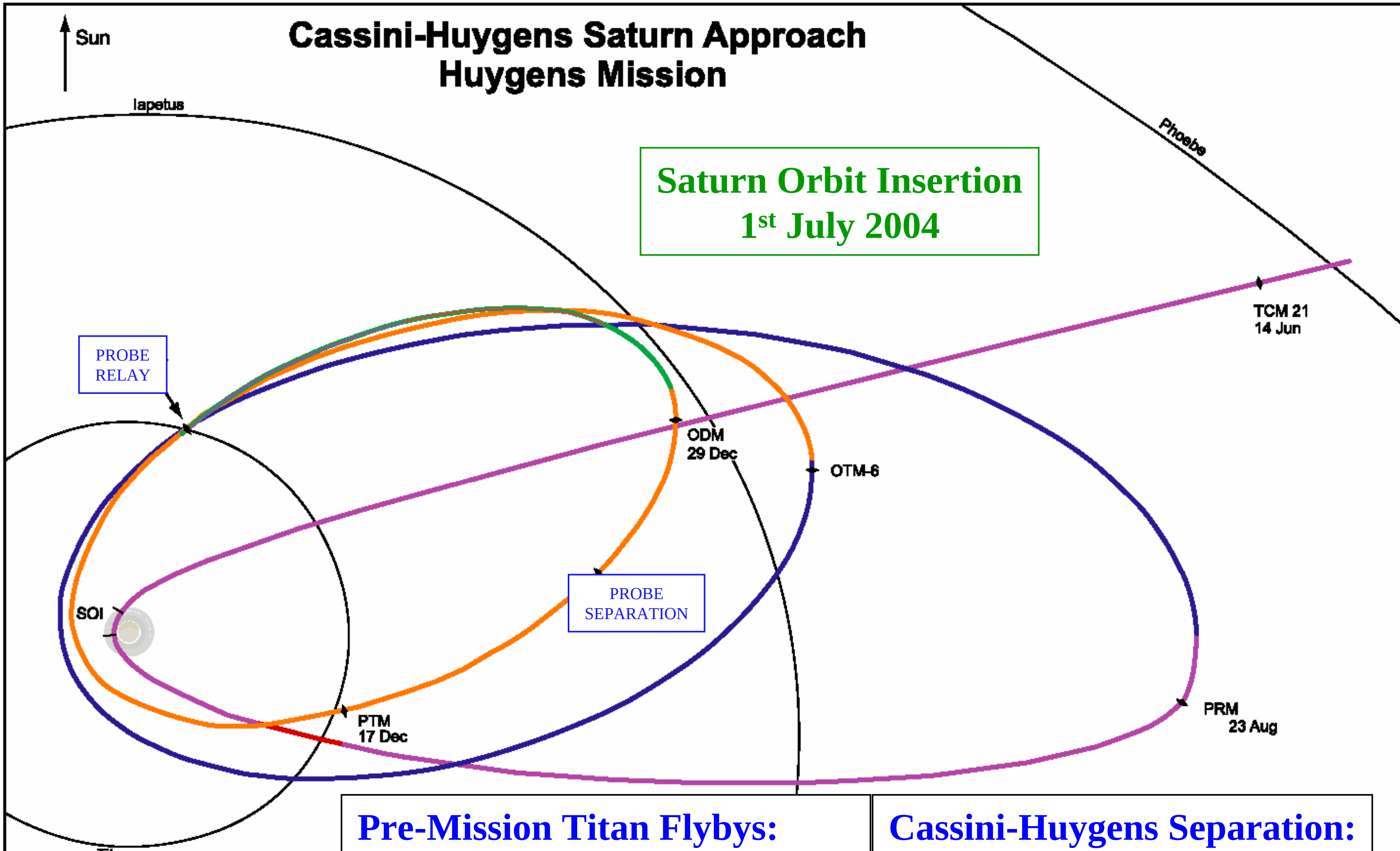
Anavyssos, Greece, 28 July 2005


Huygens Probe
ϕ 2.7 m – 320 kg
esa
Huygens

Huygens Δ-FAR Scope

- Huygens Mission was reviewed for Flight Acceptance in March 1997 and was launched on-board Cassini on 15 October 1997.
- Subsequent to the detection of a radio receiver anomaly in February 2000 during an in-flight end-to-end test of the receiving part of the Huygens radio relay subsystem, a joint ESA/NASA Huygens Recovery Task Force recommended a Mission recovery plan.
- The Huygens Delta-Flight Acceptance Review (Δ-FAR), held in Dec'03-Feb'04 was an ESA Agency-level review with the objective to examine the **changes** in the Huygens mission that were implemented since the original FAR.
- No formal ESA review of the Huygens Mission Recovery activities and of the new Huygens mission scenario had taken place before this one.

Cassini-Huygens Saturn Approach
Huygens Mission



Saturn Orbit Insertion
1st July 2004

Titan orbit
15.95 Days

Pre-Mission Titan Flybys:
- 3 July 2004, at 339000 km
- 26 October 2004, at 1175 km
- 13 December 2004, at 1200 km

Cassini-Huygens Separation:
- 25 December 2004

Huygens Titan Entry:
- 14 January 2005

Δ-FAR Objectives

The objectives of the review were:

- Validation of the new mission scenario designed to recover from the Huygens receiver anomaly
- Re-validation of the entry and descent (with respect to the revised atmosphere model)
- Confirmation of the readiness of operations preparations for the revised Huygens Mission

Huygens Entry & Descent Review

- Review of Huygens Entry & Descent scenario addressed the following aspects:
  - Atmospheric Models update
  - Aerothermodynamic studies
  - Entry detection principles re-assessment
  - Probe entry performance re-validation (Structural integrity, Thermal…)
  - Entry stability
  - Parachute performance reassessment and re-validation
  - Front Shield performance reassessment and re-validation
  - Overall system-level re-validation of the Entry and descent taking into account the Yelle atmosphere model and the Gravity wave model, and a re-assessment of the industrial design tools performance (aerothermochemistry and parachute)

Δ-FAR Entry & Descent main issues

1. **Titan Atmosphere Model – Selection of worst case envir^{nt}**
   – Introduction of Gravity Waves in addition to the Yelle model had significantly eroded performance margins of the Probe entry.
2. **Parachute deployment loads**
   – Deployment Loads increased since FAR predictions but the model needed to be validated against Flight Data.

   → MER had similar parachute design.
3. **Atmospheric Entry Heat Flux predictions Reappraisal**
   – NASA predicted peak entry Heat Fluxes 50% greater than baseline.
4. **Heat Shield material AQ60 transparency to UV radiation**
   – Assessment of AQ60 material possible transparency to UV radiation had not been addressed before.
5. **AQ60 Qualification and Thermal response**
   – Performance to be checked against higher fluxes & UV transparency

From Huygens Δ-FAR to MRR

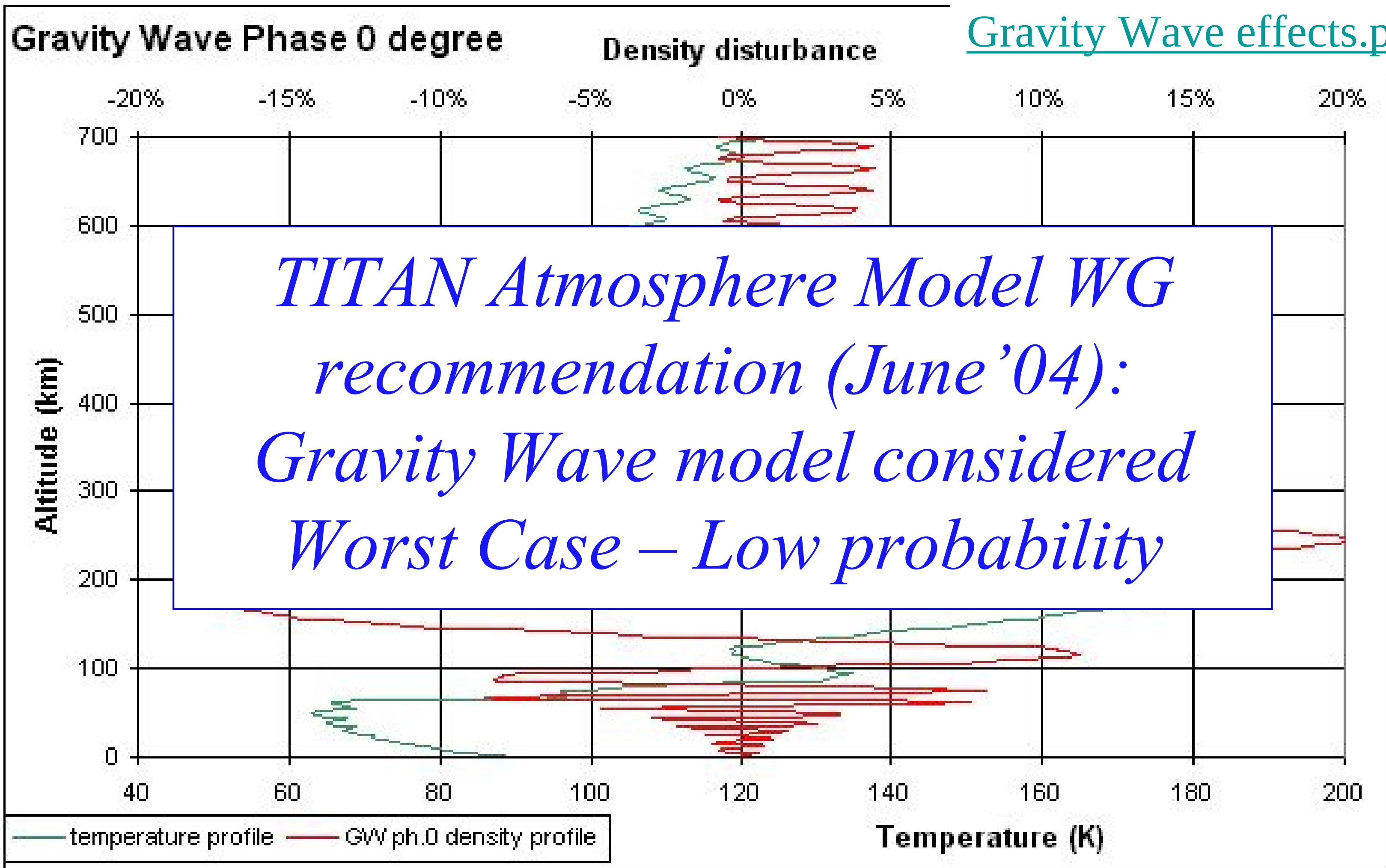
- A strong emphasis was put on verifying mission robustness and key objective was to recommend confirmation or adjustment of the baseline Entry Corridor -65 ±3 deg.

- Steep Entry trajectory (-68 deg) was constrained by:
  - Maximum G-Loads
  - Peak Entry Heat Flux
- Shallow Entry trajectory (-62 deg) was constrained by:
  - Entry detection Mechanism possible failure modes such as Inter-Chain delay (ICD) and Pyro Arming / Firing ranges overlap
  - Maximum Heat Load and resulting structure temperature increase

1- Titan Atmosphere model
Selection of the Worst case environment

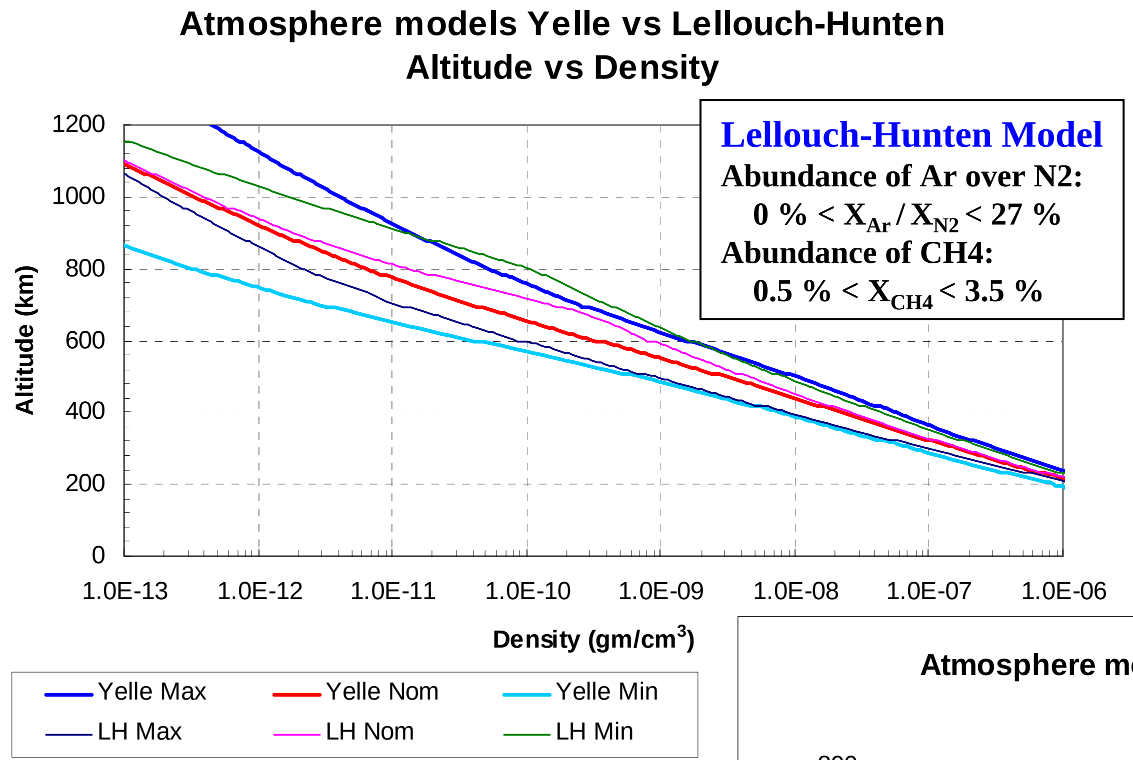
Gravity Wave (D. Strobel) effect on Density & Temperature Profiles

Gravity Wave effects.ppt



TITAN Atmosphere Model WG recommendation (June'04): Gravity Wave model considered Worst Case – Low probability

Titan Atmosphere Models & updates



Lellouch-Hunten Model

Abundance of Ar over N2:

$0\ \% < X_{Ar} / X_{N2} < 27\ \%$

Abundance of CH4:

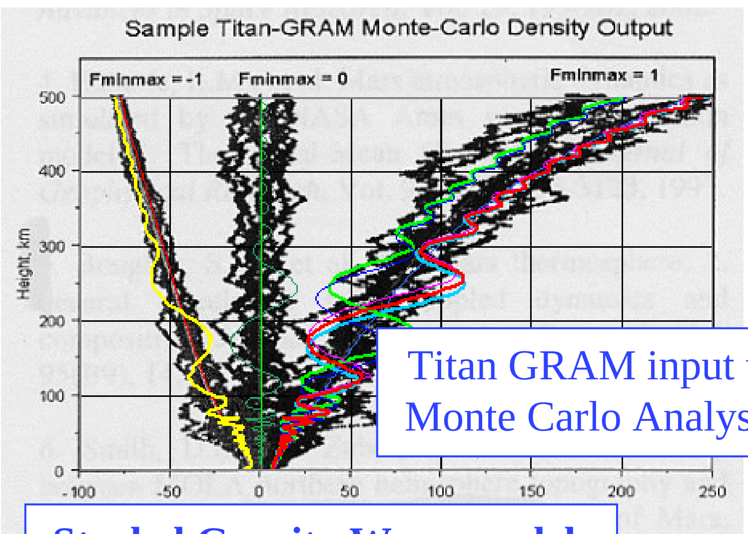
$0.5\ \% < X_{CH4} < 3.5\ \%$

Yelle Model

ρ Min [95%N2, 5%CH4, 0%Ar]

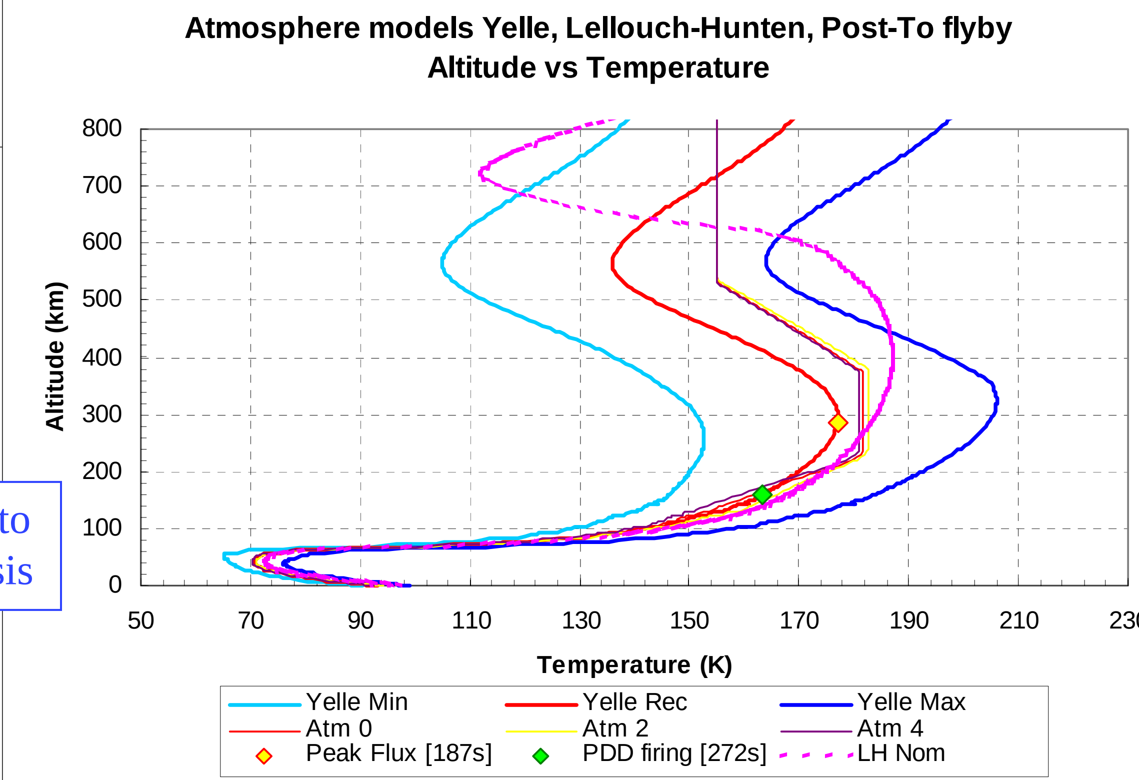
ρ Nom [95%N2, 3%CH4, 2%Ar]

ρ Max [89%N2, 1%CH4, 10%Ar]



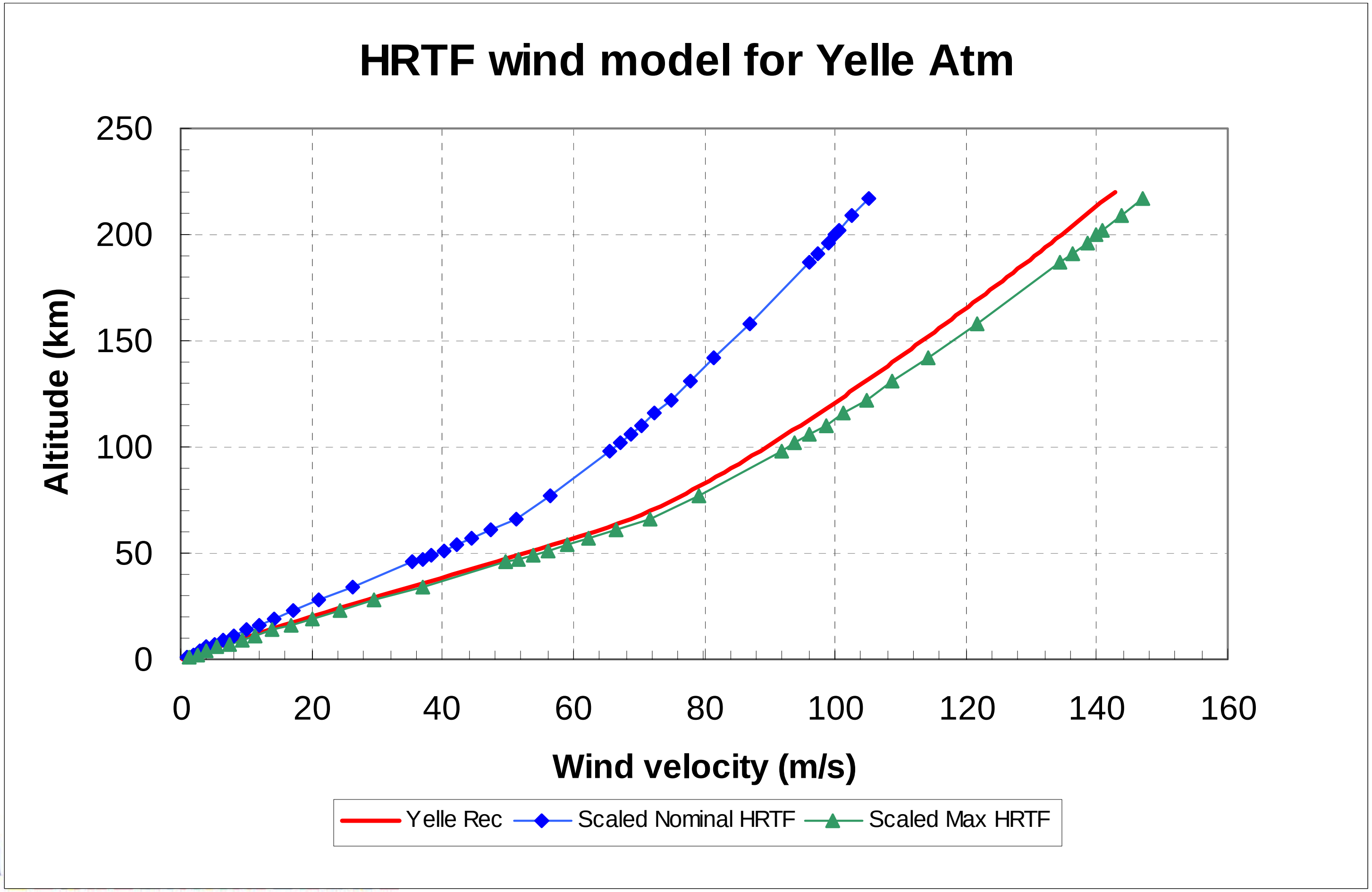
Titan GRAM input to Monte Carlo Analysis

Strobel Gravity Wave model: Worst Case – Low probability



TITAN Atmosphere Model WG recommendation:

Monte Carlo studies to use a Prograde scaled HRTF Wind profile with 100+/-40 m/s at 200km altitude



2- Predicted Parachute Deployment Loads

Validation from MER Flight Data

- The Probe design was compatible with predicted Parachute deployment loads:
  - Pilot Chute: 2100 N on Back-Cover Structure
  - Main Chute: 17600 N on Probe Inner Structure
- Validation of Parachute deployment model from MER A and MER B Flight data:
  - VORTICITY Predicted deployment time for MER in same order as recorded by MER Flight Telemetry.
  - VORTICITY Predicted deployment Loads within less than 8 % of NASA LaRC assessment of flight data.

Probe Entry detection mechanism & Parachute deployment

- Critical aspects of Entry detection and Parachute deployment verified by analysis (tracking Atmosphere model evolutions impacts) and by Tests on parachute bridle and swivel (for higher deployment Loads and velocities).

- At Huygens Mission Risk Review (MRR) Oct-Nov 2004, NASA Engineering and Safety Center (NESC) with ARC, LARC and JPL provided an independent performance assessment bringing further confidence in the design robustness.
  - **Key aspects such as Aerodynamic databases (Entry module, Descent module, Parachutes), Probe stability, Deployment algorithm spoofing, Probe descent time were further cross-checked.**

3- Probe Entry - Validation of Aerothermal environment predictions

- Heat Flux predictions in preparation for Huygens Δ FAR (Dec'03 – Feb'04) were performed for Yelle Atmosphere model + Gravity Waves by EADS-ST and by ESTEC Thermodynamics section in parallel.
- The Δ FAR involving NASA ARC concluded on significant differences between European and US Heat Flux predictions.
- An Aeroheating Convergence Working Group (ACWG) was set-up under ESA coordination in March'04.
  - Reconcile predictions & reassess Probe TPS performance capability
- In-depth validation work was performed in collaboration with:

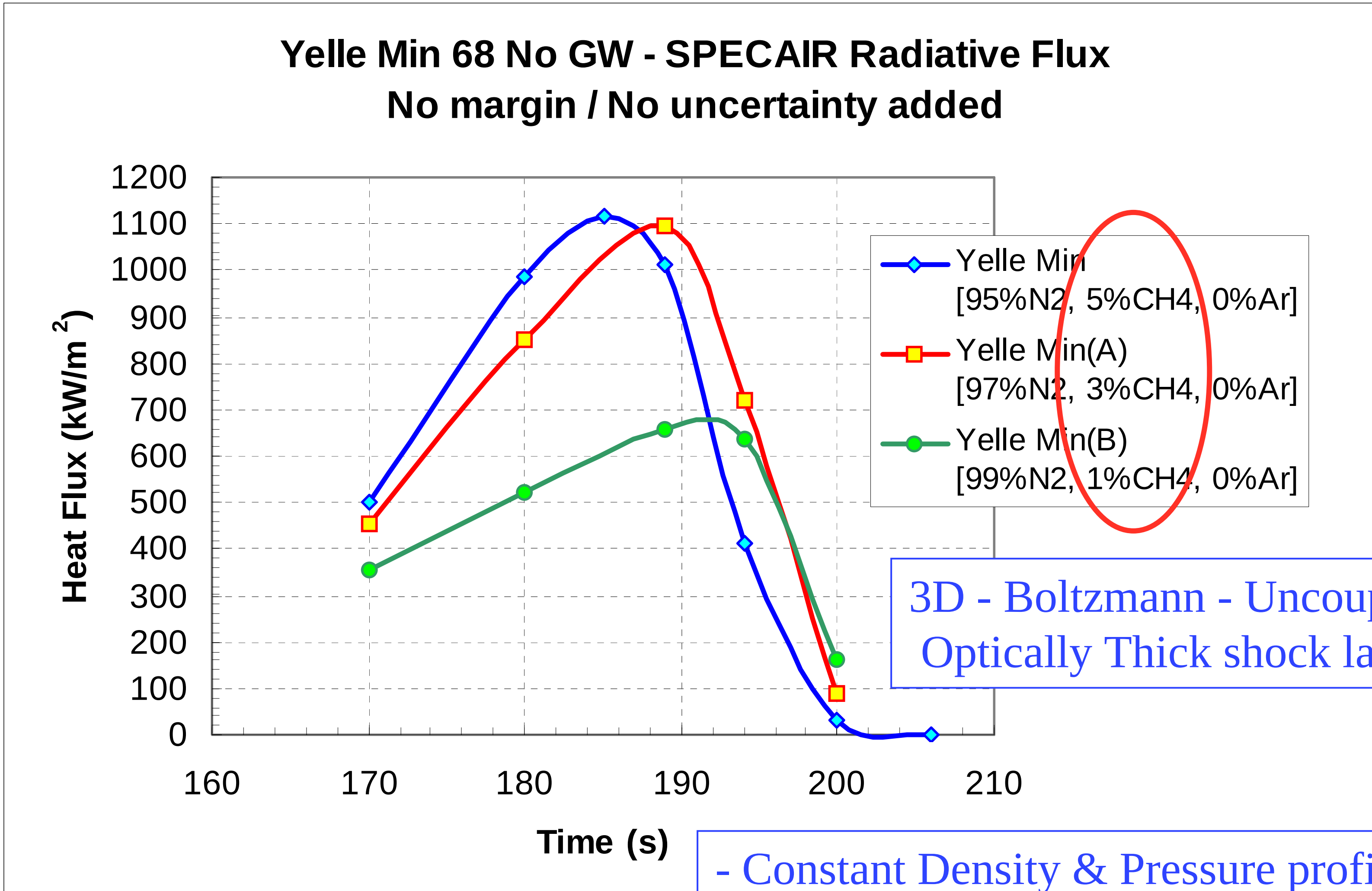
  EM2C, EADS-ST, ESTEC, NASA ARC and LaRC
- At Huygens Mission Risk Review (MRR) Oct-Nov 2004, NASA NESC with ARC, LARC and JPL provided a further Heat Flux assessment and the MRR was concluded with additional confidence in the design robustness.

Aeroheating Convergence Working Group

- **ACWG:** EM2C, EADS-ST, ESTEC, NASA ARC & LARC

- Convergence exercise has covered mainly Fore-body heating but also After-body heating…
  - Flow-Field & Convective Flux predictions
    - Chemistry Kinetics model (Nelson then Gökçen), Diffusion model (Multi species binary approach – SCEBD), Vibrational-Dissociation coupling ($\sqrt{T.Tv}$ with 1st Park correction), Wall fully catalytic (H2, N2), Turbulence transition (Baldwin-Lomax with transition at $Re_{Theta}/Me=150$)
  - Radiative Flux predictions
    - Excited states population (Boltzmann at Tv and various QSS), Absorption in the shock layer, N2 radiation, 1D to 3D conversion, Flow-Field/Radiation coupling (Tight & Loose coupling, Tauber-Wakefield correlation)
- Many Computing Tools were exercised
    - ESTEC/EM2C (LORE-SPECAIR), EADS-ST (Specific QSS), NASA ARC (DPLR-NEQAIR), NASA LaRC (LAURA-RADEQUIL), ESTEC (TINA-PARADE)

CH4 concentration sensitivity
Steep Entry Trajectory - Radiative

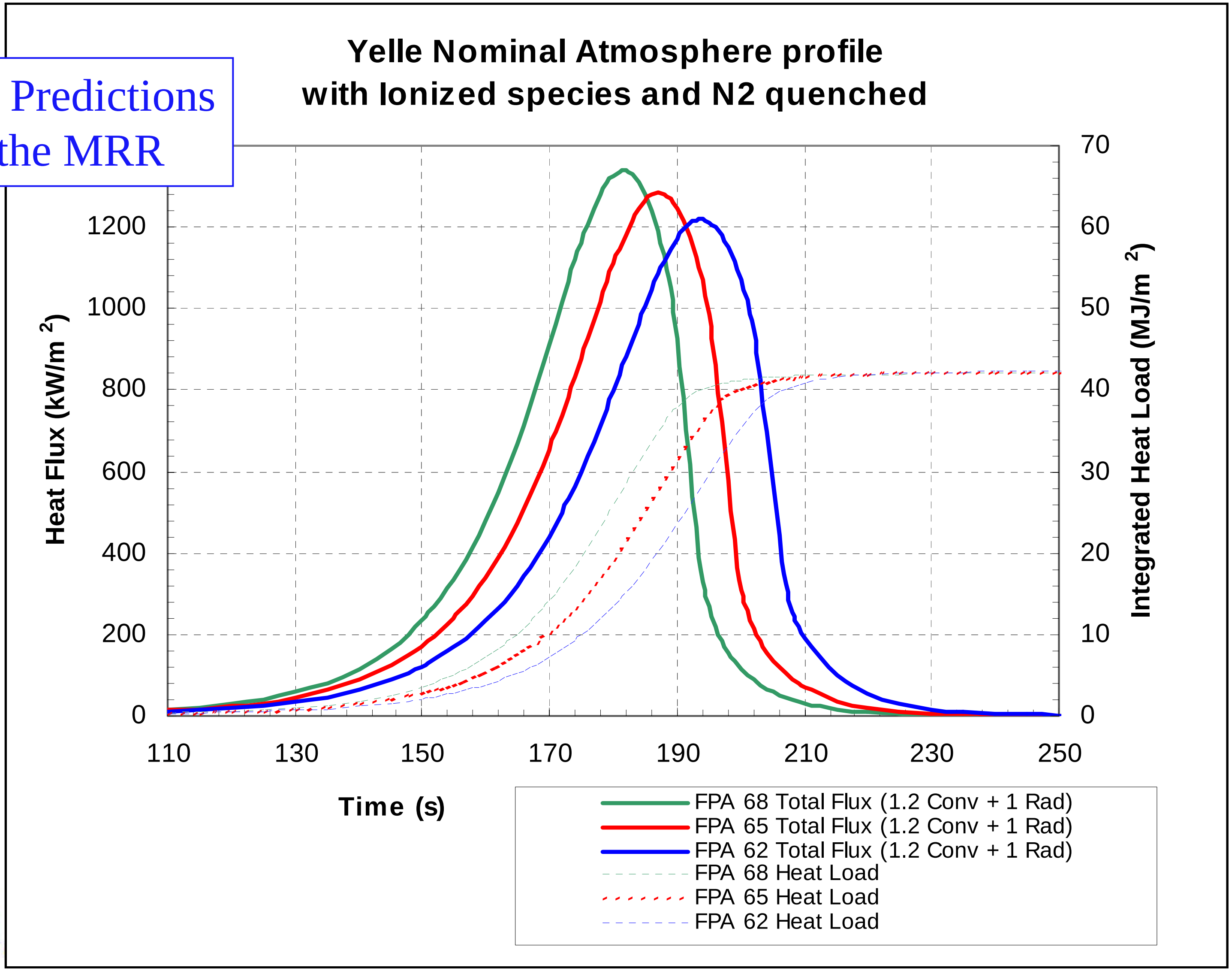


3D - Boltzmann - Uncoupled
Optically Thick shock layer

- Constant Density & Pressure profiles
- Temperature change < (-)1.8%

Yelle Nominal atmosphere profile Flight Path Angle sensitivity

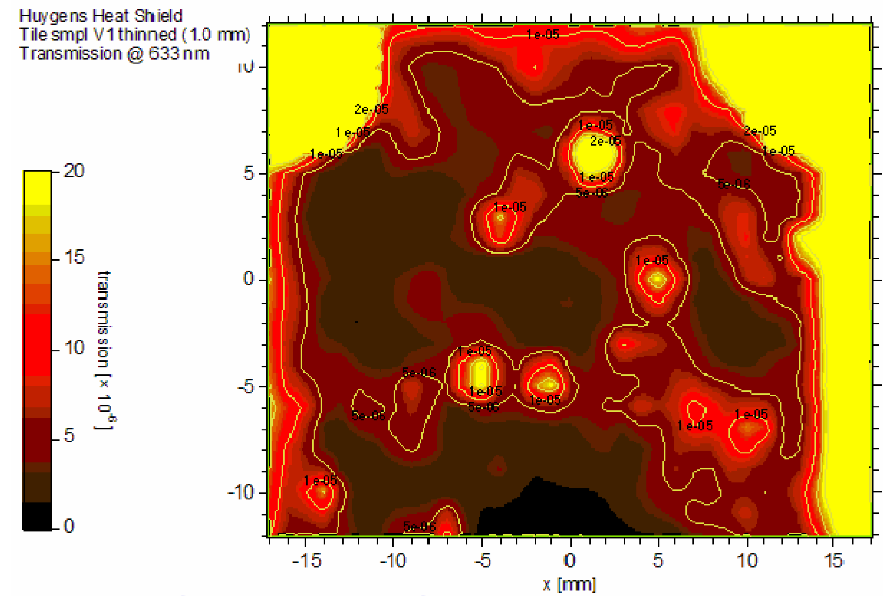
Heat Flux Predictions before the MRR



Huygens Entry Corridor Assessment
Heat Flux / Heat Load before the MRR

- **Nominal Entry Trajectory with FPA = - 65 degree**
  - Variation of Integrated Heat Load with Entry Angle is negligible but depends on considered Atmosphere.
  - Main constraint was on the Probe Back-Cover maximum Temperature.
    - Pre-MRR predictions were still about 5 deg C above maximum specified temperature of 250 deg C
  - Maximum Shield CFRP structure temperature also an issue at mid-cone location.
    - Pre-MRR predictions were still about 0.5 to 4 deg C above maximum specified temperature of 180 deg C

4- Heat Shield material UV Transparency tests



Low intensity UV illumination:

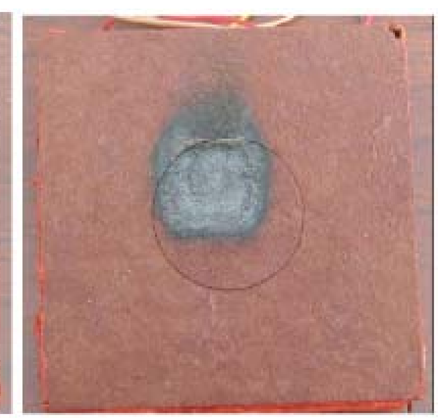
AQ60 sample of 1mm thickness - Transmission mapping at 633 nm

High intensity UV illumination tests at NASA AMES

UV Tests
50 W/cm² for 150 sec


Pre-Test Post-Test

UV Tests
150 W/cm² for 30 sec

Pre-Test Post-Test

Cassini/Huygens Mission Risk Review

- At the time of Cassini SOI, ESA, NASA and JPL management requested an in-depth risk review of the Cassini-Huygens Titan mission. The Mission Risk Review (MRR):
  - Addressed the end-to-end mission with focus on four main mission areas and cross-cutting system issues:
    - Huygens probe delivery requirements/constraints
    - Cassini-Huygens separation
    - Huygens entry/descent/landing
    - Cassini-Huygens relay link and data return
  - Presented in the risk matrix format

- The Mission Risk Review was kicked-off on October 21-22 and last remaining EDL issues were closed on December 6...!
- Preliminary preparation work from the EDL panel had started in September with an in-depth independent evaluation of the Entry & Descent performances. Very valuable work !
- MRR main issues were related to:
  - Parachute Drag model uncertainties – NASA / VORTICITY
  - TPS thermal response:
    - Initial shock tube experimental results from Ames indicated that recommended uncertainty on Radiative Heating was likely to be conservative from a risk assessment perspective.