Post-Flight Aerothermal Analysis of the Huygens Probe

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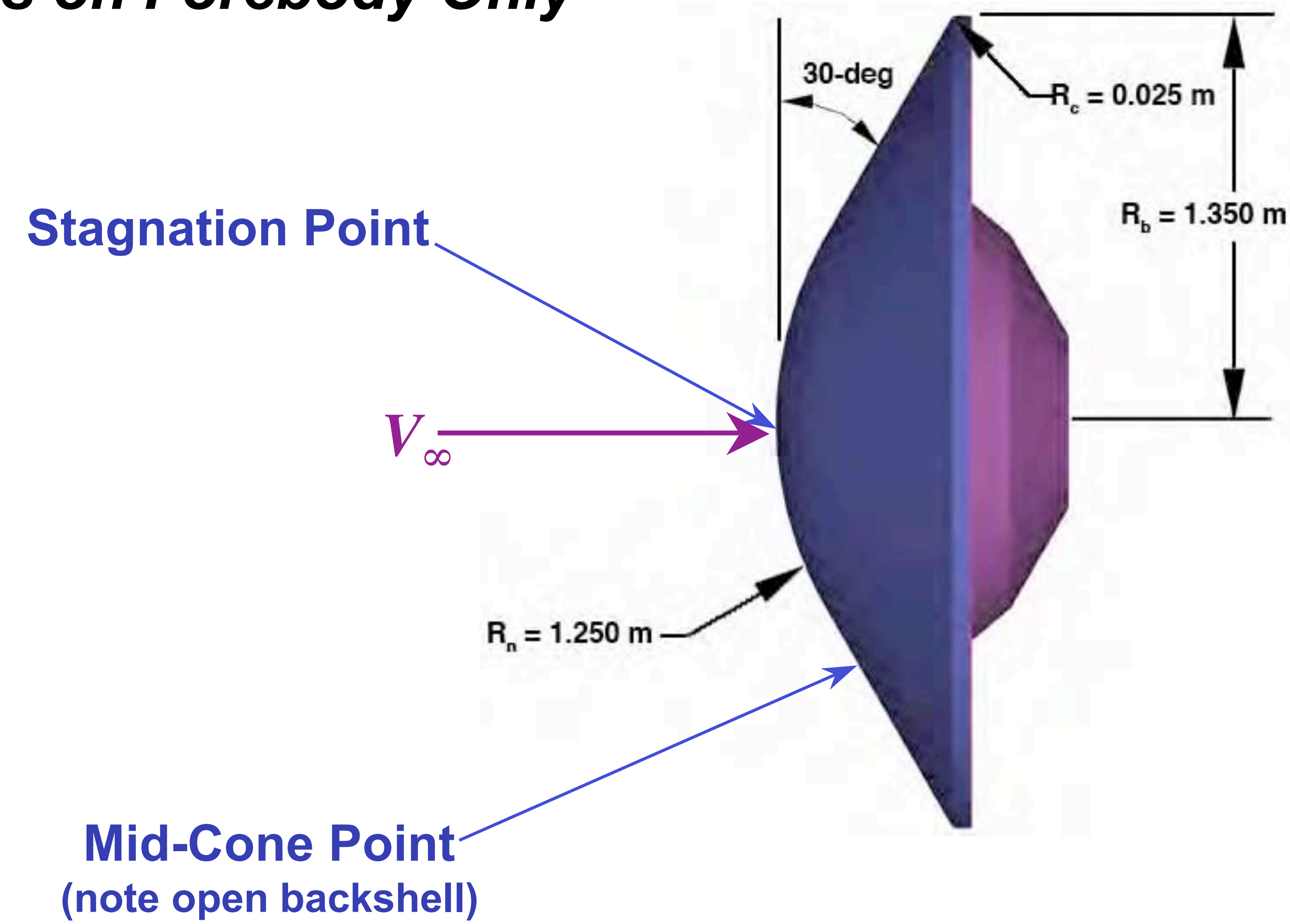
Motivations

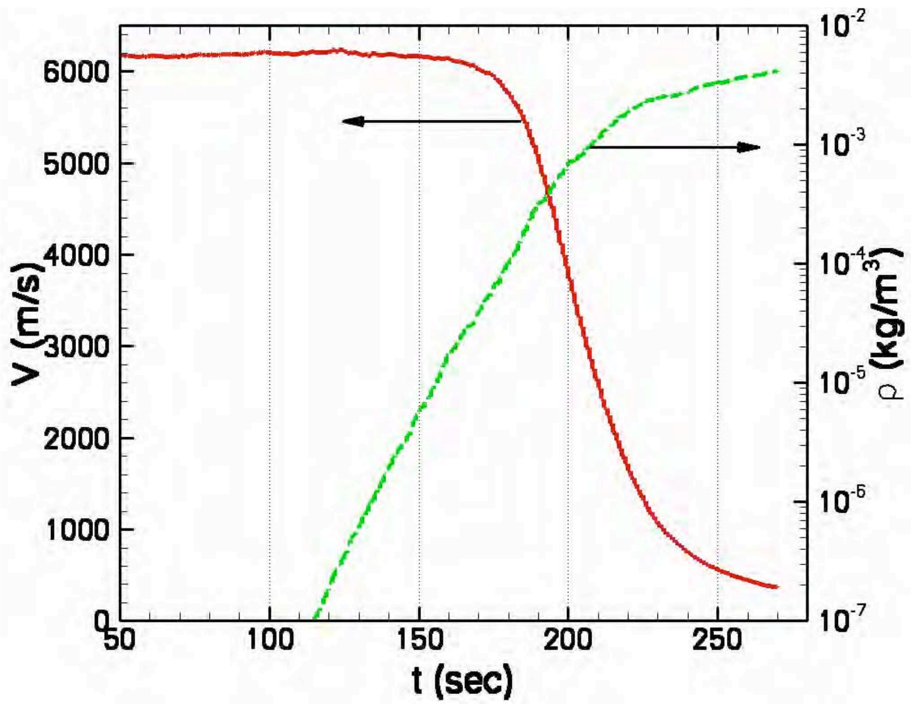
- **Highly successful Cassini mission and Huygens entry has stimulated renewed interest in further Titan Exploration**
- **Unique composition of Titan atmosphere makes for large uncertainties in aeroheating predictions ⇒ risk for future missions**
  - Trace amounts of CH_4 result in augmented radiative and convective heating
  - Radiative heating predictions for Huygens probe have ranged from essentially zero to over 150 W/cm^2 over the past 10 years (compare to convective heating of about 50 W/cm^2)
- **Aeroheating model development for Titan entries has advanced significantly in last three years**
  - NASA In-Space Propulsion Program funded Titan aerocapture systems study and associated R&D (2002-present)
  - ESA/NASA Huygens aeroheating convergence working group (2004)
  - NESC Huygens EDL independent risk assessment (2004)
- **Apply latest high fidelity models to representative entry trajectory**
  - Assess remaining differences between NASA/ESA model predictions
  - “Dry Run” for upcoming assessment on best estimated trajectory

TPS Sizing Locations

Current Results on Forebody Only



NESC Heat Rate Trajectory



- **2σ Monte-Carlo heat rate trajectory produced at NASA Langley during NESC assessment**
- **TitanGRAM atmosphere model, updated to include Cassini T0/TA pass information**
  - Use max. predicted CH_4 = 2.3%
- **More information on NESC trajectory and associated aeroheating analysis available in AIAA Paper No. 2005-4816**

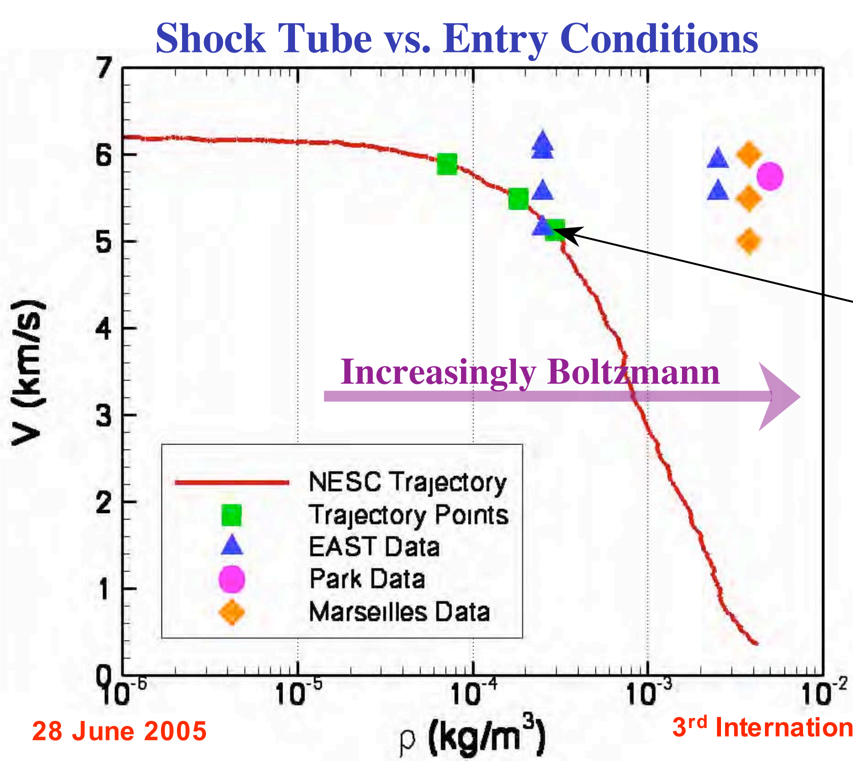
Simulation Methodology

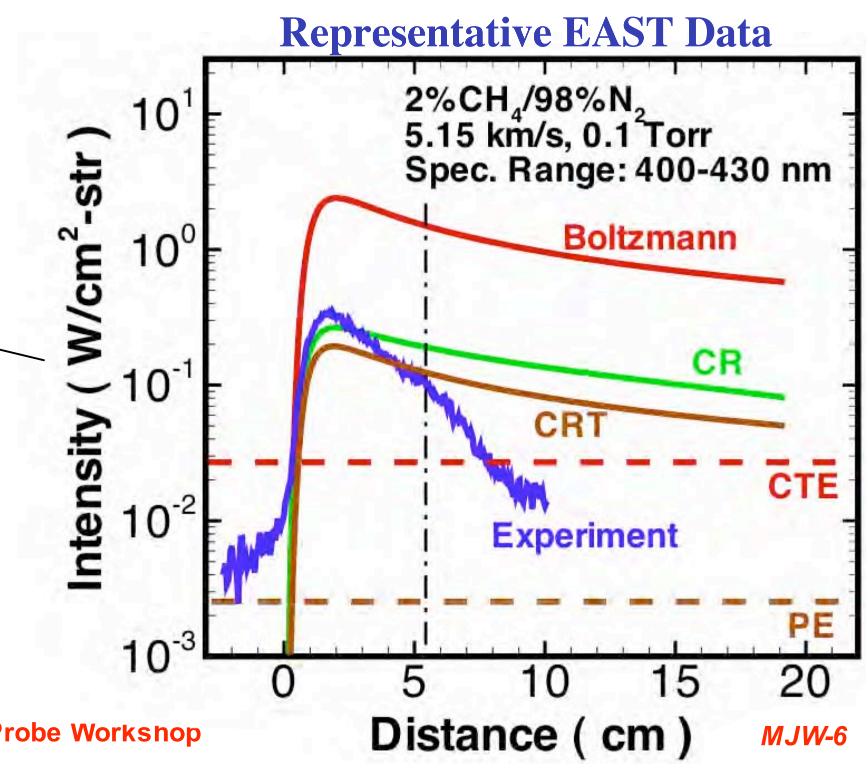
- **Three CFD Codes:**
  - DPLR (NASA Ames)
  - LAURA (NASA Langley)
  - LORE (AOES)

Three Radiation Codes:
  - NEQAIR96 (NASA Ames)
  - RADEQUIL (NASA Langley)
  - CR-Model (NASA Ames)

- **Baseline models employed agreed on by ESA/NASA aeroheating convergence working group (Nov. 2004)**
  - Fully catalytic, multicomponent diffusion model
  - Transition to turbulence at Re_θ/Me = 150
  - Boltzmann radiation model with engineering correction for coupling

- **New collisional-radiative (CR) model for CN radiation also applied**
  - Based on finite-rate (rather than equilibrium) excitation and de-excitation processes and solution of simplified master equation
  - Validated with shock tube data at correct composition, velocity, and pressure
    - Data taken in NASA Ames EAST facility, sponsored by NASA In-Space Propulsion Program. Results presented as AIAA Paper No. 2005-0768
  - Unavailable at time of prior analysis

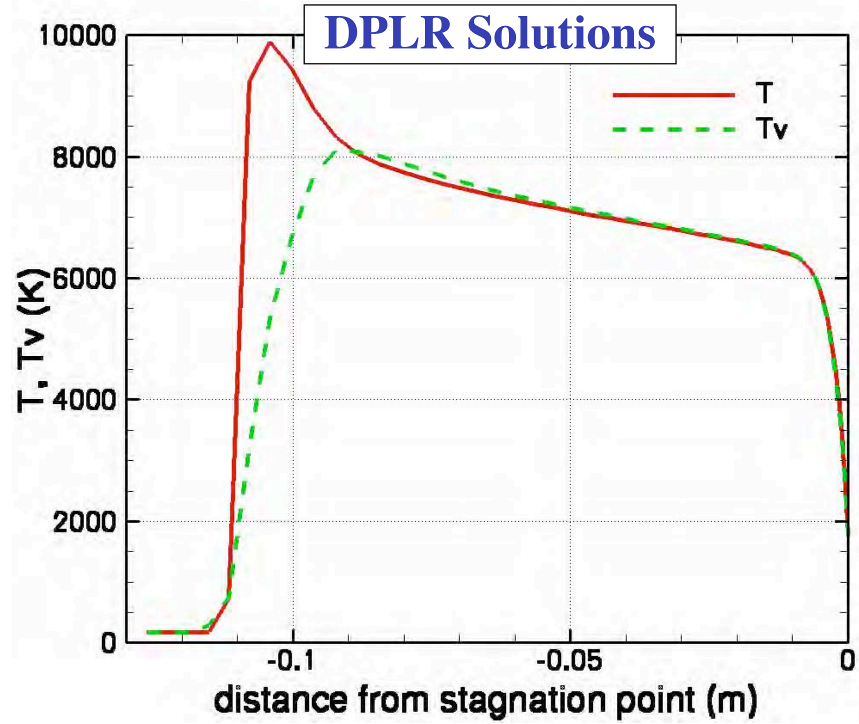


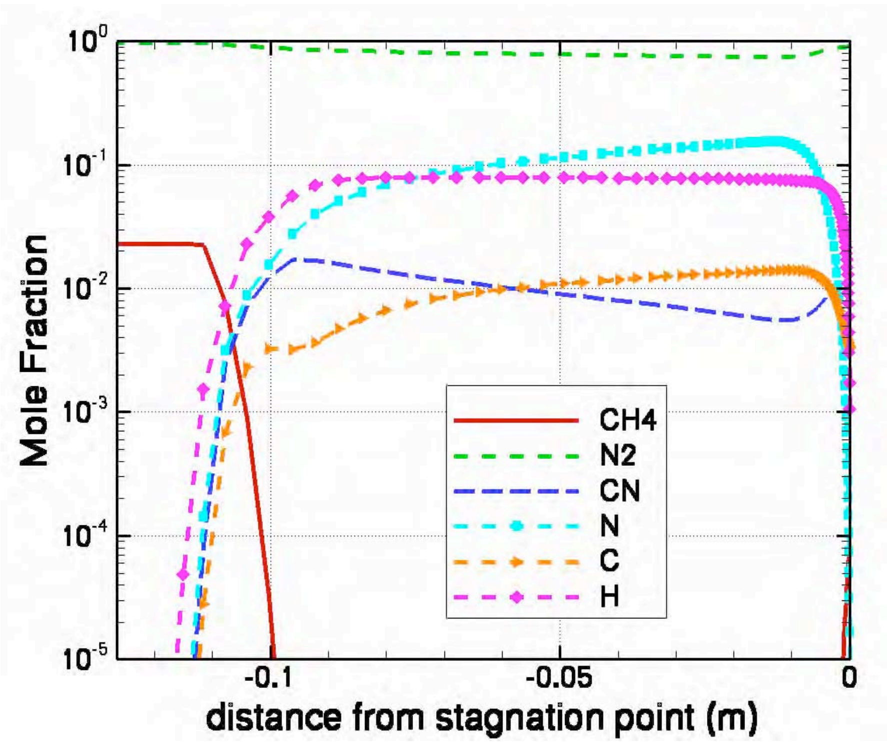


Sample Results:
Peak Heating Point

- **Shock standoff distance ~11 cm**
- **Peaks:**

  trans. temperature ~10000 K
  vibr. temperature ~8000 K





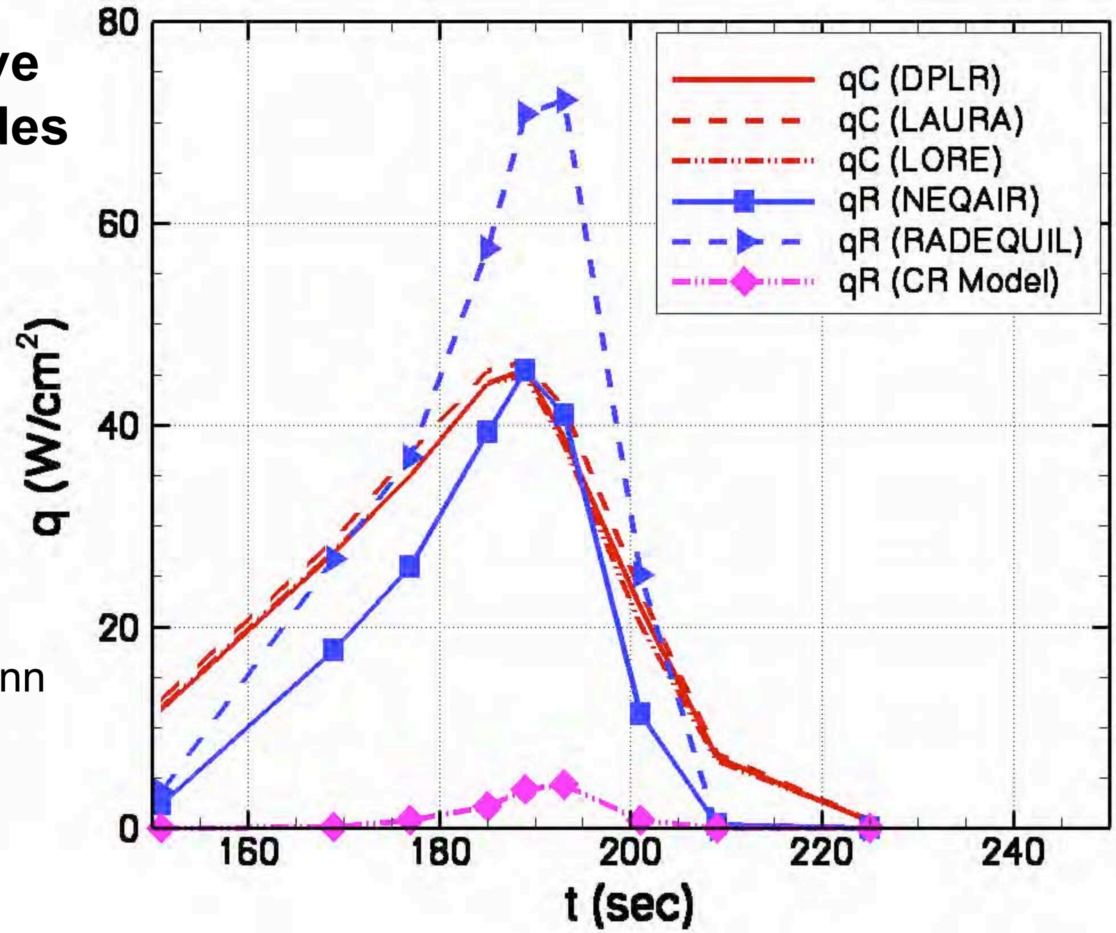
- **Post shock mass fractions:**
  - ✓ CN ~ 2% (governs radiation)
  - ✓ H ~ 9% (governs catalytic heating)

Stagnation Point Heating

Ames Research Center

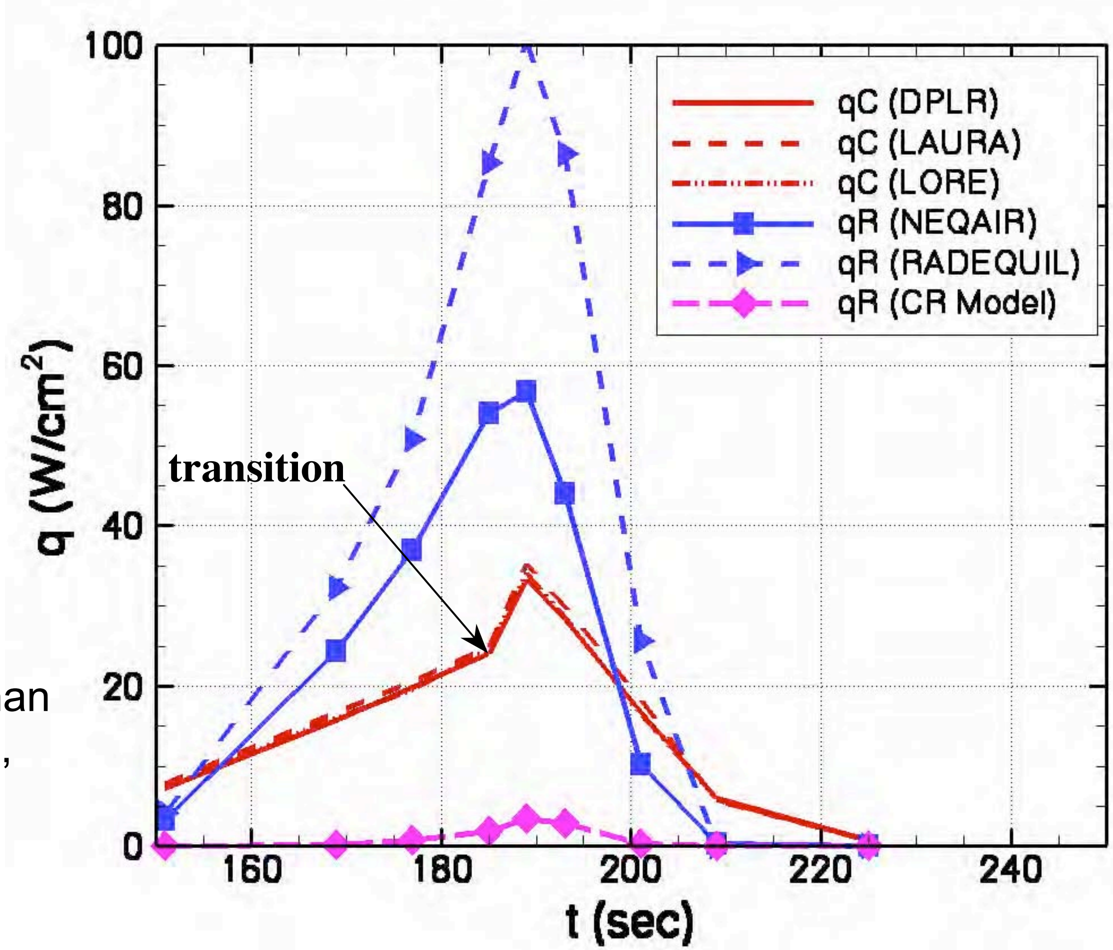
Reacting Flow Environments Branch — Space Technology Division

- **Good agreement in convective heating between all three codes**
  - peak heating of about 45 W/cm^2
  - values consistent with design
- **Large disparities in radiative heating rates**
  - largest values (~70 W/cm^2) from RADEQUIL
  - smallest values (~4 W/cm^2) from new CR model
  - differences between two Boltzmann models still not fully understood; may be due to absorption



Mid-Cone Heating

- **Again, excellent agreement between all CFD codes for laminar and turbulent heating**
  - transition predicted to occur prior to peak heating point on trajectory
  - peak turbulent flank heating is about 20% lower than stagnation point
- **Again, large disparities in radiative heating rates**
  - radiative heating on flank is higher than that at stagnation point for RAEQUIL, lower for CR model



Integrated Heat Loads

	Stag. Pt (J/cm^2)			Mid-Cone (J/cm^2)		
	Q_C	Q_R	Q_T	Q_C	Q_R	Q_T
DPLR/CR	2000	70	2070	1275	55	1330
LAURA/RADEQUIL	2150	2050	4200	1350	2600	3950
LORE	1975	–	–	1275	–	–

- **All three CFD codes agree within 10% for convective heat loads**
- **Large disparities between RADEQUIL and CR model for radiative heating**
  - CR model is based on relevant ground test data
  - However, only a limited amount of data from a single facility is available
- **Zero-margin heat loads at stagnation point with LAURA/RADEQUIL (Boltzmann) are about at probe design value (~4000-4500 J/cm^2)**
- **Zero-margin heat loads with DPLR/CR model are about 50% of those using Boltzmann model at Stag. Pt., 33% at Mid-Cone**

Conclusions

- **All three CFD codes agree to within 10% for convective heat rates and loads**
  - 30% uncertainty recommended due to remaining modeling issues
  - Quantified uncertainty analysis will be presented at AIAA Reno'06 meeting
- **Large disparities remain between Boltzmann and CR models for radiative heating**
  - CR model validated with relevant ground test data, however, only a limited amount from a single facility is currently available
  - No flight data exist to verify current predictions
  - 200% uncertainty on CR model predictions recommended for now

$\Rightarrow$ **More ground test data (especially at lower pressure) is needed to better quantify radiative heating prior to follow up Titan mission**