Aerothermodynamics for Dragonfly's Titan Entry

Presented by Aaron Brandis

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AMA Inc, NASA Ames Research Center

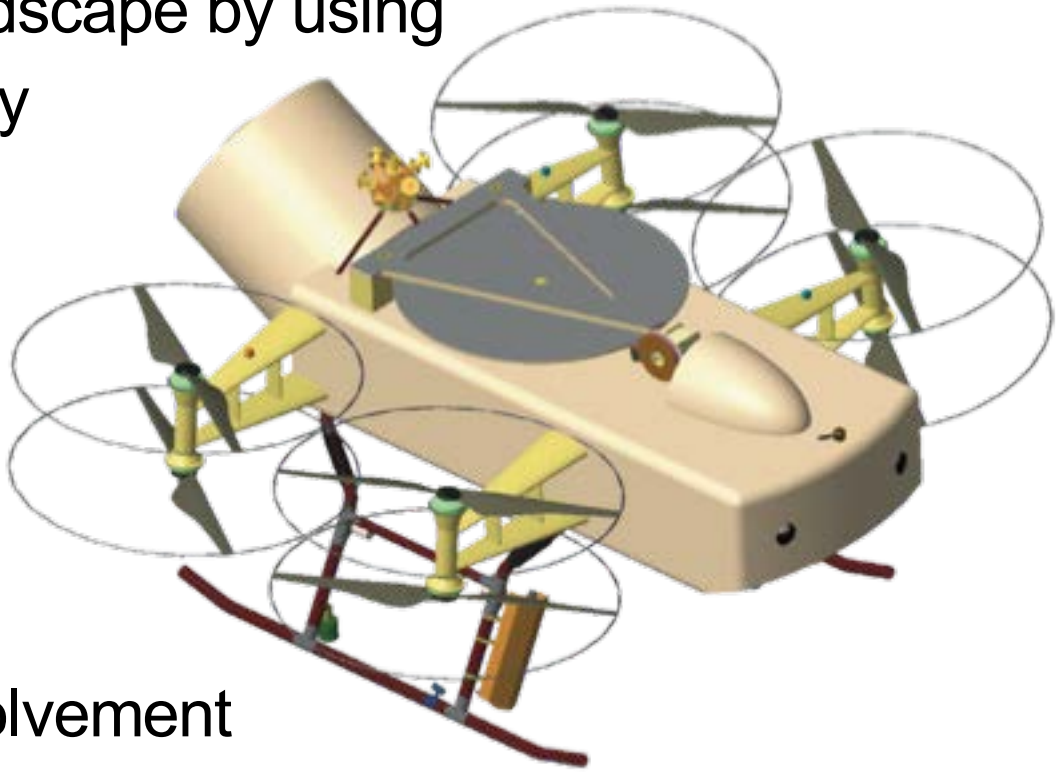
NASA Langley Research Center

Johns Hopkins Applied Physics Laboratory

Introduction

DRAGONFLY

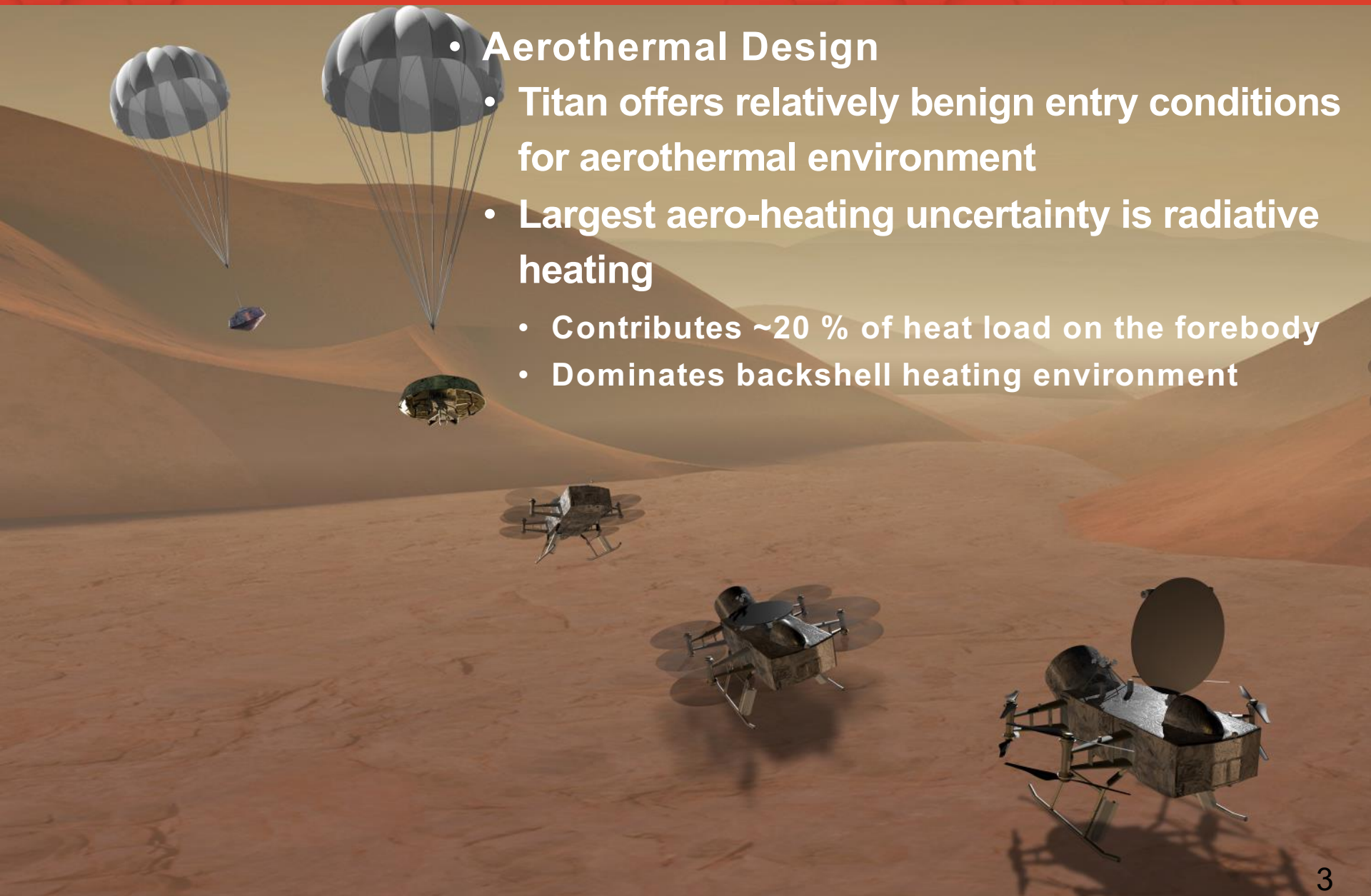
- Address Titan's diverse landscape by using a rotorcraft for aerial mobility
  - Go to the interesting material
  - Conduct surface experiments
  - Obtain aerial images



R. Lorenz & D. Adams from APL have more detailed talks about the mission on Friday

- NASA Ames & Langley Involvement
  - Partnering as the leads for the entry system to provide the completed EDL Assembly
  - Provides an opportunity for continued development of Titan entry capability
  - Leverages unique capabilities at both LaRC and ARC

Titan Arrival



- Aerothermal Design
- Titan offers relatively benign entry conditions for aerothermal environment
- Largest aero-heating uncertainty is radiative heating
  - Contributes ~20 % of heat load on the forebody
  - Dominates backshell heating environment

Entry and Descent

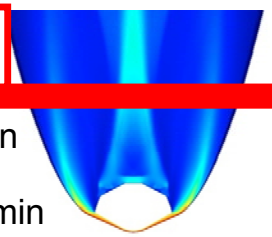
Wake-up avionics, begin telemetry transmission, E-25 min

Vent heat rejection system, E-20 min

Turn to entry, switch to tone transmission, E-15 min

Cruise stage separation

Relevant to Aerothermal



Entry interface, h=1270 km, v=7.3 km/s, γ=-47.7°, E-0 min

Peak heating, h=254 km, v=5.9 km/s, a=7.8 g's, E+4 min

Drogue chute deploy, h=154 km, supersonic, E+6 min

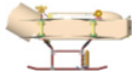
Descent on drogue

Main chute pilot deployed in lower atmosphere

Heatshield separation

Landing skid deployment

Radar and lidar active



Lander release

Entry Preparation

Ballistic Entry

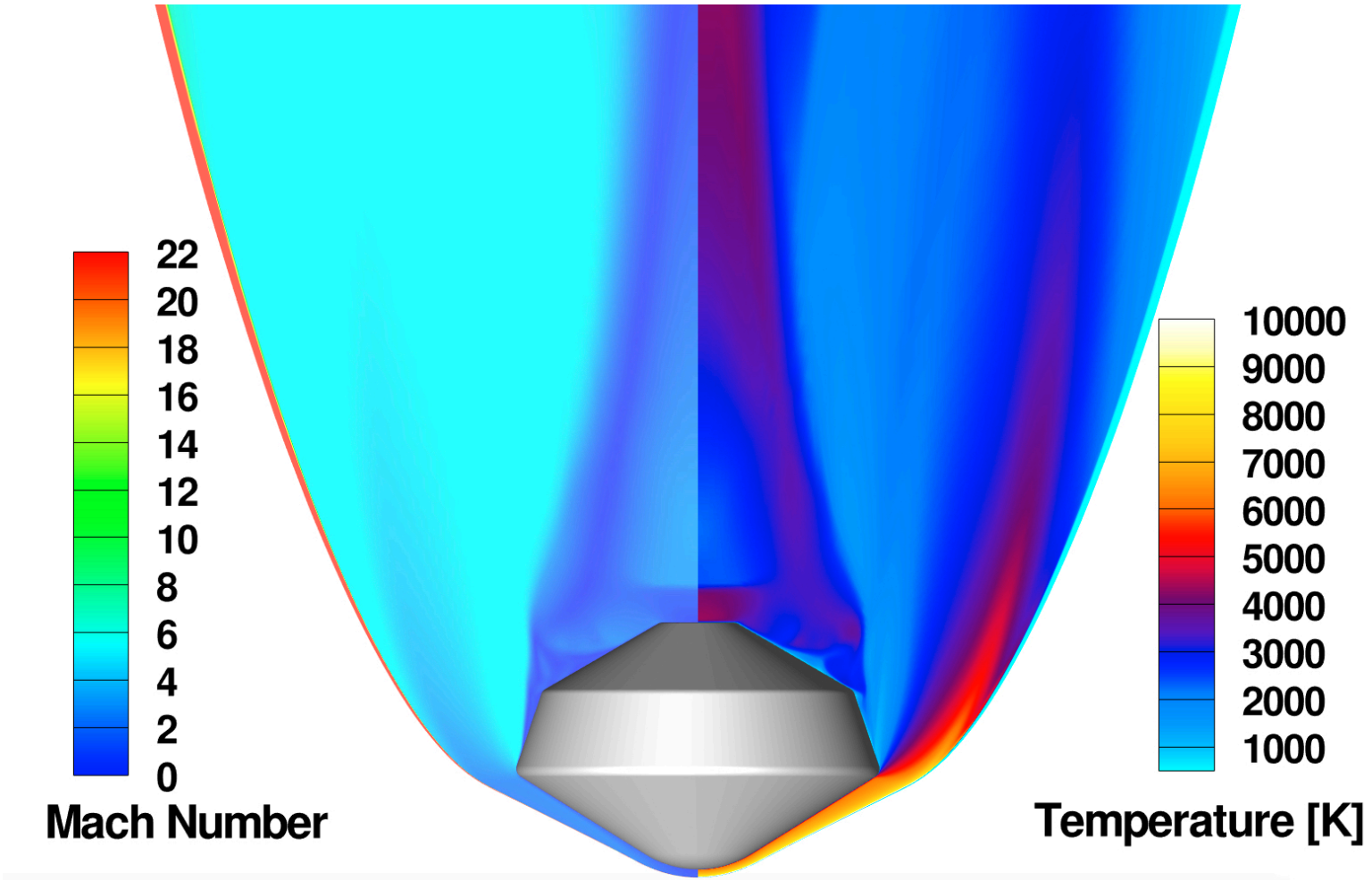
Parachute Phase

Powered Flight

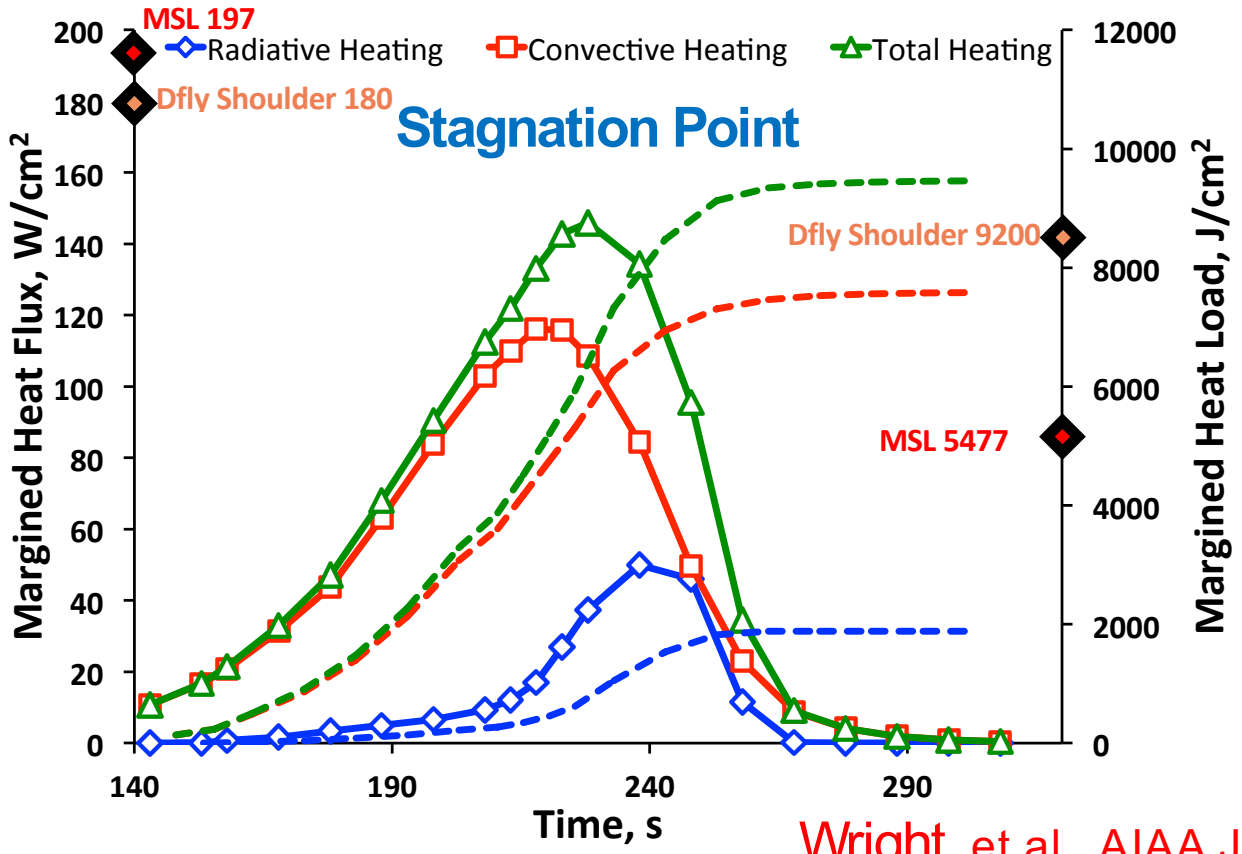
For reference, Huygens took 152.5 min from entry to the surface. Dragonfly's descent is a bit shorter by design.

Entry and Descent (pre Phase A)

- Relatively benign Titan ballistic entry at EFPA of -47.7° and 7.3 km/s
- Genesis scaled 60° 3.7m sphere cone heatshield / biconic backshell geometry
- In terms of TPS materials, Forebody: Tiled PICA. Aftbody: Acusil-II



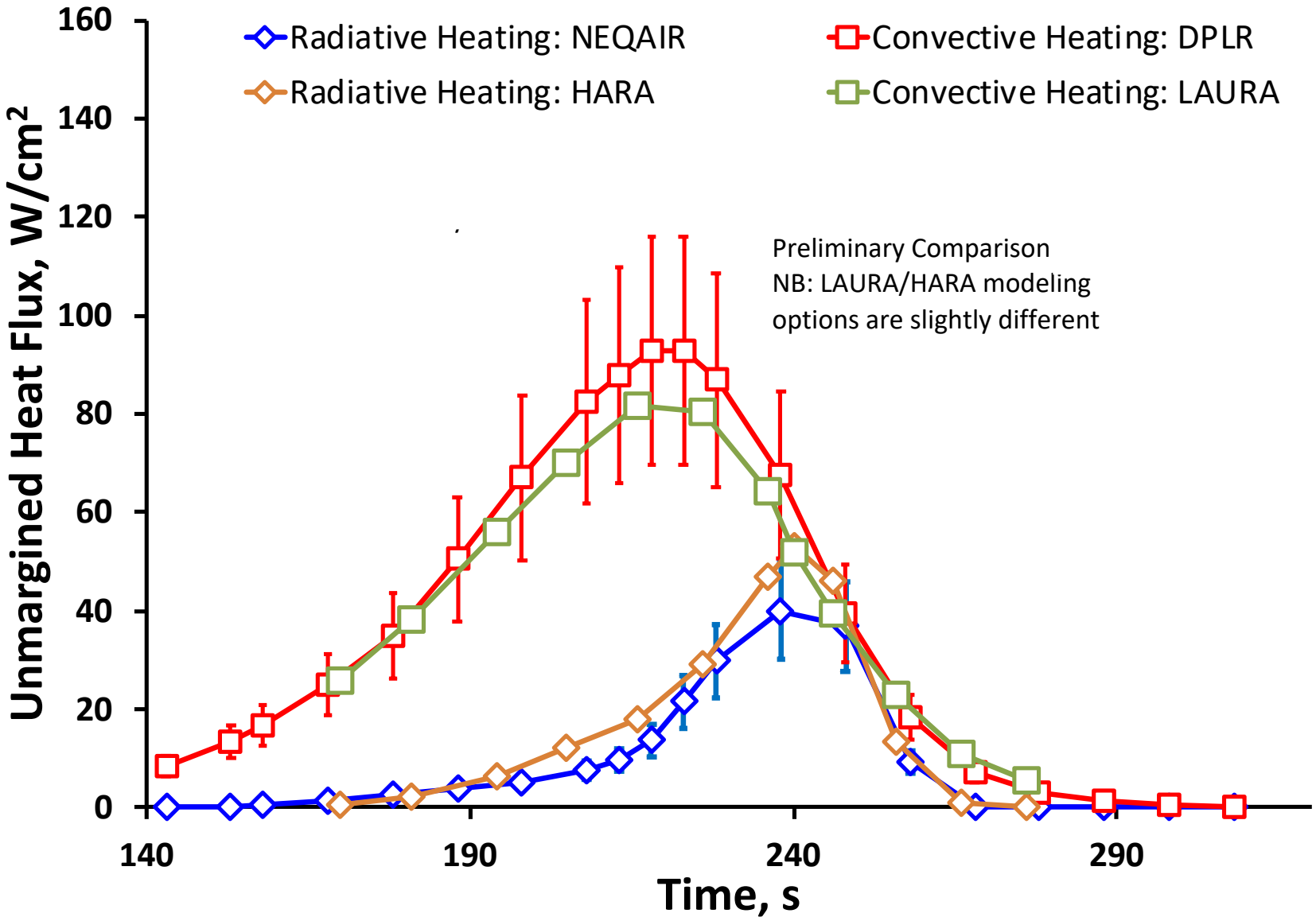
Forebody Heat Loads (Pre Phase A)



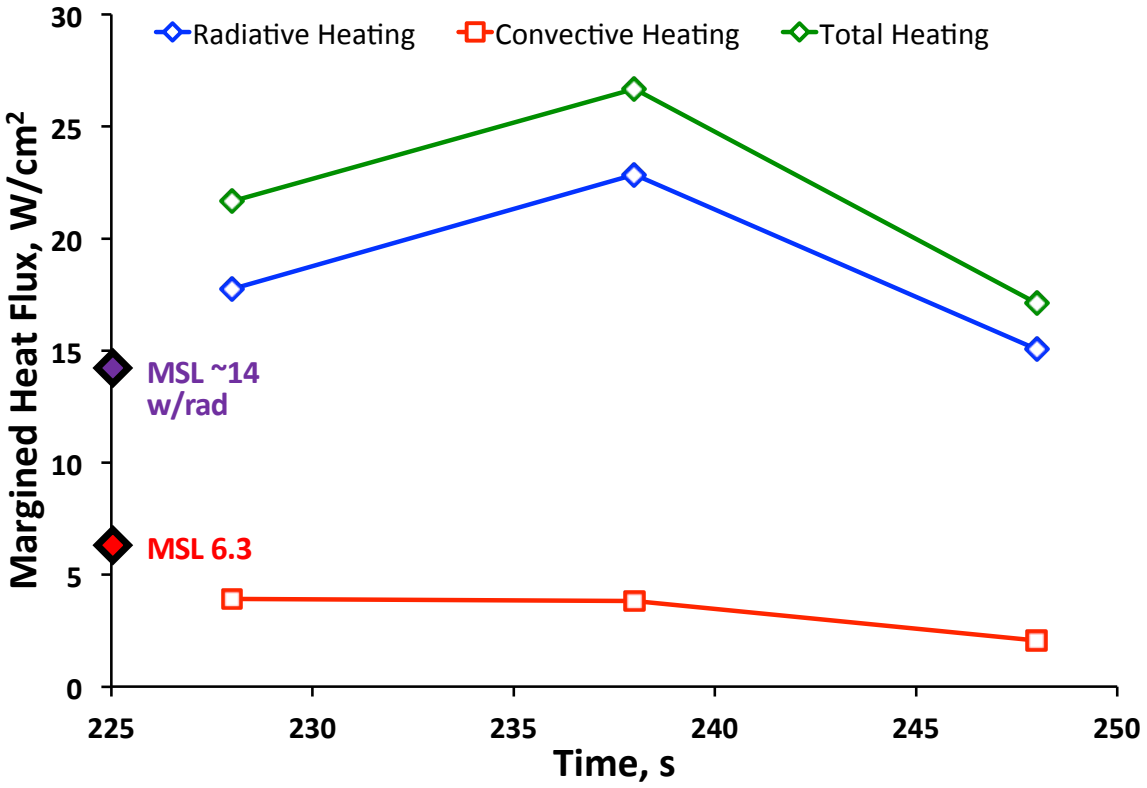
Wright, et al., AIAA JSR 2014

- Peak margined heat flux ~ 145 W/cm^2
- Margined heat load ~ 9.5 kJ/cm^2
- Even though shoulder loads were higher, stag point was driving TPS sizing location
- In family with MSL environments and thus similar TPS thickness
  - PICA is flight proven for such fluxes/loads and more than capable

Preliminary Phase A Aerothermal V&V



Aftbody Heat Flux (Pre Phase A)



- Heat flux calculated at shoulder seal for zero degree angle of attack
- Peak margined heat flux ~ 25 W/cm^2
- Preliminary analysis suggests these environments are relatively insensitive to the increase in mass and size
- Trade study currently taking place for aftbody TPS material

Previous Titan Radiation Studies

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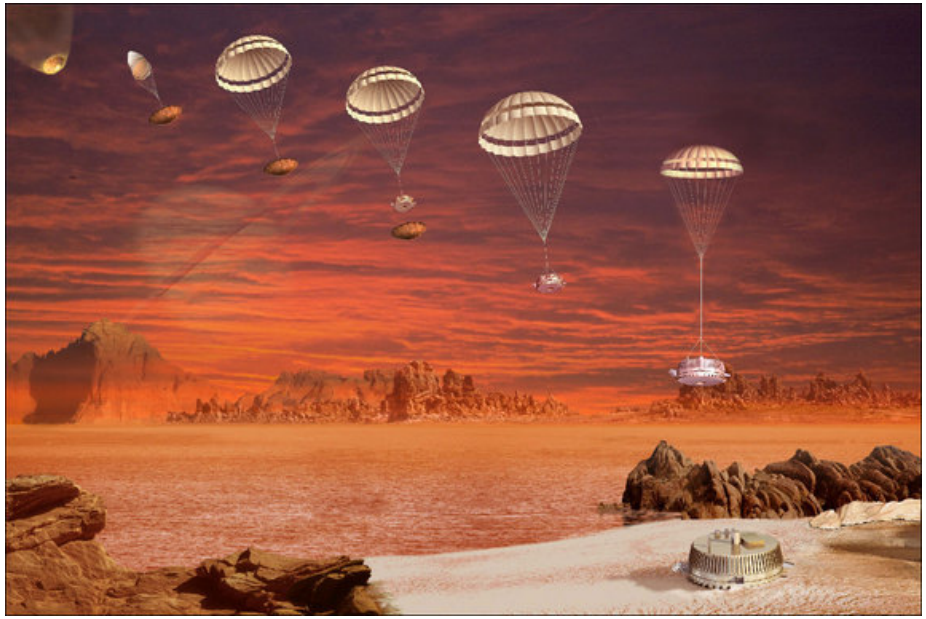
- The joint NASA/ESA Cassini/Huygens mission resulted in significant efforts to understand radiative heating for Titan
- Post flight simulations were conducted assuming a Boltzmann distribution of CN excited states
- Consequently, experiments were performed in shock tubes and QSS/CR models developed

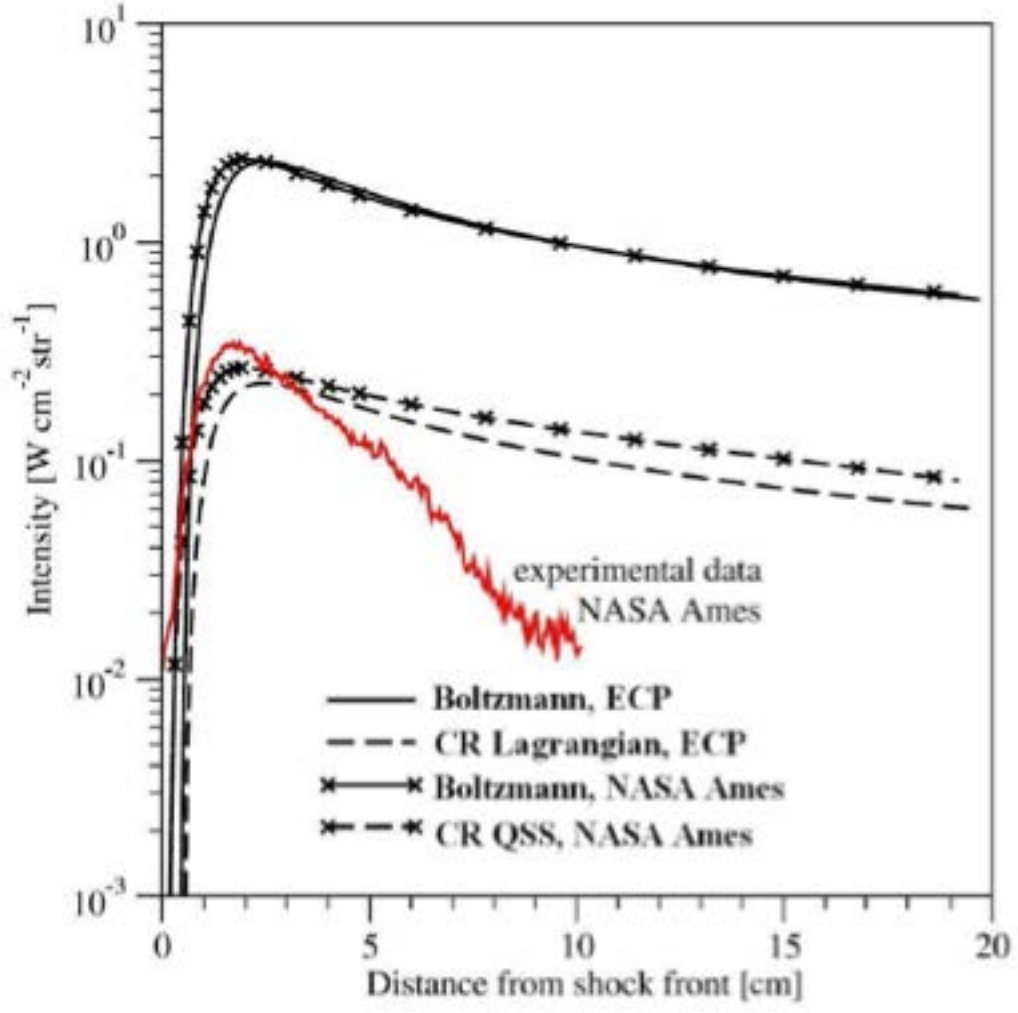
- Reasons to believe there were issues with previously reported Titan (pre-upgrade) EAST data
- Warranted to update previously published data:
  - Advanced mission proposals to Titan
  - Improvements available with the current EAST set up

Brandis, et al., AIAA JTHT 2010



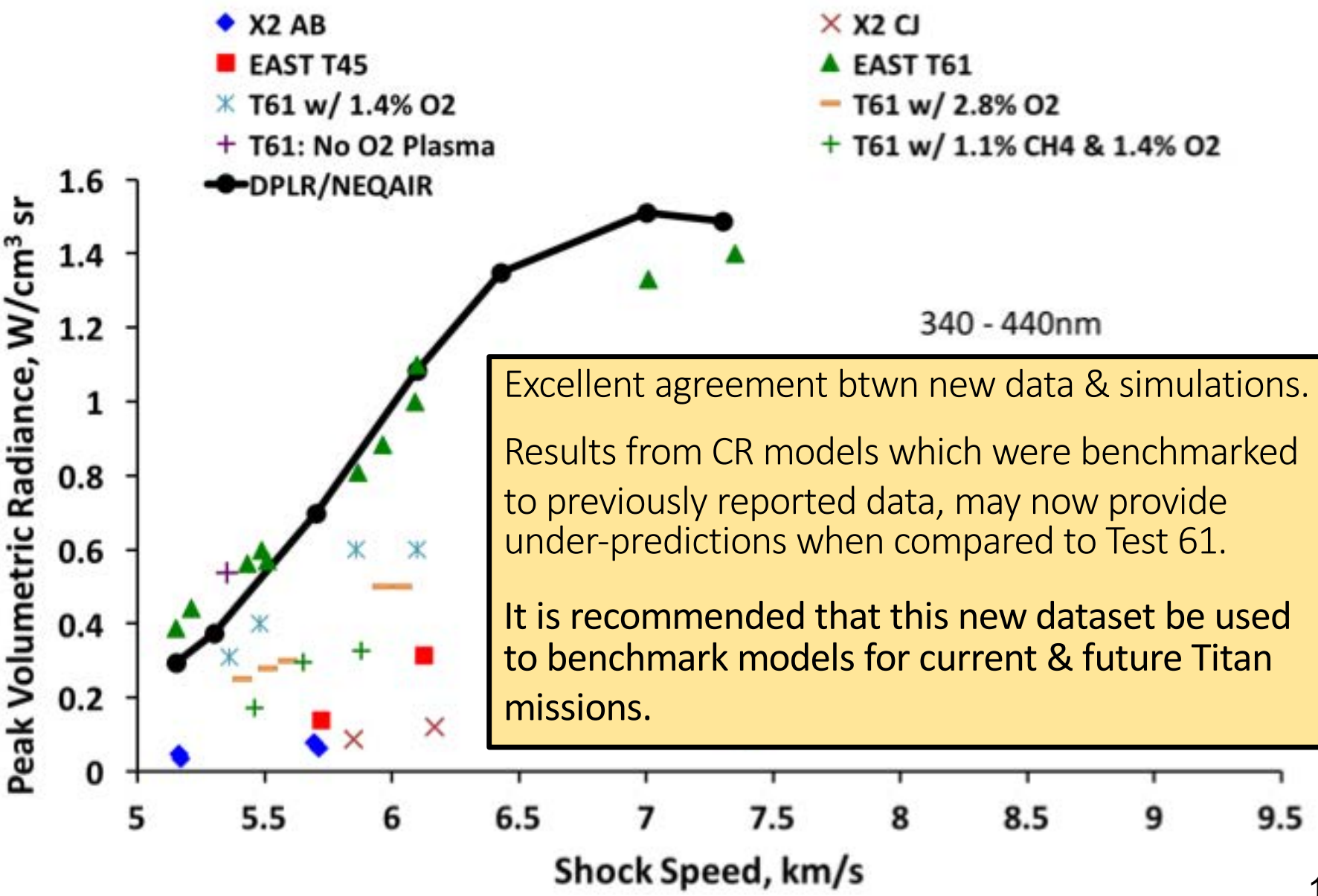
Previous Titan Radiation Studies

5.15 km/s, 98% N_2 : 2% CH_4, 0.1 Torr, 400 – 430nm. EAST T43-25



- Two shock tube facilities:
  - EAST at NASA Ames
  - X2 at U. Queensland
- Test 43 & 45 from EAST (2003 to 2005)
- Boltzmann predictions shown to substantially over-predict
- CR models deemed to adequately match peak (within a factor of ~2)
- Simulations showed slower decay rate than experiment

Comparisons To Previous Data: X2, Test 45
New Test 61 EAST data funded by NASA's ESM project



Excellent agreement btwn new data & simulations.

Results from CR models which were benchmarked to previously reported data, may now provide under-predictions when compared to Test 61.

It is recommended that this new dataset be used to benchmark models for current & future Titan missions.

Current & Future Work

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- Aerothermal indicator update in progress for Titan entry to aid picking a worst case design trajectory
- Run aerothermal analysis for Phase A study, including analyzing heating on the long gain antenna on the backshell at an angle of attack
- Perform a parametric study for relevant CFD and radiation parameters to inform design margins
- With updated aerothermal environments and informed margins, the Phase A TPS sizing will take place
- There is also an Engineering Science Investigation (ESI) study happening simultaneously along side the aerothermal work with the goal of obtaining aerothermal flight data

Conclusion

- Dragonfly is a proposed mission that would send a rotorcraft to Titan in order to study prebiotic chemistry and extraterrestrial habitability
- Aerothermal analysis from both Ames and Langley's suite of codes has been run for Dragonfly, with good agreement shown
- Models for radiative heating have been validated by recent shock tube testing in the EAST facility
- The entry conditions are relatively benign and can readily be accommodated with a tiled PICA heatshield similar to MSL and a number of flight proven materials for the backshell

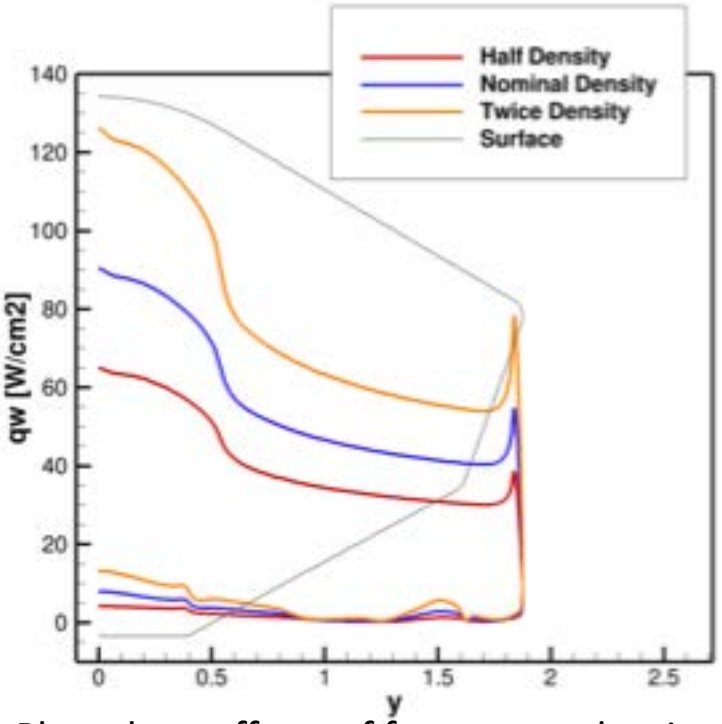
Questions?

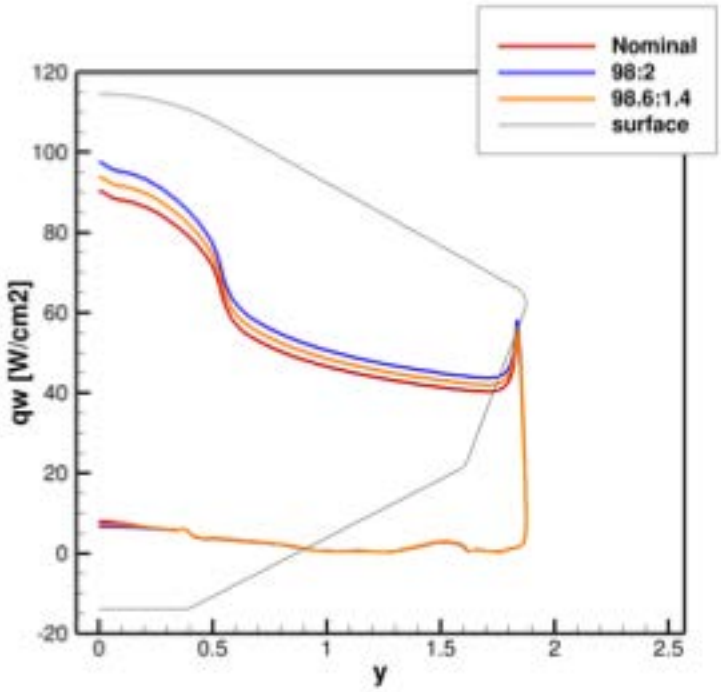
- Reminder for Friday
  - 10:08am - Ralph Lorenz: “Sample acquisition and transfer for a Titan lander”
  - 11:06am - Doug Adams: “Dragonfly: Rotorcraft landing on Titan”

Backup

Effect of Density & Chemical Composition

Time 223s, Velocity 6.25 km/s, nominal density 3.17 e-4 kg/m3





- Plots show effects of freestream density and composition on the surface aerothermal environment at peak convective heating
- Pre phase A nominal chemical composition was 98.2N_2 : 1.6 CH_4 : 0.1 H_2 : 0.1 Ar, the present trade study looked at 98:2 and 98.6:1.4 variation of N_2 and CH_4
- Future analysis will be based on expected maximum values for methane in the upper atmosphere, so will be running a composition of 97.8 N_2 : 2.2 CH_4
- These simulations will be used to determine heating indicators for turbulent shoulder locations, and for points of interest on the backshell