National Aeronautics and Space Administration

Ground Plane and Near-Surface Thermal Analysis for NASA's Constellation Programs

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- Near-Surface Thermal Modeling Challenges
- Cases Where Vehicle Effects on the Ground Plane are Significant
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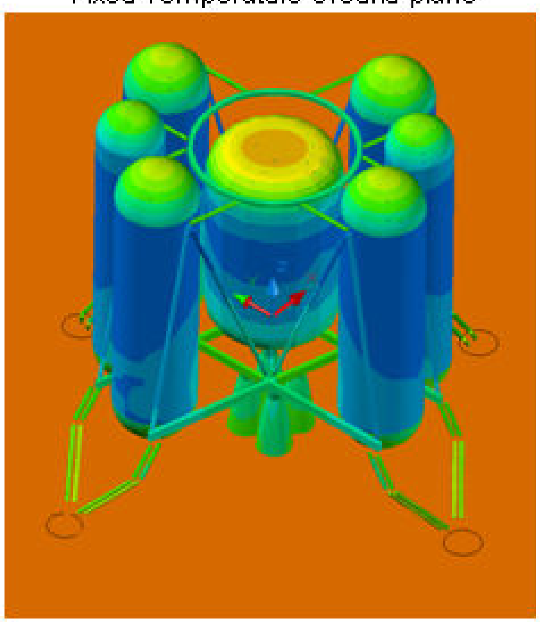
- Parametric Study Results
- Conclusions

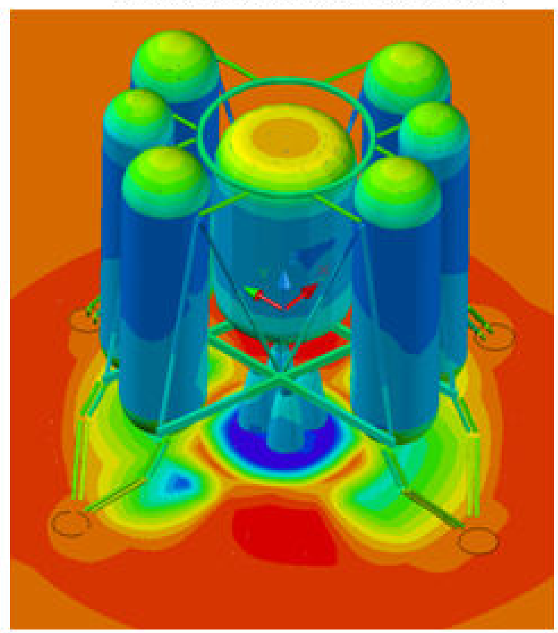
Near-Surface Thermal Modeling Importance

- **Ares I and Ares I-X utilize passive thermal control of the avionics**
  - Pre-launch ground-supplied purge to pre-condition avionics to survive ascent w/o purge (thermal capacity)
  - KSC on-pad environments significant in determining initial temperatures
- **For lunar-based vehicles/habitats, surface regolith temperature can be greatly influenced by vehicle and vice versa**
  - Example: Regolith range of ~200°C in proximity to lander, engine nozzle predictions different by 50°C compared to constant surface temperature.

Fixed Temperature Ground-plane



Floating Adiabatic Ground-plane



Near-Surface Thermal Modeling Challenges

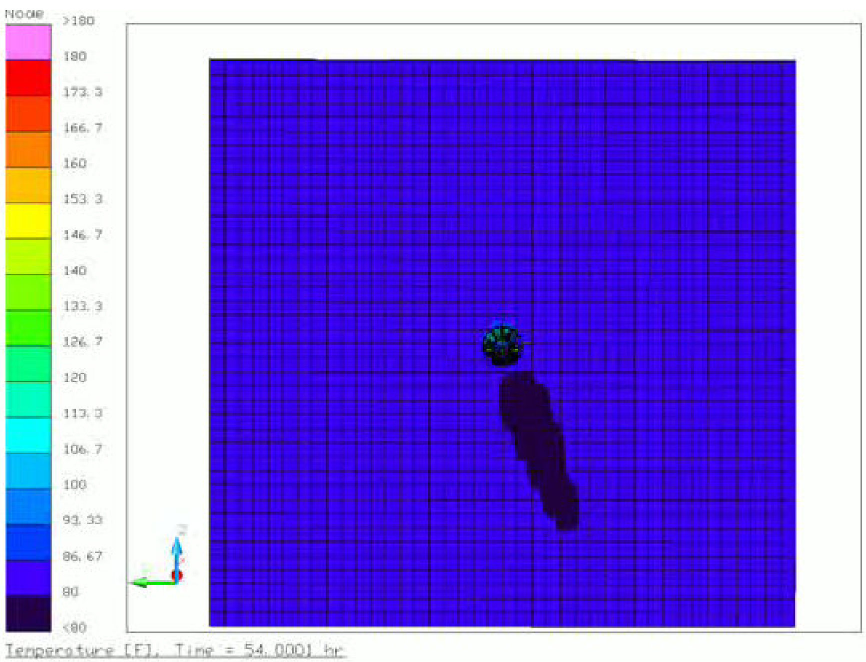
- Most software tools for spacecraft thermal analysis were originally designed for spacecraft in orbit
- Vehicle on surface presents different challenges
- Using standard TD orbit calculations, planet IR load overestimated
  - Vehicle coupled to 'space' sink over entire spherical 360°
  - 'Space' is relatively warm sky temperature
  - Planet IR heat load counted on top of space/sky sink
- Using modeled planet surface can lead to run time issues
  - Large planet surface → large bounding box
  - Many rays must be shot from planet to accurately characterize vehicle interaction
- Methods developed for two scenarios
  - Substantial vehicle effect on ground (short/close)
  - Negligible vehicle effect on ground (tall/thin)

Cases Where Vehicle Effects on Ground Plane Are Significant

- **Vehicle substantially affects ground temperature variation**
  - Vehicle close to surface
  - Vehicle form short/squat
  - Substantial vehicle shadow on surface
  - Examples
    - Orion Flight Test Program's Pad Abort tests
    - Lunar surface missions
- **Ground thermal variation affects vehicle**
  - Ground temperatures modeled with ground plane
  - Ground plane modeled to constant-temperature depth
  - Low conductivity lunar regolith intensifies shadow effect
- **Modeled ground plane used for planet IR and albedo**

Cases Where Vehicle Effects on the Ground Plane are Significant

Orion Pad Abort 1 Flight Test

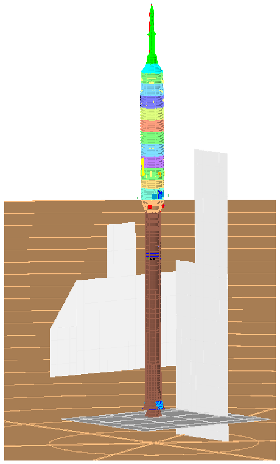


Slideshow of PA-1 Test Article showing diurnal shadow contours (6 AM – 7 PM LST)

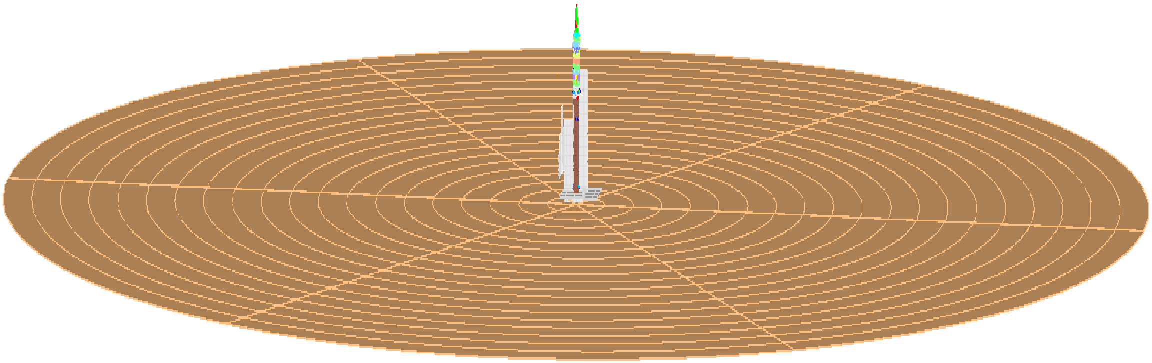
- **First set of Orion flight tests to be held at White Sands Missile Range (WSMR) in NM**
- **Pad Abort Test: Orion Launch Abort System and Crew Module placed on separation ring approx. 1 m off ground**
- **Interaction of ground and vehicle effects internal heat load and sizing of environmental control system**
- **Shadow to sunlit ground gradients up to 60ºF**
- **Progression of shadow follows path of sun overhead; dependent on time of year**

Cases Where Vehicle Effects on Ground Plane Are Negligible

- **Ares I, V and I-X:**
  - Vehicle form tall, thin
  - Blockage from the Mobile Launch Platform
  - Vehicle has little effect on ground temperature variation
  - Local ground temperature variation has little impact on vehicle



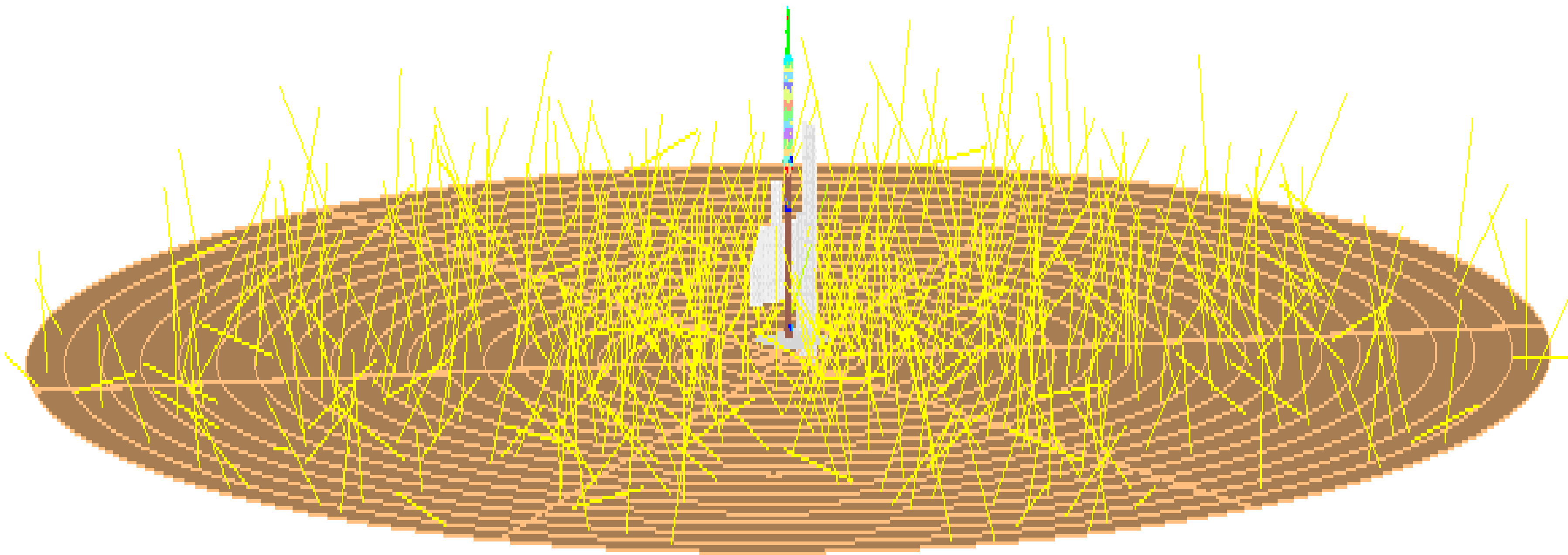
- **When ground temperature not influenced by vehicle, avoid including modeled ground plane in radiation calculations**
  - Bounding box for radiation calculation becomes huge, oct cells large, renders oct cell division less useful
  - Shooting rays from ground plane takes enormous number of rays to get accurate calculation



Ares I-X with Entire Ground Plane

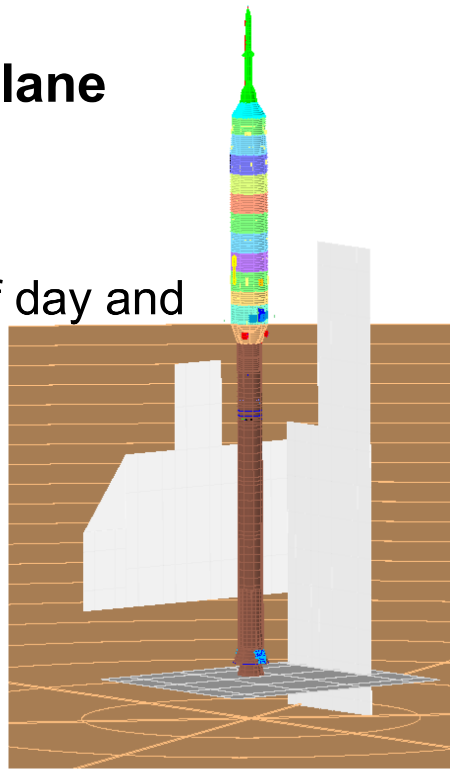
Why to Avoid Rays Shot From Planet

- With tall/thin vehicle, tremendous number of rays needed to hit vehicle from planet
- Shooting rays only from vehicle allows faster, more accurate calculations



Ares I, I-X Analysis

- **Tall, thin vehicle: little effect on ground**
- **Ground temperatures defined, not calculated**
- **Hybrid of planetary heating and ground surface plane methods used**
- **Solar flux calculations:**
  - Solar flux and albedo: geo lat/long orbit type with time of day and location; modeled planet unused
  - Diffuse solar flux: radiation from entire sky hemisphere; modeled planet included for blocking (no rays shot)
- **IR calculations:**
  - Use modeled planet surface
  - Do not shoot rays from planet
  - Radiation conductors calculated vehicle-to-planet only
  - If planetary IR modeled via orbit, IR heating from planet would be double book-kept since vehicle radiatively coupled to a 360° spherical “sky radiation” sink temperature

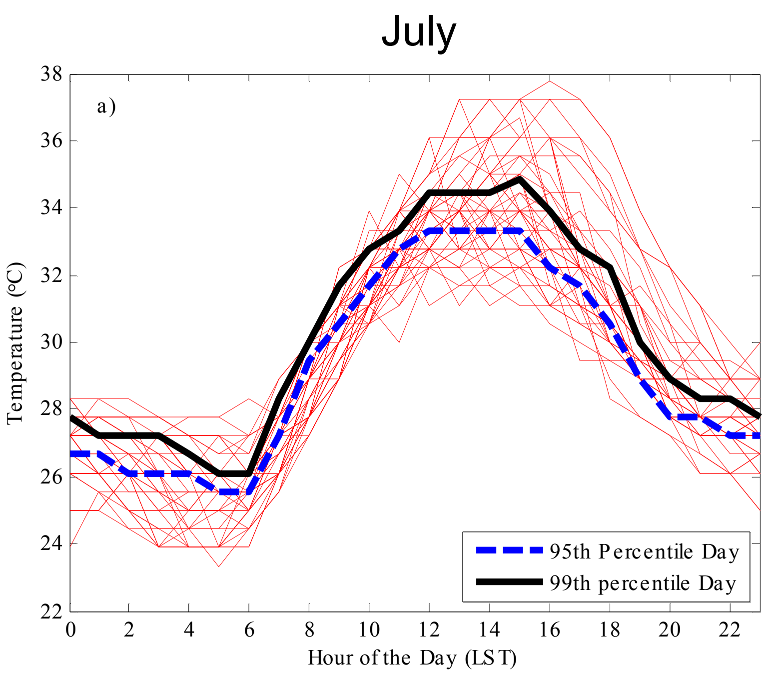


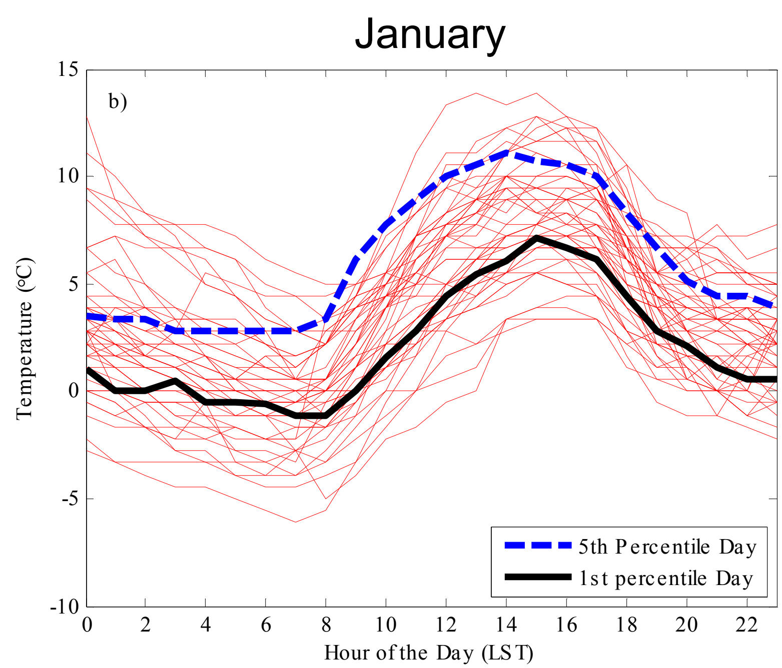
Near-Surface Natural Environments

- Definition of the surrounding natural environment is an important factor to consider when performing near-surface thermal analysis
- Natural environments include diurnal variation of air temperature, solar flux, and sky temperature
- Currently, these data have been obtained for the primary launch site (Kennedy Space Center, FL) and the testing site for the Ares I launch abort system (White Sands Missile Range, NM)
- Hot and cold diurnal profiles are obtained by calculating the high (95^{th} or 99^{th}) and low (5^{th} or 1^{st}) percentiles, respectively, for each hour of the hot and cold months (July and January)

Air Temperature Diurnal Thermal Profile

- **Hot and Cold Diurnal Temperature Profiles for KSC**
  - Red lines represent the 50 hottest and coldest days in the KSC POR
  - 95th and 99th profiles are from July
  - 5th and 1st profiles are from January

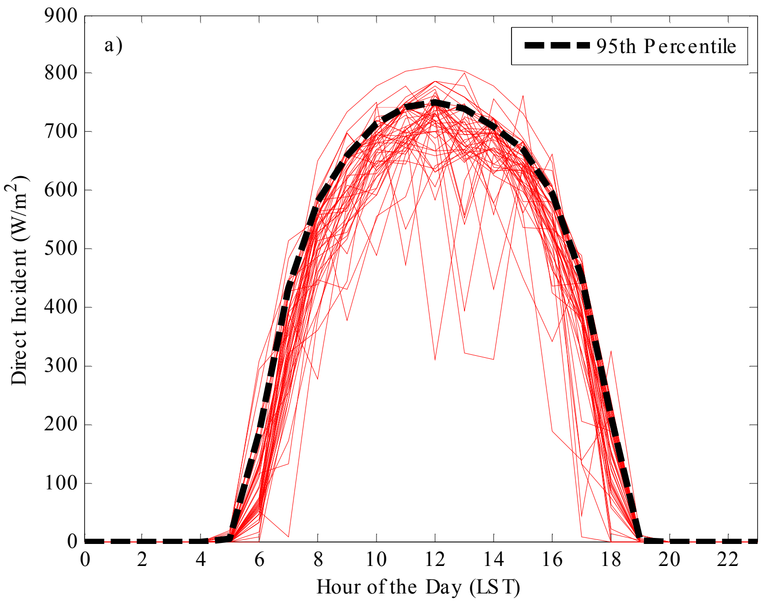




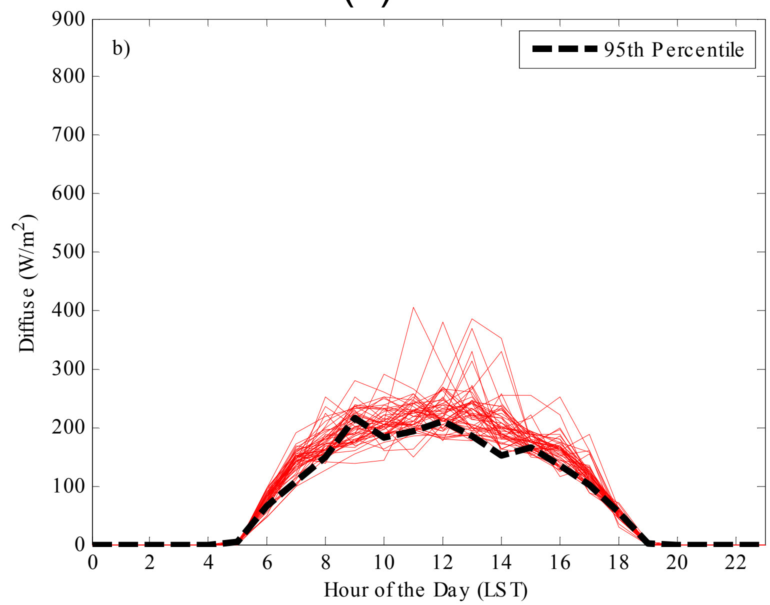
Solar Insolation Data

- **Hot Diurnal Solar Insolation Profile for KSC**
  - Days with high direct incident (a) will be clear, sunny days, therefore the diffuse (b) will be low
  - Cloudy days will have little to no direct incident, and mostly diffuse (not shown here)
  - Red lines represent the 50 highest days of direct incident in July

(a) Direct



(b) Diffuse

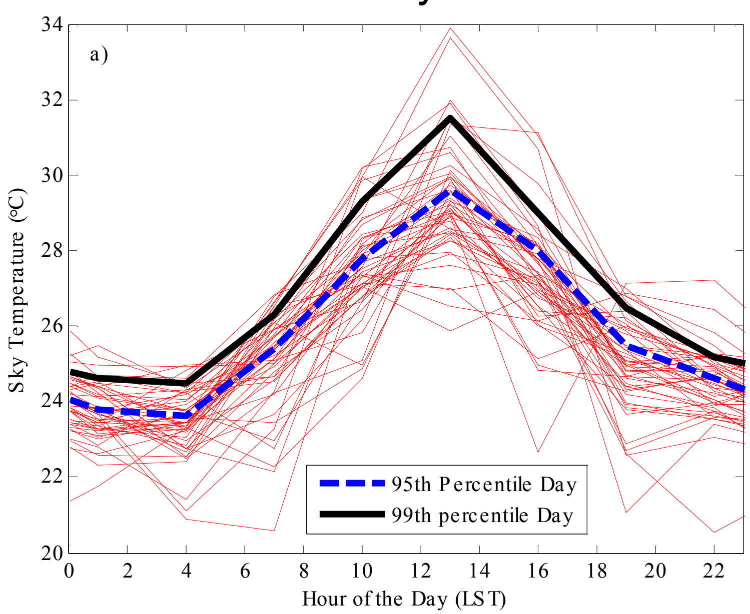


Sky Radiative Sink Diurnal Thermal Profile

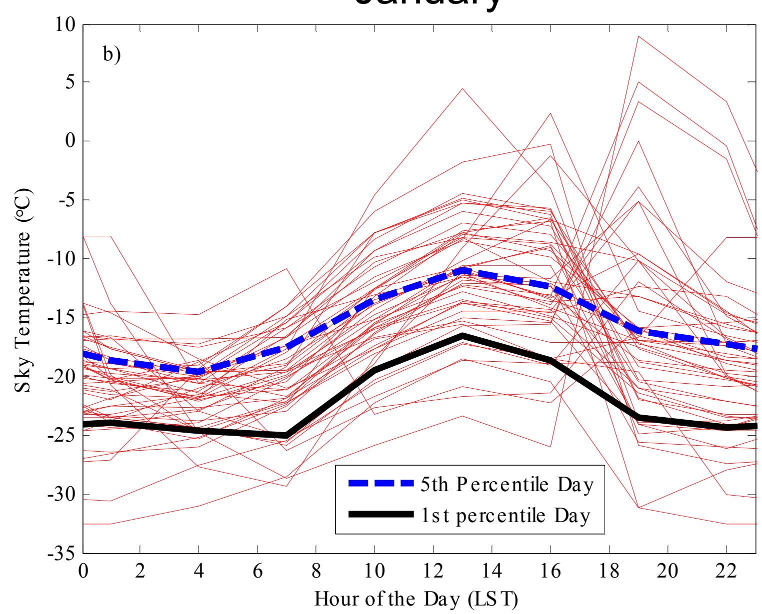
♦ Hot and Cold Diurnal Sky Temperature Profiles for KSC

- Red lines represent the 50 highest and lowest sky temperature days in the KSC POR
- 95th and 99th profiles are from July
- 5th and 1st profiles are from January

July

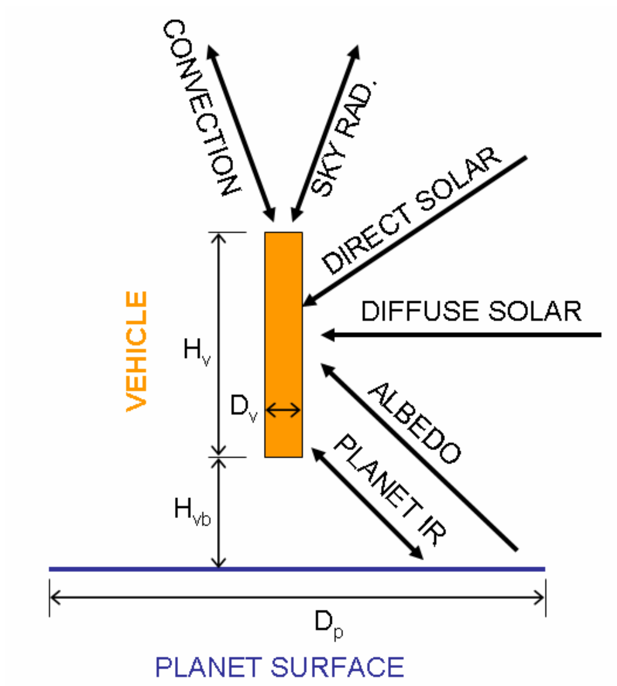


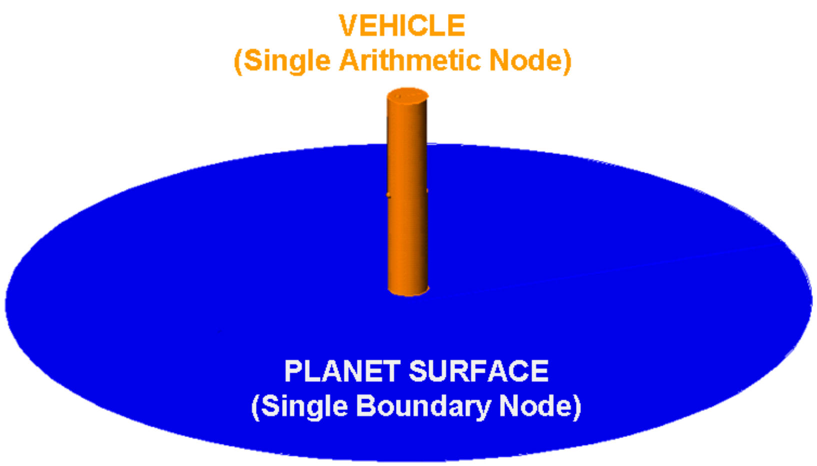
January



Parametric Study Method

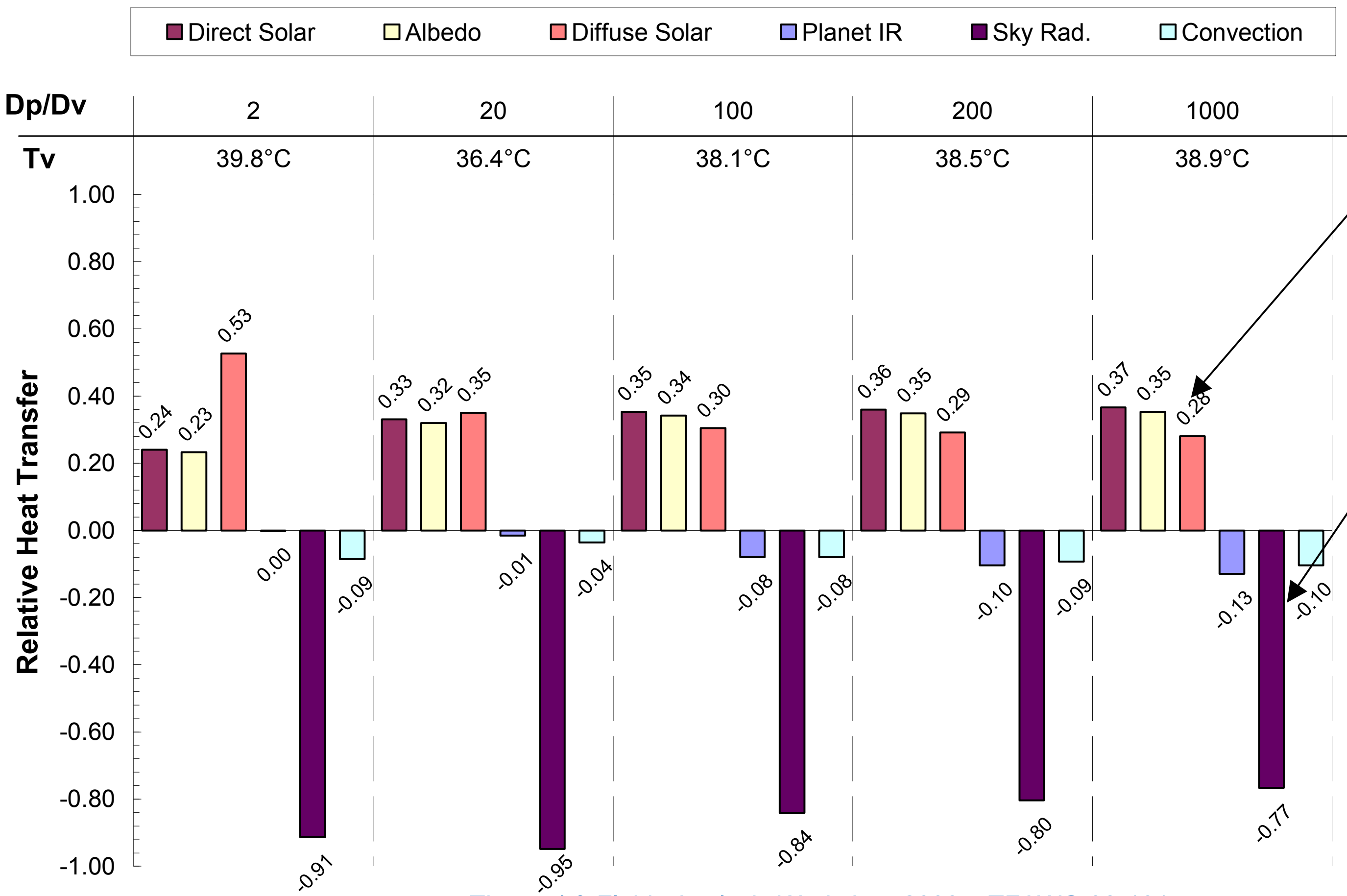
- Planet size & relative environmental effects should be determined early in the analysis process
- Significantly reduced models can be used for this purpose
- All environmental loads should be applied to reduced model





Parametric Study Results

- Reduced models can provide relative heat transfer for each mode
- Quickly shows which modes are most significant
- Quickly shows effects of planet size on the total energy balance

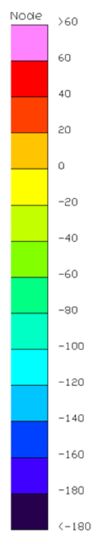


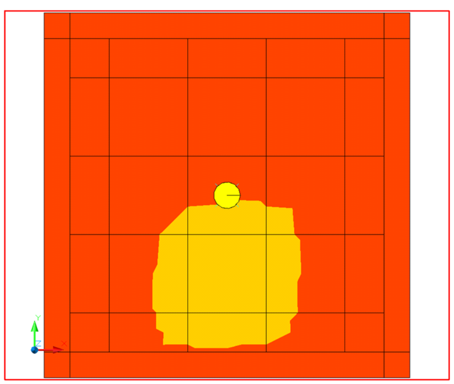
In this example, direct solar, albedo, diffuse all of same order

In this example, sky radiation is huge factor

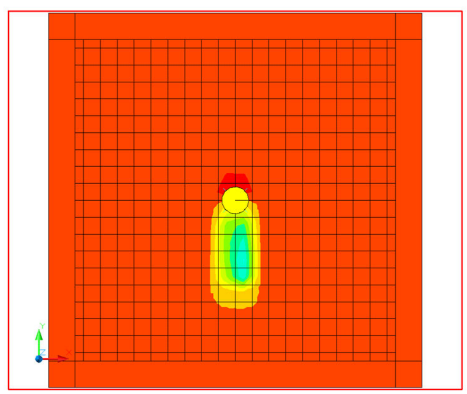
Parametric Studies

- Reduced models also helpful for resolving shadow regions
- Small, light components will be affected differently depending on shadow resolution
- Relative heat transfer plots can also be produced

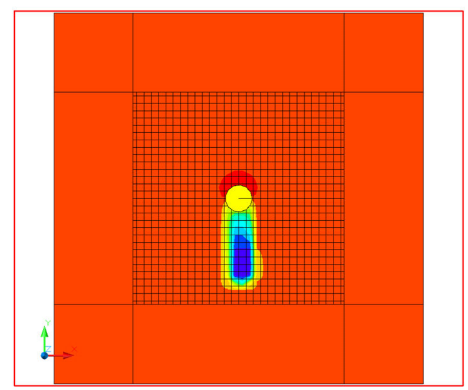




a.) Low inner region nodalization, determine effective area



b.) Higher inner region nodalization, determine effective area



c.) Higher inner region nodalization, smaller inner area

Summary

- **This paper describes thermal modeling techniques of ongoing Constellation projects**
- **No current flight or test model correlation of methods**
  - Results verified by hand-calculations and previous modeling methods
- **Constellation thermal engineers plan to correlate using measured ground data as soon as possible**
  - Pad Abort testing at White Sands, Ares I-X demonstration flight from KSC, etc.
- **Future refinements and improvement based on ground data correlations and environmental parameters will be done**
- **Natural environment data well-characterized for KSC and WSMR**
- **Parametric studies allow determination of most important parameters**

Acknowledgments

- Ken Kittredge and Mark Wall of Marshall Space Flight Center for their inputs in developing the ground-based modeling techniques for Ares I and Ares I-X
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