THERMAL & FLUIDS ANALYSIS WORKSHOP

GSFC · 2015

Common Modeling Mistakes

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Agenda

- Philosophy
- Setup / Assumptions
- Heat loads
- Radiation
- Convection
- Contact
- Materials
- Correlation
- Summary

Philosophy

The Deadly Placeholder

- Beware of the place holder that you're going to "go back and fix later"
- If you don't know the actual value, using a rough estimate is safer than putting in a placeholder
- Make at least a rough calculation
- Note that with your value

1.0

Document, Document, Document…

- Have a standard way to document changes in the model
- Keep log of case results
- Version control the model file
- Have a standard quick way to document trade studies
- Leave yourself a reminder if you make a “what-if” change in the model

Chg case back to 1

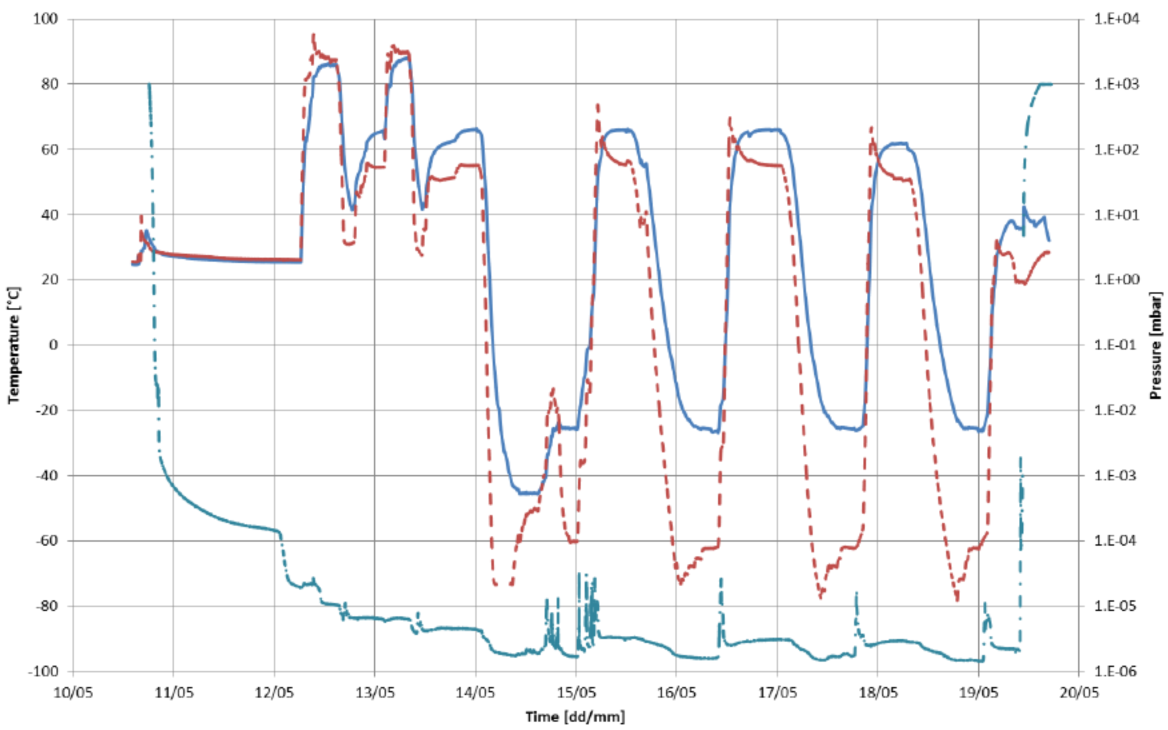
- Have a consistent naming scheme
- In TD, name everything so it is easy to identify in the Model Browser

Sample log file

5/19/2015	SAGE_ISS_v55.dwg	Kaitlin	Renamed IP TVAC cases Changed emissivity of GSE heater plates based on measured values Corrected numbering on ExPA heater plate zones (1 and 3 were switched) Updated TC locations and numbers based on GSE characterization test actuals
5/20/2015	SAGE_ISS_v55a.dwg	Ruth	disable CMP1 aux surv htr, import chgd mate cases, fix NVP contactors so they disable in mate cases
5/22/2015	SAGE_ISS_v55b.dwg	Ruth	put in detailed HEU model

Use Your Data!!

- If you have any test data, use it!!
  - Doesn't matter how unlike flight it is, it can still help you correlate
- Fight to get data from any previous tests

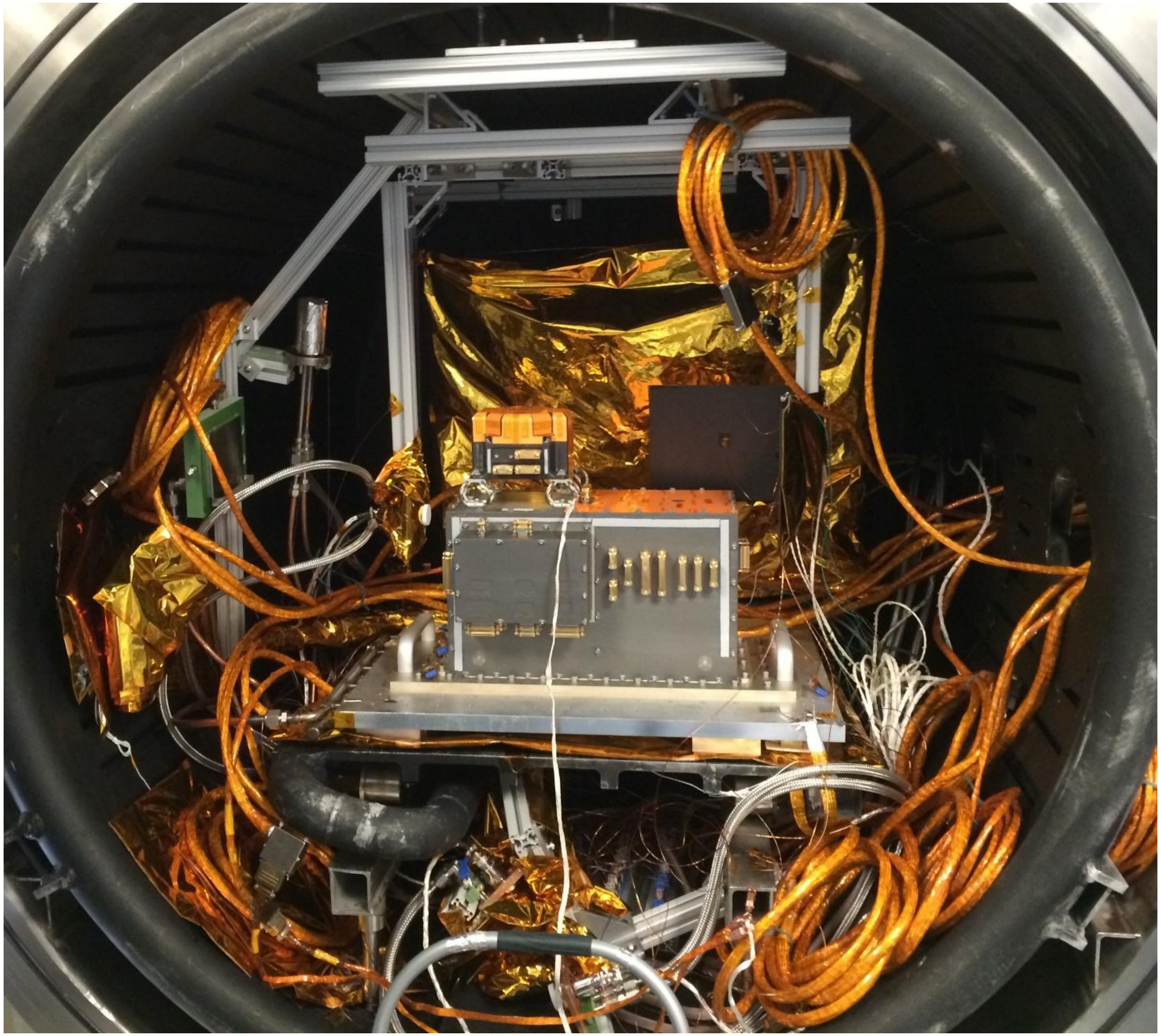


Setup / Assumptions

"Test as you fly, fly as you test"

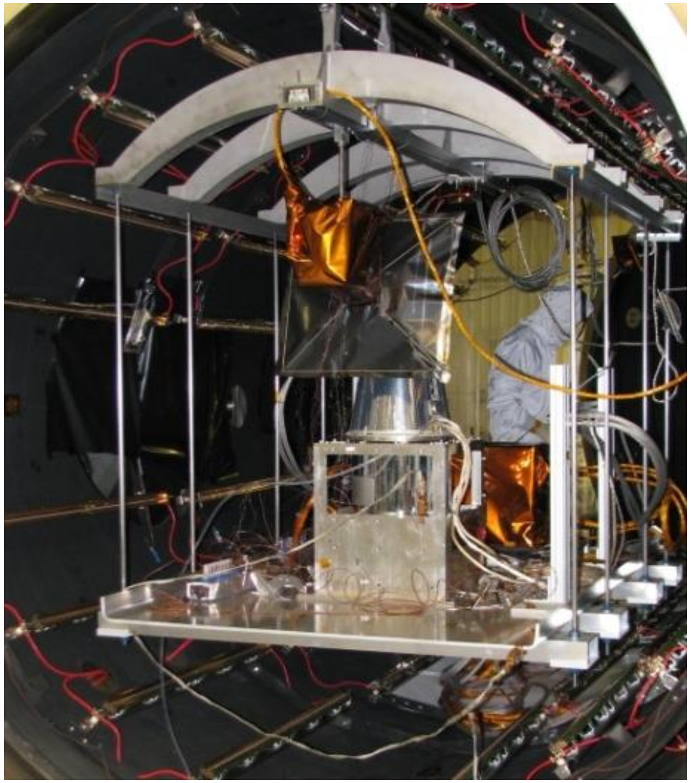
- Analyze as you test & fly
- Make sure you are modeling the real test or flight scenario
- Include all basic conditions
  - Air
  - Moisture
  - View to test hardware
  - GSE
- In addition to hot and cold cases, have a nominal case as well as others such as maximum gradient

Sample TVAC



Test Setup

- Model sensors explicitly in exact locations
- Check chamber measurements and view blockages
- Model controls accurately, including lamp spectrum
- Check model against photos of test setup
  - Cable masses and blockages
  - Shroud penetrations
  - Auxiliary hardware and GSE in view
  - Heater and lamp locations



Basic Model Checks

- Before you run a flight scenario, do basic checks
  - Good idea to have a checklist for your org (or for you)
- Connect a heat source to one corner and look at gradient
- Change temperature of environment
- Change time step
- Check against simplistic hand calc
  - Radiation equilibrium
  - Total heat load
  - Flow rates
- Whenever you get cautions or warnings in your output file, *look at them!*

Sample TD Model Checklist

- Check units
- View thermal results on model; look for unexpected sharp gradients or unreasonable values, including on insulation.
- View model by analysis groups and display active surfaces. View different assembly locations.
- View model by material & optical properties
- View only surfaces that have insulation
- View model by symbols
- Display all contactor markers
- View absorbed solar/planetary flux on model surfaces
- View by assemblies/trackers and ensure no extraneous surfaces or surfaces left out.
- Check operation of trackers by viewing model around orbit
- Check heaters and heatloads; verify consistent units
- Check all warning messages for contactors and consistent units
- Check material and optical properties for duplicative properties with similar spellings
- Check logic blocks, in particular ones that use logic in enabled block, so they show set to disabled but may activate in certain cases. Check for unit consistency.
- Check overrides for density and conductivity on surfaces and solids
- Check nodes over-ridden for thermal mass, especially as boundary or arithmetic
- Do model mass check
- Check for duplicate nodes
- Check overlapping surfaces
- Create cc file and check for errors
- Check orbits for valid parameters
- Case Set Manager checks
    - A/DRLXCA, DTIMEI
    - Radiation case sets
    - Steady-state versus transient, and sufficient length of transient.
    - BUILD statement.
    - Optical property aliases
    - Symbol overrides.

Example Hand Calcs

- Radiation equilibrium

  $q = \sigma\,\varepsilon\,(T_1^4 - T_2^4) \rightarrow T_1 = (q / \sigma\,\varepsilon + T_2^4)^{0.25}$

  100 W/cm^2 into surface with $\varepsilon = 0.8$

  $T = [100E4 / (5.67E\text{-}8 * 0.8)]^{0.25}$ $[W/m^2]/[W/m^2K^4]$

  = 2166K [Note: Use absolute temperature units!]

- Heat input

  $Q = k \frac{A}{l} (T_1 - T_2)$

  60°C and 25°C separated by Cu bar 1 cm^2 x 4 cm

  Q = 400 * (.01*.01/.04) * 35 [W/mK] * [m*K] = 35W

  $\Delta T = Q / (m\,C_p)$

  50W for 1 min into 1 kg steel block

  ΔT = 50 * 60 / (1 * 450) [J] / [kg * J/kg°C] = 6.7°C

Tool Choice

- Don't use a sledge hammer to swat a fly
- For a space mission, pick a tool that can do orbital analysis
- If you need radiation, pick a tool that's good at it
- Same for convection
- Pick the tool to suit the job, not just the tool you're comfortable with

Steady-State versus Transient

- If you have active components in a model (heaters, TECs, pumps), then steady-state will often be misleading
- Steady-state can be used to get a “quick-look”
- Transient almost always more accurate and robust

Symbols/Registers

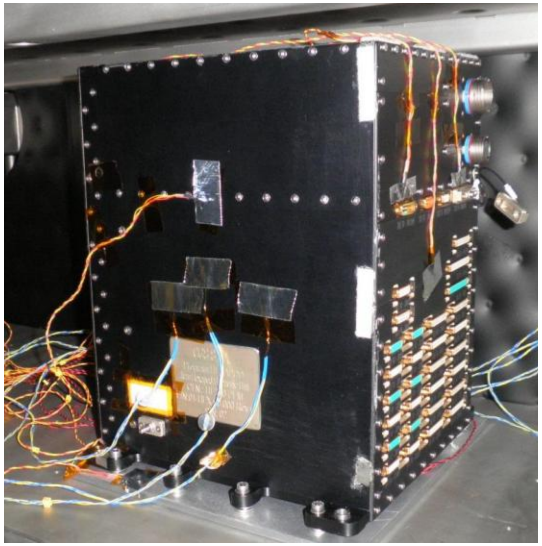
- If you use a symbol, make the initial value reasonable
  - E.g. a temperature symbol with an initial value 0K can be dangerous
- The initial value may be used before your custom-written logic defines a better value, and can affect model operation

Units

- Meet with interested parties at the beginning of a project to determine units to be used
- Consider mechanical input units, science, testing, heat load inputs, optical, etc.
- Make every effort to maintain one consistent set of units throughout the life of the model
- If you make a change, document it well and check all logic blocks
- Consider dual-unit model if necessary
- Mixed SI and English units are not desirable but not a show-stopper

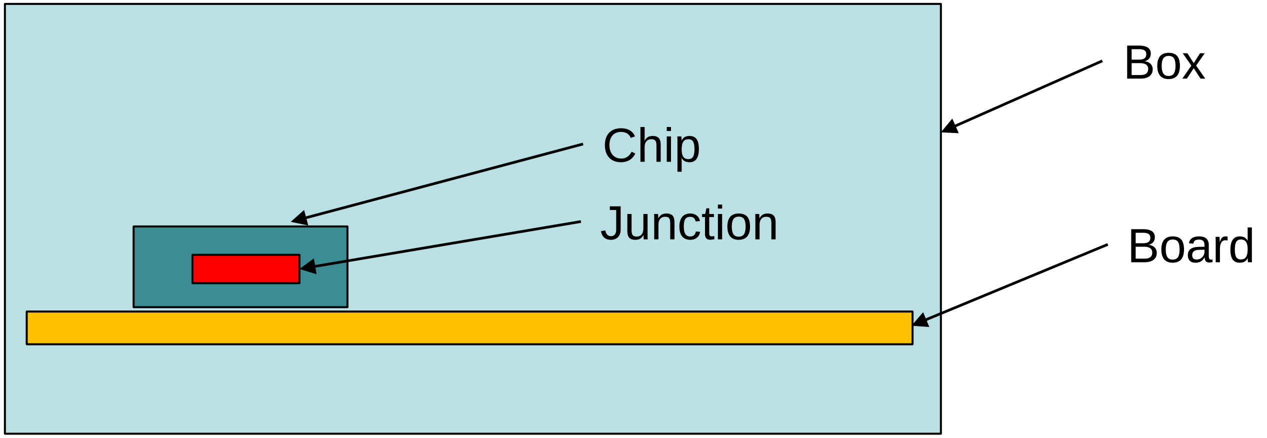
Reality Check

- If at all possible…. GO LOOK AT THE REAL THING!!!!
- It is very easy to start believing that what is on your screen is real
- A look at the hardware may reveal basic inconsistencies in your model
- Look at heat flows between submodels to make sure they make sense



Part Limits

- For electronics, differentiate between box limit, board limit, chip limit, junction limit
- Differentiate between operational and survival limits
- May have different short-term versus continuous use limits
- Make sure limit is defined for your environment such as vacuum versus air, or moist air versus dry air



Sample	Limit (°C)
Box	50
Board	75
Chip	90
Junction	125

Mesh Density

- Mesh should encompass the detail you need
  - Contacts
  - Heat loads
  - Expected gradient
  - Radiation

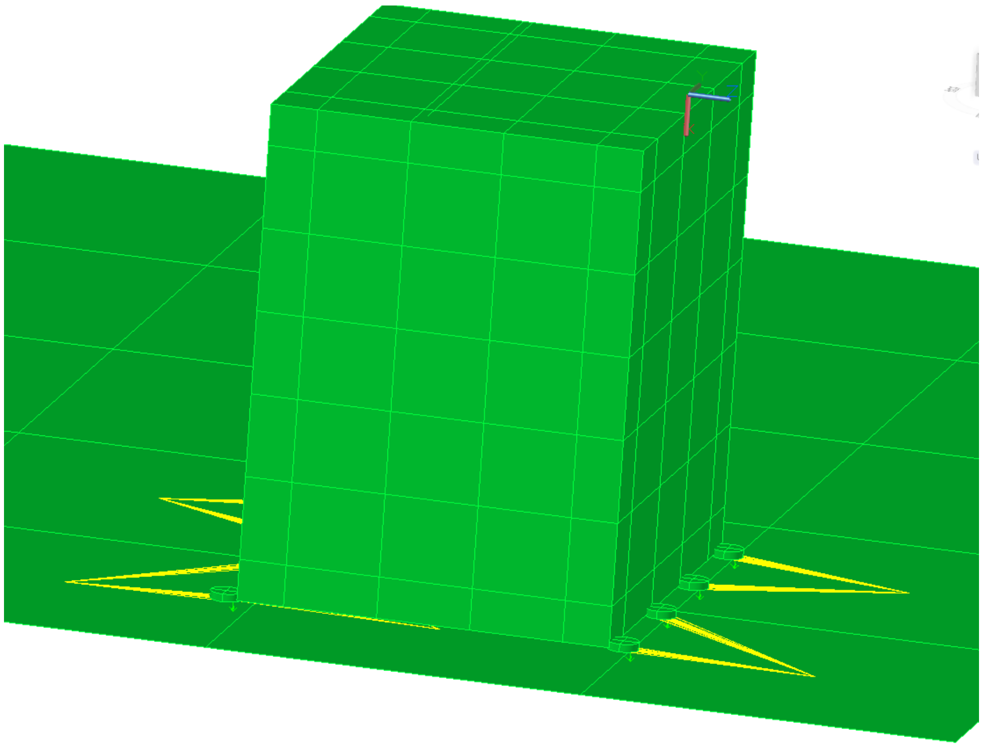
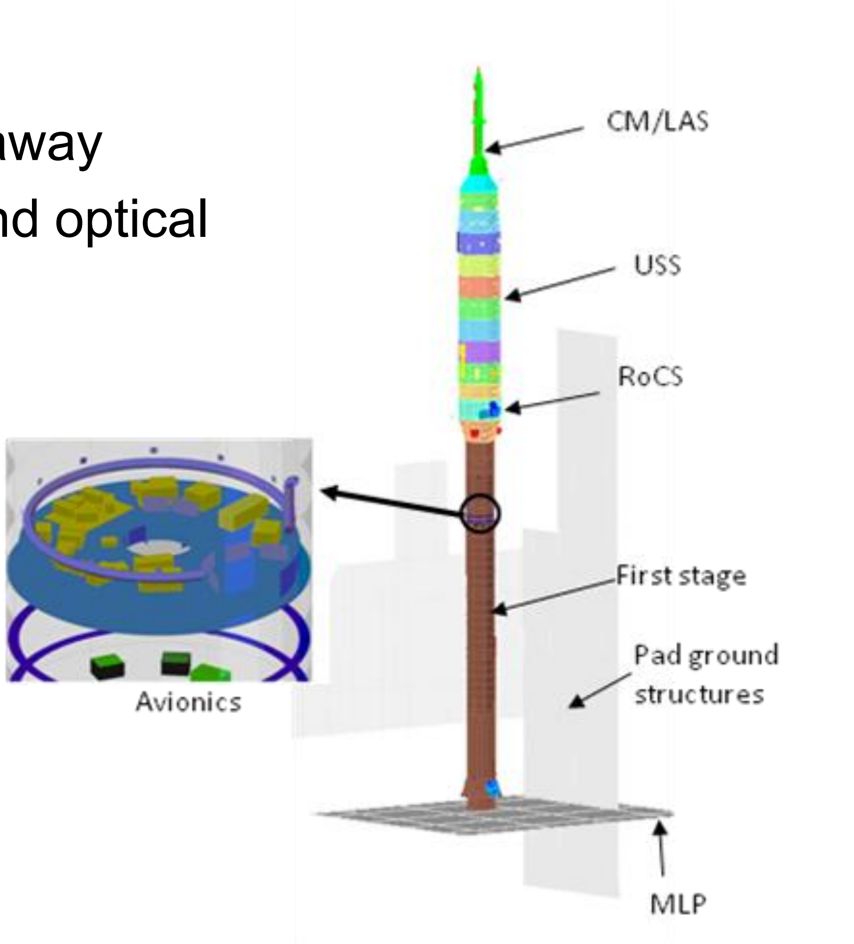


Plate: too coarse

What To Include

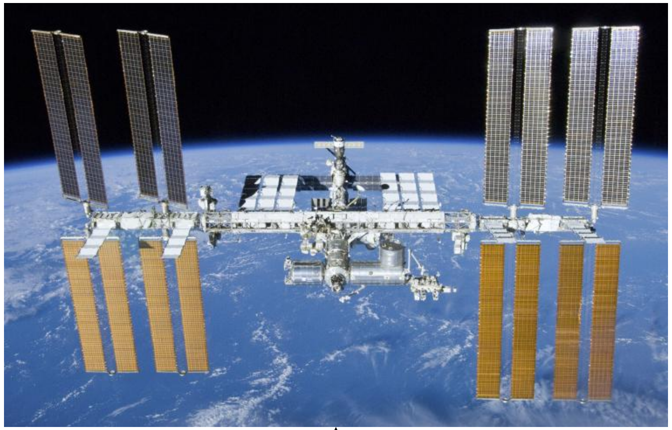
- Look for things that could make >10% difference in model
- Ares I-X example:
  - Don't need buildings 3 miles away
  - Don't need difference in ground optical properties
  - Do need basic mass
  - Do need solar flux, Earth, sky



Heat Loads

Air Mass *What?*

- Most thermo-optical properties are given for space
- If you are on Earth or a planetary surface, the solar spectrum will be different
- This can lead to substantial change in solar α!!!
- On Earth, air mass 1 means solar noon at sea level



Air mass 0

Air mass 1

Air Mass (con't)

Air Mass Coefficient = AM = $L/L_O \approx 1/\cos(z)$

L = path length through atmosphere

L_O = zenith path length normal to Earth's surface at sea level

z = zenith angle

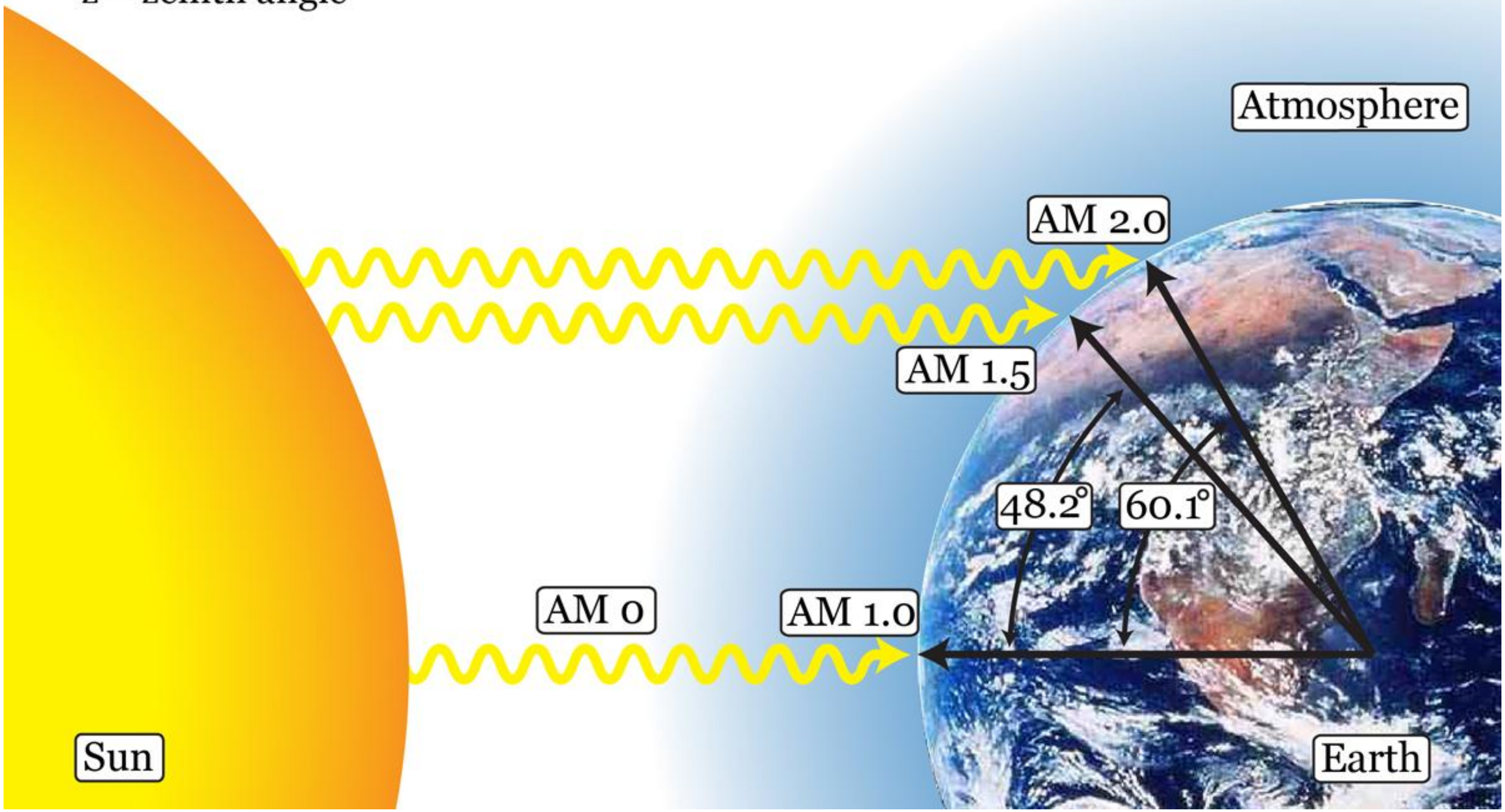
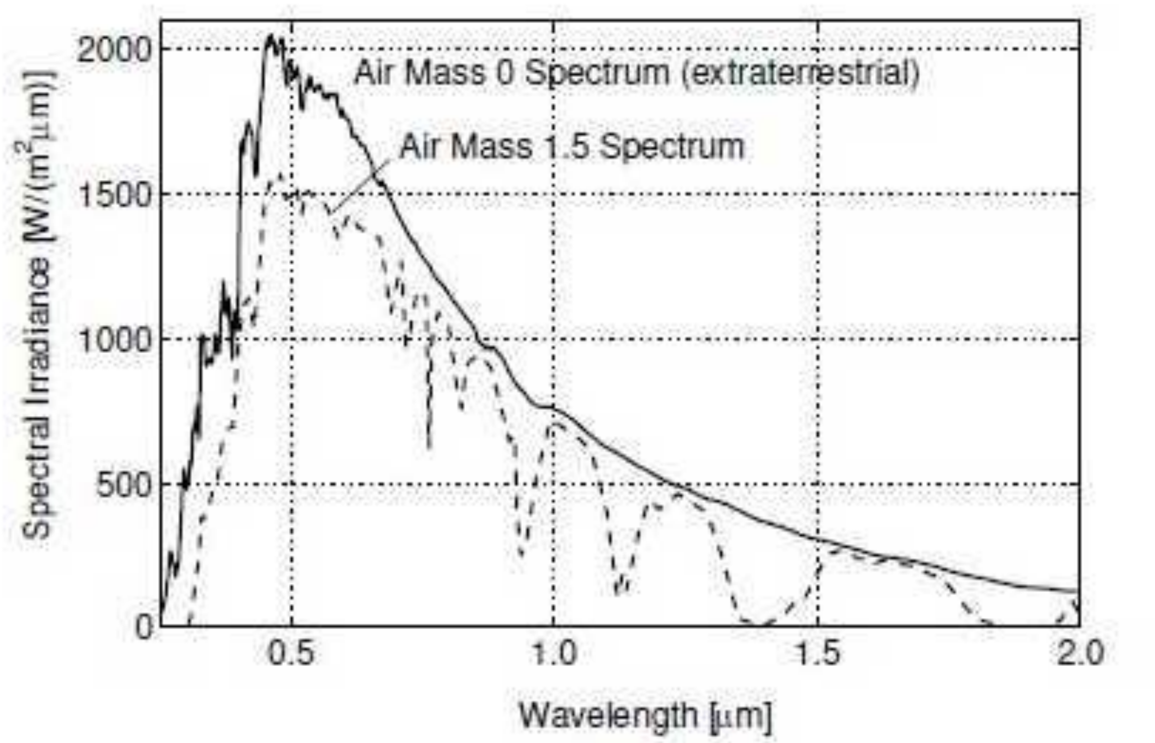


Image courtesy www3.nd.edu

Air Mass (con't)



Examples	α AM 0	α AM 1.5
White Rustoleum	0.34	0.29
Hentzen white	0.23	0.18
Acryshield A590	0.30	0.26

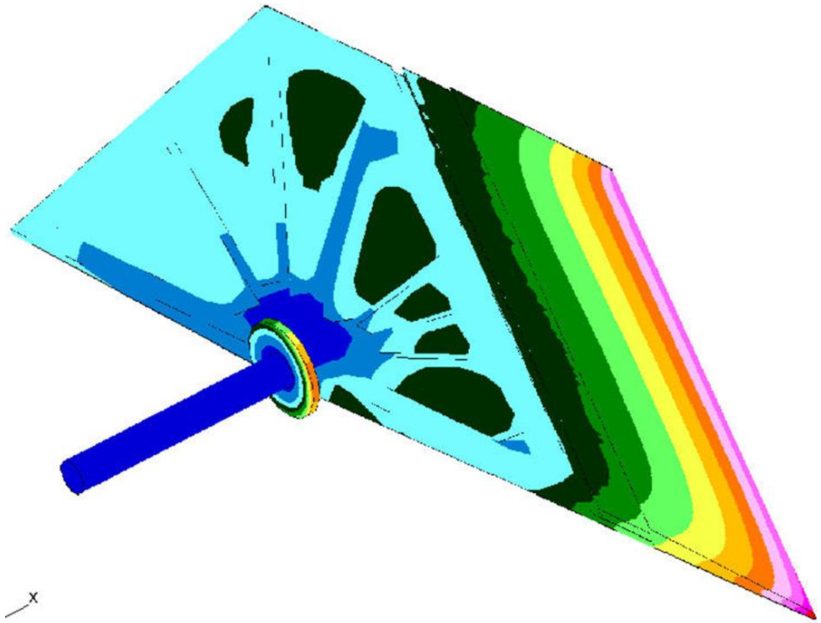
Images courtesy Newport.com, www.assignmentpoint.com

Aeroheating Loads

- Beware of undocumented aeroheating convective heat loads
- Questions to ask:
  - Cold wall or hot wall?
  - Radiation included?
  - Enthalpy-based or temperature-based?
  - Units?
- Remember that the heating will change over the surface of your part, over time, and with the temperature of the surface, so make sure you are interpolating on all three

Cold Wall versus Hot Wall Heat Flux

- Cold wall heating assumes the surface is all at one temperature (often 300K)
- Applying that to a surface where the leading edge is at 2200K will obviously not be correct

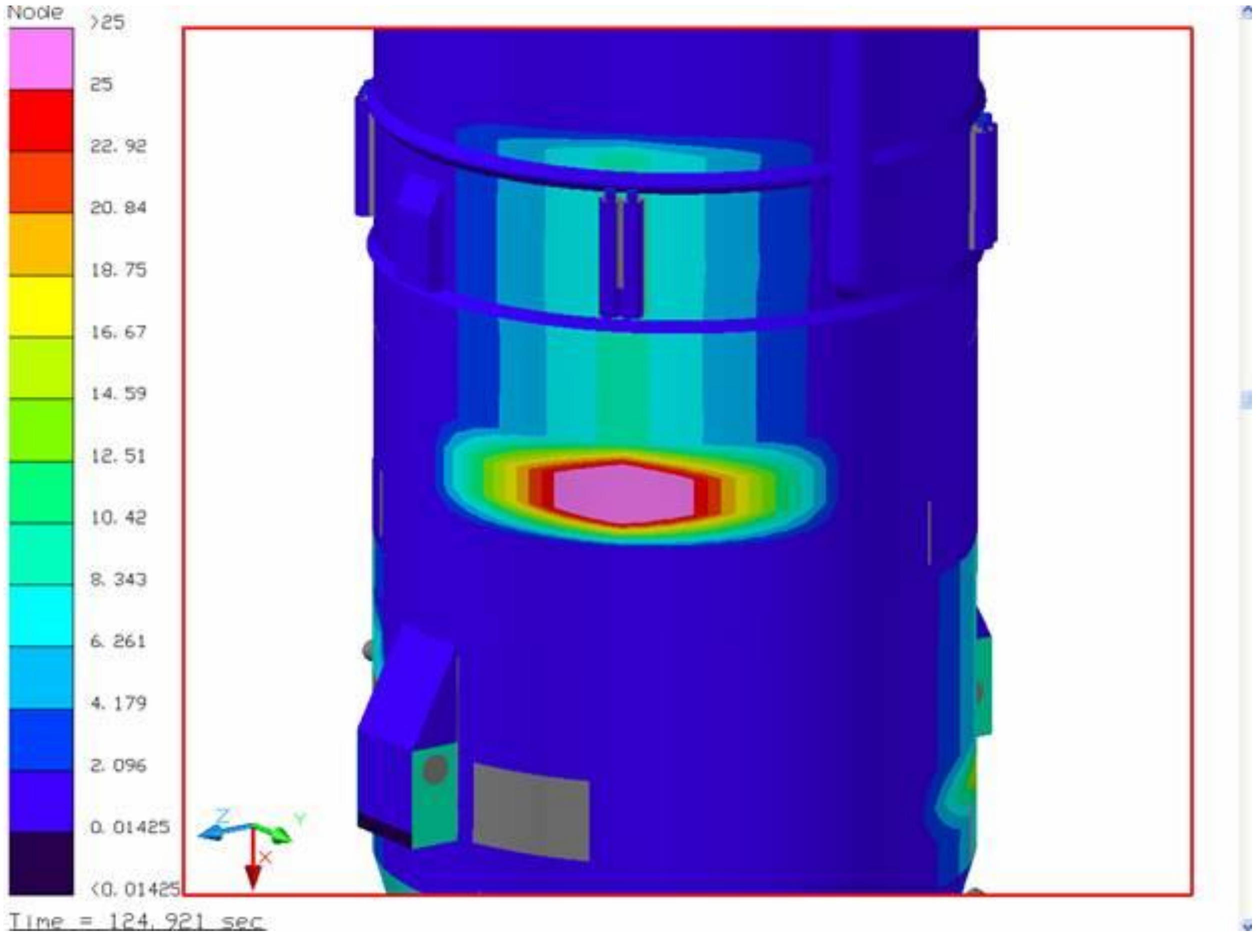


Methods for Heat Flux Input

- Apply cold wall with correction factor for surface temp
  - Ignores dependence of h_c on temperature
- Interpolate between Q's for different wall temperatures
- Request h_c and T_{fluid} (or T_{fluid}) rather than Q
- Use hot wall and iterate between T and Q
- Use integrated tool that applies Q based on surface temperature
- Use Boundary Condition Mapper in TD
- Look at heat loads graphically before and after applying them

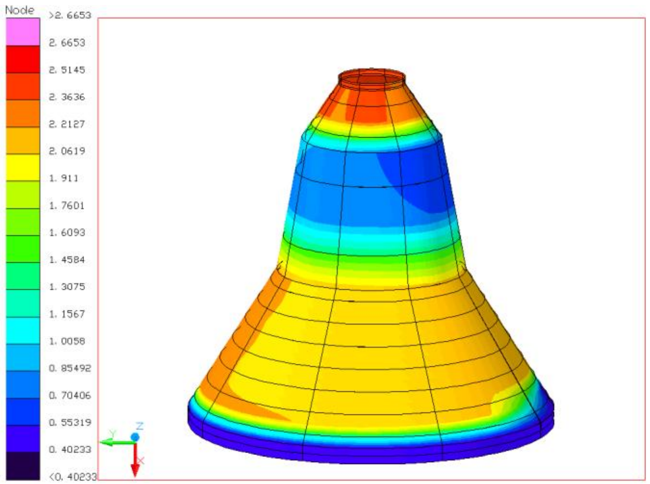
Graphical Heat Flux Check

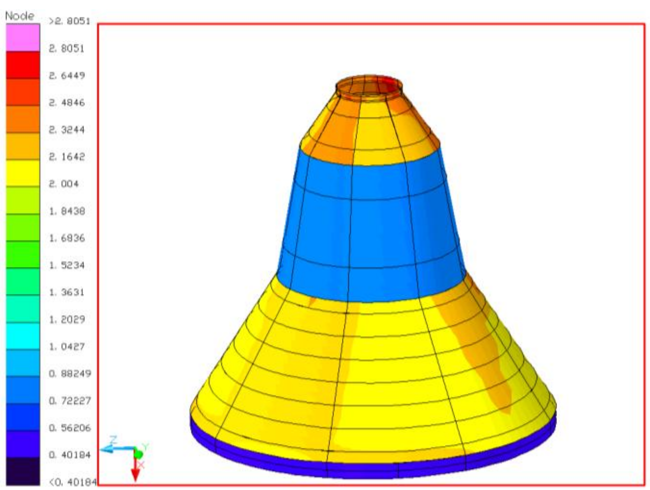
- Example of heat flux loads not checked graphically
- Engine plume where there is no engine



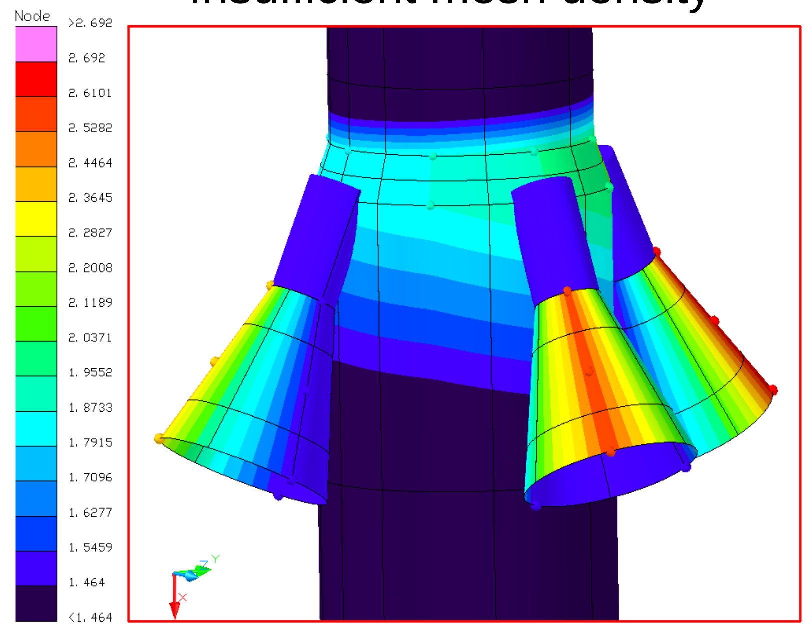
Heat Flux Mapping – Mesh Issues

Incorrect and corrected map across boundary





Insufficient mesh density

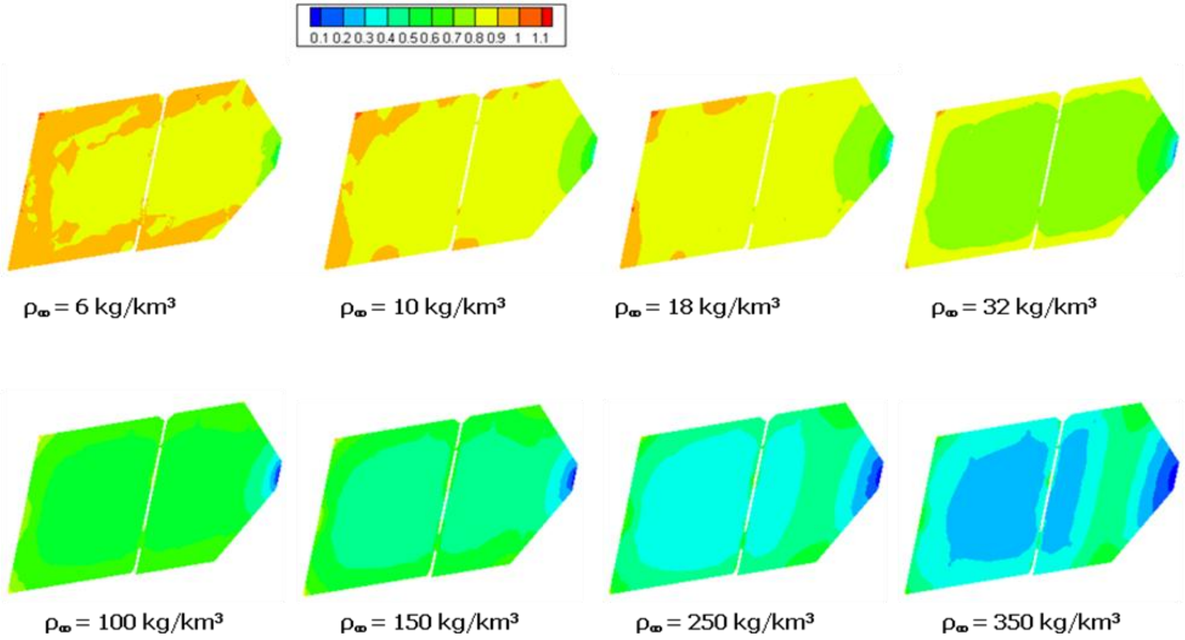


Temperature-based versus Enthalpy-based

- Temperature-based: $q = h_c * (T_{fluid} – T_{surface})$
- Enthalpy-based: $q = h * (H_{recovery} – H_{wall})$
- These two h's have different units
  - T-based h: $W / m^2\text{-}K$
  - Enthalpy-based h: $kg / m^2\text{-}s$
- Be aware that T_{fluid} and H_{fluid} may vary around vehicle

Don't Make your Job Harder

- For Mars Reconnaissance Orbiter, we had aerobraking heat loads as a function of atmospheric density instead of time
- Before starting the labor of transforming huge boundary condition matrices, I asked C&R if they could add an option to use density instead of time, and they agreed

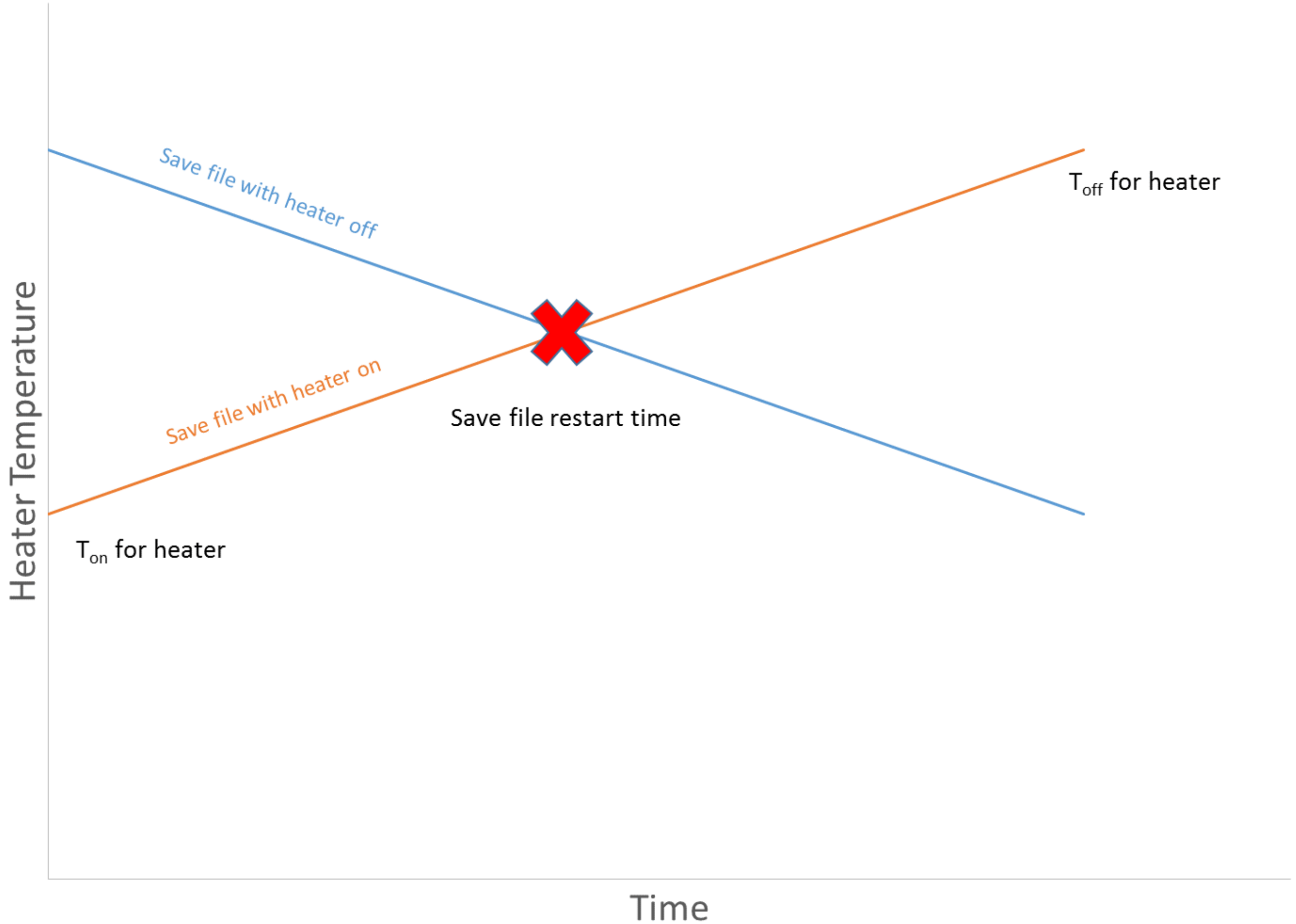


TD Heat Loads & Heaters

- If you apply an absolute heat load across multiple parts, make sure you multiply the heat load value by the number of parts
- Simpler to use a register for heat load and define time array, than use time-dependent option on heat load form
- Remember if you disable a heater in the enable block, it will not be built, so you will have to also disable any logic you have that uses those heater variables
- Be aware that if you set the off temp lower than the on temp for a heater, it will apply negative heat to try to reach the set point temperature
- If you set the heater in steady-state to hold temp, it may use more power than you have

Restarts and Heater Hysteresis

- When restarting from save file, be wary of using registers, as heater register being on or off may change results



Electronics Heating

- If you are calculating a power using I*V, make sure the I and V are the ones actually reaching the part
  - E.g., if voltage is used for control, the full bus voltage is not reaching the part
- If you have any motion, transmission or mechanical action, determine how much of the input power load is actually lost to dissipation

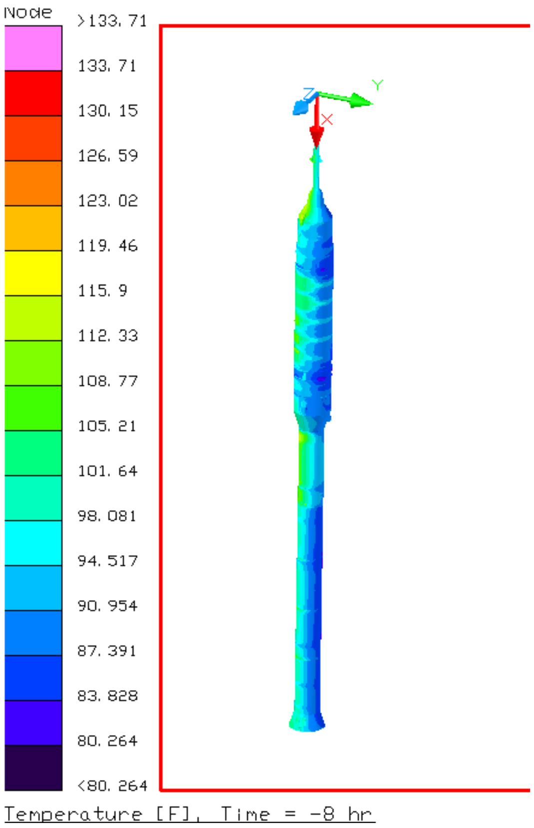
Radiation

Radiation

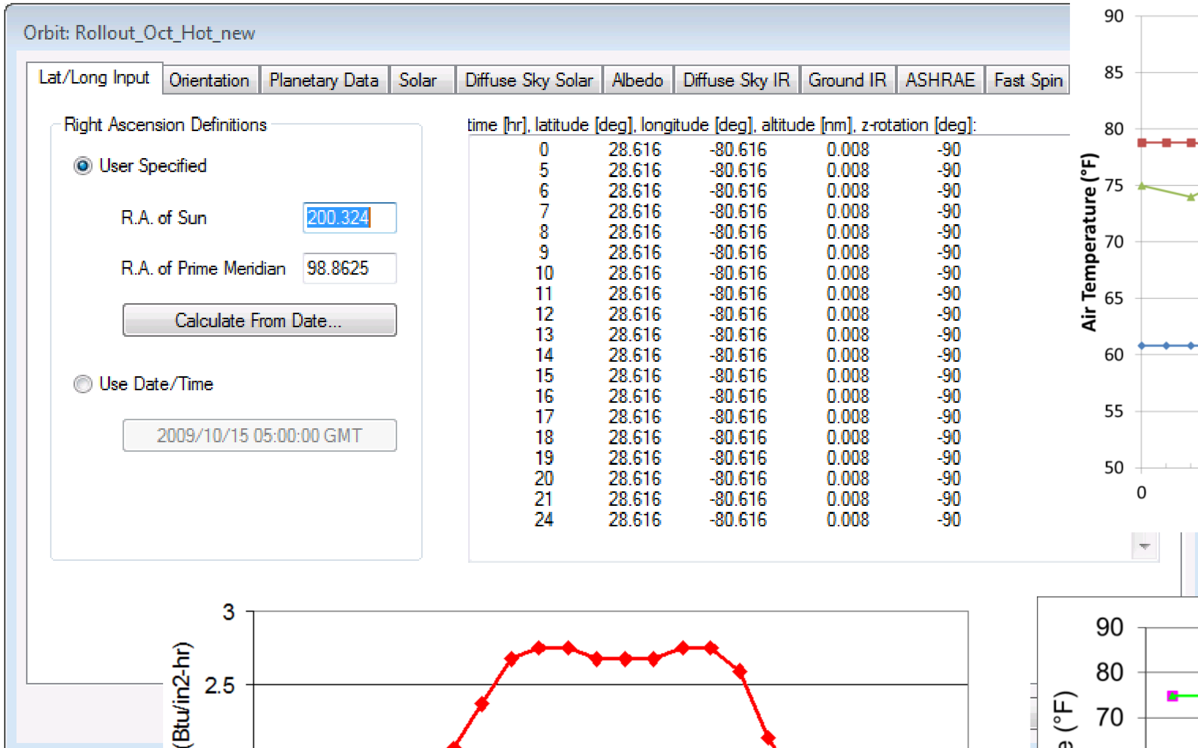
- Don’t be afraid to do a hand-calc for radiation estimate
- Don’t assume view factor is 100%
- Don’t use temperature-dependent emissivity to substitute for a non-grey analysis
  - If you have surfaces at substantially different temperatures with emissivity that changes as a function of temperature, do a non-grey analysis
- If you manually add a boundary condition for radiation between two surfaces, make sure that surface is inactive in the radiation calculations
- When starting from someone else’s model, don’t assume which are the top sides of surfaces
- Always do visual check of active sides and radiation groups

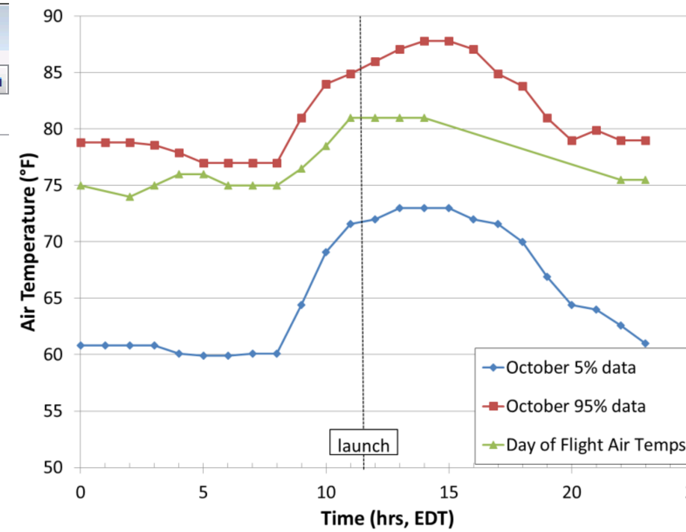
Planetary Surface Radiation

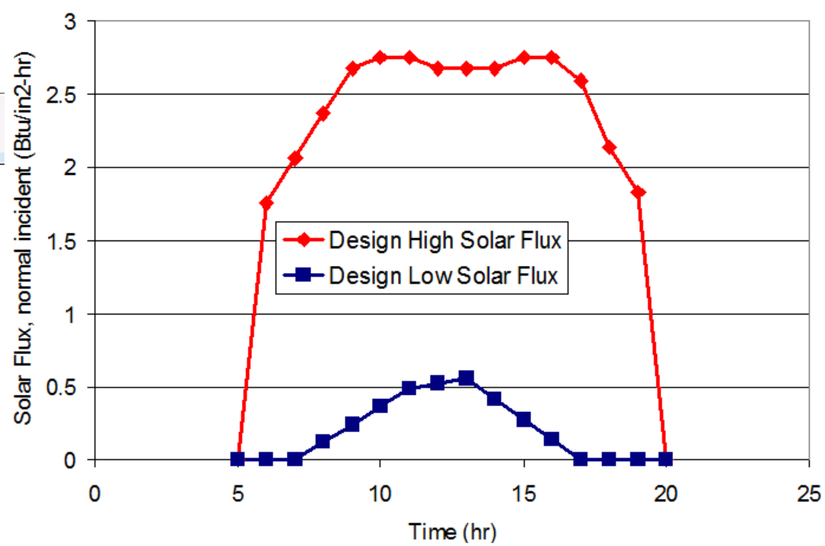
- For modeling on a planetary surface using TD, use planet surface location option in TD
- Requires additional radiation case with radiation to space node (see manual)
- Additional heat sources: diffuse sky solar radiation, diffuse sky IR, planet IR; need transient data
- Data sources
  - North American Regional Re-analysis (NARR)
  - National Solar Radiation Database (NSRD)

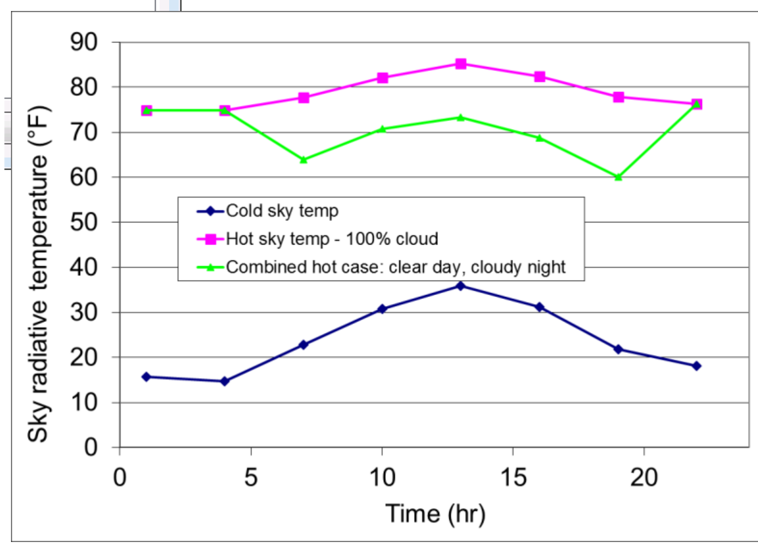


Sample Surface Data









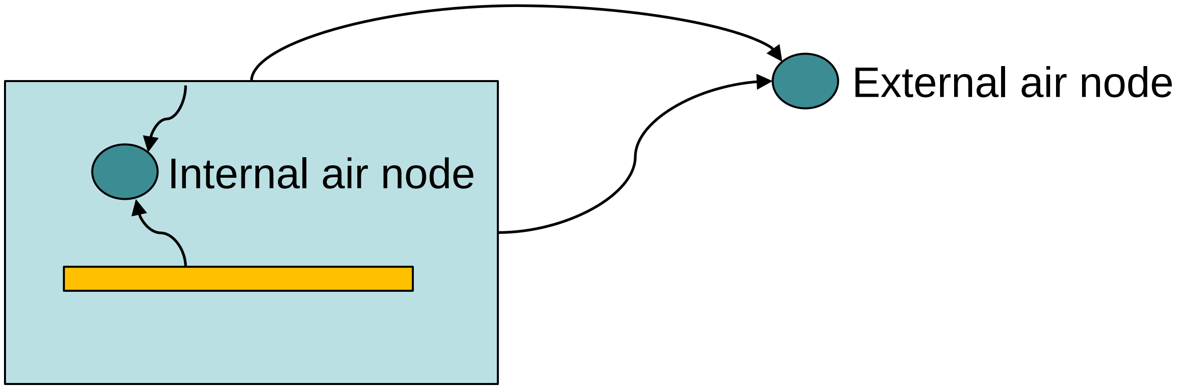
Orbits

- If you have moving parts, ensure you have motion appropriately captured in your orbit time steps
- Use registers for albedo, Earth IR, solar flux, altitude if you plan to change them, or if they change between hot and cold cases
- Custom TD logic exists for changing albedo and Earth IR during orbit, also for environments based on inclination, beta angle, hot/cold case
- In the TD radiation case, be aware that symbol for sink node (e.g. SPACE.1) will not be used; this has to be defined in the model as boundary node

Convection

Finding h_c

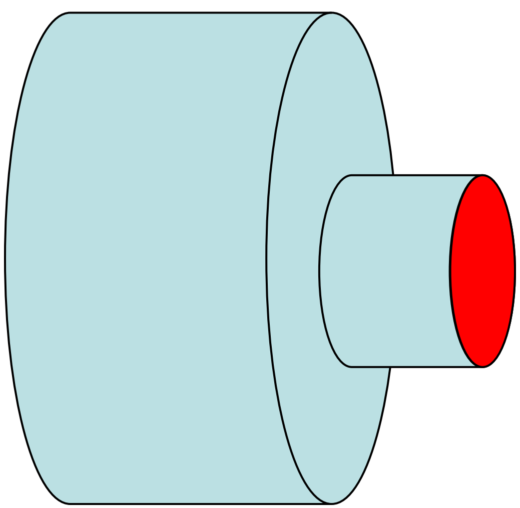
- Treat natural convection and forced convection separately
- If using a tool that models natural convection, treat vertical and horizontal surfaces differently
- Use hand-calc to ensure your h is in the right ballpark
- If the air you are convecting to is in contained volumes (boxes), separate the air volume meshes and convect internal parts to internal air (box walls convect to internal and external air)



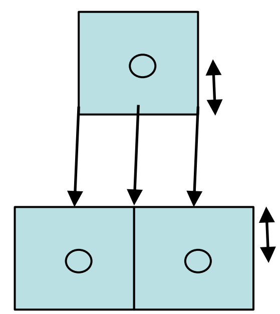
Contact

Contact Area

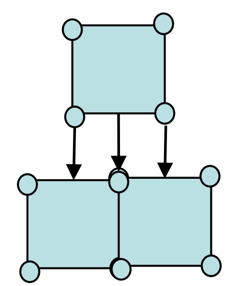
- Use the correct h_c and contact area
  - Don't use a contact h_c that is measured at the bolt, over the entire flat side of a box
  - Use care between edge and face contactors
  - Use the area of the part in contact
  - Make sure the meshing of the parts allows correct contact
  - Edge nodes give accurate contact; center node element contacts must be adjusted



Center node contact should be adjusted for thickness of material



Edge node contact needs no correction

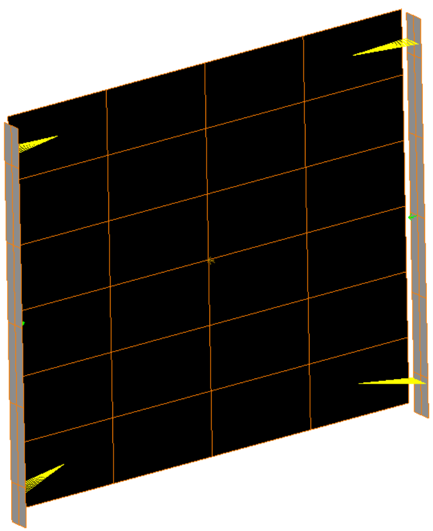


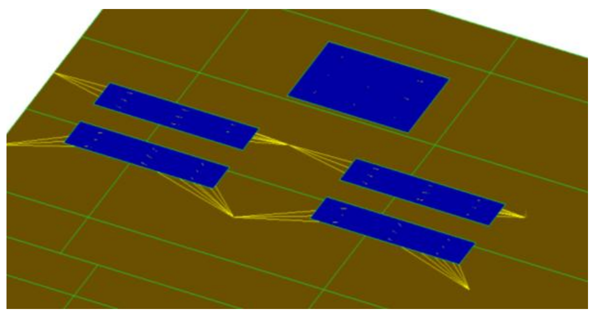
Gap Type

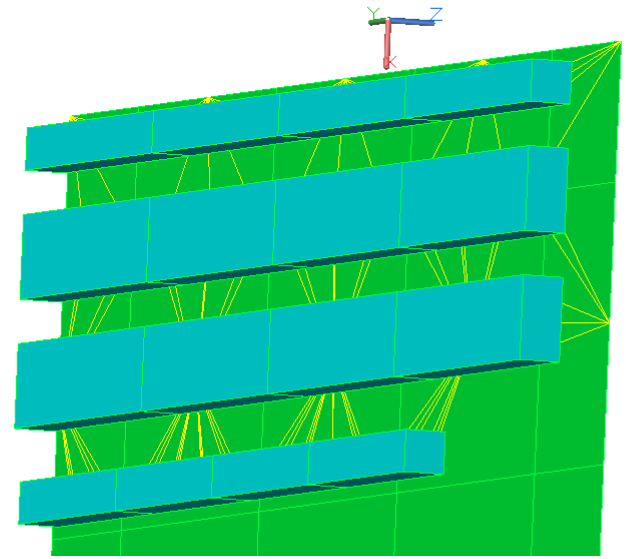
- Use data for contact that represents your scenario
  - Material type
  - Surface roughness
  - Contact pressure
  - Air/vacuum
  - Gap filler/grease
- Bound the problem by using reasonable high and low values

Checks

- Always do a check of contactor markers to ensure the correct parts are in contact
- Always look at the message file for contactor warnings
- If you apply an absolute contactor across multiple parts, remember to multiply by the number of parts







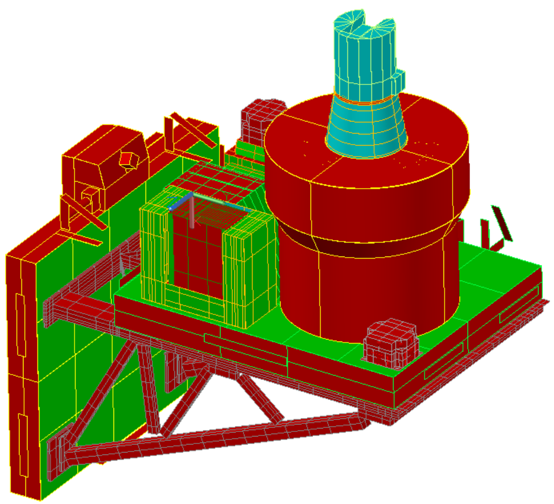
Materials

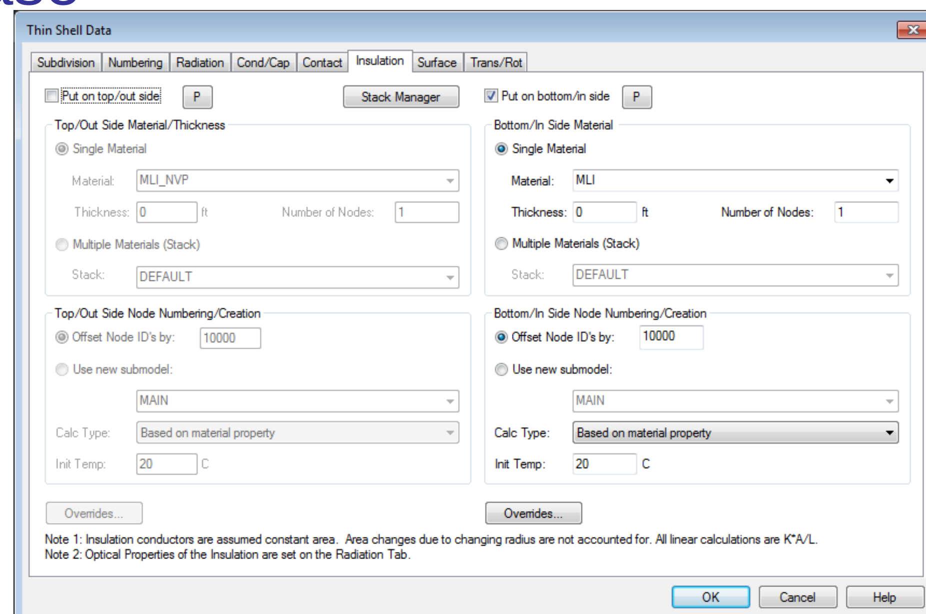
Property Measurement

- Measure optical properties of surfaces whenever you can
  - Aluminum (ε=0.02 to 0.8, α=0.1 to 0.9 depending on treatment)
- Make sure you are using the properties for the correct alloy / heat treatment
- Make sure your properties cover the temperature range you will see

MLI Blankets

- Ensure correct optical properties on external surfaces
- Use thickness of 0 for radiation-only
- Cryo blankets may need conduction modeled in addition to radiation
- Do not model each side explicitly – use single surface
- ε^* encompasses top to base
- Visual check



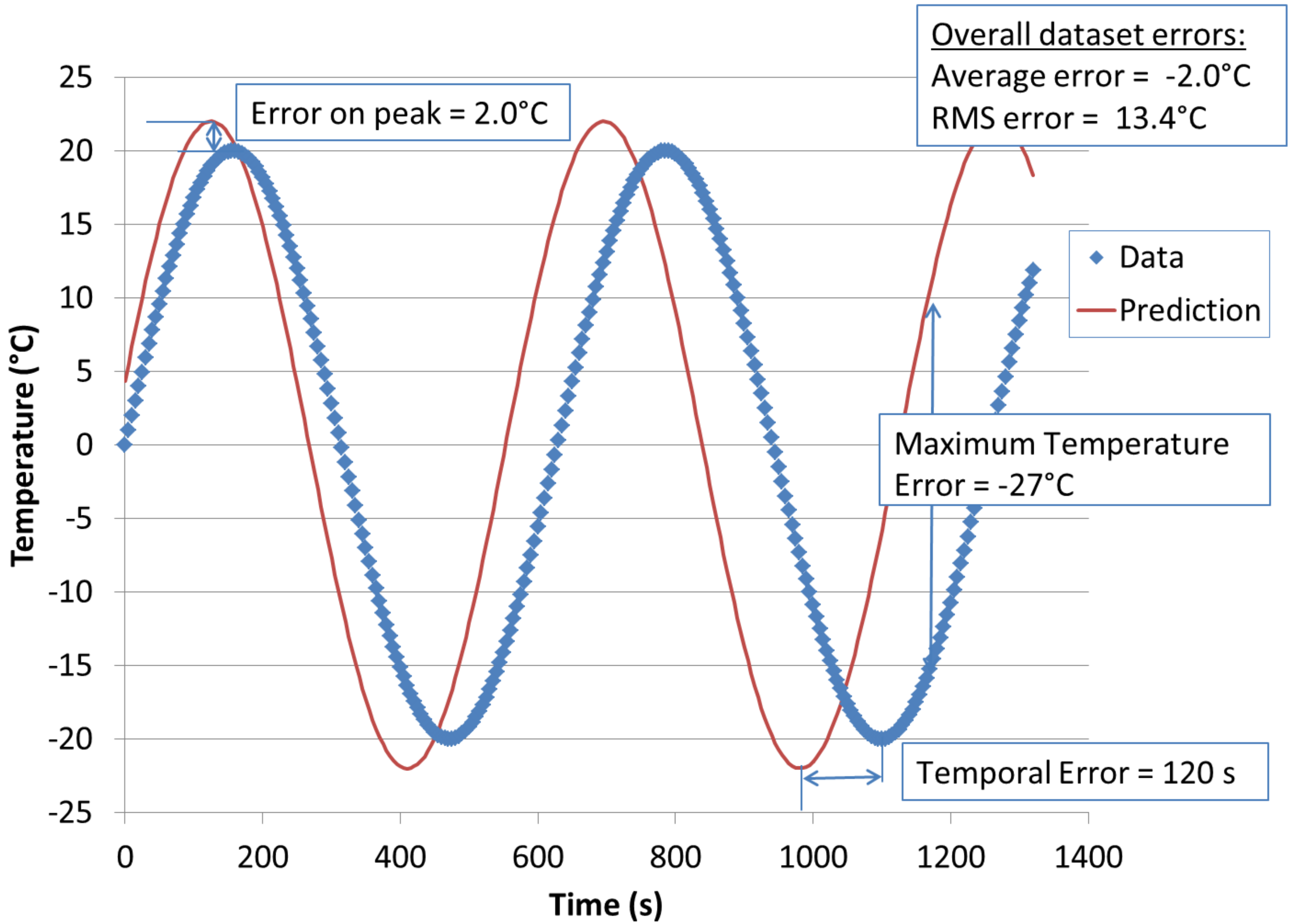


Correlation

Model Correlation

- If possible, correlate to unpowered or heater-only cases first
- Determine your primary correlation goal before starting
- Don’t run steady-state unless it really was (100 year rule)
- Use unpowered cooldowns to check thermal masses
  - Note: Ask for unpowered cooldowns in your test plan
- Use balance to check connections, transient to check thermal masses
- Use RMS or absolute error rather than average
- If your initial conditions are off, can correlate to change in temperature
- If your data is on a fine scale, you can effectively use slope for correlation

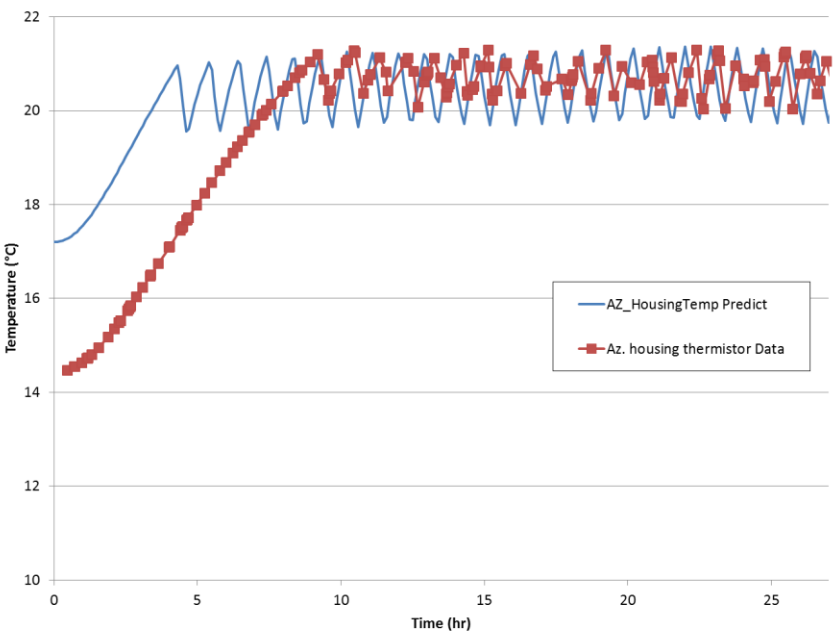
Error Types



Overall dataset errors:
Average error = -2.0°C
RMS error = 13.4°C
Error on peak = 2.0°C
Data
Prediction
Maximum Temperature Error = -27°C
Temporal Error = 120 s
Temperature (°C)
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
200
400
600
800
1000
1200
1400
Time (s)

Heater Correlation

- If center of deadband is off, either heater deadband is wrong or gradient between sensor and heater is wrong
- If size of deadband is off, either thermal mass is wrong, or sensor is wrong distance from heater
- If slope of spikes is off, thermal mass or connection of heater to part is wrong



Model Correlation Files

- Set up a template file which will show you error calculation against your test data
- Refresh that template with each run
- Keep a log that shows progress of correlation and results of each run as far as RMS error and any important nodes
- If possible, maintain all runs made separately in your model, so you can refer back to them
- Look at results graphically in your model once in awhile to ensure things are making sense

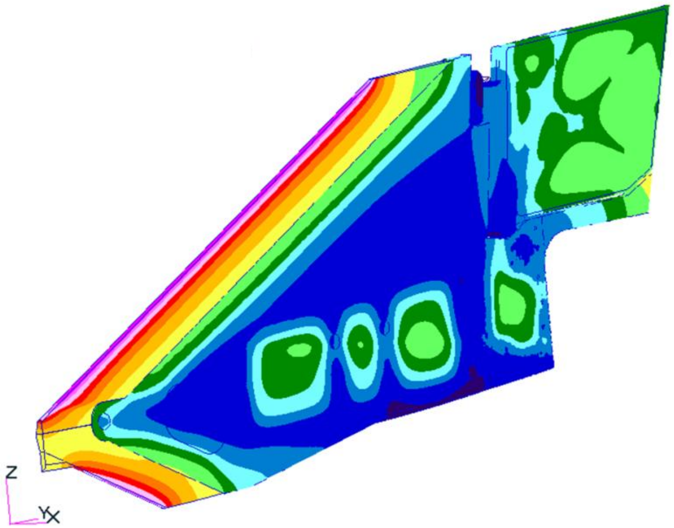
Summary

Summary

- Philosophy
  - Document model, results
  - Use all available data
- Setup / Assumptions
  - Analyze as you test & fly
  - Model checks and hand-calcs
  - Look at the real thing
  - Part limits
- Heat loads
  - Air mass > 0 for on-Earth
  - Aeroheating
- Radiation
  - Surface radiation module
- Convection
  - Finding hc, nodalization
- Contact
  - Contact area
  - Correction for center nodes
  - Visual check
- Materials
  - Measurement
  - Modeling MLI
- Correlation
  - Set up template file
  - Use RMS error
  - Heaters

Conclusions

- Time spent in documentation and checking will pay for itself
- Take the time to think out your scenarios and make sure everything makes sense
- Bounding runs and “what-if” runs are a great way to understand the fundamentals of your model, as are heat flow maps
- Don’t be afraid to ask questions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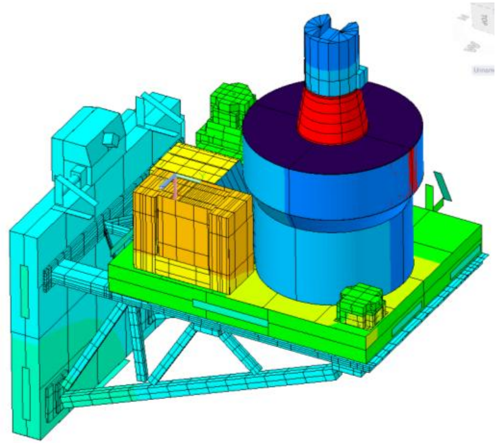
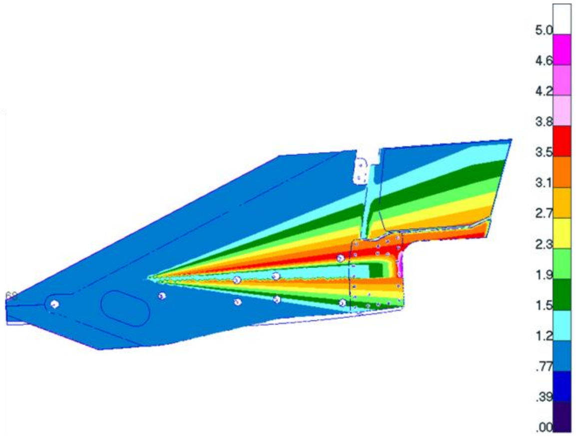
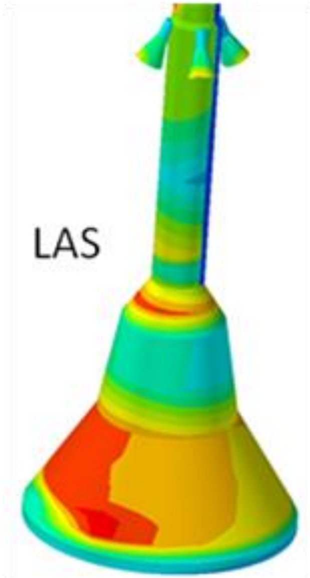
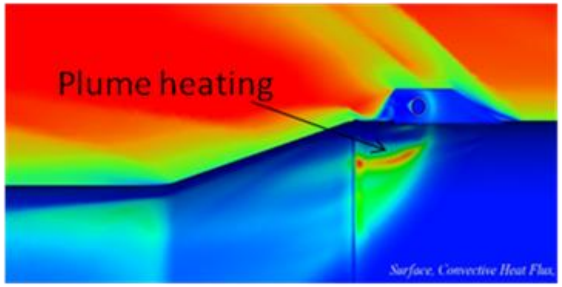
Y
X

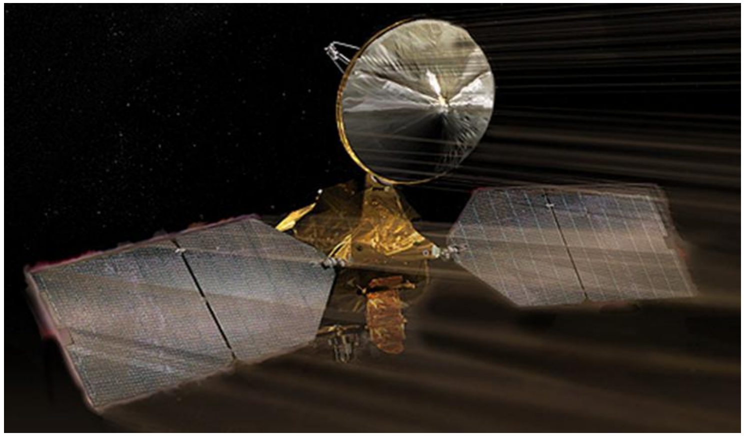



5.0
4.6
4.2
3.8
3.5
3.1
2.7
2.3
1.9
1.5
1.2
.77
.39
.00

Questions?

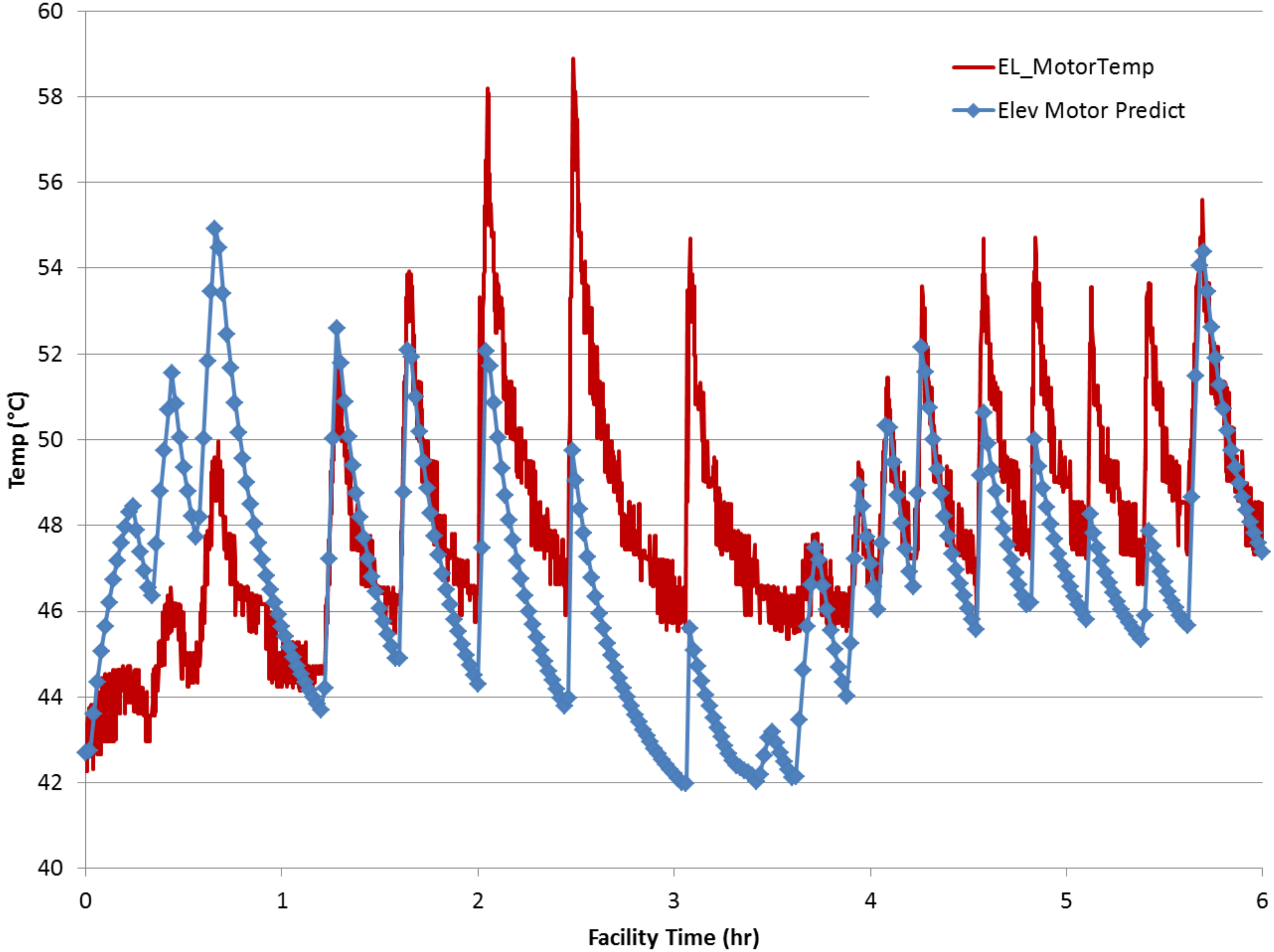

LAS


Plume heating
Surface, Convective Heat Flux



Backup

Initial Correlation to Elevation Motor Events



Final Correlation to Elevation Motor Events