National Aeronautics and Space Administration

Thermal Model Development for Ares I-X

TFAWS-08-1018

Ruth M. Amundsen, Joe Del Corso

NASA Langley Research Center

TFAWS 2008

August 21, 2008

Outline

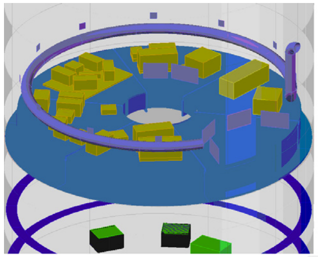
- Background
- Modeling Process
- Lessons Learned
- Aeroheating Application
- Conclusions

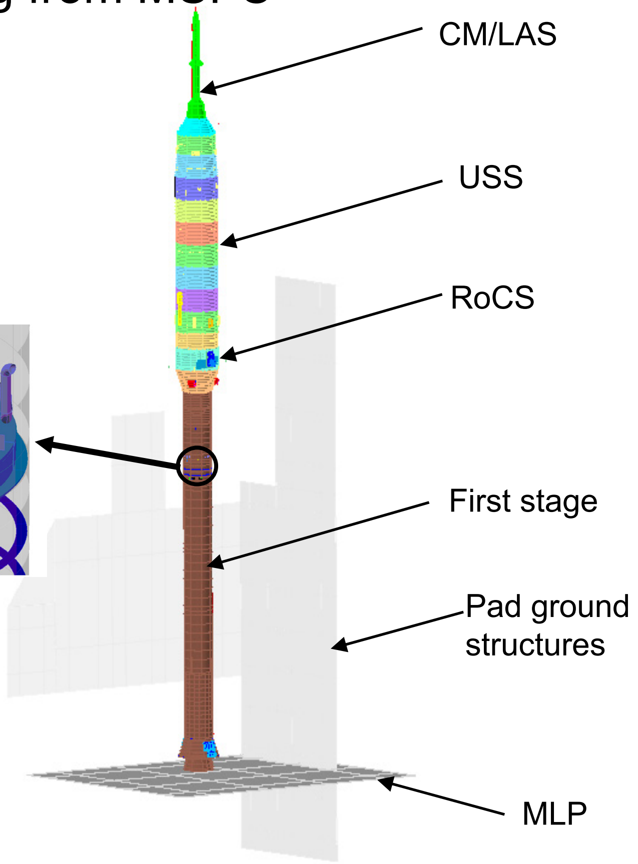
Ares I-X: Background

- **Flight test vehicle for CLV**
- **Operational first stage (SRB)**
- **Active Roll Control System (RoCS) on Upper Stage**
- **Upper Stage, Crew Exploration Vehicle, and Launch Abort System portions**
  - Inactive with representative mass and OML
- **Scheduled launch from KSC April 15, 2009**
- **Developed and built by multiple organizations**
  - JSC, MSFC, LaRC, GRC, KSC, ATK, LMA/ULA, TBE
- **Purpose is to test and measure launch and separation of CLV-style vehicle**

Thermal Model Development

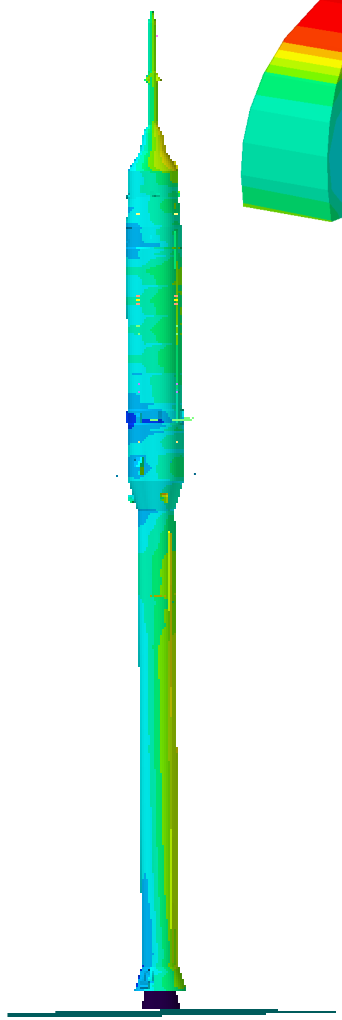
- **Full vehicle model**
  - Model in Thermal Desktop 5.1, Mechanical Desktop 2008
  - Model template and code for applying aeroheating from MSFC
  - CM/LAS and FS models developed at LaRC
  - USS model from GRC
  - FSAM model from LMA
  - RoCS model from TBE
  - Model integration and runs at LaRC



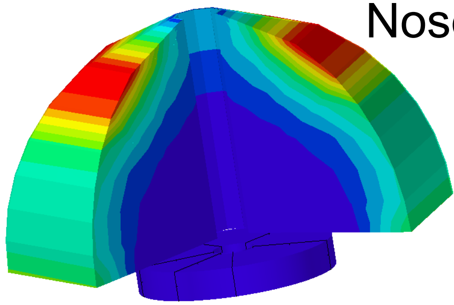


- **Temperatures mapped to NASTRAN for thermal stress analysis**

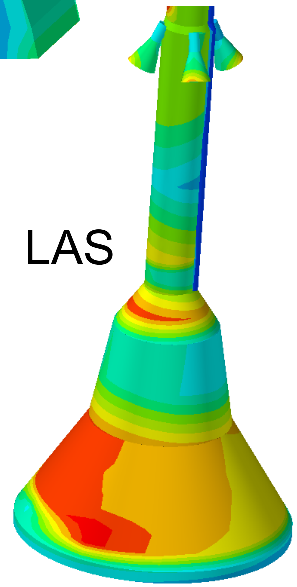
Ares I-X Thermal



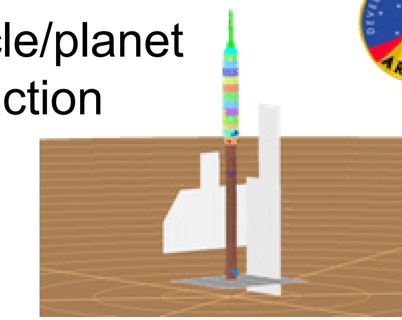
Nose



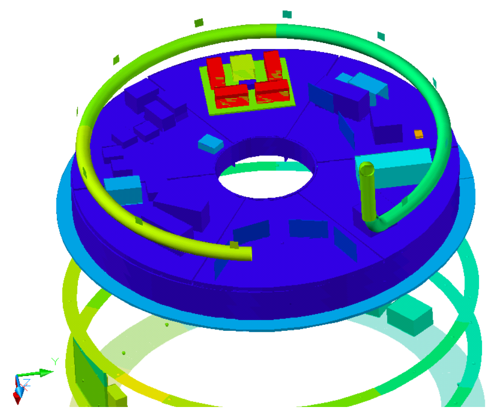
LAS



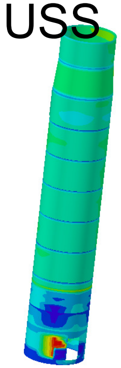
Vehicle/planet interaction



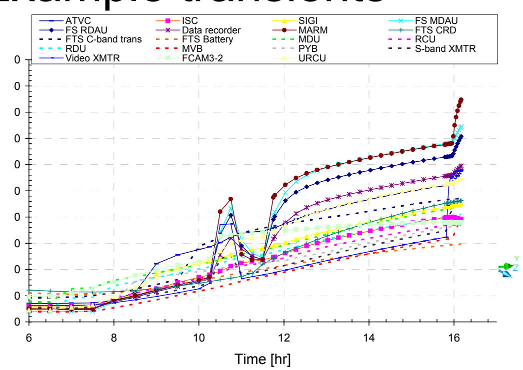
Avionics

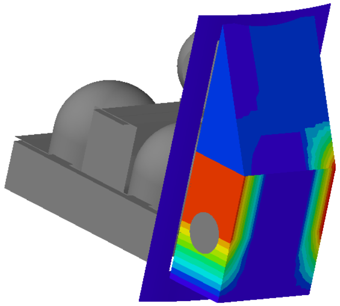


RoCS plume on USS

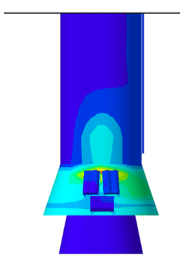


Example transients





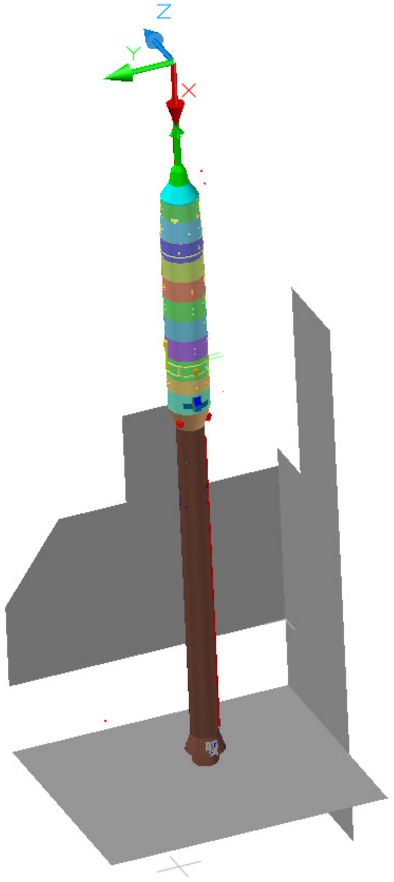
RoCS plume



Aft skirt

Thermal Model Details

- **Full vehicle model includes:**
  - Full 3D exterior vehicle geometry and mass
  - Temperature dependent material properties
  - Solar and earth flux, ambient air and winds (planet modeling method in TFAWS-08-1017)
  - Interior air conduction, convection
  - Internal and external radiation
  - Contact and air exchange between segments
  - Through-thickness gradients
  - Ground structures
  - Ascent aeroheating
  - Avionics size, mass, power
  - ECS, fan, avionics timelines
  - Personnel and lighting powers
  - Aft skirt purge, igniter heater, propellant temp
  - Hot/cold cases
- **7000 nodes**
- **1,781 klb (2% low)**

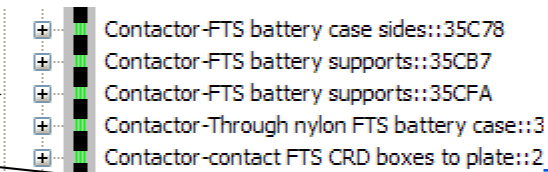


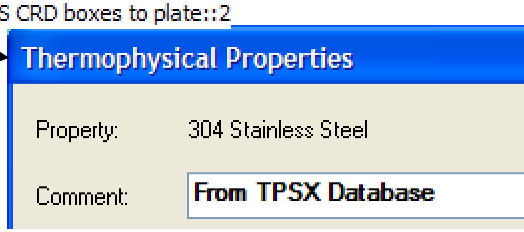
Thermal Cases

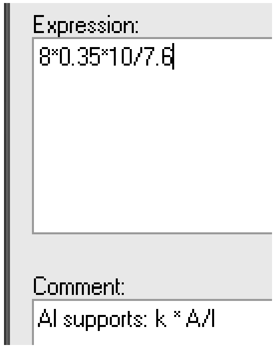
- **Vehicle Assembly Building (VAB)**
  - Ambient from measured thermal data
  - Can run with ECS and avionics on or off
  - Sets start temperature for rollout
- **Rollout**
  - Run for 24 hr following 24 hr in VAB with ECS off
  - Solar and earth radiation load
- **On-pad**
  - ECS/fan functionality, aft skirt purge
  - Solar and earth radiation, avionics power timeline
- **Ascent**
  - Ascent aeroheating, avionics heating
  - Runs 125 seconds
- **Descent**
  - FS only; aeroheating, avionics heating

Modeling Lessons Learned

- **Import of multiple submodels led to greater understanding of how pre-work and model standardization save integration time**
- **Naming**
  - Standardized (e.g., 1st 3 characters of submodel name define segment)
  - Simple
  - Applies to submodels, layers, radiation groups, case sets
- **Limit number of submodels, layers**
- **Comments**
- **Utilities>Notes to comment model**
- **Calculated expressions**
- **Standard coordinate system**
- **Boxes instead of separate surfaces**

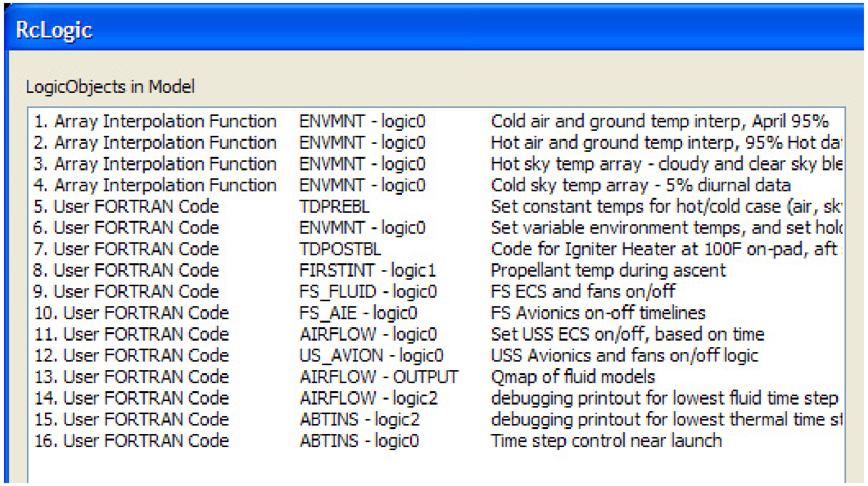






Pre-modeling Coordination

- **Pre-define**
  - Software and version
  - Units
  - Symbols
  - Symbol Groups
  - Coordinate system
  - Planet modeling method
  - Deliverables
- **Use template model file if possible, with**
  - Units
  - Symbols
  - Symbol Groups
  - Coordinate system(s)
  - Material and optical properties
  - Common logic blocks


RcLogic

LogicObjects in Model

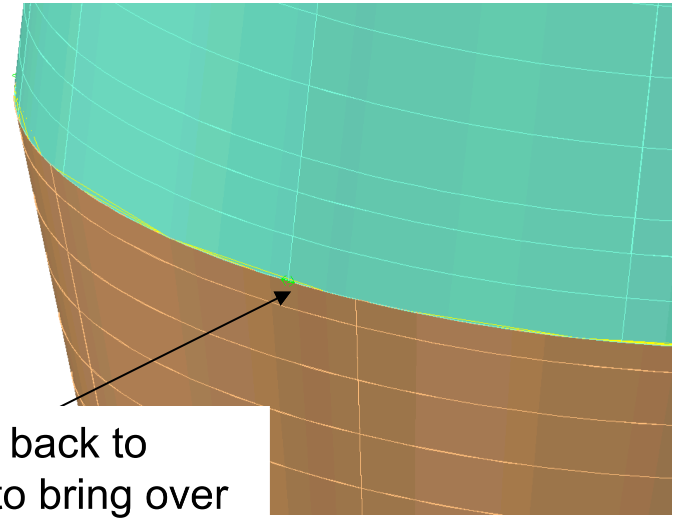
1. Array Interpolation Function	ENVMNT - logic0	Cold air and ground temp interp, April 95%
2. Array Interpolation Function	ENVMNT - logic0	Hot air and ground temp interp, 95% Hot da
3. Array Interpolation Function	ENVMNT - logic0	Hot sky temp array - cloudy and clear sky ble
4. Array Interpolation Function	ENVMNT - logic0	Cold sky temp array - 5% diurnal data
5. User FORTRAN Code	TDPREBL	Set constant temps for hot/cold case (air, sk
6. User FORTRAN Code	ENVMNT - logic0	Set variable environment temps, and set hol
7. User FORTRAN Code	TDPOSTBL	Code for Igniter Heater at 100F on-pad, aft
8. User FORTRAN Code	FIRSTINT - logic1	Propellant temp during ascent
9. User FORTRAN Code	FS_FLUID - logic0	FS ECS and fans on/off
10. User FORTRAN Code	FS_AIE - logic0	FS Avionics on-off timelines
11. User FORTRAN Code	AIRFLOW - logic0	Set USS ECS on/off, based on time
12. User FORTRAN Code	US_AVION - logic0	USS Avionics and fans on/off logic
13. User FORTRAN Code	AIRFLOW - OUTPUT	Qmap of fluid models
14. User FORTRAN Code	AIRFLOW - logic2	debugging printout for lowest fluid time step
15. User FORTRAN Code	ABTINS - logic2	debugging printout for lowest thermal time st
16. User FORTRAN Code	ABTINS - logic0	Time step control near launch

Model Checking

- **Verify submitted model before importing into integrated model**
  - View by thermal & optical props, radiation groups, etc.
  - Run a mass check and make sure the model mass is correct
  - Output SINDA data to check
  - Look for duplicate nodes
  - View active sides
  - Check units (both thermal and fluid submodels)
  - Run submitted model and check results against those submitted

Model Import Process

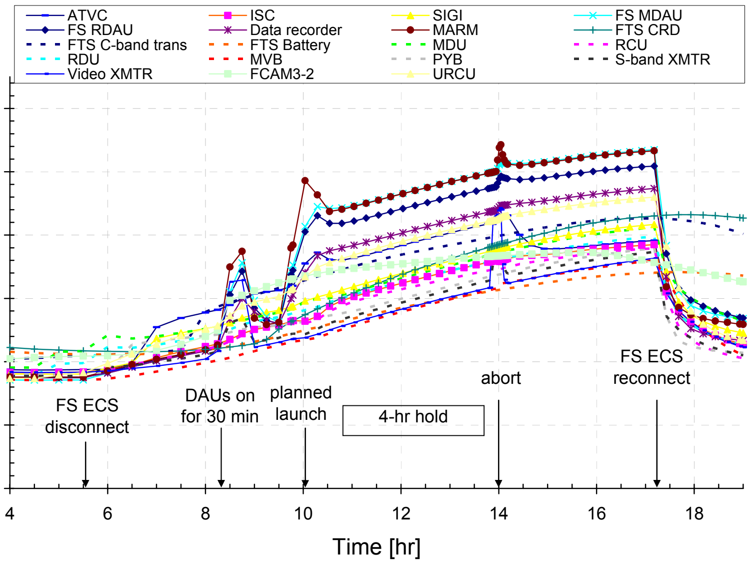
- Run check cases of both integrated and submitted models beforehand; compare to post-integration results
  - SUBMAP or similar useful to check heat flow between submodels
- Multiple steps necessary to ensure correct transfer
- Detailed export/import process steps given in manuscript
  - Tip: to bring over a contactor or conductor and re-attach it, temporarily attach it to something exported
- Consider:
  - Symbols
  - Units and coordinate system
  - Properties and aliases
  - Radiation groups
  - Contactors
  - Correspondence data
  - Logic Manager objects
  - Orbits and case sets
  - Layers



Fold contactor back to imported part to bring over

Model Logic

- **Logic blocks used for all scenarios across multiple cases**
- **Logic actions based on symbols**
  - Hot/cold case, location, hold, abort
  - Sequencing times, power levels
  - ECS flow and temperature
  - Number of personnel

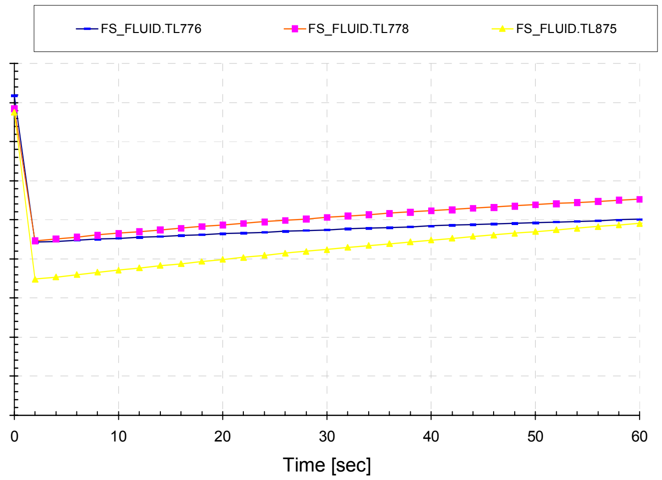


- **Simplifies**
  - Switch between hot/cold case
  - Launch time change
  - Timeline changes
  - Power level changes
  - Sequencing updates
- **Ares I-X examples**
  - STRTIME, RUNTIME, OFFSETL (launch time of day), TIME2L (time remaining until launch), sw_ & pw_ for avionics switching and power, casedef, loc_def, casehold, caseabt, SKY_TMP, AIR_TMP, GND_TMP
  - Symbol naming guidelines (th_, cc_, etc)

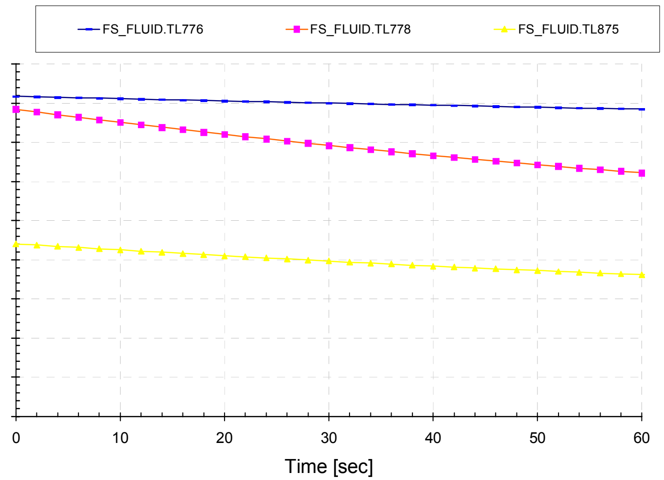
Restarts with Fluid Lumps

- Standard restarts use only thermal node temperatures in restart
- Ares I-X incorporates huge air volumes - 100's of lbs of air
  - Important to capture air state between cases
- Ares I-X method modified to include fluid temps in restart
- TD 5.2 will include this option

Restart with nodes only



Restart with air volumes included

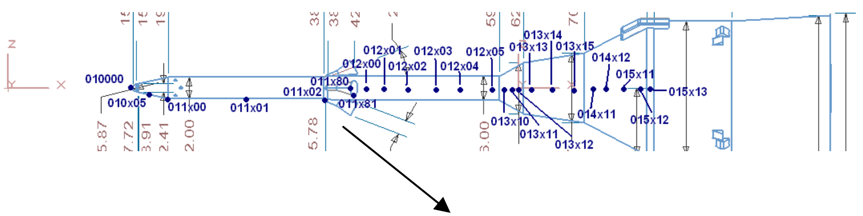


Software Standardization

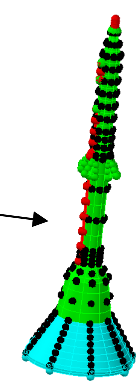
- **Version of software standardized between model developers**
  - Thermal Desktop
  - AutoDesk
- **Compiler version also critical**
  - E.g., built-in (Lahey) versus Intel compilers
  - Compiler settings and defaults
  - Differing compilers between organizations led to different model behavior

Aeroheating Application

- Aeroheating applied to Ares I-X during ascent and descent
- Aeroheating loads supplied in MINIVER text files
  - Enthalpy and convective coefficient at three wall temps at each time
  - Times in 0.5 to 5 sec increments
  - 2000 body points over vehicle
- User logic applied heating during Sinda/Fluint run
  - Interpolation for time, wall temperature
- Manual mapping of body points to TD model time-consuming
- BPMapper code developed for automated mapping

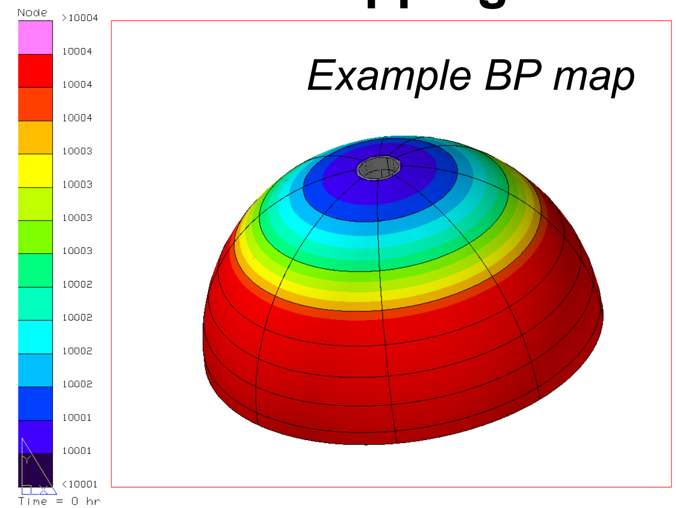


BP	Time	Alt	hc	hc	hc	Hrec	Hwall	Hwall	Hwall	qdotr	hcp	hcp	hcp	Hrecp	Hwallp	Hwallp	Hw
			(0F)	(760F)	(2000F)		(0F)	(760F)	(2000F)		(0F)	(760F)	(2000F)		(0F)	(760F)	(2
	sec	ft	lbm/ft2-s	lbm/ft2-s	lbm/ft2-s	Btu/lbm	Btu/lbm	Btu/lbm	Btu/lbm	Btu/ft2-s	lbm/ft2-s	lbm/ft2-s	lbm/ft2-s	Btu/lbm	Btu/lbm	Btu/lbm	Bt
X10020	0.00	0.00	0.190E-04	0.405E-01	0.391E-01	124.5	110.3	299.8	634.8	0.000	0.000E+00	0.000E+00	0.000E+00	0.0	0.0	0.0	
X10020	5.00	239.30	0.117E+00	0.173E+00	0.167E+00	124.5	110.3	299.8	634.8	0.000	0.000E+00	0.000E+00	0.000E+00	0.0	0.0	0.0	
X10020	10.00	1077.53	0.264E+00	0.260E+00	0.251E+00	124.7	110.3	299.8	634.8	0.000	0.000E+00	0.000E+00	0.000E+00	0.0	0.0	0.0	
X10020	15.00	2598.21	0.332E+00	0.327E+00	0.315E+00	125.2	110.3	299.8	634.8	0.000	0.000E+00	0.000E+00	0.000E+00	0.0	0.0	0.0	

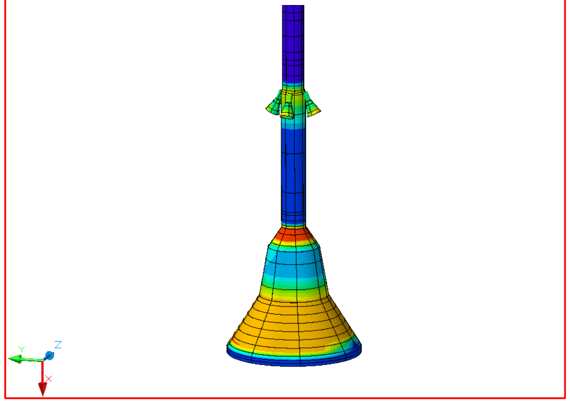


BPMapper

- Maps each TD node to closest body point (BP)
- Divides nodes into clean skin and protuberance for mapping
- Select coordinate transformation
- Define custom mappings
- Lists:
  - Distance and BP for each node
  - All nodes exceeding pre-set error distance
- Rapid remapping for new mesh or model import
- Graphical verification critical
  - BPMapper writes file for graphical verification of BP mapping
  - Sinda/Fluint run writes file for graphical verification of aeroheating map
    - Crucial to verify mapping and aeroheating assumptions



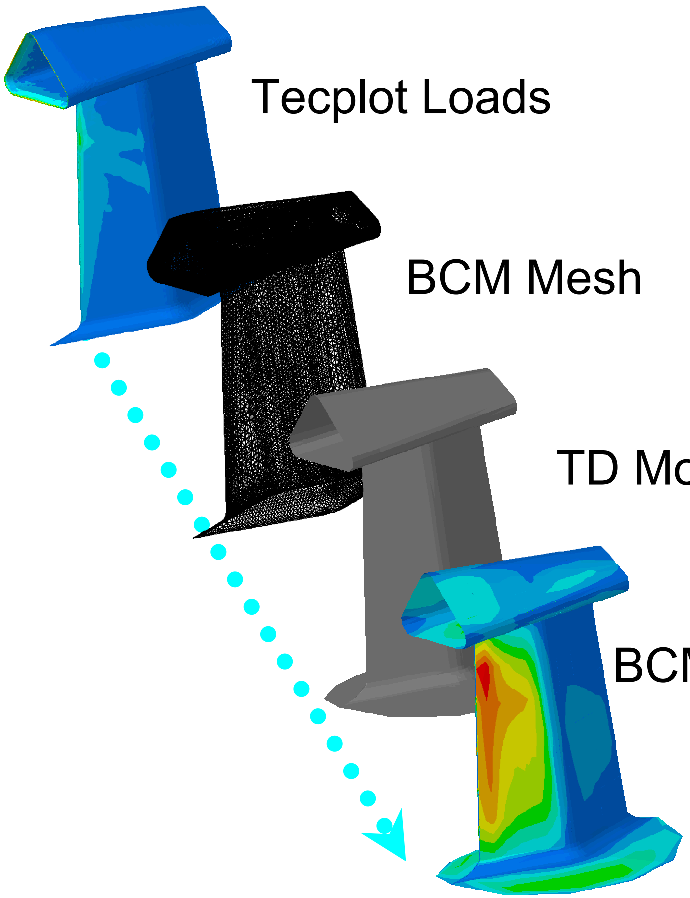
Example BP map



Example aeroheating map

Boundary Condition Mapper for CFD

- **New feature in TD 5.2 for interpolated heating from CFD file**
  - Boundary Condition Mapper (BCM)
- **Map2CFD code developed at LaRC**
  - Imports Tecplot file format
  - Scale, invert, combine multiple geometries
  - Outputs file for TD BCM use
- **Aeroheating loads**
  - Used for thermal run
  - Automatic interpolation for location, time, wall temperature
- **Benefits**
  - Use CFD results directly
  - Avoid mapping single BP to location



Conclusions

- **Pre-model development coordination crucial**
  - Use template file
- **Model standardization saves time and headaches**
- **Consistent model import process developed**
- **Powerful model logic facilitates analysis**
- **Improved aeroheating options developed**
  - BPMapper
  - Map2CFD
- **Graphical aeroheating verification reduces errors**
- **Lessons learned on Ares I-X can be applied to other missions involving import of multiple models**
  - Critical for future Constellation work
  - Useful for others performing large-scale analysis

Acknowledgments

- Aeroheating application software and initial model structure supplied by Mark Wall of NASA MSFC, from CLV US model
- USS model developed by Josh Giegel, Marcus Studmire, Jim Yuko, Bob Christie and Jim Myers of NASA GRC
- RoCS submodels supplied by Preston Beatty (TBE)
- Avionics submodels supplied by Gary Holmstead (LMA)
- The expertise of MSFC personnel in supplying aeroheating (Mark D'Agostino, Craig Schmitz, Jason Mishtawy, and Colin Brooks) is gratefully acknowledged
- The technical support from the team at Cullimore & Ring was outstanding
- The assistance of Tory Scola at NASA LaRC in development of the BPMapper code is gratefully acknowledged