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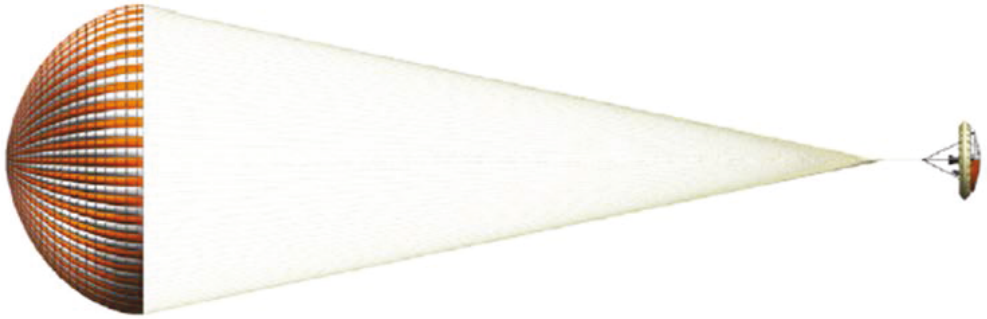

Thermal Design and Analysis of the Supersonic Flight Dynamics Test Vehicle for the Low Density Supersonic Decelerator Project

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Jet Propulsion Laboratory, California Institute of Technology

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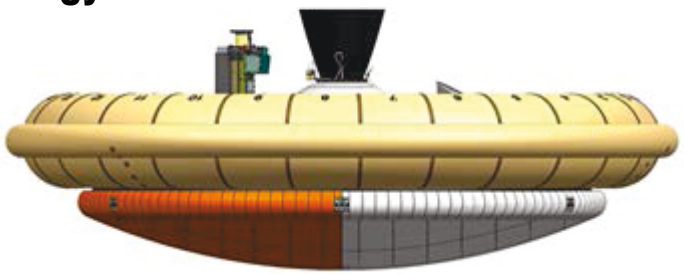


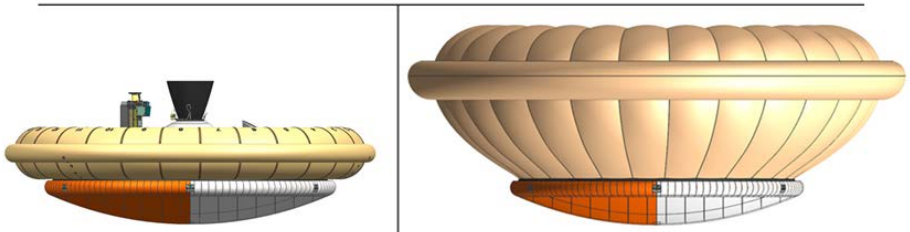
Agenda

- LDSD Project Overview
- SFDT Vehicle Description and Bounding Mission Timelines
- SFDT Thermal Environments
- SFDT Thermal Analysis
  - Thermal Analysis of the Electronics Pallet Assembly
  - Thermal Analysis of the Core Structure Assembly (CSA)
  - Thermal Analysis of the Main Motor Mount
- Conclusions & Acknowledgements

LDSD Project Overview (1/2)

- Charged by NASA's Office of the Chief Technologist to advance the state of the art for Mars EDL
- 3 new EDL technologies under development
  - 33.5 m diameter Ring Sail Parachute
  - Robotic Class SIAD (6 m torus)
  - Exploration Class SIAD (8 m isotensoid)
- Supersonic Flight Dynamics Test (SFDT) Vehicle will provide the experimental platform for testing these new technologies
- Stratospheric tests using helium carrier balloons are planned for the summers of 2014 and 2015 at the PMRF on Kauai, Hawaii

33.5-meter Supersonic Ring Sail Parachute



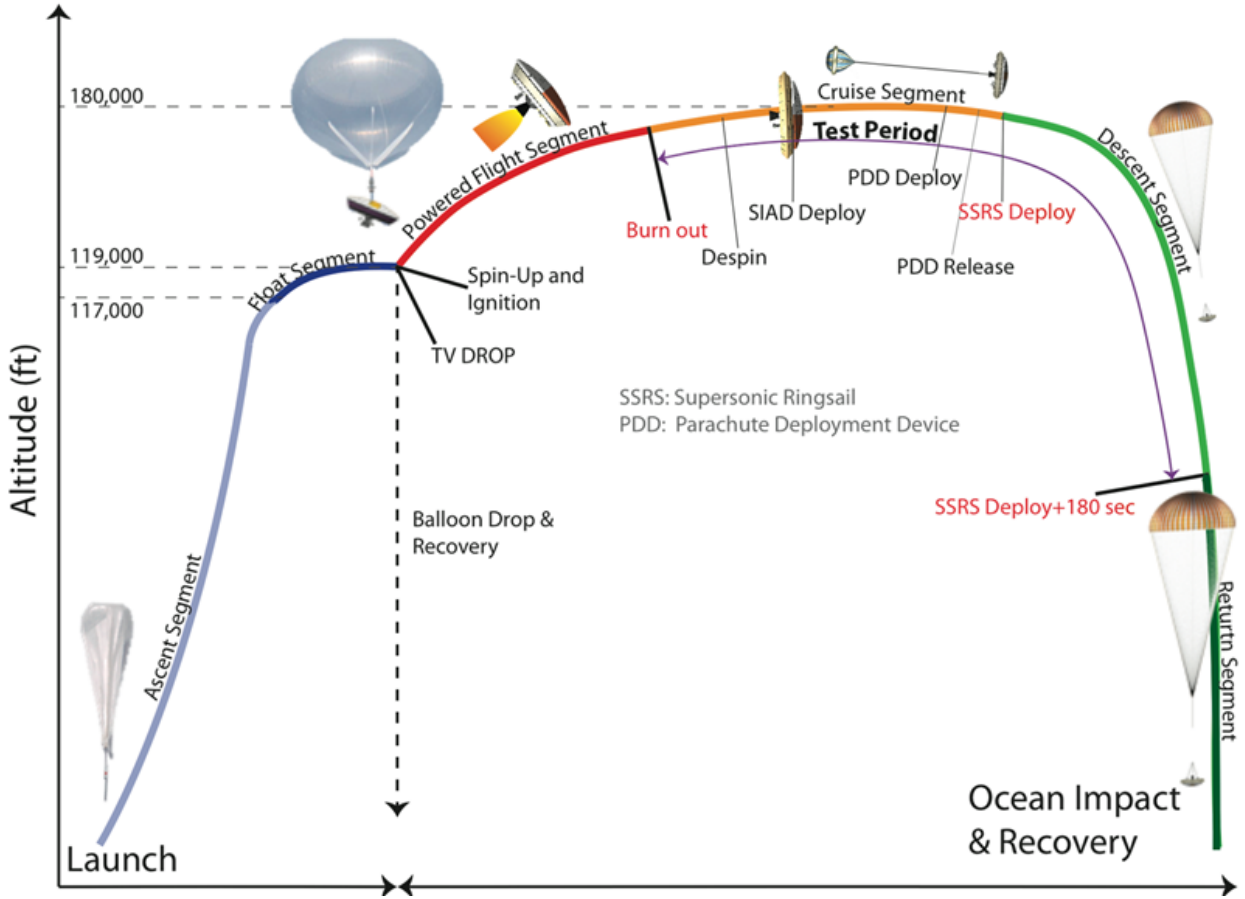
6-meter SIAD-R

8-meter SIAD-E

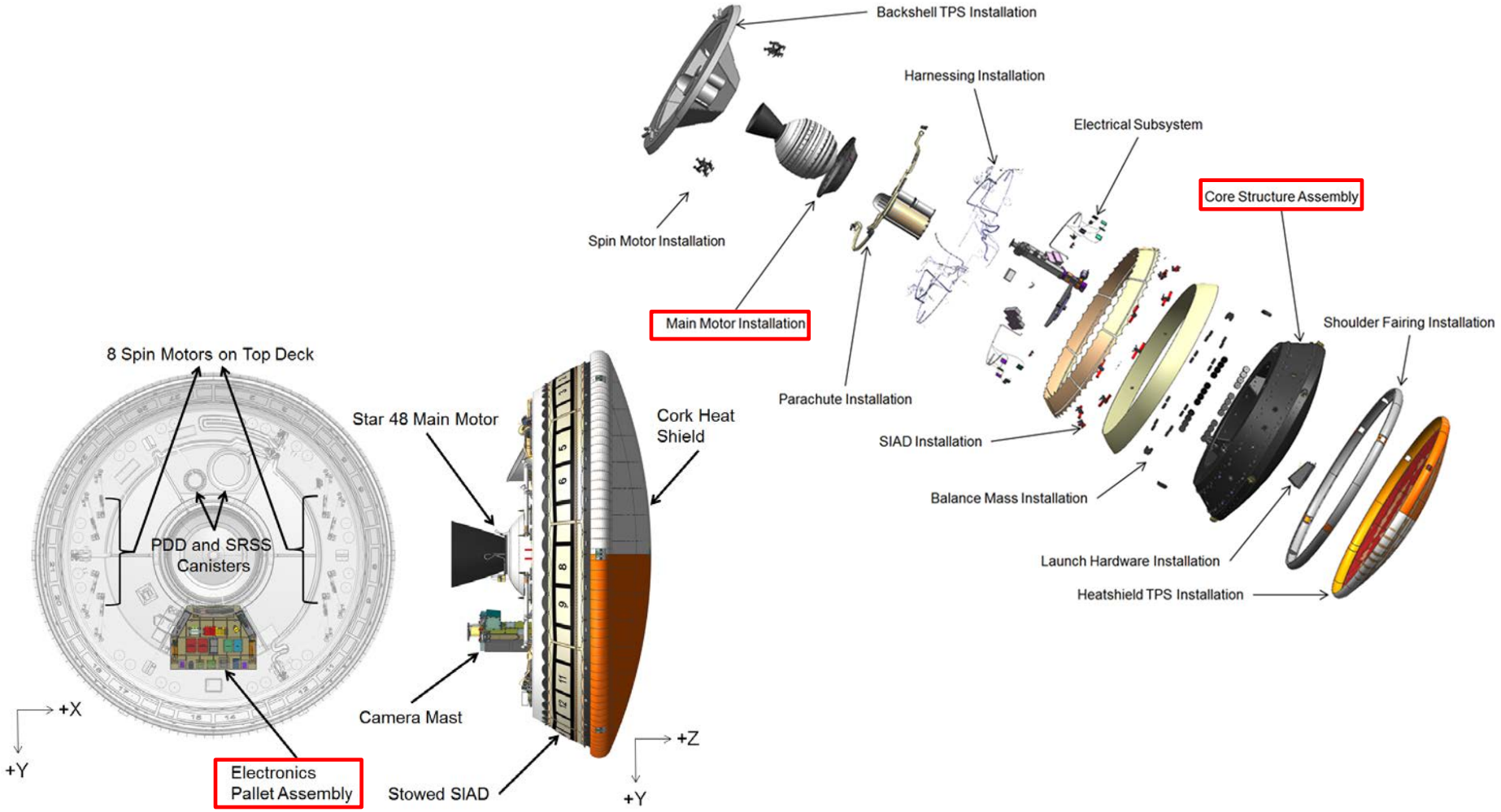
Supersonic **I**nflatable **A**erodynamic **D**ecelerator (SIAD)

LDSD Project Overview (2/2)

Proposed Flight Profile for High Altitude LDSD Tests using the SFDT Vehicle



SFDT Vehicle Description



SFDT Vehicle Bounding Mission Timelines

Definitions for Bounding Thermal Analysis

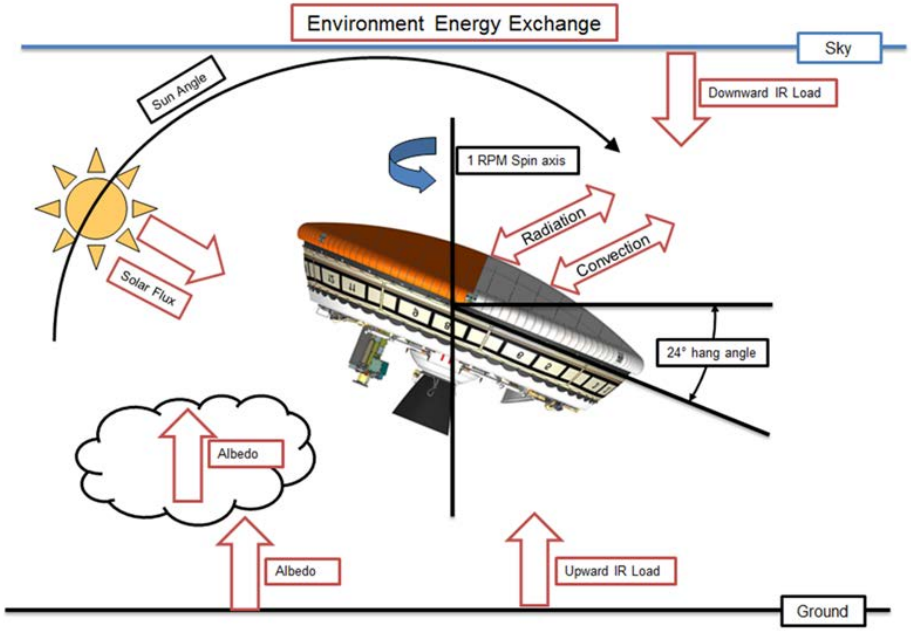
Worst Case Cold (WCC):	Worst Case Hot (WCH):

– longest ascent: 3.75 hr
– shortest float: 2.25 hr
– 6:30 AM launch
– cold boundary conditions
  – Sky Temperature
  – Ground Temperature
  – Ambient Air Temperature
  – Internal/External Convection
  – Solar/albedo
– CBE power
– CBE mass
	– shortest ascent: 2.75 hr
	– longest float: 3.25 hr
	– 8:00 AM launch
	– hot boundary conditions
	  – Sky Temperature
	  – Ground Temperature
	  – Ambient Air Temperature
	  – Internal/External Convection
	  – Solar/albedo
	– PBE power
	– CBE mass

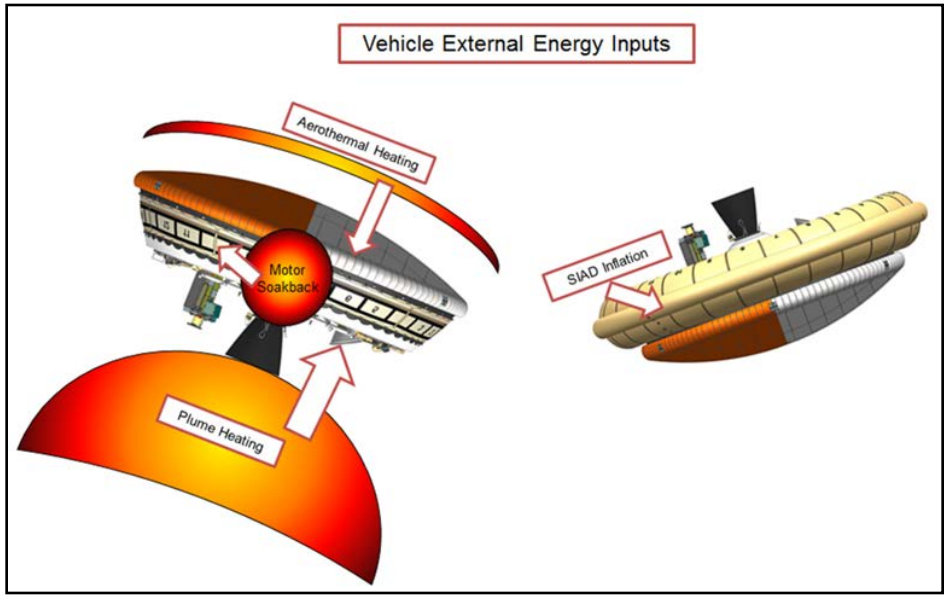
WCH Mission Timeline (8AM Launch)

Mission Phase	Mission Event	Local Time HH:MM:SS	Elapsed Time Sec
Ground Operations	Pre-Lift Checkout, Power ON	4:15:00	0
	Pre-Lift Checkout, Power OFF	5:00:00	2700
	Vehicle Transfer	5:01:00	2760
	Post-Lift Checkout Power ON	6:00:00	6300
	Post-Lift Checkout Power OFF	6:30:00	8100
	Balloon Inflation	6:31:00	8160
	Pre-Launch Power ON	7:30:00	11700
Ascent	Launch	8:00:00	13500
Float	Float Start	10:45:00	23400
	Pre-Release Power ON 1	10:46:00	23460
	Power Down and Hold 1	11:31:00	26160
	Pre-Release Power ON 2	12:01:00	27960
	Power Down and Hold 2	12:46:00	30660
	Pre-Release Power ON 3	13:16:00	32460
	Release	14:01:00	35160
Powered Flight	Spin Up Motor Burn	14:01:00	35160
	Main Motor Burn	14:01:01	35162
	Spin Down Motor Burn	14:02:13	35233
Test	SIAD Deployment	14:02:52	35272
	PDD Deployment	14:04:29	35369
	SSRS Deployment	14:04:43	35383
Recovery	Splashdown	14:51:35	38195

SFDT Thermal Environments (1/3)



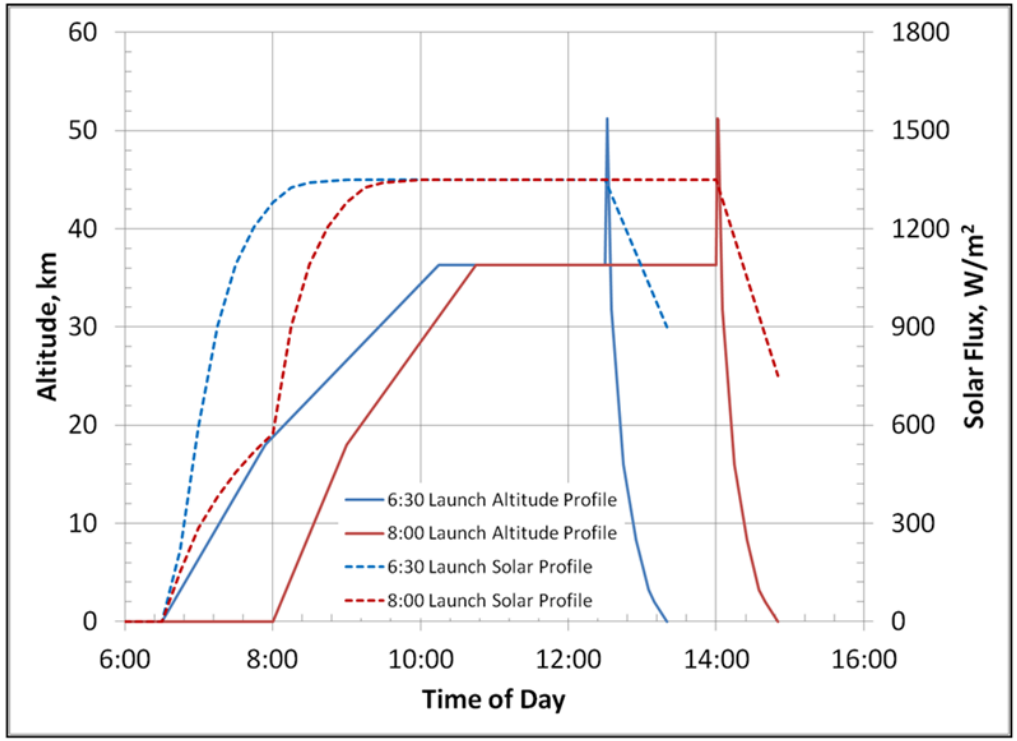
Ascent/Float Configuration



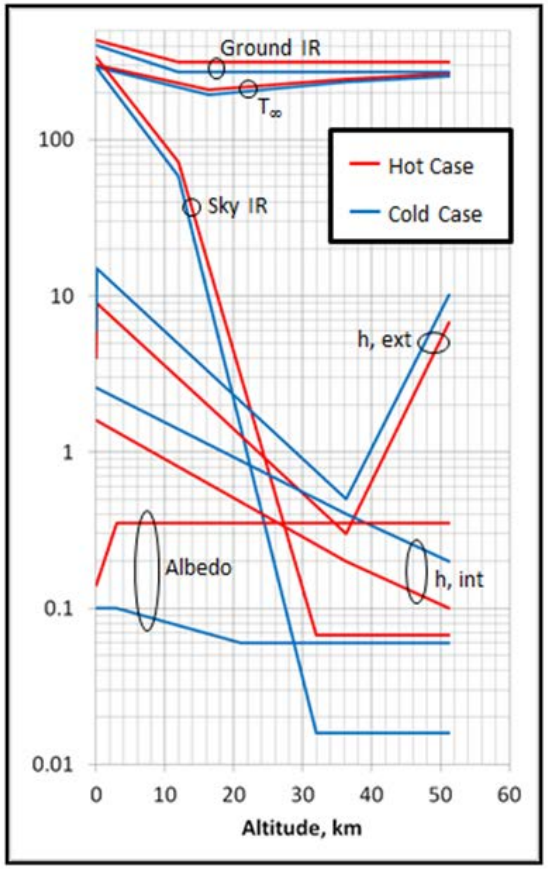
Powered Flight/Test Configuration

SFDT Thermal Environments (2/3)

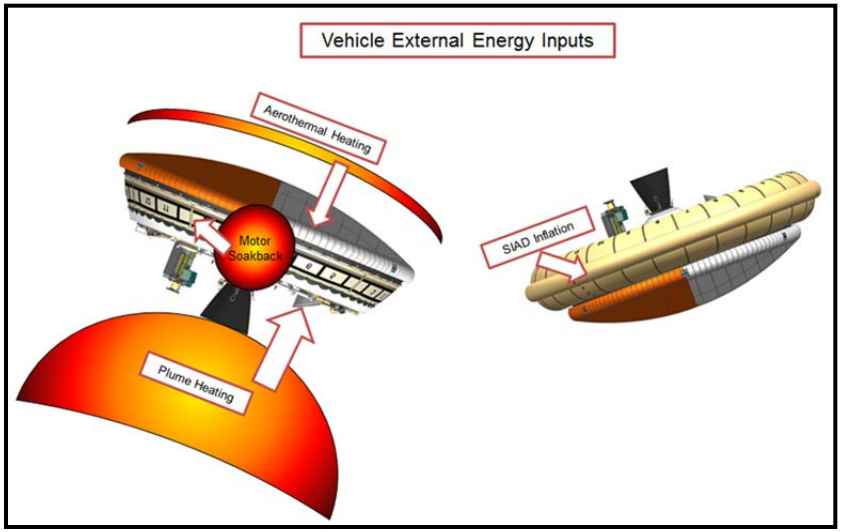
Altitude and Direct Solar Flux vs. Time



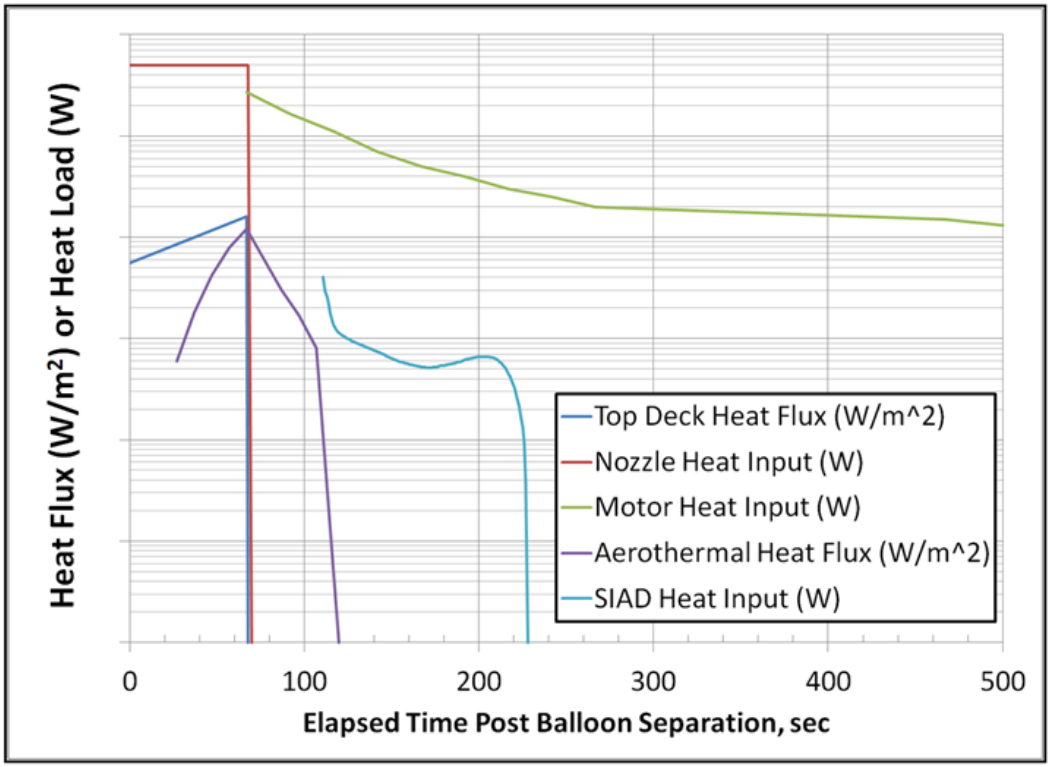
Vertical Axis Units:
Ground IR: W/m²
Sky IR: W/m²
T_∞: K
h, ext, int: W/m²K
Albedo: none



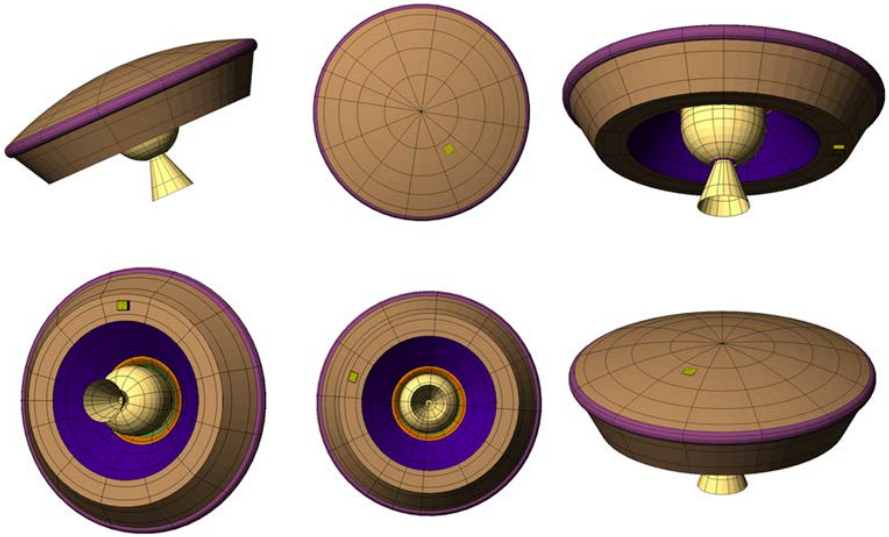
SFDT Thermal Environments (3/3)



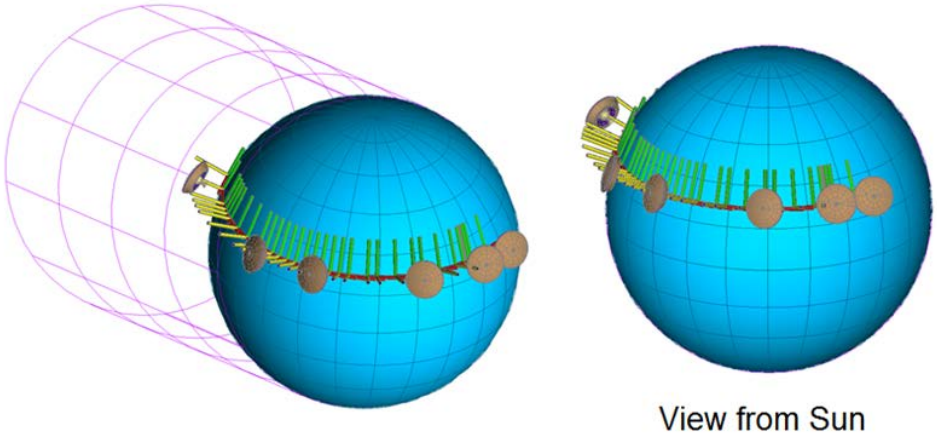
During Powered Flight & Test Phases



SFDT Thermal Analysis

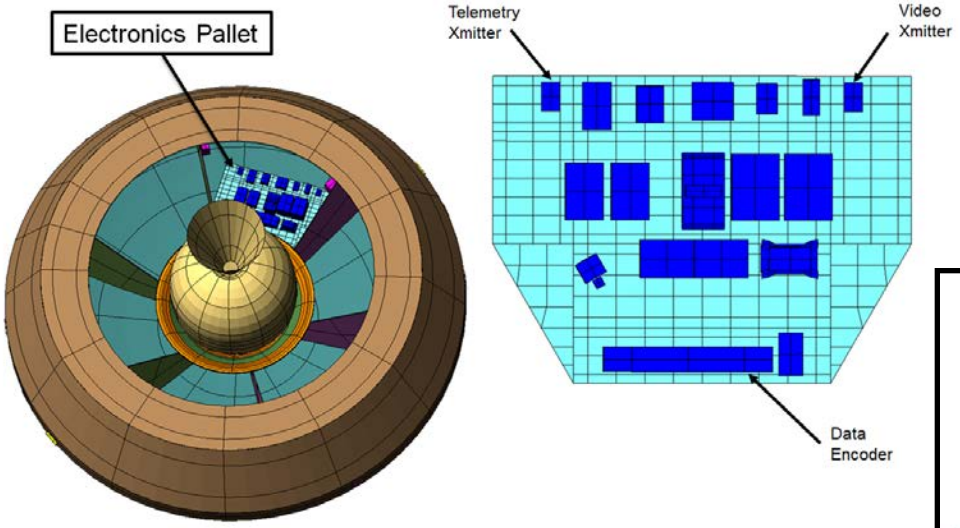


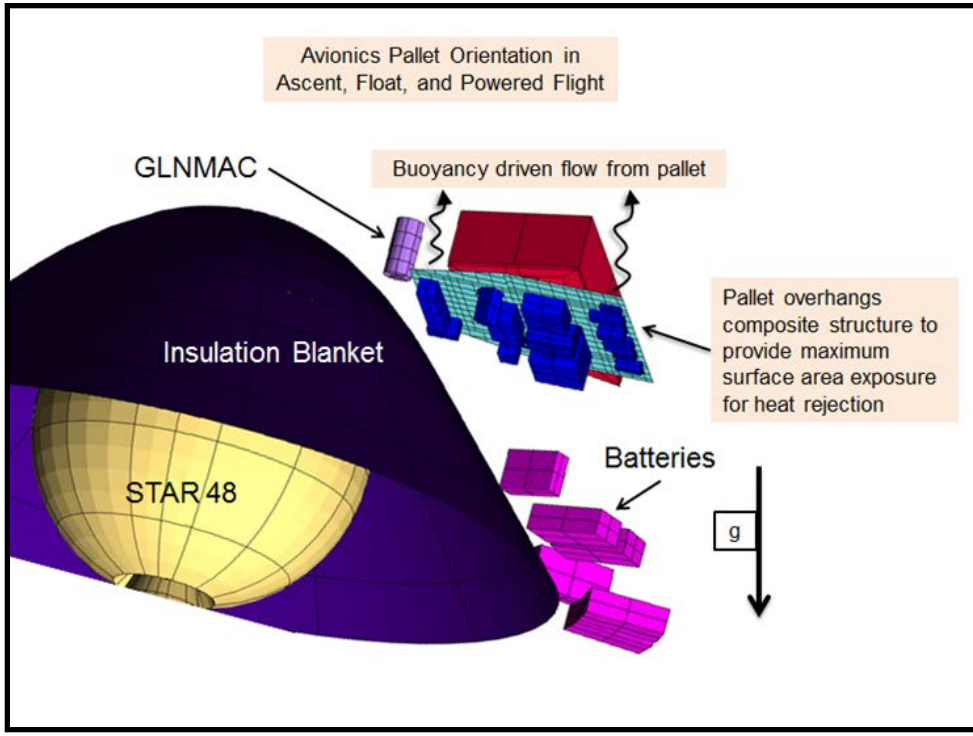
Thermal Desktop® Model of SFDT Vehicle



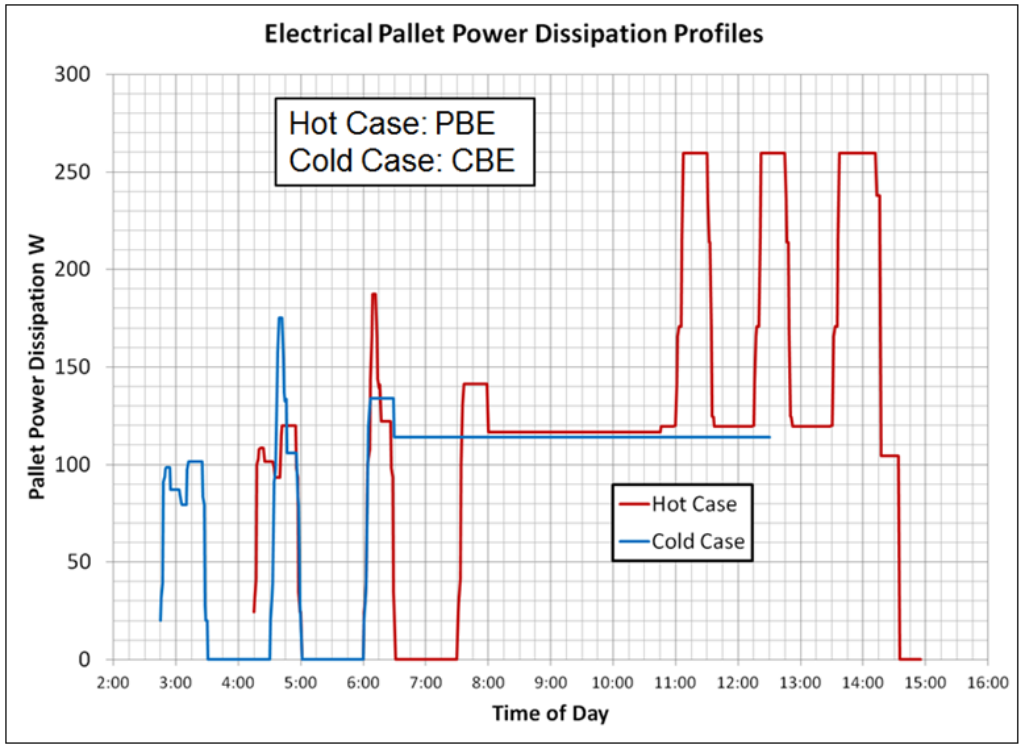
Longitude, Latitude, and Altitude Trajectory Positions

Thermal Analysis of the Electronics Pallet (1/4)





Thermal Analysis of the Electronics Pallet (2/4)

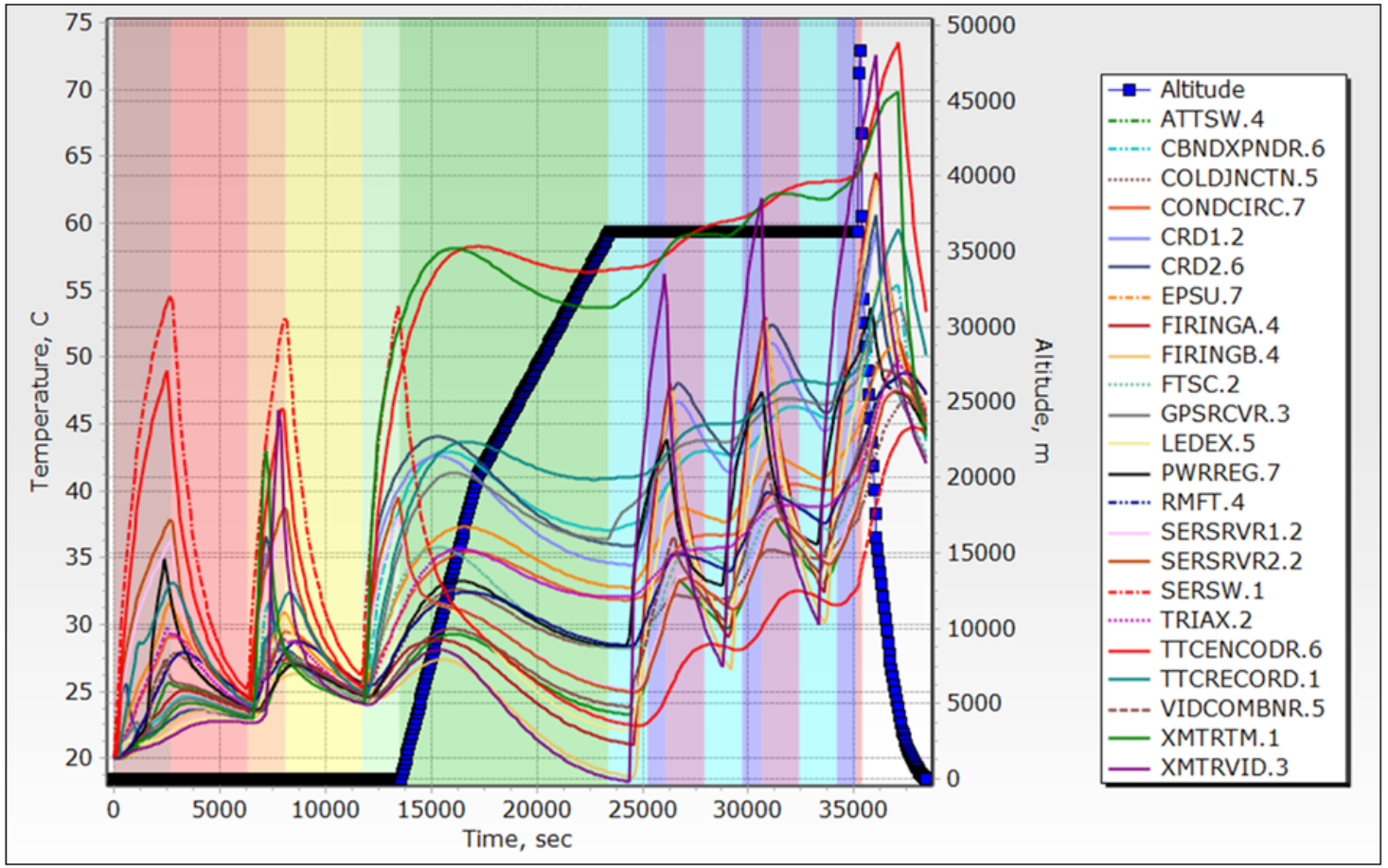


Pallet Components Temperature Requirements

SFDT Hardware Thermal Submodel Name	Temperature Requirements, C			
	Allowable Flight			
	Operational		Nonoperational	
	min	max	min	max
Wallops On-Pallet Components				
ATTSW	-39	51	-39	51
CBNDXPNDR	-25	61	-47	75
COLDJNCTN	-40	130	-40	130
CONDCIRC	-25	65	-25	65
CONDCIRC	-14	51	-44	75
CRD1	-39	65	-47	75
CRD2	-39	65	-47	75
EPSU	-25	65	-25	80
FIRINGA	-25	65	-25	65
FIRINGB	-25	65	-25	65
FTSC	-14	51	-24	61
GPSRCVR	-20	55	-25	65
LEDEX	-40	60	-40	60
PWRREG	-20	65	-25	80
RMFT	-14	51	-44	75
SERSRVR1/SERSRVR2	-25	60	-25	65
SERSW	-25	55	-25	65
TRIAX	-40	90	-40	90
TTCENCODR	-40	85	-40	85
TTCRECORD	-20	65	-40	65
VIDCOMBNR	-5	60	-5	60
XMRTVID	-40	85	-40	85
XMTRTM	-40	85	-40	85

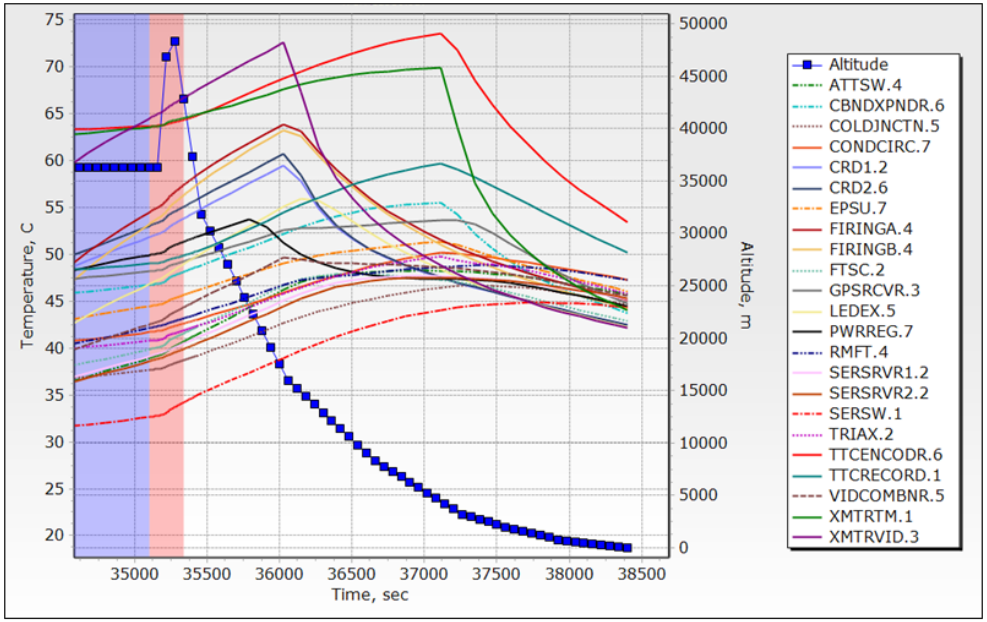
Thermal Analysis of the Electronics Pallet (3/4)

WCH Results

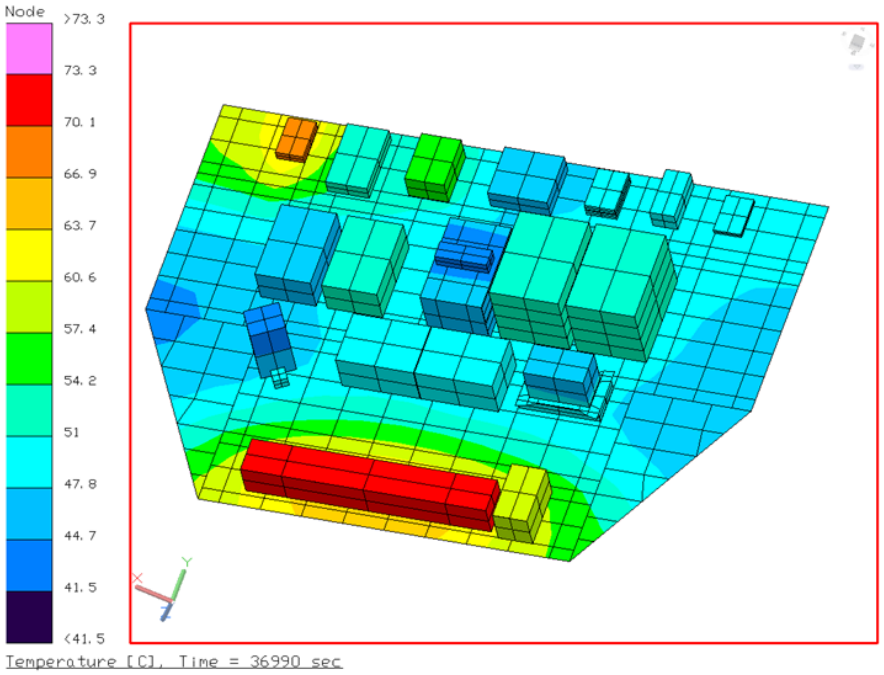


Thermal Analysis of the Electronics Pallet (4/4)

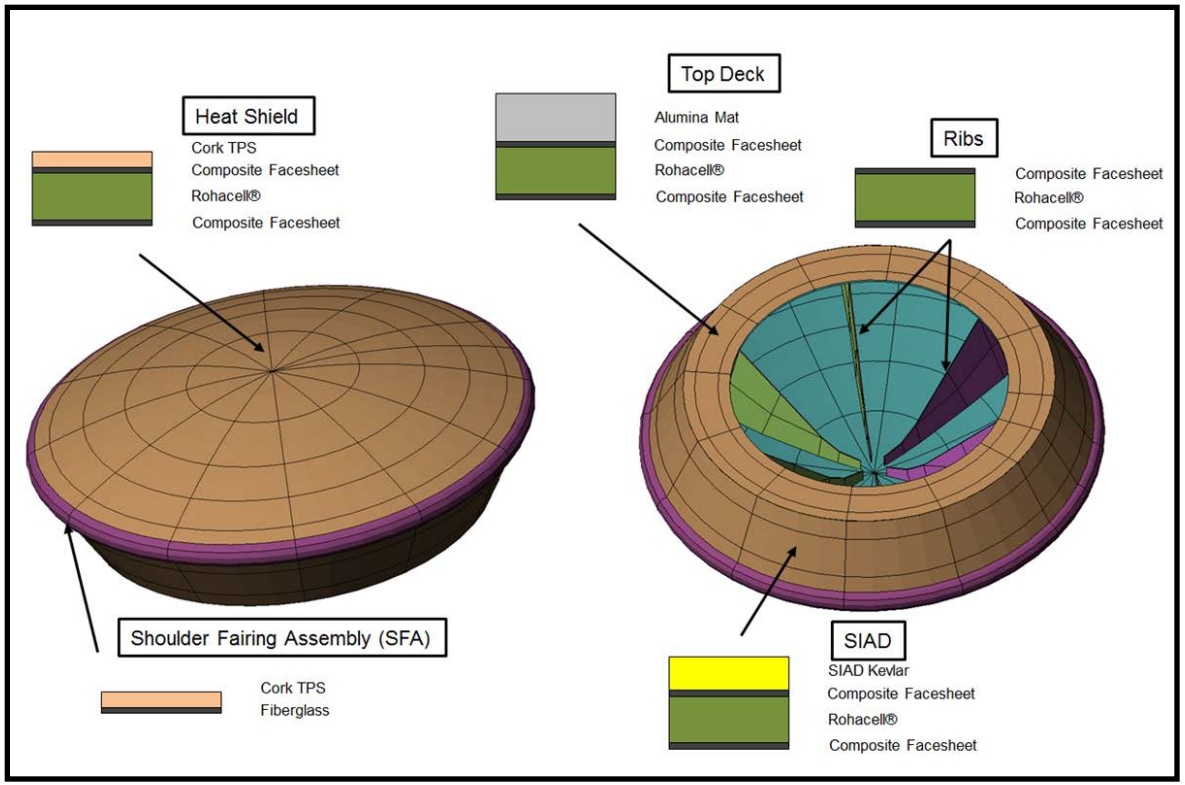
WCH Results During and After Powered Flight Phase

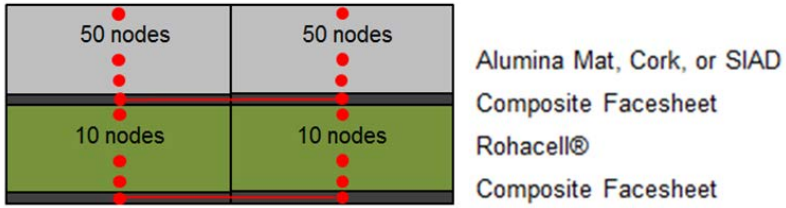


Contour Plot at Time of Peak Temperature for the Data Encoder



Thermal Analysis of the Core Structure Assembly (1/4)

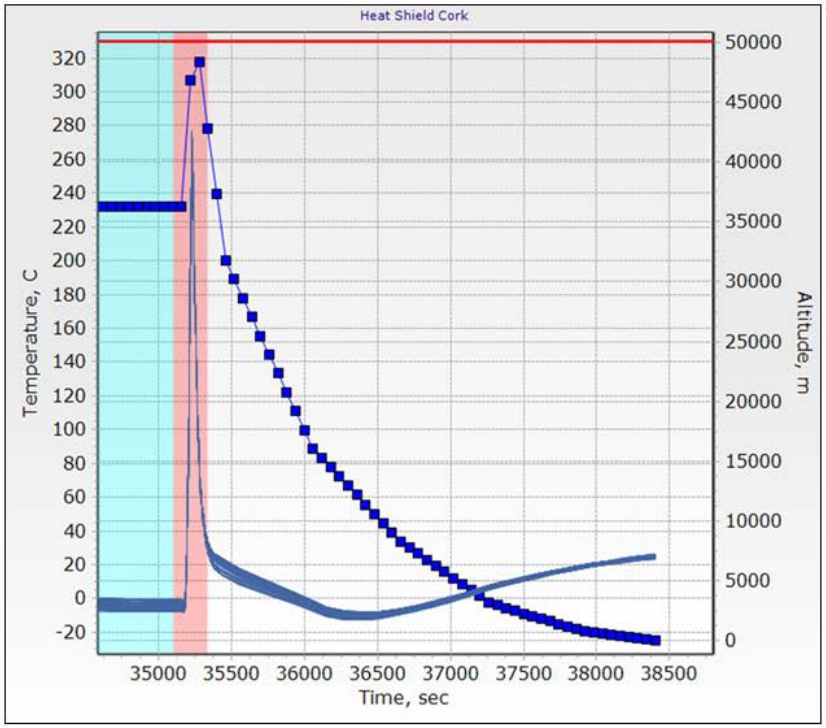




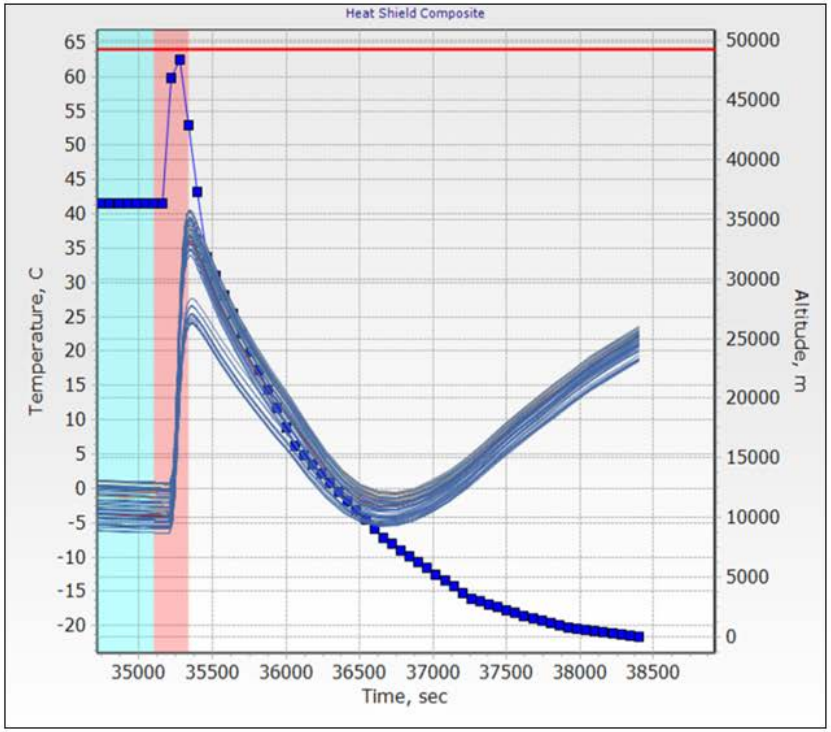
Appropriate nodal fidelity is critical through thickness of low thermal diffusivity material

Thermal Analysis of the Core Structure Assembly (2/4)

WCH Results



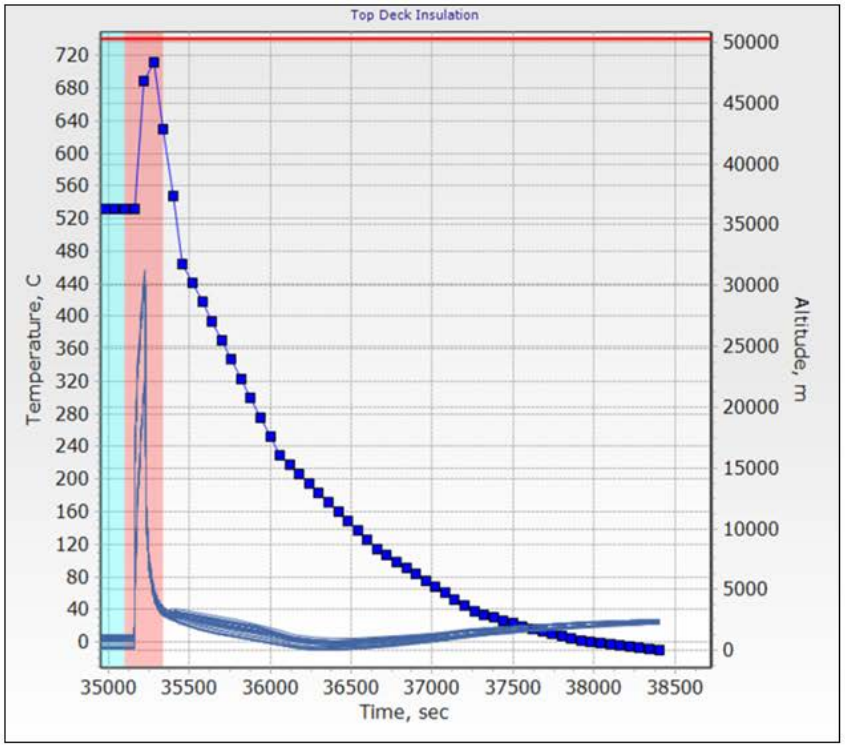
Heat Shield Outer Cork Layer



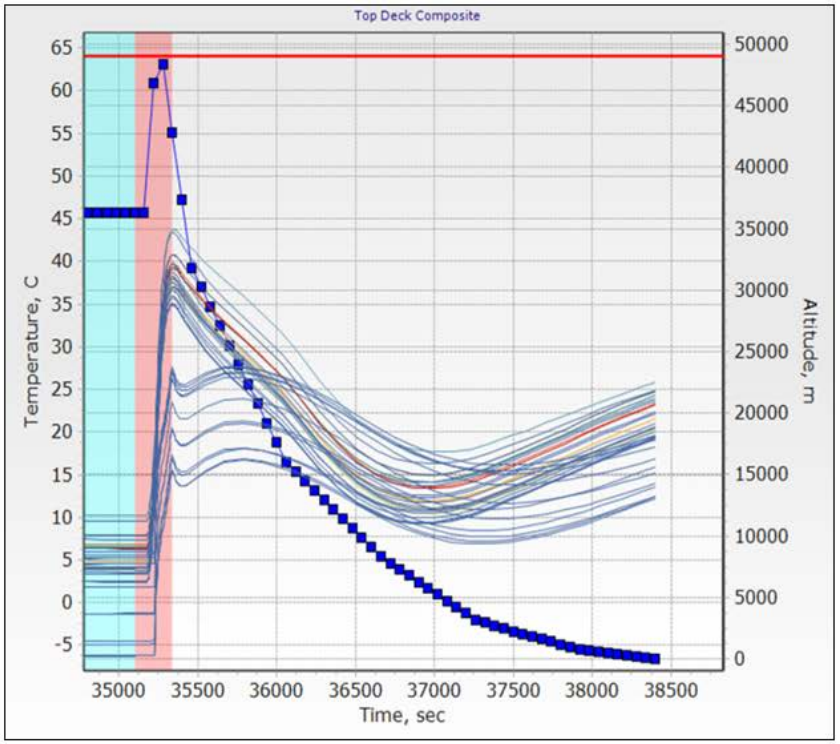
Exterior Composite Facesheet Underneath Heat Shield

Thermal Analysis of the Core Structure Assembly (3/4)

WCH Results



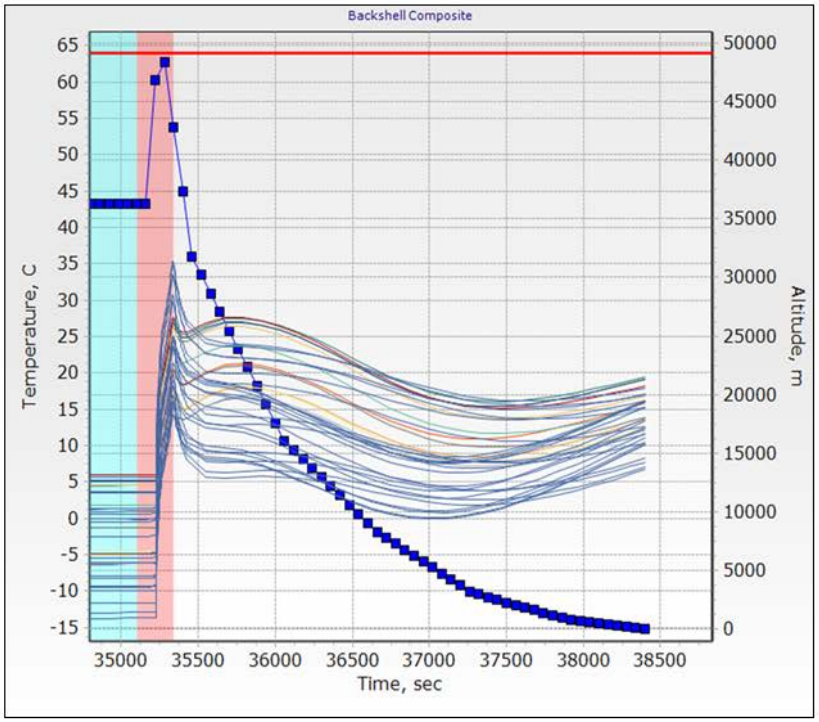
Top Deck Outer Insulation Layer



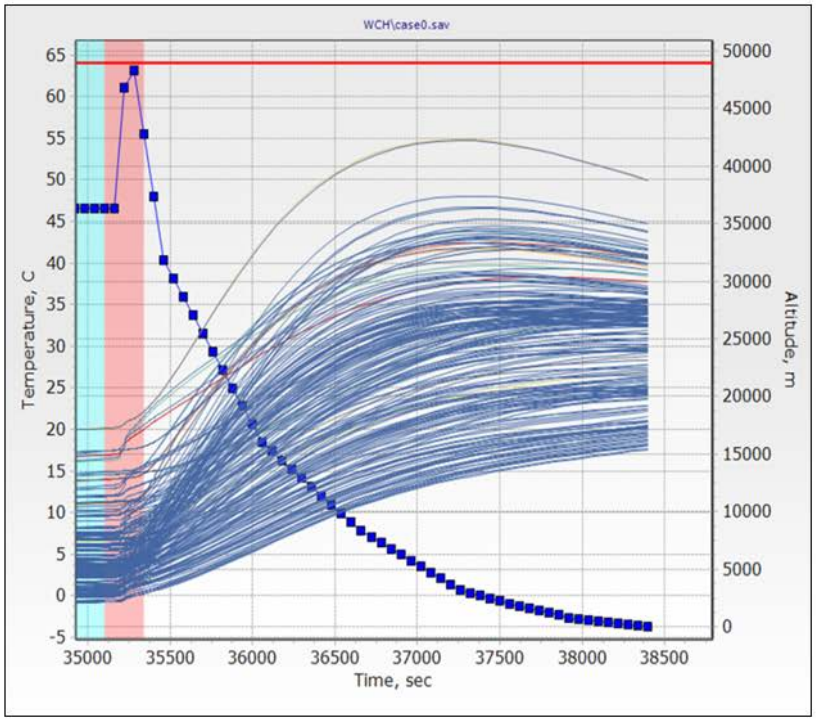
Top Deck Exterior Composite Facesheet Underneath Insulation

Thermal Analysis of the Core Structure Assembly (4/4)

WCH Results

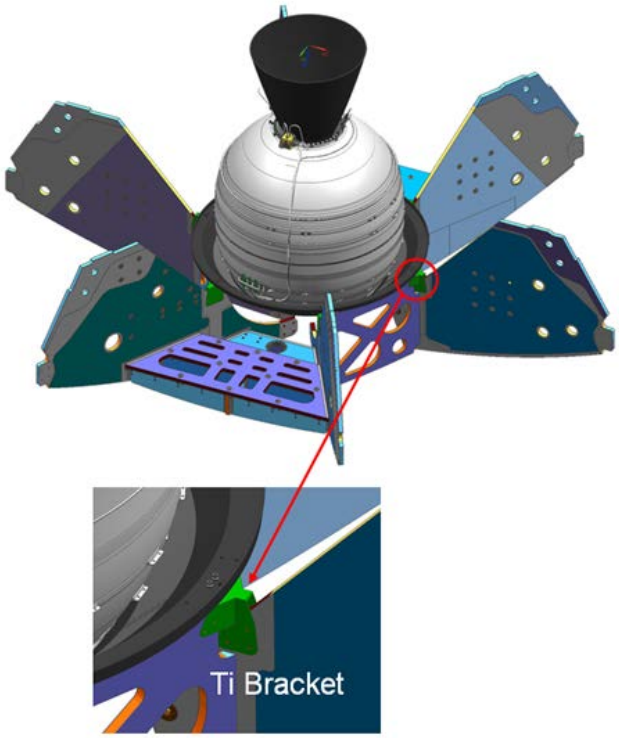


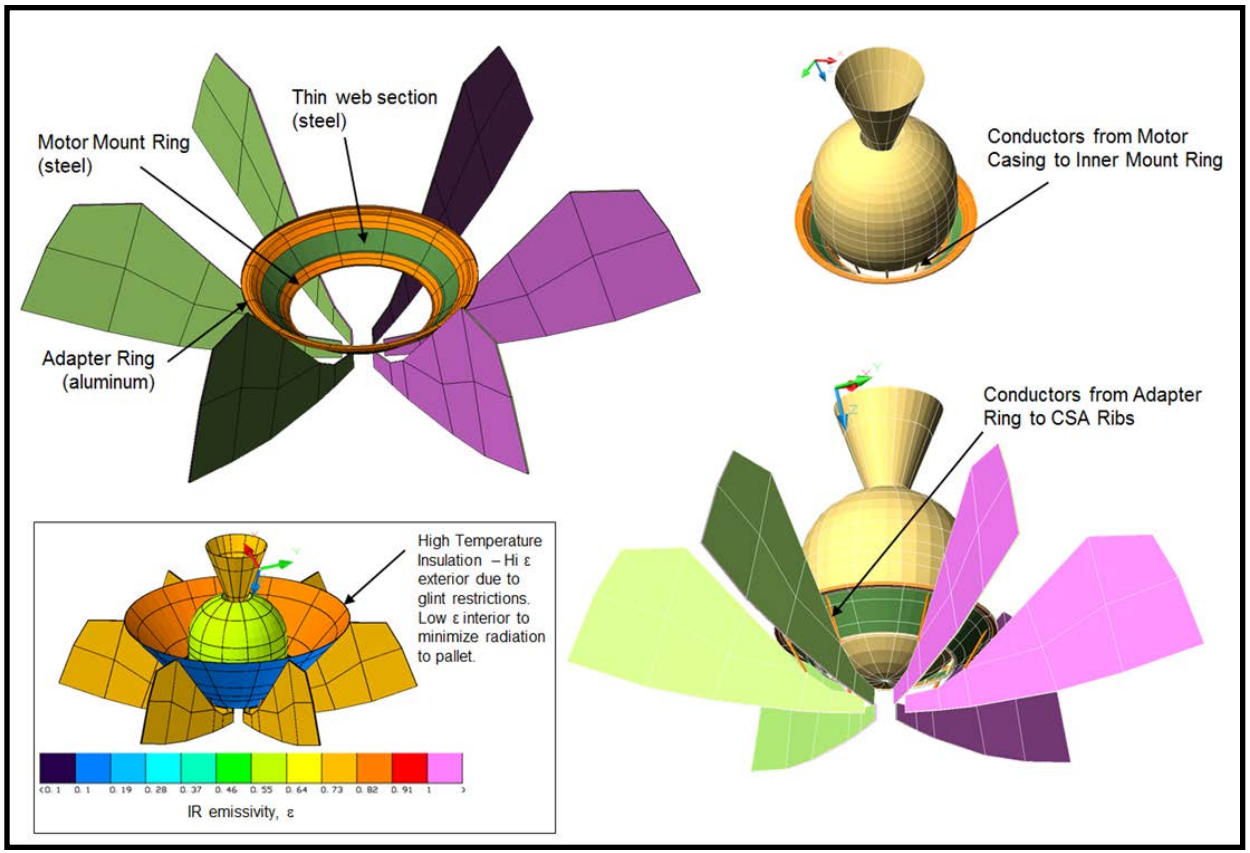
Exterior Composite Facesheet Underneath SIAD



Interior Ribs

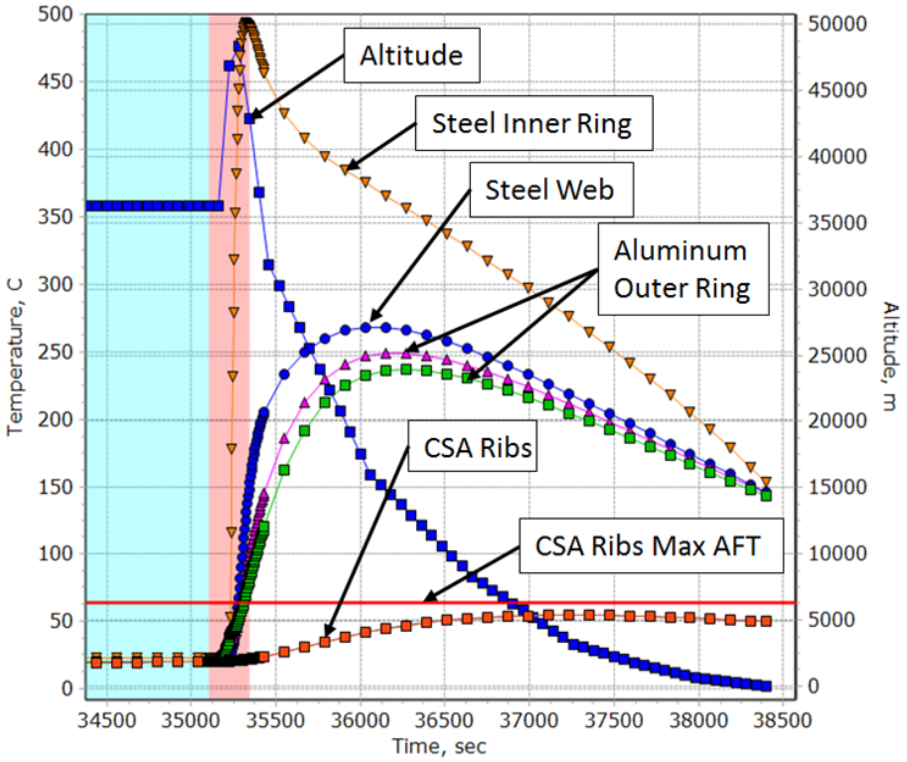
Thermal Analysis of the Main Motor Mount (1/2)

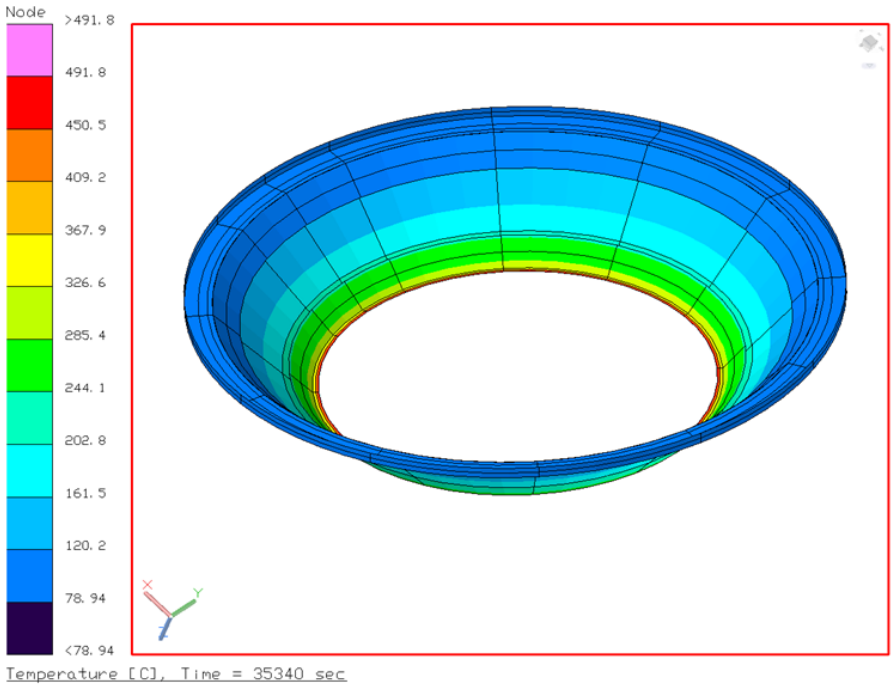




Thermal Analysis of the Main Motor Mount (2/2)

WCH Results





Conclusions

- Thermal design of the primarily composite SFDT vehicle has been extremely challenging due to multiple complex and highly transient heat loads that must be passively mitigated.
- A passive thermal design approach was analytically verified for the Electronics Pallet Assembly, the Core Structure Assembly, and the Main Motor Mount; all components are currently predicted to meet their allowable flight temperature limits.

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The development described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors express their thanks to NASA's Office of the Chief Technologist for supporting this effort and enabling a select few to push the envelope. The authors wish to thank several of their colleagues at JPL who have been instrumental to the thermal design task at hand: Brant Cook, Kevin Burke, John Luke Wolff, Steven Schroeder, George Chen, Jason Gates, Mark Duran, Gabriel Molina, Grace Tan-Wang, Thomas Randolph, Carl Guernsey, Mark Yerdon, Morgan Parker, and Rebekah Tanimoto as well as Virgil Mireles, Tony Paris, Pradeep Bhandari, and Bob Krylo for serving as the thermal review board members. The authors also wish to thank the following individuals from other NASA Centers including Brian Abresch, Joel Simpson, Chris Purdy, Scott Hesh, and Joe O'Brien from WFF and Brandon Mobley (MSFC), Bud Smith (MSFC) and Jay Grinstead (ARC) who provided critical inputs to the SFDT thermal model. Lastly, the authors would like to take this opportunity to acknowledge Mark Welch and Cindy Beer from C&R Technologies® for providing valuable modeling advice.

BACKUPS

Thermal Analysis of the Electronics Pallet (WCC)