Thermal Analysis of SFDT Parachute System for the Low Density Supersonic Decelerator Project

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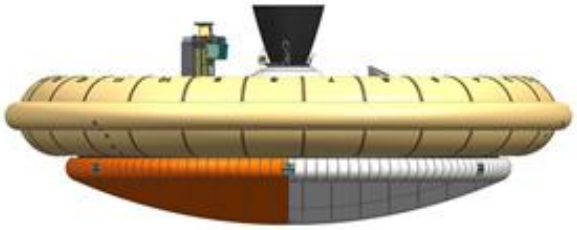
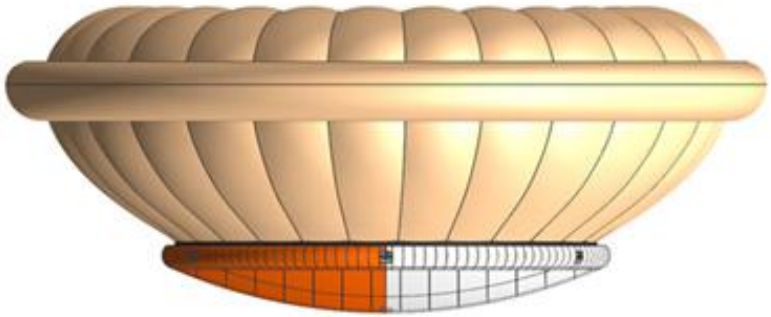
New Technologies

33.5-meter Supersonic Ring Sail Parachute

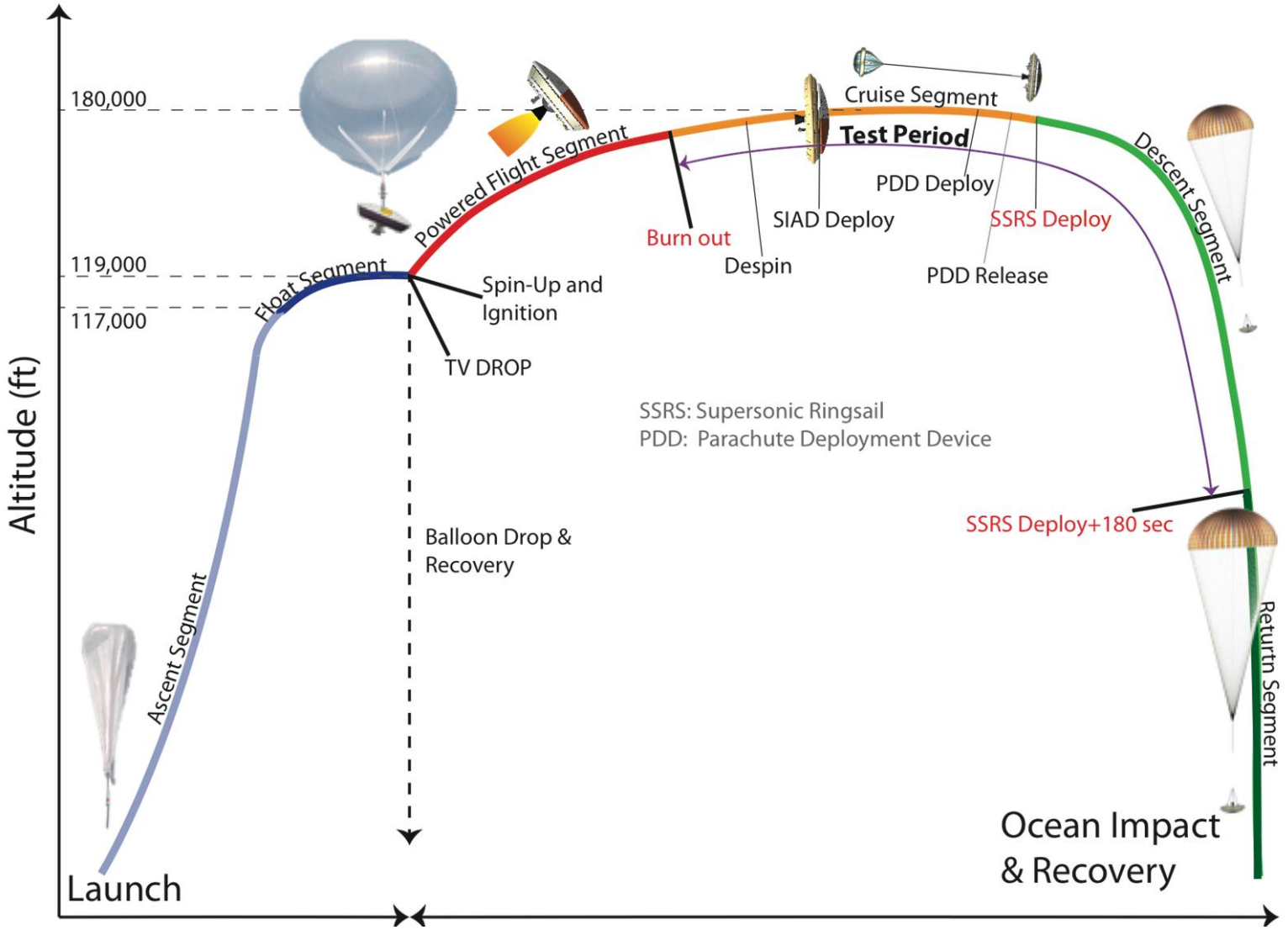


6-meter SIAD-R



8-meter SIAD-E

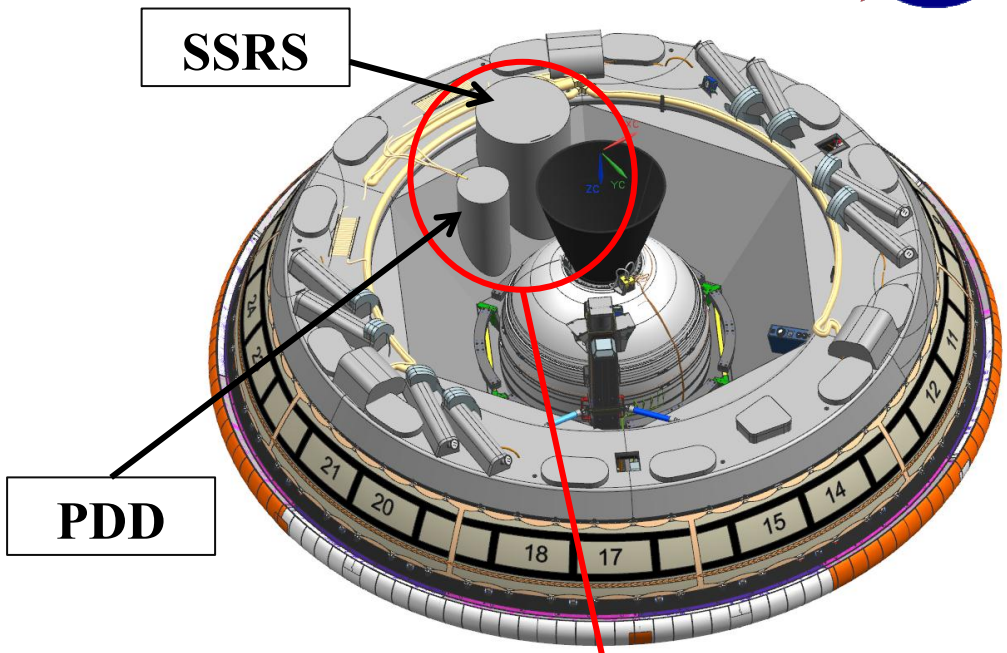
SFDT Mission Overview



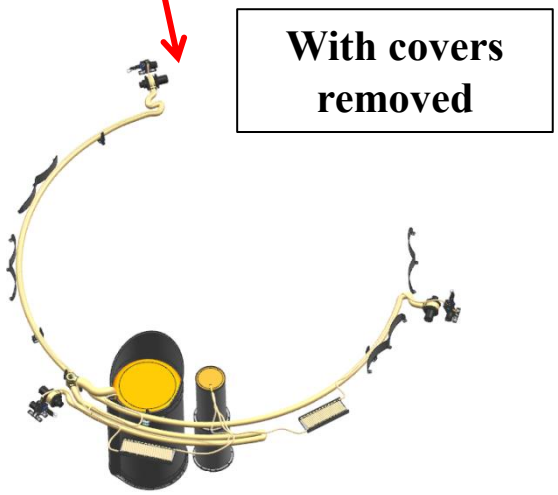
Scope of Thermal Analysis

A Thermal Analysis on a Parachute System with the following components prior to post deployment:

- Parachute Packed SSRS
- Parachute Packed Ballute
- PDD Mortar



Component	AFT Min (°C)	AFT Max (°C)
Parachute Packed SSRS	-30	30
Parachute Packed Ballute	-24	60
PDD Mortar	-24	60



Source: LDSD-SFDT-TRT-4-25-2013

SFDT Vehicle Bounding Mission Timelines

Definitions for Bounding Thermal Analysis

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

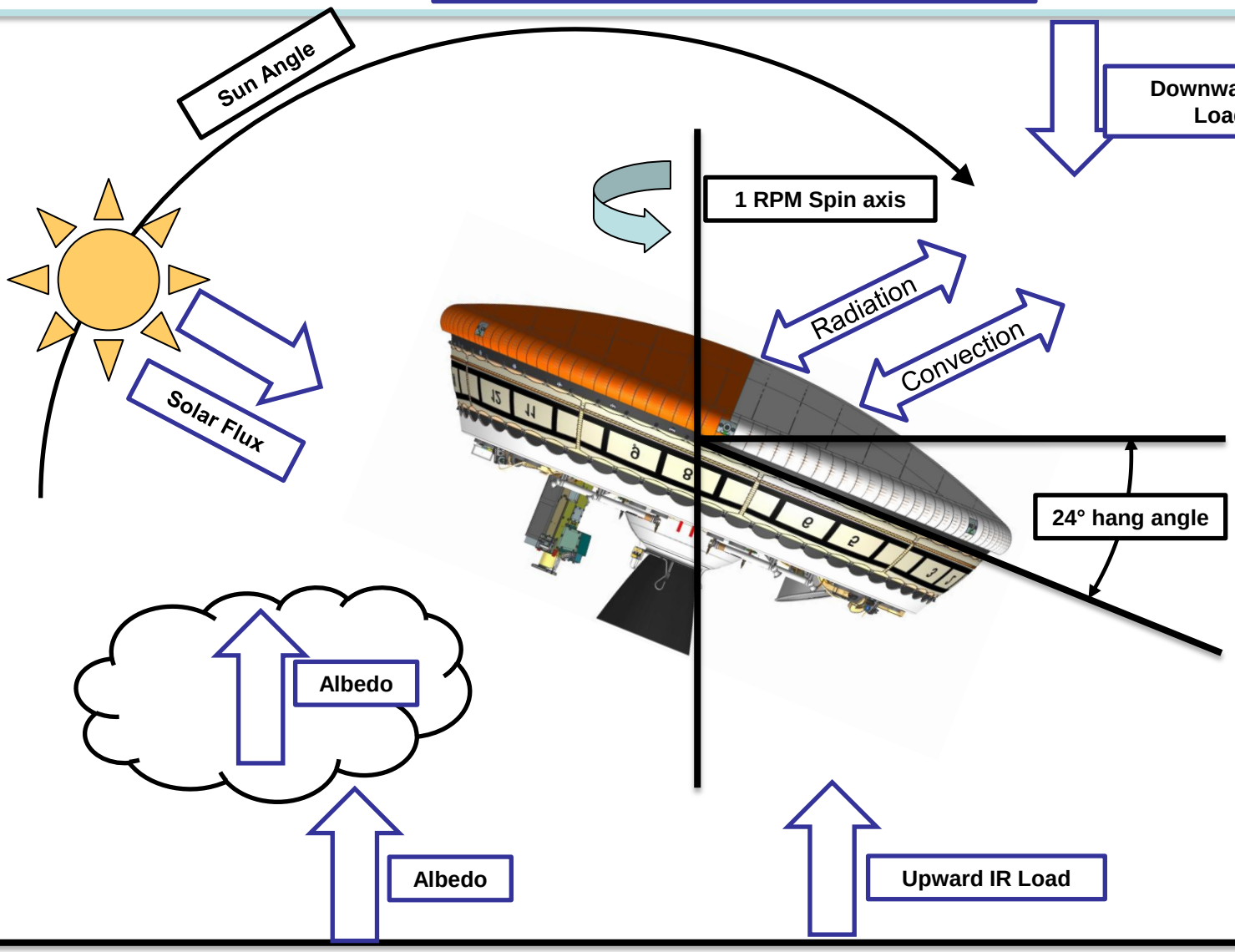
– longest ascent: 3.75 hr
– shortest float: 2.25 hr
– 6:30 AM launch
– cold boundary conditions
  – Sky Temperature
  – Ground Temperature
  – Ambient Air Temperature
  – Internal/External Convection
  – Solar/albedo
– CBE power
– CBE mass
	– shortest ascent: 2.75 hr
	– longest float: 3.25 hr
	– 8:00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

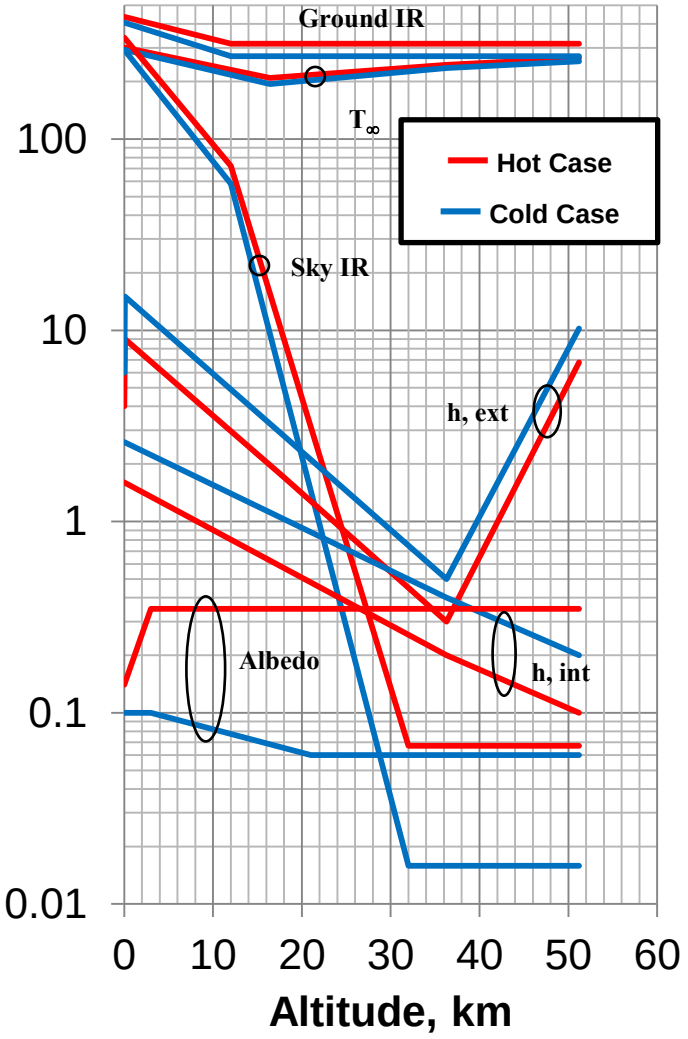
Environmental Boundary Conditions

Environment Energy Exchange



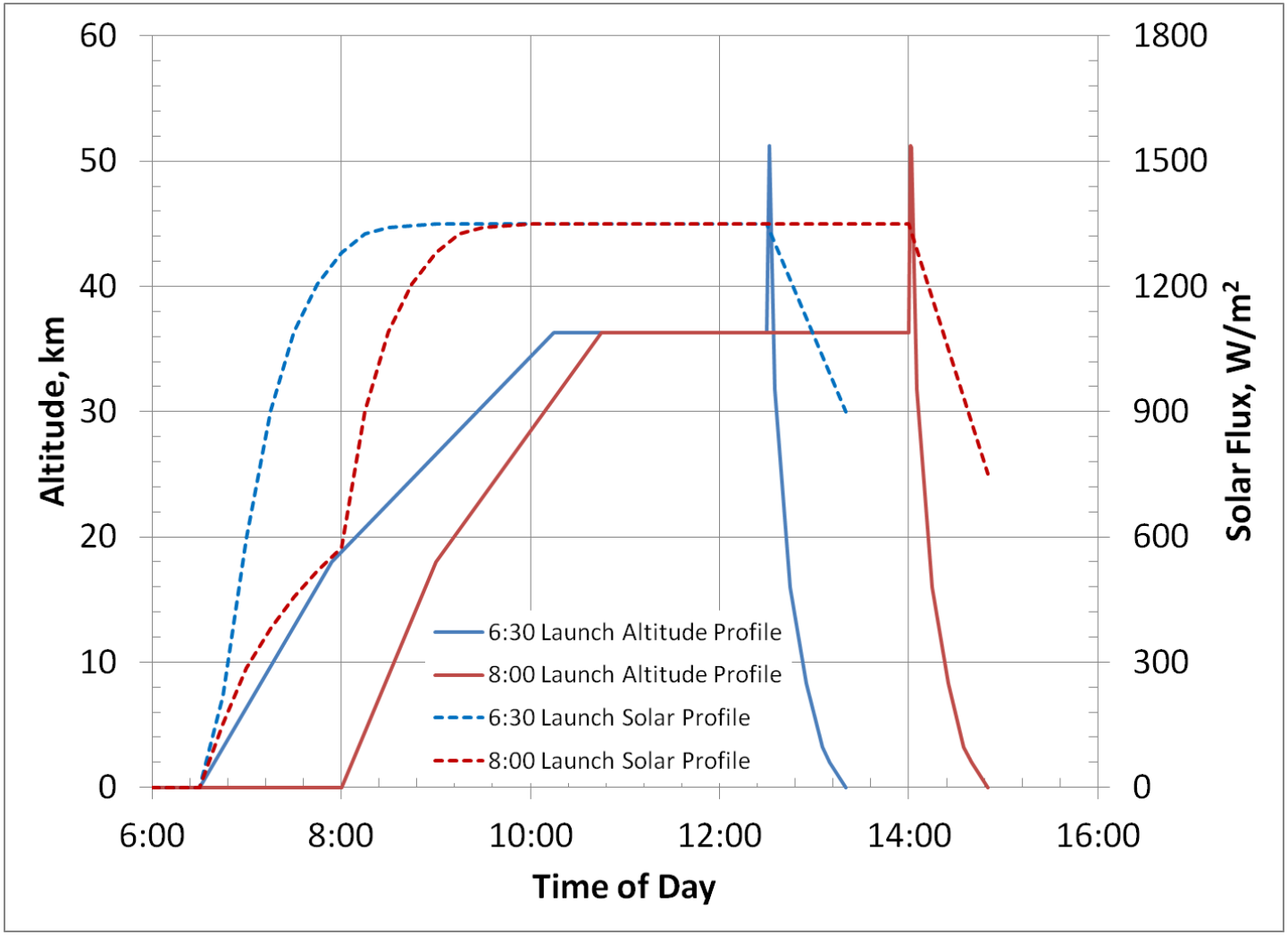
Boundary Conditions: Sky IR, Ground IR, T_∞, h_{ext}, and h_{int} vs. Altitude

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



T_∞: Lihue Station RadioSonde Data and Space Science and Engineering Center, University of Wisconsin-Madison
Sky IR and albedo: CSBF
WCC h_{ext}: compared against BLDT

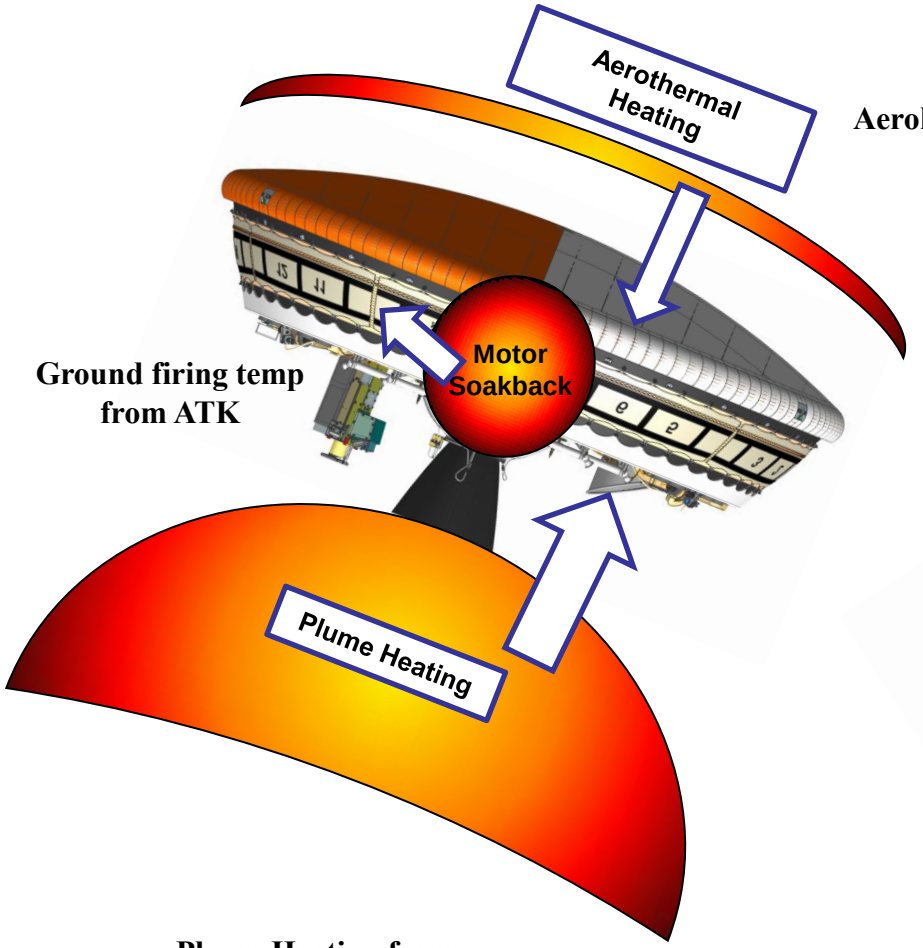
Boundary Condition: Direct Solar Flux



Balloon ascent analysis by CSBF

SFDT Vehicle Additional Heat Loads

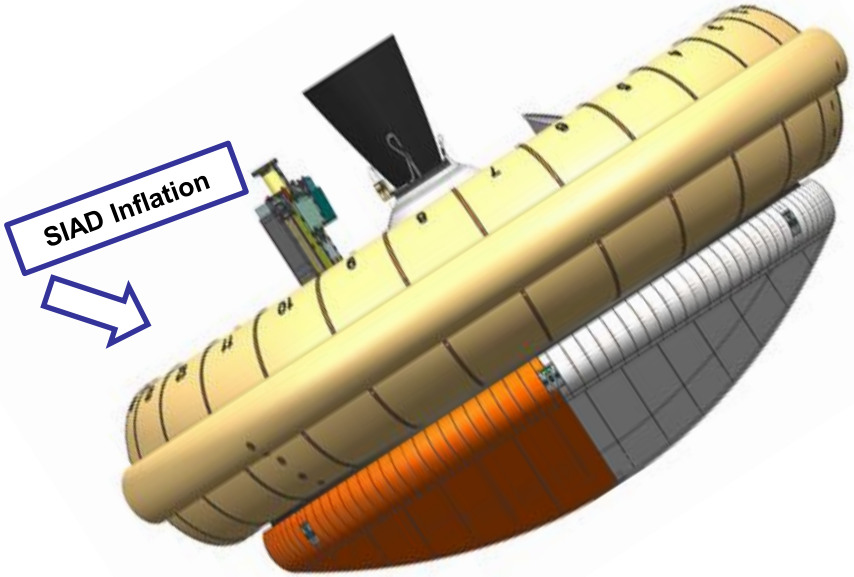
Vehicle External Energy Inputs



Aeroheating fluxes from NASA ARC

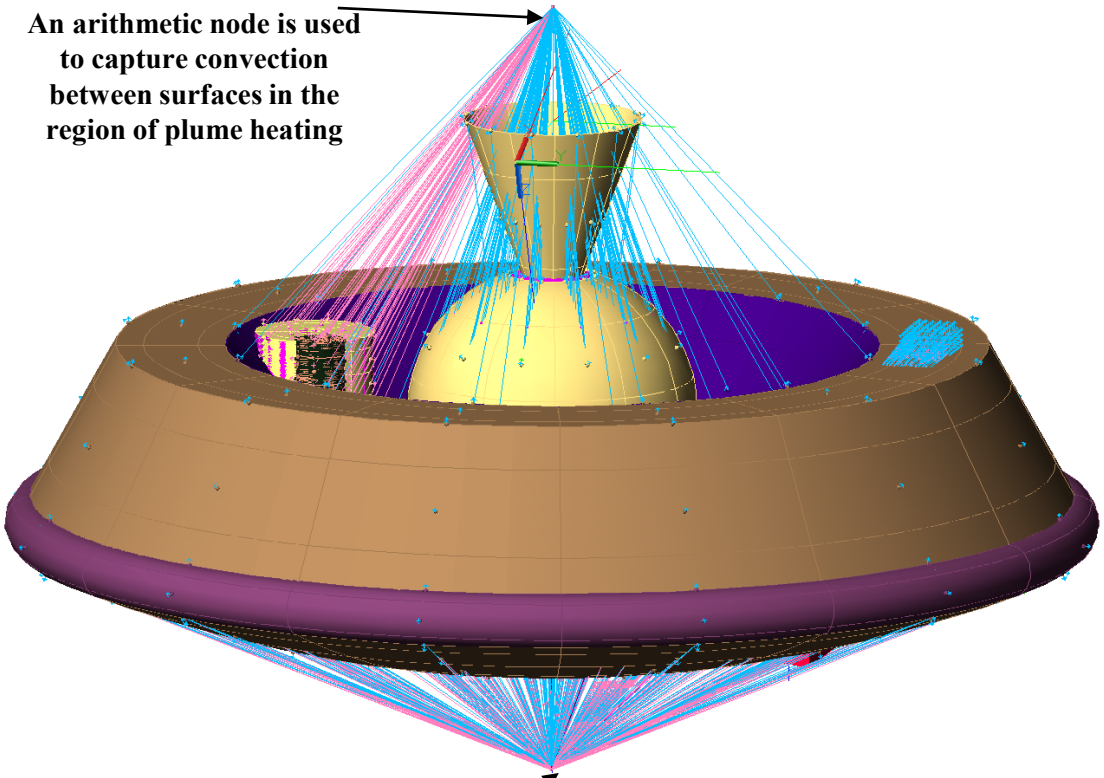
Ground firing temp from ATK

Plume Heating from NASA MSFC



Boundary Condition: External Convection

External convection modeled top and side of SSRS and PDD cover



SSRS & PDD Plume Heating Inputs

SSRS Top Face Heat Flux

Time (Seconds)	Total (W/m^2)
0	11129
67	27595

SSRS Side Face Heat Flux

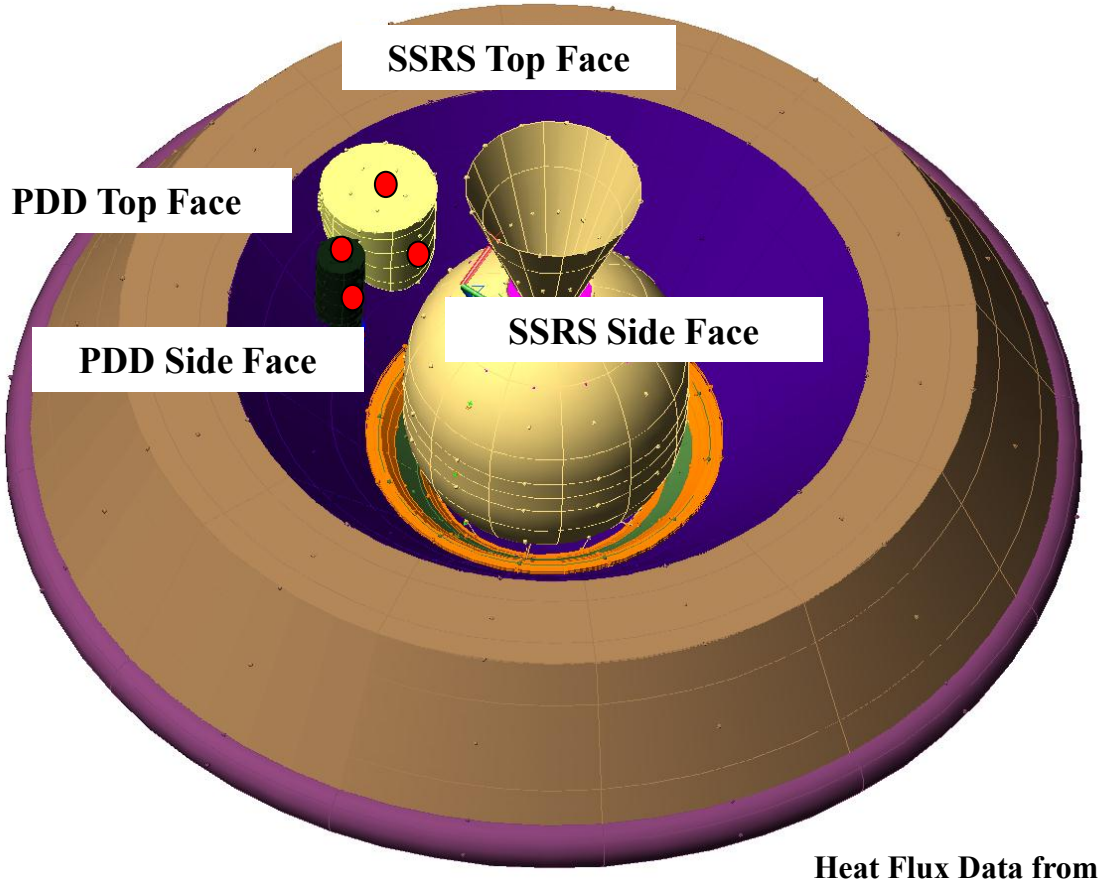
Time (Seconds)	Total (W/m^2)
0	6246
67	16920

PDD Top Face Heat Flux

Time (Seconds)	Total (W/m^2)
0	5224
67	19532

PDD Side Face Heat Flux

Time (Seconds)	Total (W/m^2)
0	11583
67	25210



Heat Flux Data from NASA MSFC

Single heat flux is applied to each surface by combining:

$$Q_{flux} = \varepsilon * Rad + Conv$$

Material Layup of SSRS and PDD

Physical Representation:

Exterior Insulation Layer
Interior Insulation Layer
Exterior Insulation Layer
Canister
Parachute[1], Ballute[1] or Mortar[2]

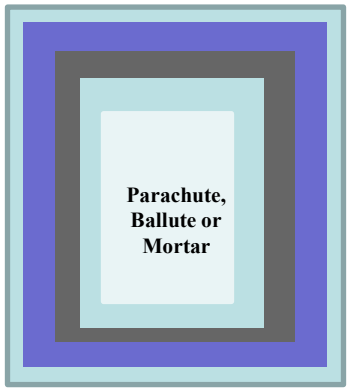
Nextel SLI, ε = 0.88

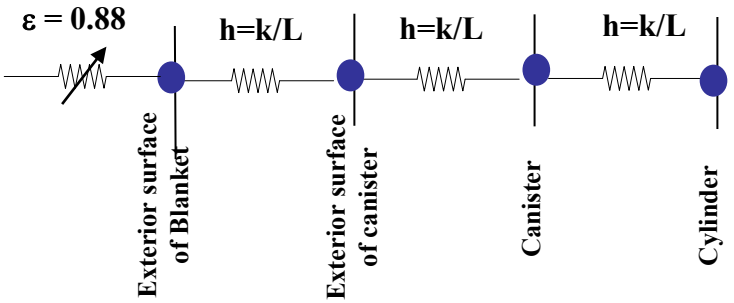
Alumina Mat, k = 0.07 W/m-K

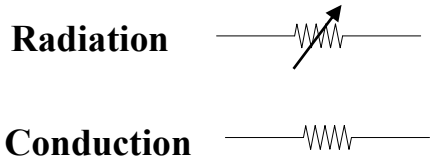
Nextel SLI, ε = 0.88

Aluminum, k = 121.2 W/m-K

Nylon[1], k = 0.281 W/m-K
Star48 Propellant[2], k = 3.22 W/m-K



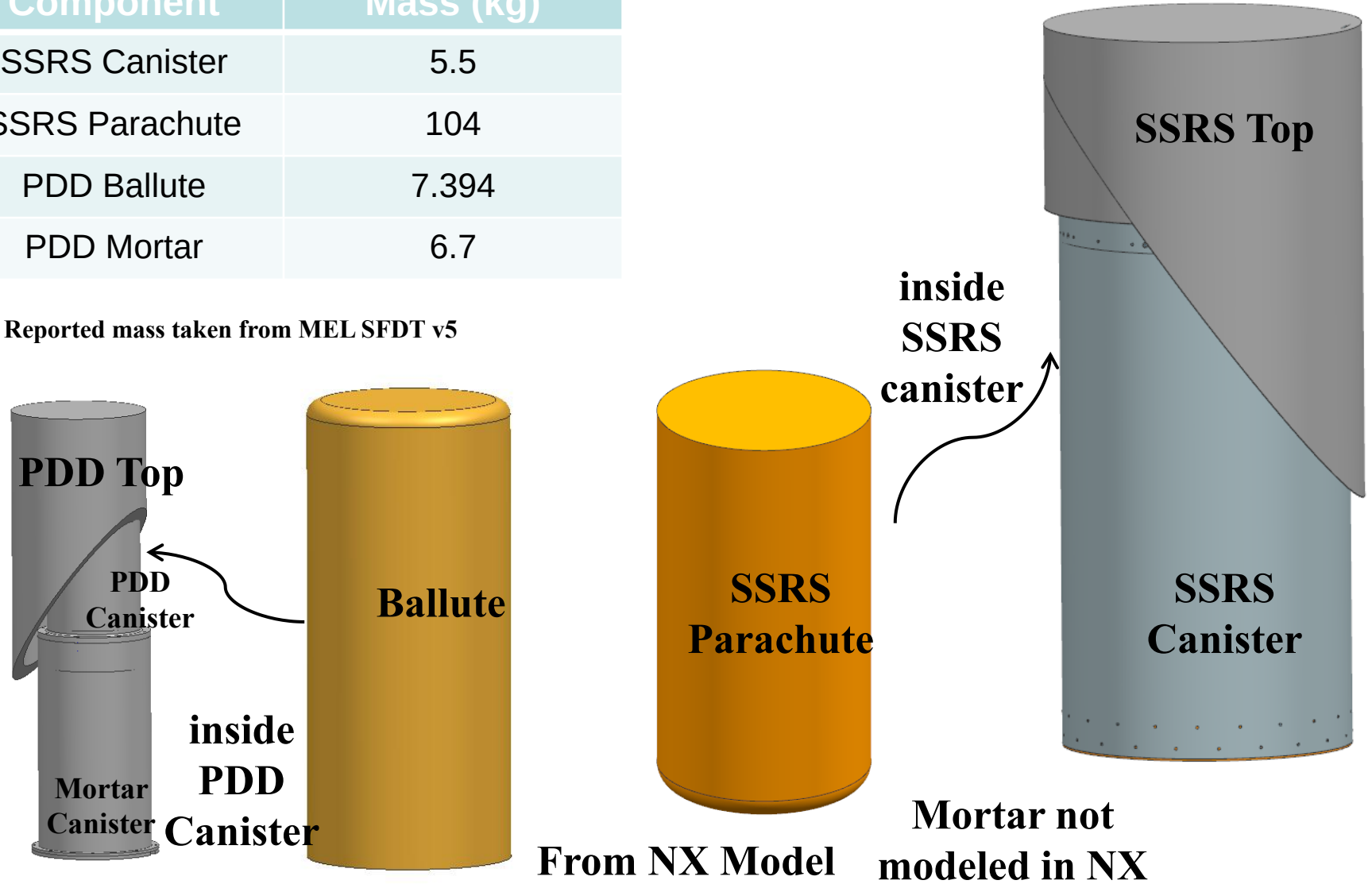




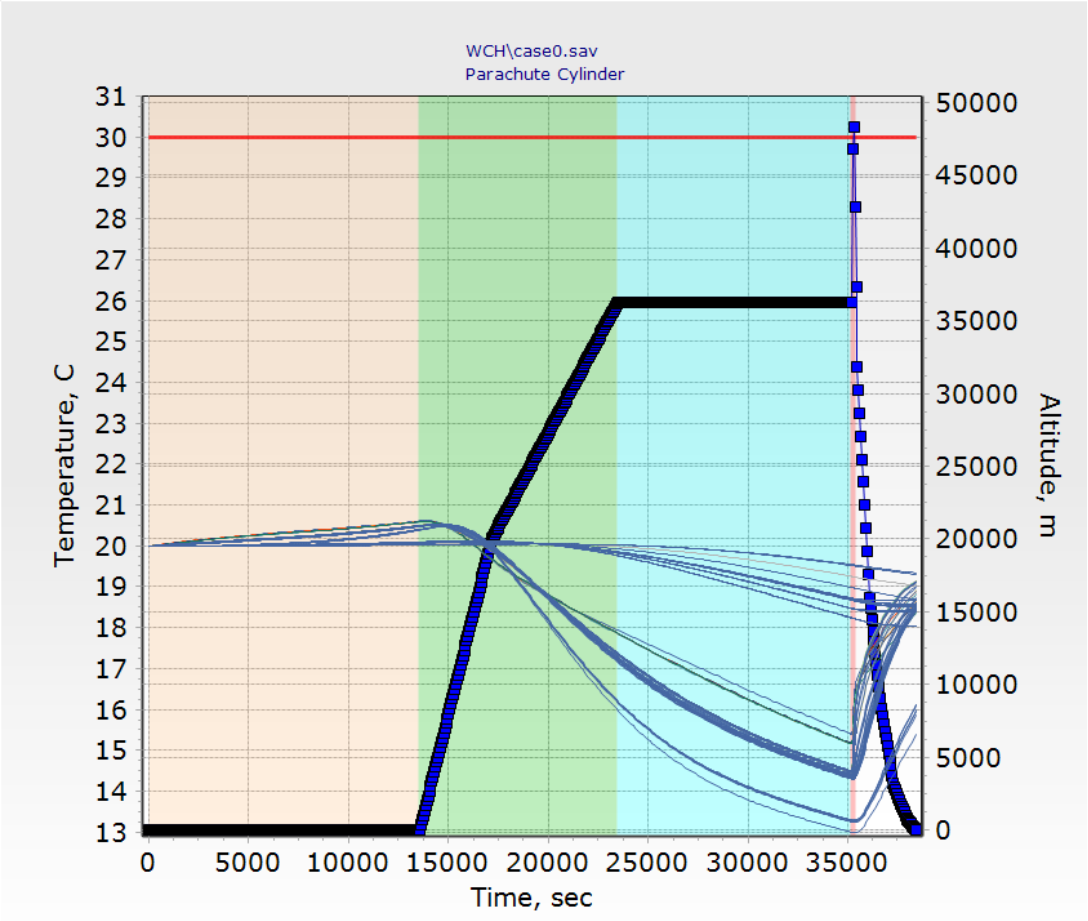
Mass of Parachute System

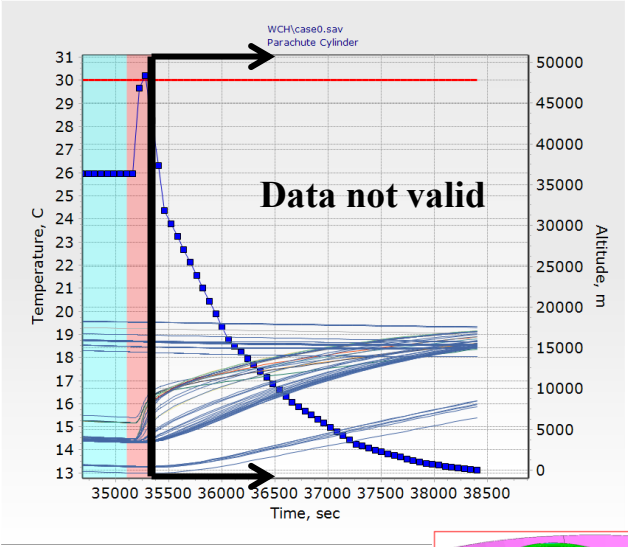
Component	Mass (kg)
SSRS Canister	5.5
SSRS Parachute	104
PDD Ballute	7.394
PDD Mortar	6.7

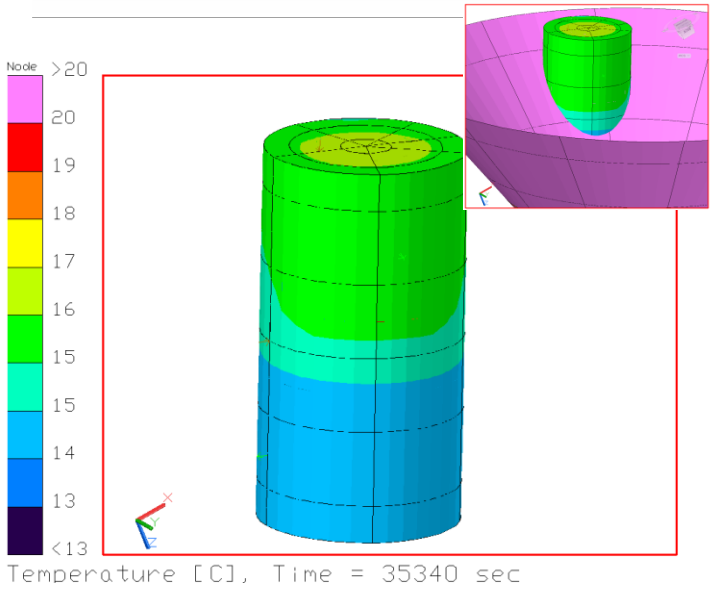
Reported mass taken from MEL SFDT v5



WCH Predicts: Parachute

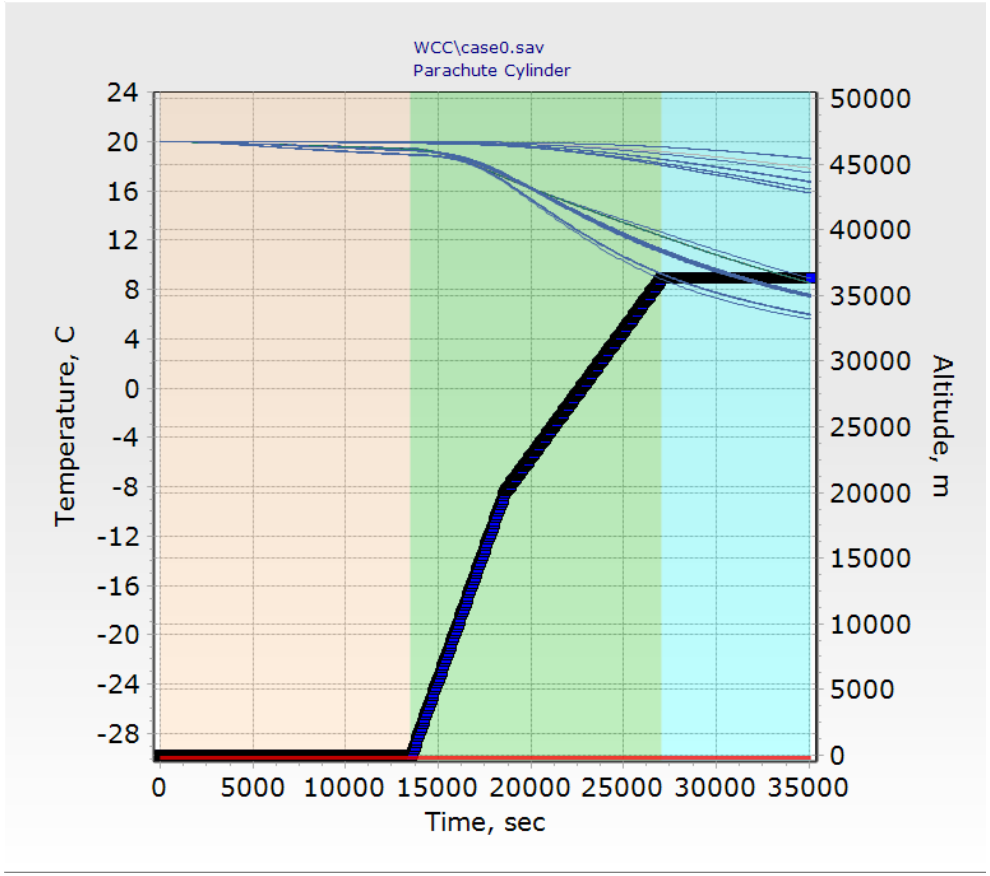


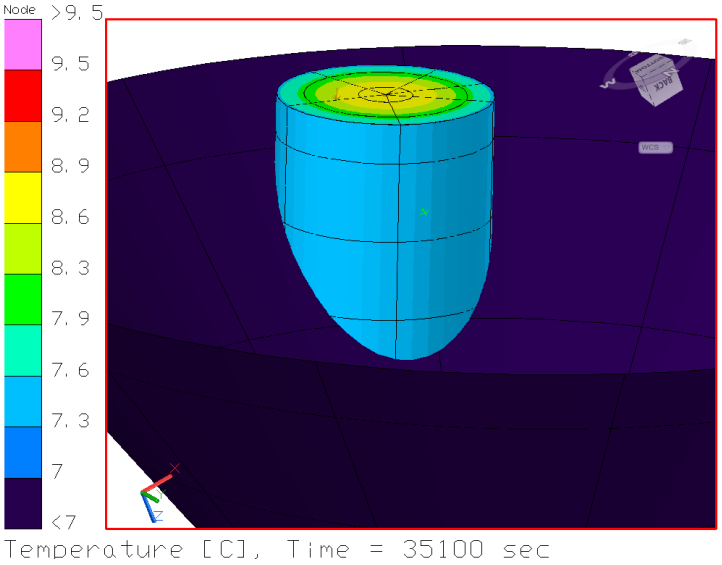


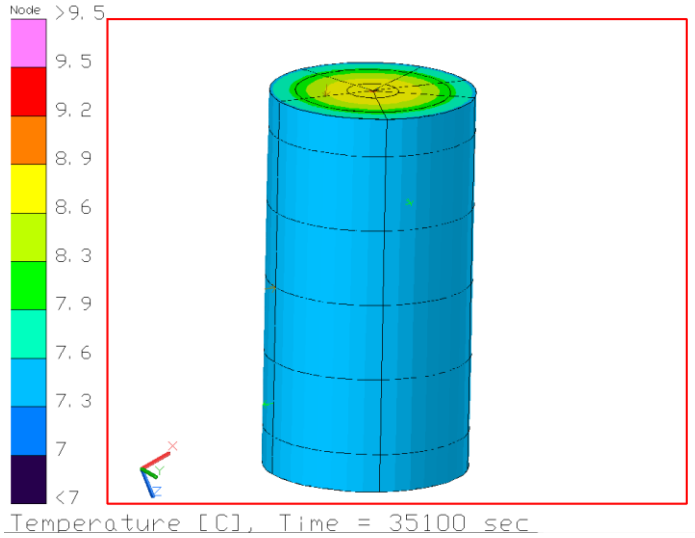


The gradient at deployment is ~ 4 degrees C. AFT limit not exceeded.

WCC Predicts: Parachute

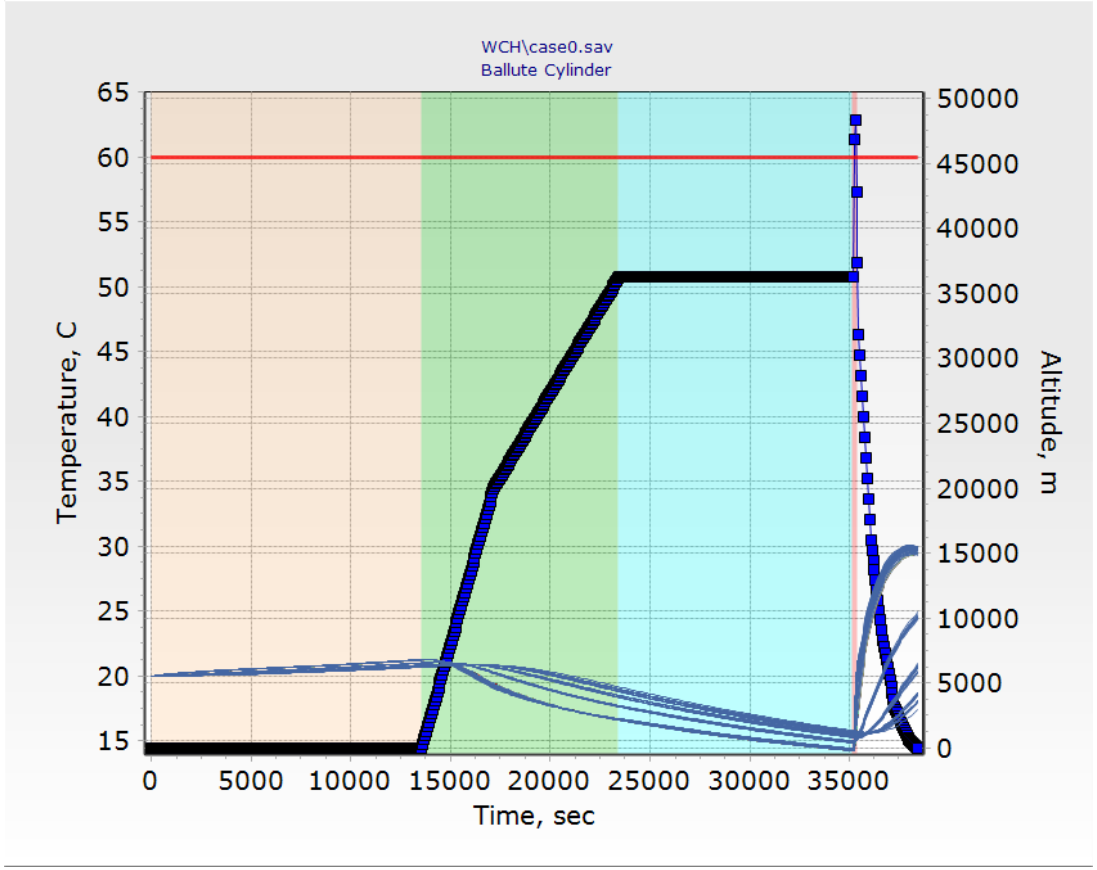


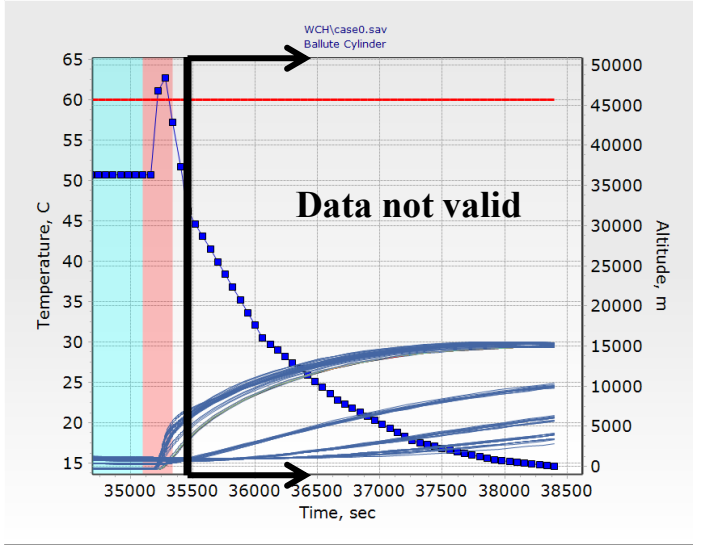


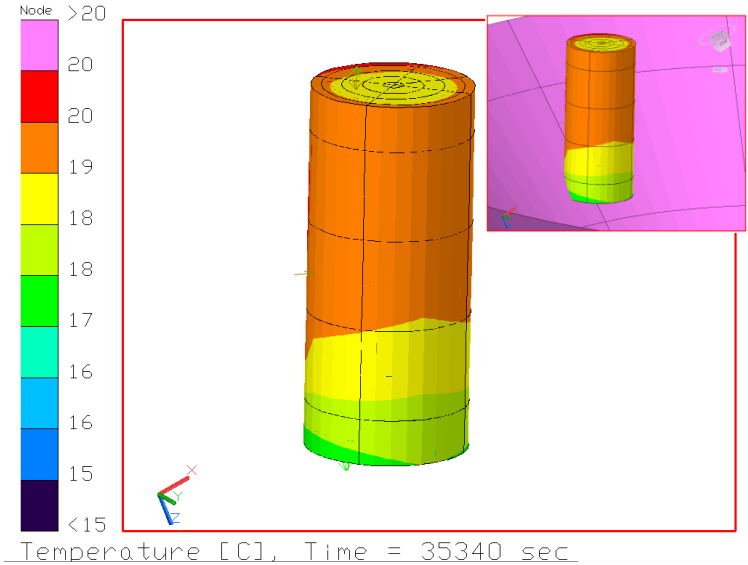


The largest gradient is ~ 12 degrees C. AFT limit not exceeded.

WCH Predicts: PDD Ballute

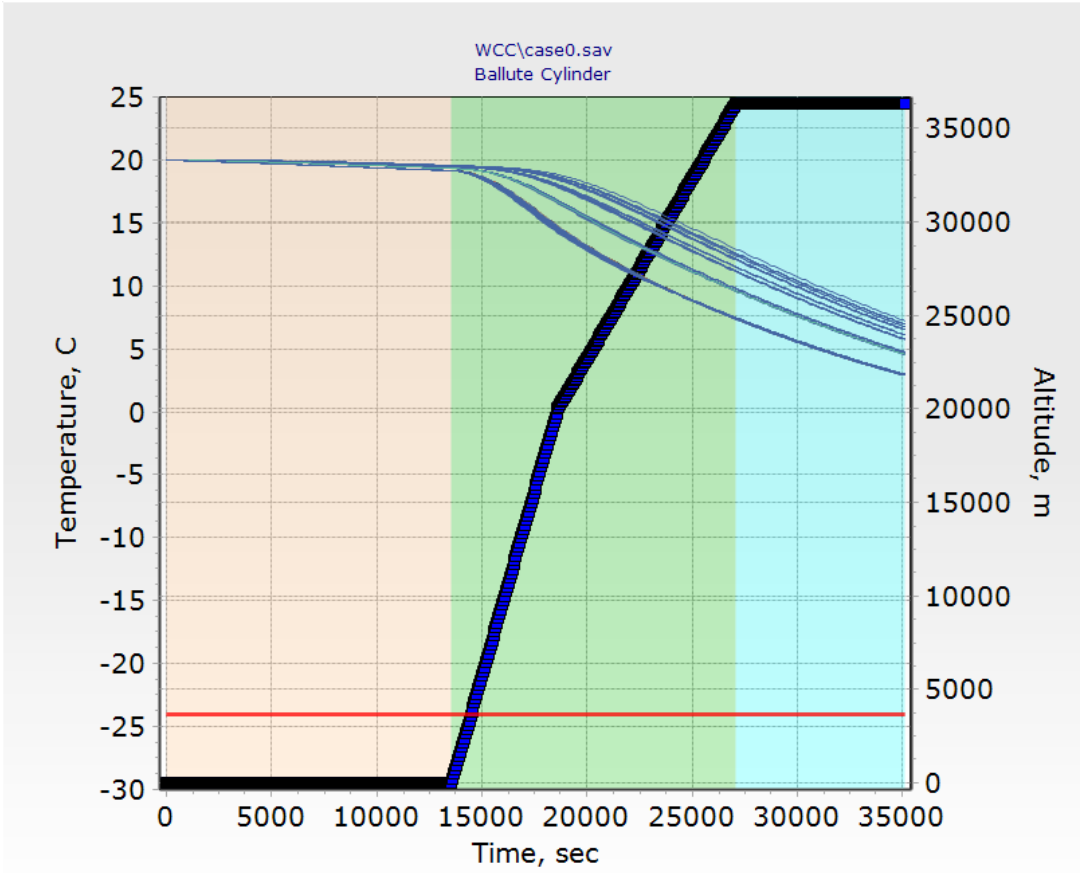


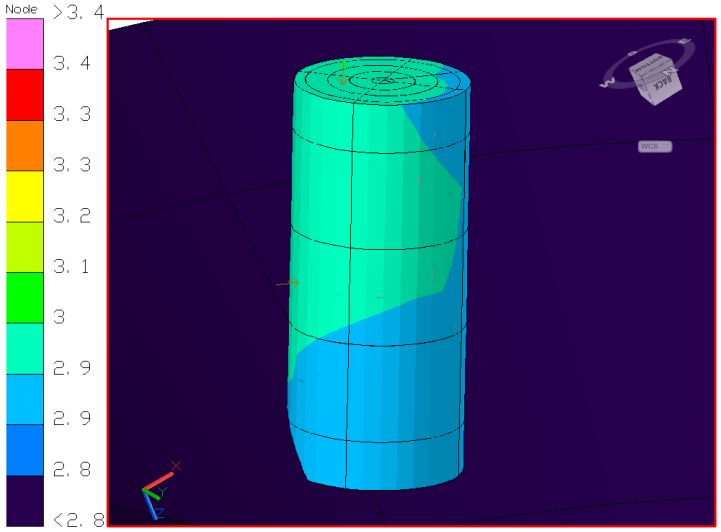


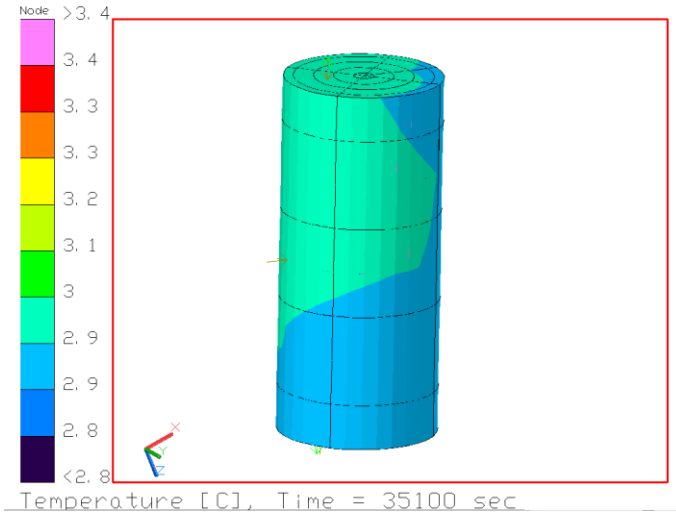


The gradient at deployment is ~ 4 degrees C. AFT limit not exceeded.

WCC Predicts: PDD Ballute

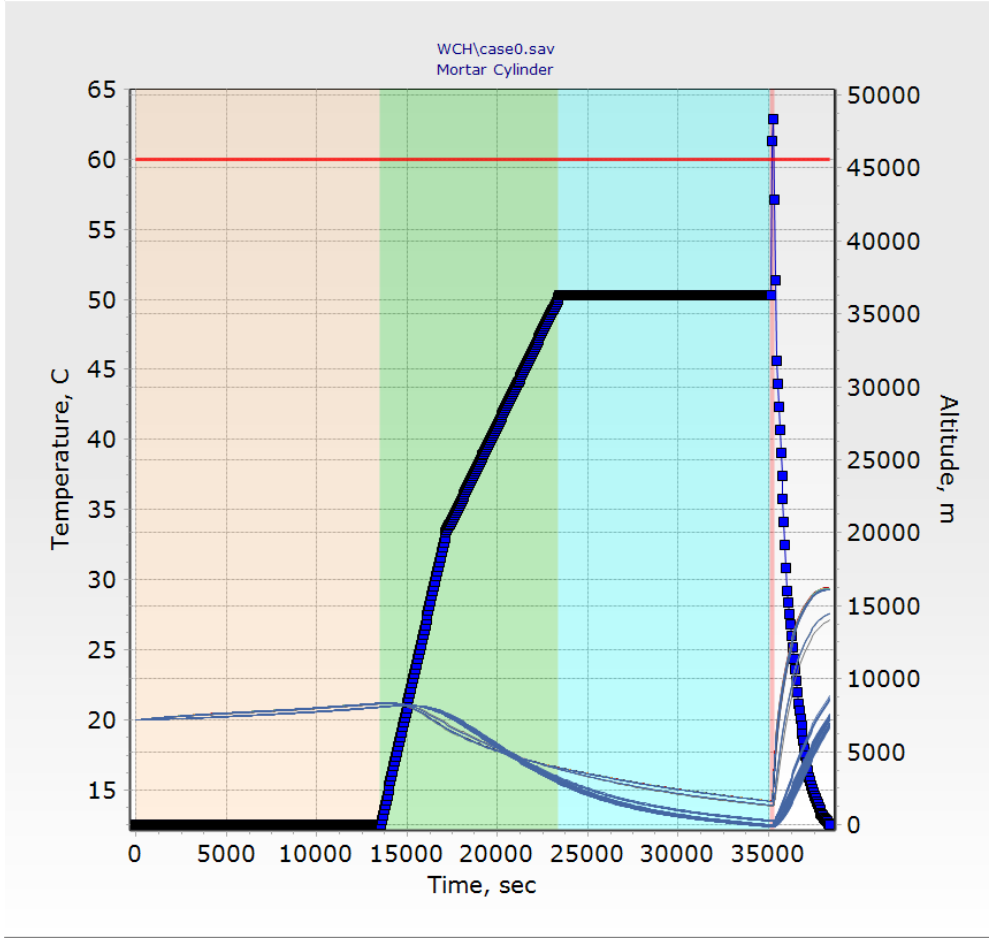


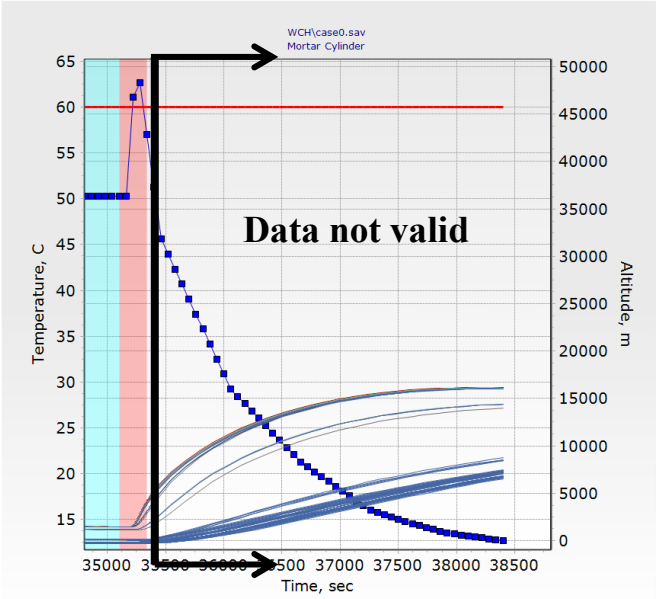


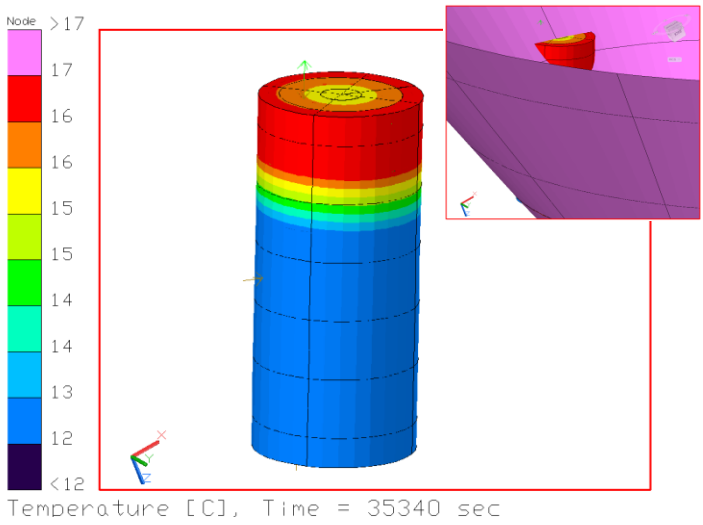


The largest gradient is ~ 5 degrees C. AFT limit not exceeded.

WCH Predicts: PDD Mortar

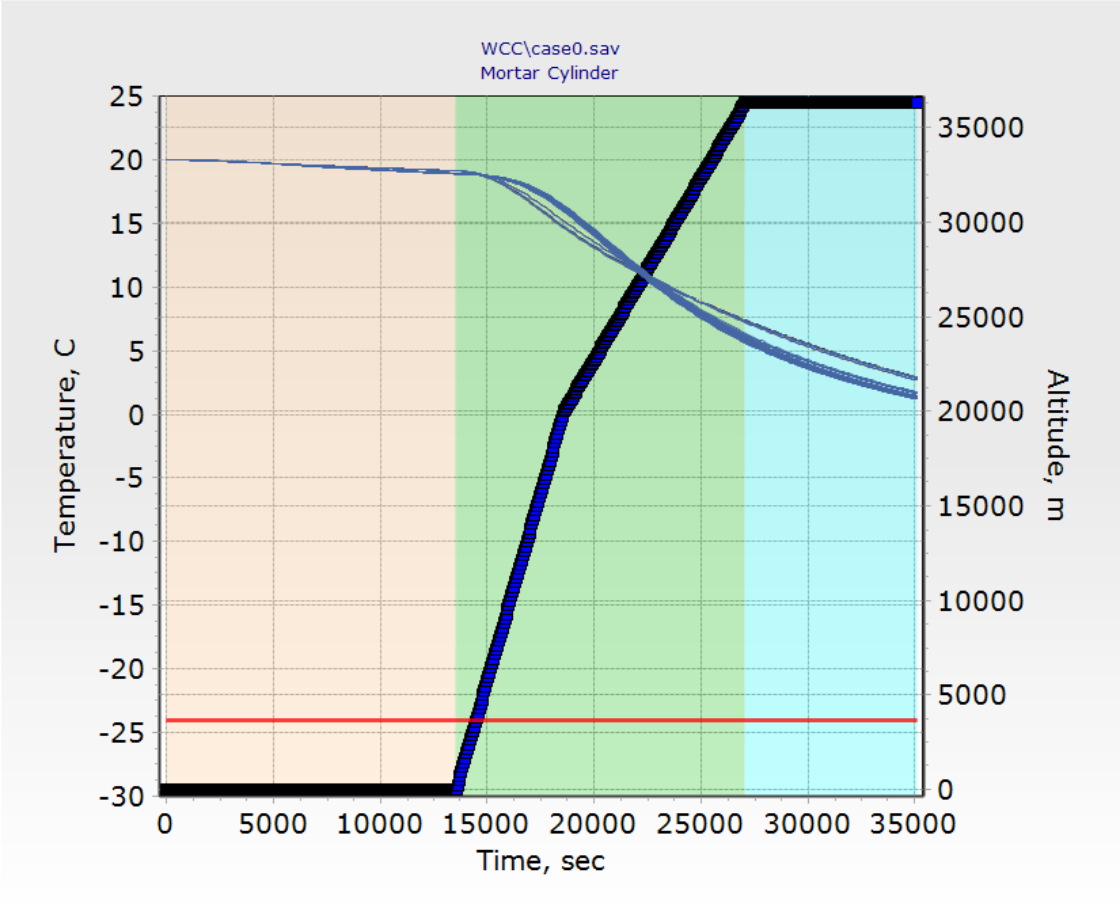


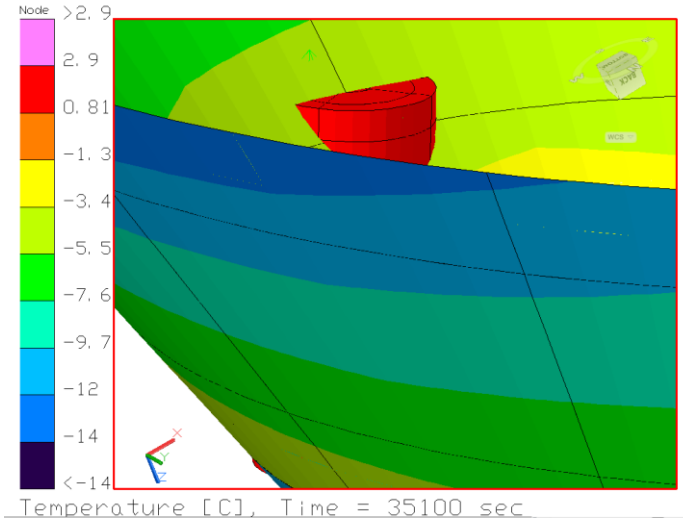


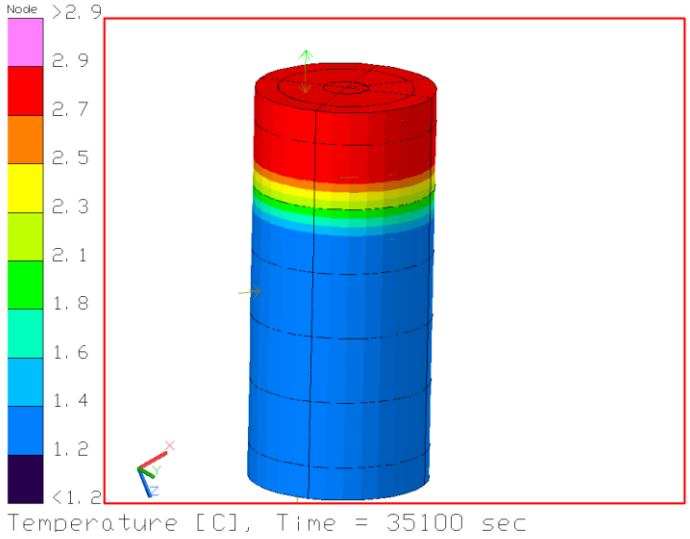


The gradient at deployment is ~ 4 degrees C. AFT limit not exceeded.

WCC Predicts: PDD Mortar

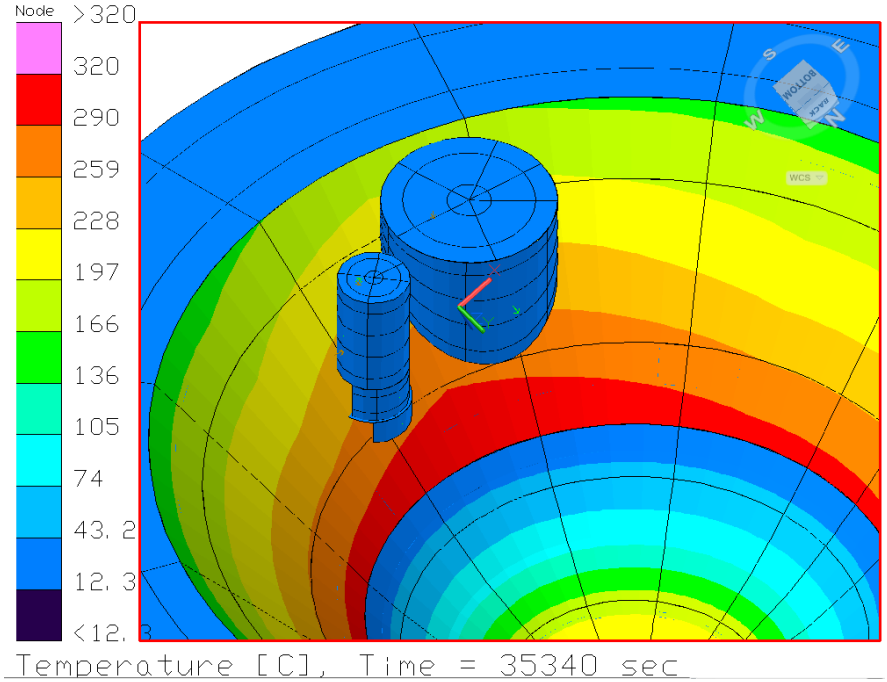




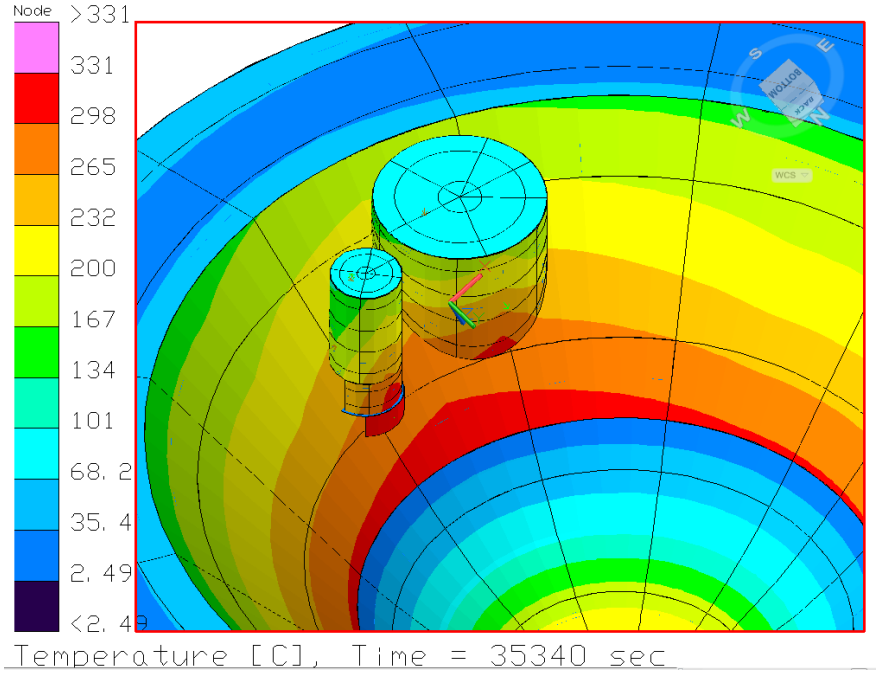


The largest gradient is ~ 2 degrees C. AFT limit not exceeded.

WCH Contour of SSRS and PDD

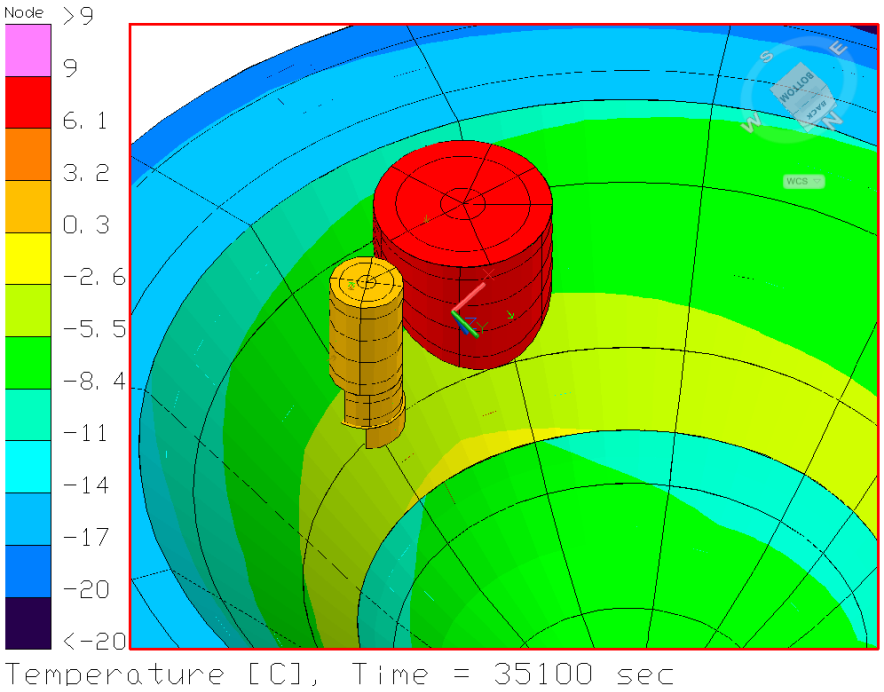


Underneath Insulation

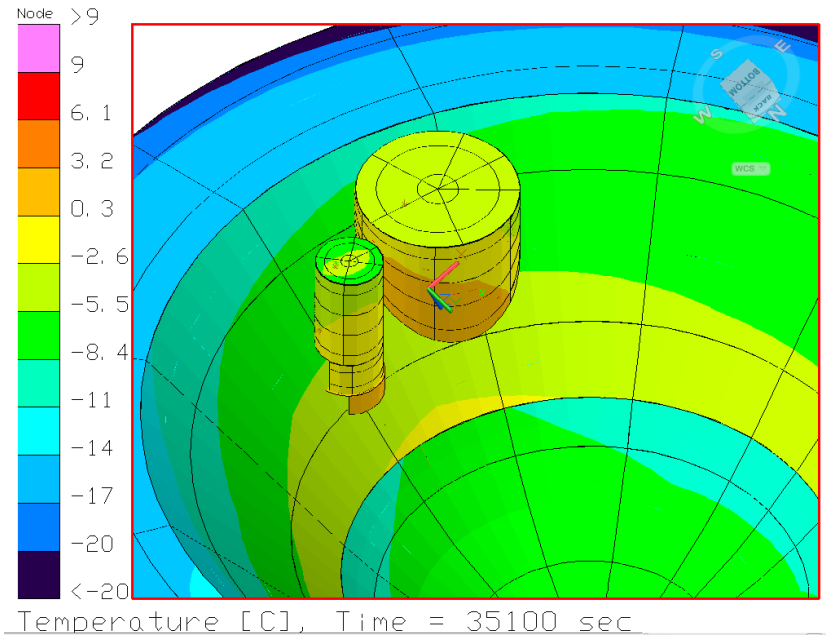


On top of Insulation

WCC Contour of SSRS and PDD



Underneath Insulation



On top of Insulation

Summary

- All components meet the AFT requirements for the Parachute System
- The Nextel SLI and 0.0254 m thick Alumina Mat insulation layers are sufficient for the parachute system