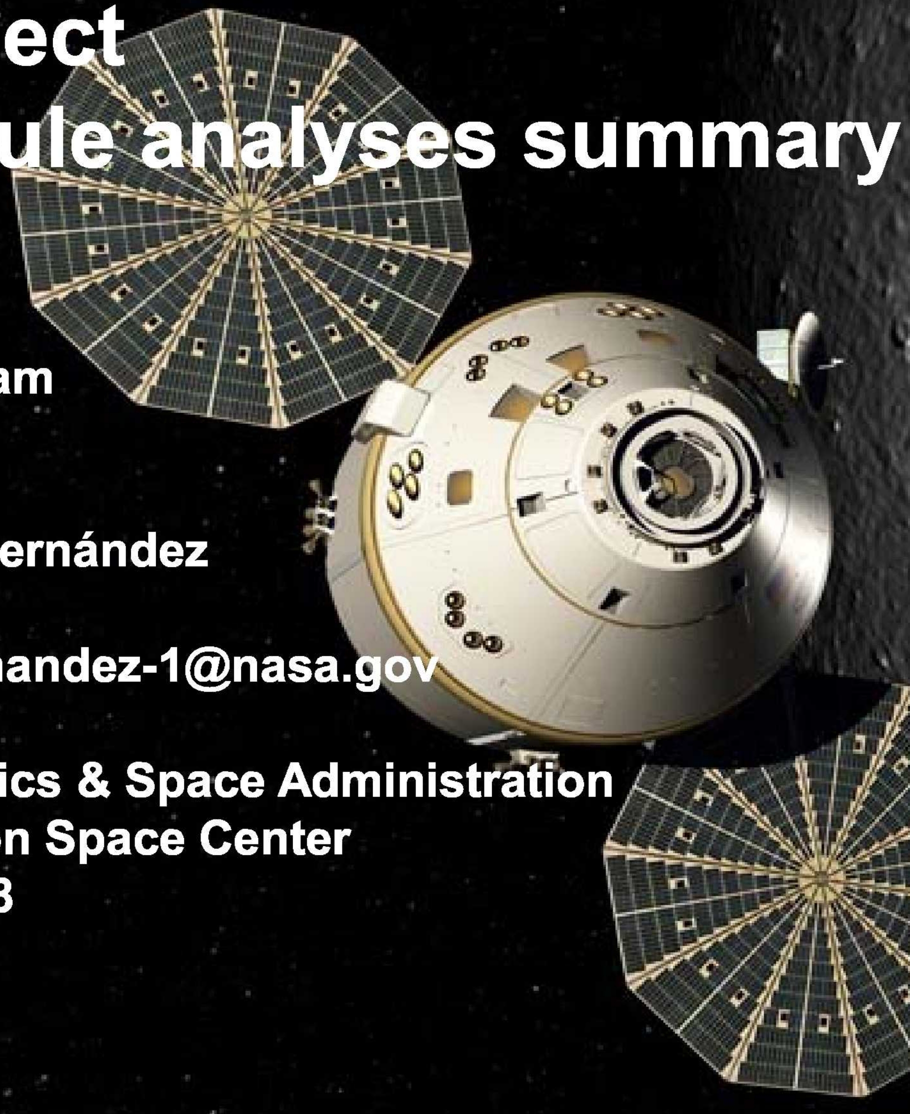
TFAWS 2009
Orion Project
Crew Module analyses summary



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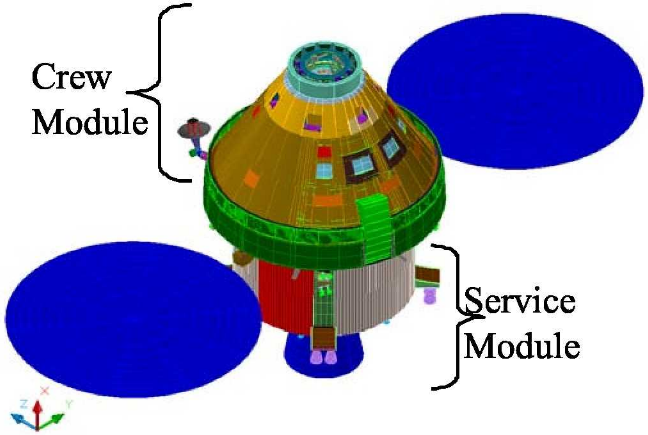
Agenda

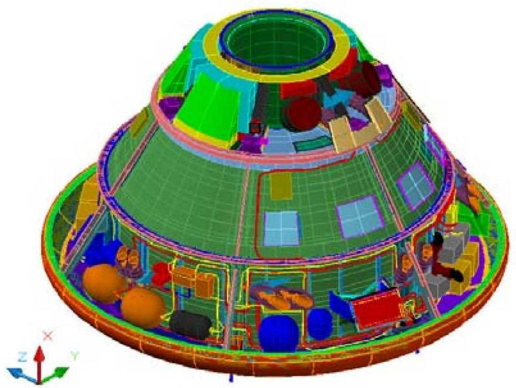
- Introduction
- Integrated Thermal Model (ITM)
- Crew Module (CM) on-orbit analysis & results
  - General violations
  - Case specific violations
- CM entry/post-landing analysis & results
- CM special trade studies
- GFE analysis
- Conclusions
- Back-up charts

Introduction

- Before going into the Orion Subsystem Design Review (SSDR) this year numerous analysis and trade studies have been performed to assess the current design and vehicle performance. A summary of the effort made by LM & NASA for the Orion Crew Module (CM) will be presented.

Integrated Thermal Model

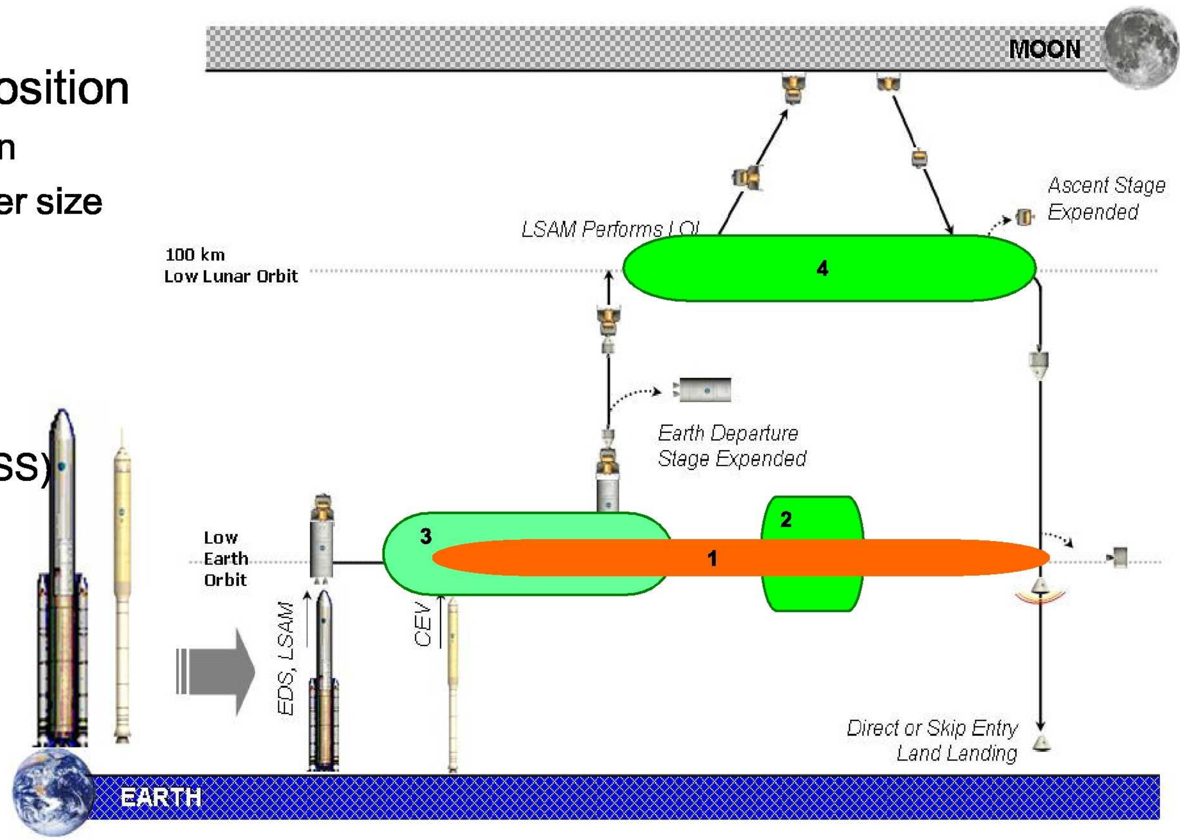




- Lockheed Martin has developed an integrated vehicle model for the Orion Design Analysis Cycle 3.
- The model is complex with over 25,000 nodes
  - There are also numerous logic blocks written to simulate the Active Thermal Control System (ATCS) and the Power Generation and Storage system.
- Model Statistics
  - 26668 Nodes
  - 3099622 Conductors
  - 358 Submodels
  - 11 Analysis groups (active)
  - 700 Heaters
  - 1748 Symbols
  - 5063 Registers
  - 120 Case Sets
  - 54 Logic Objects
  - 16 Subroutines

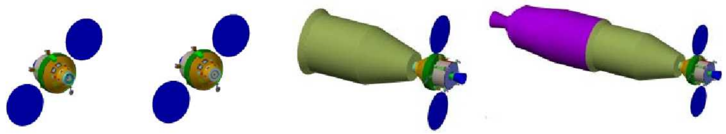
CM on-orbit analysis

- DAC-2 analysis used to define driving cases and reduce the analysis matrix.
- Analysis case matrix composition
  - Min/Max component prediction
  - Prediction of component heater size
  - Prediction of pressure vessel temperatures
- Mission phase
  - (1) Low Earth Orbit (LEO) International Space Station (ISS) mission
  - (2) ISS docked
  - (3) LEO, lunar mission
  - (4) Low Lunar Orbit (LLO)
- Mission attitude
  - Solar inertial
    - tail to sun (TTS)
  - Local Vertical Local Horizontal (LVLH)
    - Nose/Tail Nadir
    - Nose/Tail Forward

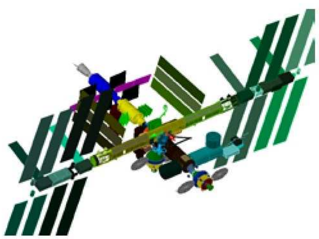


CM on-orbit analysis

- Vehicle configurations



Orion | Orion No LIDS | Orion and LSAM | Orion, LSAM and EDS



Orion docked

Orbital trajectory

LEO lunar mission

172.5 < Alt < 251 km
0 < Beta < 56

(10) Hot Cases
(5) Cold Cases

LLO mission

80 < Alt < 200 km
0 < Beta < 90

(28) Hot Cases
(5) Cold Cases

ISS LEO mission

172.5 < Alt < 460 km
0 < Beta < 75

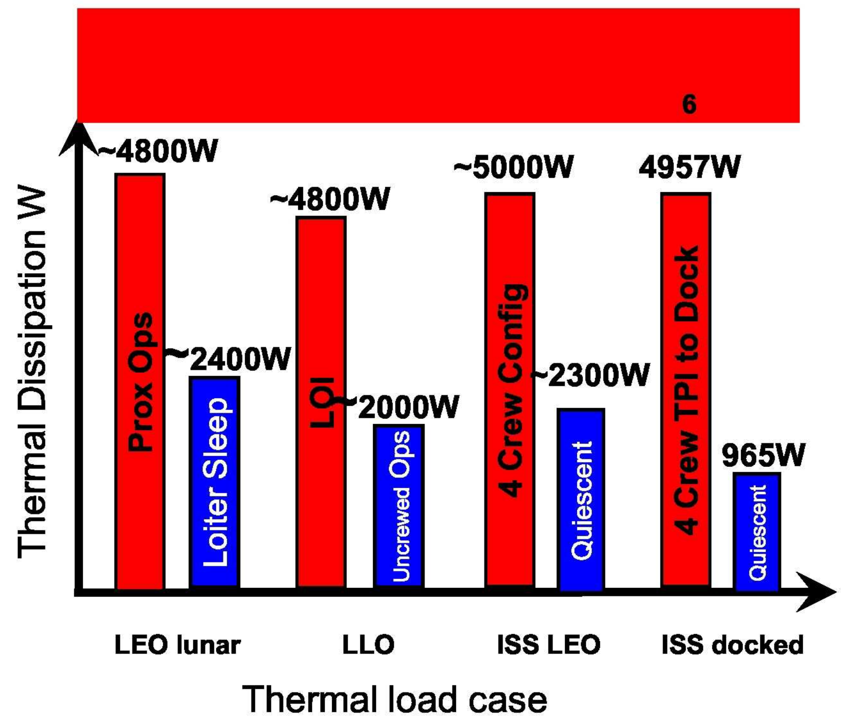
(10) Hot Cases
(3) Cold Cases

ISS docked mission

277.8 < Alt < 460 km
-75 < Beta < 75

(6) Hot Cases
(5) Cold Cases

- Applied vehicle thermal loads



CM on-orbit analysis-General violations

CM Avionics

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VPU #1	003062_llottscold		32	003040_llottshot		-2
GPS Electronics #1	003030_ltttscold		40	300005_leoissdockedhot		-101
GPS Electronics #2	300001_leoissdockedcold		39	300005_leoissdockedhot		-116

Mitigation Table

Component	Exceedance	Issue	Mitigation
VPU	2°F High	Power applied for entire run.VPU only powered during docking and video editing.	Re-run transient case
GPS Electronics #1	101°F High	Not on a cold plate or connected to structure Power maybe too high	Connect to a cold plate or structure Verify applied power
GPS Electronics #2	116°F High	Not on a cold plate or connected to structure Power maybe too high	Connect to a cold plate or structure Verify applied power

CM on-orbit analysis-General violations

CM Avionics

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
Display Unit Cold Plate # 1a	003062_llottscold		-5	300005_leoissdockedhot		-27
Display Unit Cold Plate # 1b	003062_llottscold		-5	300005_leoissdockedhot		-27
Display Unit Cold Plate # 2a	003062_llottscold		-5	003020_leolunarnfhot		-22
Display Unit Cold Plate # 2b	003062_llottscold		-5	003020_leolunarnfhot		-22
Display Unit Cold Plate # 3a	003062_llottscold		-5	003020_leolunarnfhot		-27
Display Unit Cold Plate # 3b	003062_llottscold		-5	003020_leolunarnfhot		-27

Mitigation Table

Component	Exceedance	Issue	Mitigation
Display Units	5°F Low	Unmanned/Evacuated cases cause low loop temperatures. (PV temp req't is 35°F)	ECLSS to Avionics IRD does NOT address the evacuated/unmanned condensation requirements. Update IRD
Display Units	22°F to 27°F High	Model UA is too low *	Increase model UA value

*UA is the overall heat transfer coefficient

CM on-orbit analysis-General violations

CM EPS and ECLSS

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
Aft Bay - 8 (PDU C1)	003062_llottscold		60	300005_leoissdockedhot		-7
Aft Bay - 9 (PDU C2)	003062_llottscold		61	300005_leoissdockedhot		-6
GO2 Tank	003062_llottscold		-8	003006_leoissnnhot		52
CM Battery #2	003062_llottscold		-2	003058_llotfhot		26
CM Battery #1	003062_llottscold		-2	003058_llotfhot		26
CM Battery #3	003062_llottscold		-3	003056_llotfhot		26
CM Battery #4	003062_llottscold		-3	003056_llotfhot		26

Need a non-operational requirement

Mitigation Table			
Component	**Exceedance**	**Issue**	**Mitigation**
PDU C1	7°F High	Model UA is too low	Increase model UA value
PDU C2	6°F High	Model UA is too low	Increase model UA value
GO2 Tank	8°F Low	No Heater	Add Heater
CM Battery #1-4	2°F to 3°F Low	Unmanned cases cause low loop temperatures	Re-run with S-loops OFF

CM on-orbit analysis-General violations

CM Propulsion

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
Hydrazine Lines	003062_llottscold		4	003032_ltttshot		-11
Helium Lines	003062_llottscold			300001_leoissdockedcold		-12

Mitigation Table			
Component	**Exceedance**	**Issue**	**Mitigation**
Hydrazine Lines	11°F High	Heater zones are too big. Large gradients within a heater zone.	Optimize Heaters
Helium Lines	12°F High	Heater zones are too big. Large gradients within a heater zone.	Optimize Heaters

Heater Sizing Cases

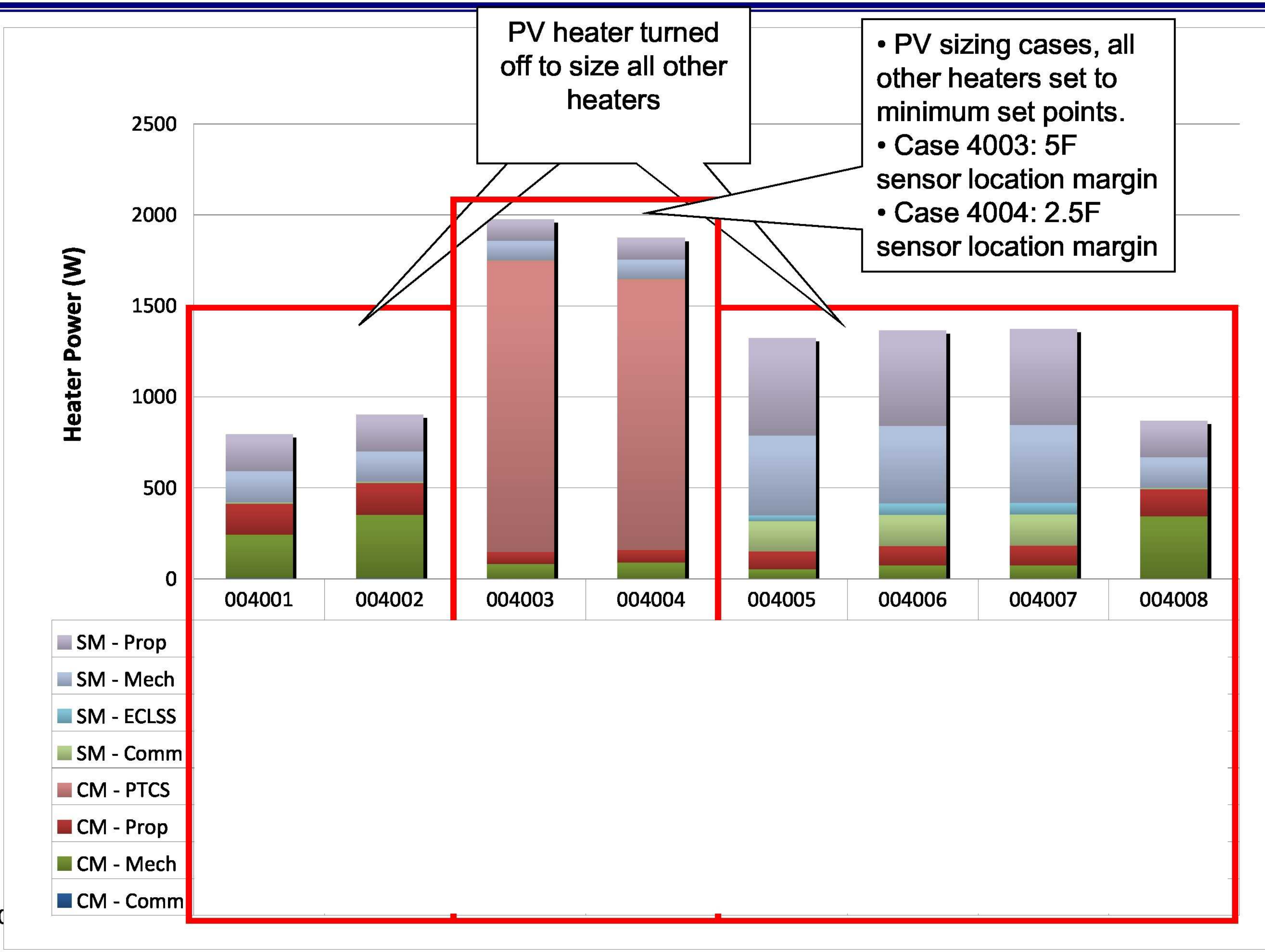
- Free Flight: (8) Heater Sizing (4000 series)
  - Purpose:
    - Predict the heater size of component heaters
  - Setup:
    - Thermal environment set to cold conditions
    - Heaters set to primary (higher) set points for cold conditions
    - Cases cross checked with component min/max to make sure have heater stressing cases
    - Cases to size PV heater set all other heaters at secondary set point and the S-Loops were off
    - Cases to size heaters other then PV heaters disabled the PV heaters and the S-Loops were on

Case #	Orbit	Beta (°)	Env	Alt (km)	Orient	Power (W)	Evac?
4001	LT	-	Cold	-	TtS	2430	Yes
4002	LLO	90	Cold	200	TtS	2010	Yes
4003	LLO	90	Cold	200	TtS	2010	Yes
4004	LLO	90	Cold	200	TtS	2010	Yes
4005	LLO	0	Cold	200	NN	2010	No
4006	LLO	40	Cold	200	NN	2010	No
4007	LLO	40	Cold	200	NN	2010	No
4008	LLO	90	Cold	200	TtS	2010	No

Possible need of heaters

- Components that are not in the ITM but may need heaters
  - Sublimator Duct
  - Urine-vent
  - CM water lines
  - SM water lines

Vehicle Heater Sizing Results



CM on-orbit analysis summary

	Pressure vessel		Backshell/FBC bondline	
	Max temp (ºF)	Min temp (ºF)	Max temp (ºF)	Min temp (ºF)
LEO ISS	87	>55	134	-138
ISS docked	95	58*	114	-117
LEO lunar (ORION/EDS/LSAM config.)	89	>55	103	-65
LEO lunar (Orion config.)	85	>55	99	-88
LLO	83	54**	103	-171

- *Dew point temperature limit is 60 ºF for ISS docked per IRD.
- **Dew point temperature limit is 55ºF for occupied CM.

On-orbit analysis- ISS docked results

Pressure Vessel Temperatures

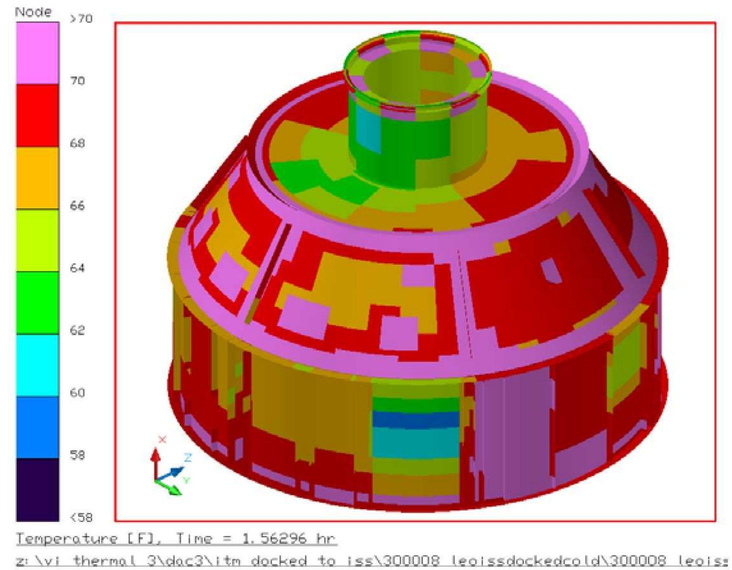
- Min temp case: ISS docked (cold)
  - Most PV locations above min dew point temp req (60F, ISS)
  - 1 location below: 58 F at RCS bracket
- Max temp case: ISS docked (hot)
  - No PV locations above max PV touch temp req (113F)
  - Max PV temp 95 F on cone

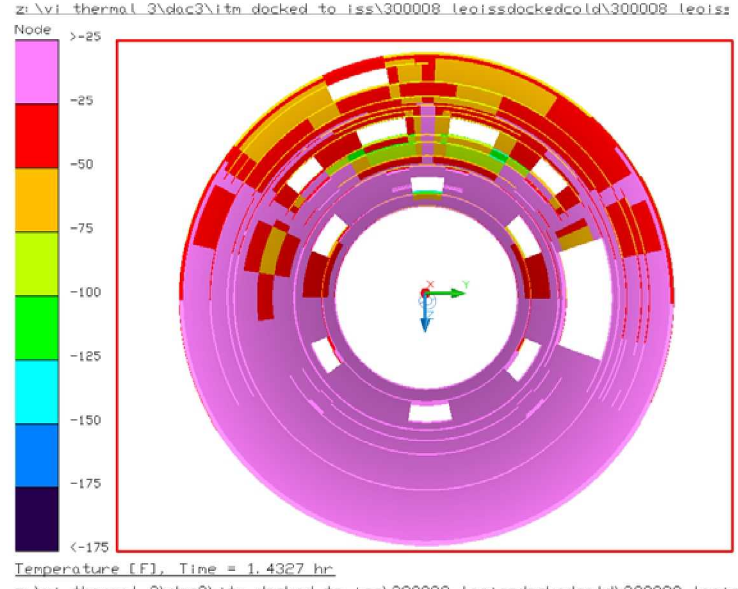
Backshell and FBC Bondline Temperatures

- Min temp case: ISS docked (cold)
  - No bondline below min temp req (-150 F)
  - Min temp is -117F at backshell bondline
- Max temp case: ISS docked (hot)
  - No bondline above max temp req (550 F)
  - Max temp is 114 F at FBC tile bondline

Mitigation Table

Component	Exceedance	Issue	Mitigation
Pressure Vessel at RCS Bracket	2°F Cold	Cold environment is driving temperature	Heater location needs to be optimized





On-orbit analysis- ISS docked results

Components inside the PV

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VMC	300201_leoissdockedcold		4	300205_leoissdockedhot		11
Port Avc Wing Cold Plate BFCS	300201_leoissdockedcold		5	300205_leoissdockedhot		31
CM Micro RIU	300201_leoissdockedcold		5	300205_leoissdockedhot		20
PTU	300005_leoissdockedhot		12	300203_leoissdockedhot		4
DU switch Panel	300201_leoissdockedcold		11	300205_leoissdockedhot		-2
Star Tracker Elec	300202_leoissdockedcold		9	300203_leoissdockedhot		25
Ka Band Transceiver	300201_leoissdockedcold		4	300205_leoissdockedhot		7
X/Ka Base Band Processor	300201_leoissdockedcold		4	300205_leoissdockedhot		9
Base Band Processors	300201_leoissdockedcold		4	300205_leoissdockedhot		8
S Band Transponder	300201_leoissdockedcold		4	300205_leoissdockedhot		16
S Band Swith Matrix	300201_leoissdockedcold		4	300205_leoissdockedhot		16
S Band Baseline Processor	300201_leoissdockedcold		4	300205_leoissdockedhot		8
S Band LNA Lo Power	300201_leoissdockedcold		5	300205_leoissdockedhot		20
DV/EC/LP Radio	300202_leoissdockedcold		7	300203_leoissdockedhot		25
UHF/VHF SAR Radio	300202_leoissdockedcold		7	300203_leoissdockedhot		25
Sar Sat Beacon	300201_leoissdockedcold		5	300205_leoissdockedhot		21
Audio Control Unit 1	300201_leoissdockedcold		4	300205_leoissdockedhot		12
Audio Comm Unit Speaker Box	300201_leoissdockedcold		5	300205_leoissdockedhot		22
Ammonia Boiler Controller	300201_leoissdockedcold		4	300205_leoissdockedhot		17

Mitigation Table

Component	Exceedance	Issue	Mitigation
DU Switch Panel	2°F Hot	Model maturity	Refine thermal model to determine if there really is a problem

On-orbit analysis- ISS docked results

Components outside the PV

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
OIMU-1, -2, -3	300201_leoissdockedcold		39	300205_leoissdockedhot		34
Star Tracker-1, -2	300201_leoissdockedcold		25	300205_leoissdockedhot		36
Phased Arrays	300201_leoissdockedcold		58	300205_leoissdockedhot		44
Main Parachute	300201_leoissdockedcold		166	300205_leoissdockedhot		23
Drogue Parachute	300201_leoissdockedcold		161	300204_leoissdockedhot		24
Uprighting Pressurant Tank	300201_leoissdockedcold		180	300204_leoissdockedhot		46
LIDS Electronics Boxes	300201_leoissdockedcold		98	300204_leoissdockedhot		100
LIDS Soft Capture Ring	300201_leoissdockedcold		78	300204_leoissdockedhot		98
LIDS Load Cells	300201_leoissdockedcold		123	300204_leoissdockedhot		261
LIDS Tunnel	300201_leoissdockedcold		116	300204_leoissdockedhot		
GO2 Tank	300201_leoissdockedcold		2	300205_leoissdockedhot		53
Ammonia Tank	300201_leoissdockedcold		29	300205_leoissdockedhot		43
Helium Tank	300201_leoissdockedcold		201	300205_leoissdockedhot		12
Hydrazine Tank	300201_leoissdockedcold		13	300205_leoissdockedhot		13

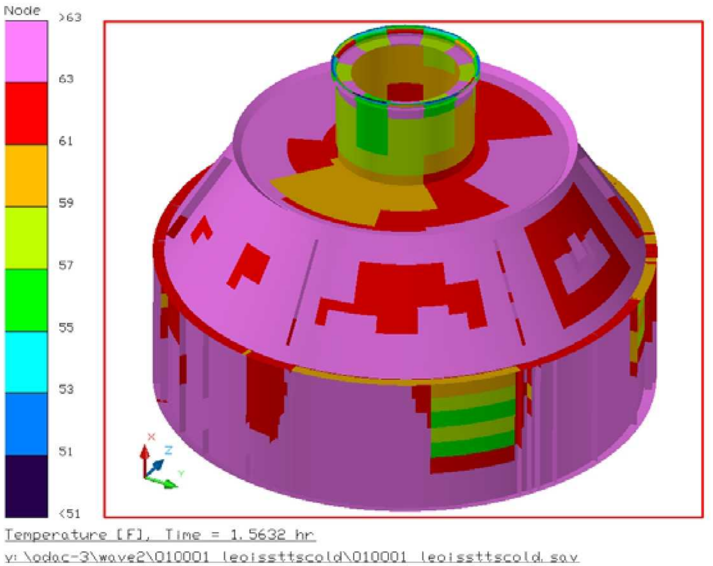
On-orbit analysis- ISS LEO

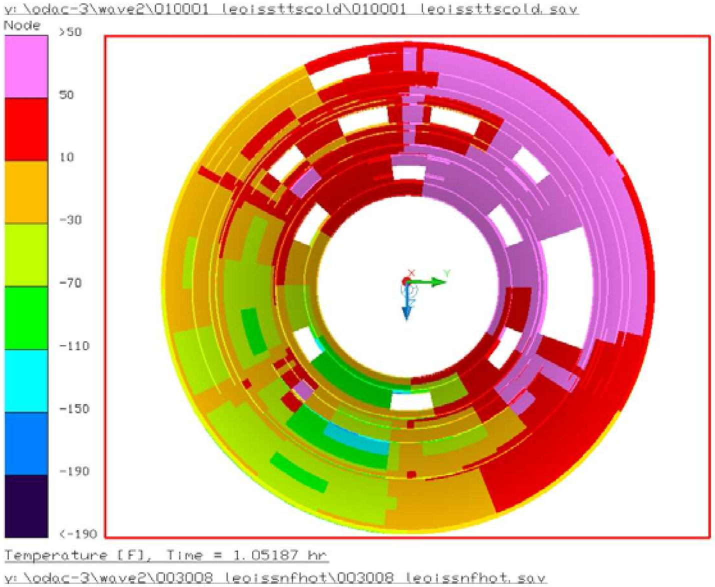
Pressure Vessel Temperatures

- MEETS REQUIREMENTS
- Min temp case : Tail to Sun (cold)
  - No PV location below min dew point (55F)
- Max temp case : Nose Nadir (hot)
  - No PV location above max PV touch temp req (113F)
  - Max PV temp 87 F on cone

Backshell and FBC Bondline Temperatures

- MEETS REQUIREMENTS
- Min temp case: Tail to Sun
  - No bondline below min temp req (-150 F)
  - Min temp is -138F at backshell bondline
- M[redacted]x temp case: Nose Nader (hot)
  - No bondline above max temp req (550 F)
  - Max bondline is 134 F at FBC RCS tile





On-orbit analysis- ISS LEO

Crew Exploration Vehicle Project Office

Components inside the PV

Component Description	Cold Case ID	Temperatures (°F)	Margin	Hot Case ID	Temperatures (°F)	Margin
VMC	003011_leoissttscold		9	003008_leoissnfhot		10
Port Av Wing CP BFCS	003011_leoissttscold		2	003008_leoissnfhot		32
CM Micro RIU	003011_leoissttscold		11	003008_leoissnfhot		22
PTU	003011_leoissttscold		5	003008_leoissnfhot		40
DU switch Panel	003011_leoissttscold		16	003008_leoissnfhot		1
Star Tracker Elec	003011_leoissttscold		8	003008_leoissnfhot		35
Ka Band Transceiver	003011_leoissttscold		16	003008_leoissnfhot		7
X/Ka Base Band Proc	003011_leoissttscold		8	003008_leoissnfhot		9
Base Band Proc's	003011_leoissttscold		13	003008_leoissnfhot		8
S Band Transponder	003011_leoissttscold		13	003008_leoissnfhot		16
S Band Swith Matrix	003011_leoissttscold		13	003008_leoissnfhot		16
S Band Baseline Proc	003011_leoissttscold		13	003008_leoissnfhot		8
S Band LNA Lo Power	003011_leoissttscold		13	003008_leoissnfhot		22
DV/EC/LP Radio	003011_leoissttscold		4	003008_leoissnfhot		40
UHF/VHF SAR Radio	003011_leoissttscold		4	003008_leoissnfhot		40
Sar Sat Beacon	003011_leoissttscold		17	003008_leoissnfhot		23
ACU 1	003011_leoissttscold		13	003008_leoissnfhot		12
ACU Speaker Box	003011_leoissttscold		10	003008_leoissnfhot		25
NH3 Boiler Controller	003011_leoissttscold		8	003008_leoissnfhot		18

No additional violations

On-orbit analysis- ISS LEO

Components outside the PV

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
OIMU-1, -2, -3	003011_leoissttscold		37	003008_leoissnfhot		37
Star Tracker-1, -2	003011_leoissttscold		29	003006_leoissnnhot		29
Phased Arrays	003013_leoisstncold		54	003006_leoissnnhot		53
Main Parachute	003011_leoissttscold		162	003008_leoissnfhot		26
Drogue Parachute	003011_leoissttscold		161	003006_leoissnnhot		24
Uprighting Press Tank	003011_leoissttscold		178	003008_leoissnfhot		52
LIDS Electronics Boxes	003010_leoisstnhot		21	003006_leoissnnhot		108
LIDS Soft Capture Ring	003011_leoissttscold		4	003006_leoissnnhot		102
LIDS Load Cells	003010_leoisstnhot		44	003006_leoissnnhot		244
LIDS Tunnel	003011_leoissttscold		101	003013_leoisstncold		TBD
GN2 Tank	003011_leoissttscold		11	003006_leoissnnhot		47
GO2 Tank	003010_leoisstnhot		6	003006_leoissnnhot		52
Ammonia Tank	003012_leoissnfcold		27	003008_leoissnfhot		45
Water Tank	003011_leoissttscold		36	003008_leoissnfhot		40
Helium Tank	003011_leoissttscold		201	003008_leoissnfhot		16
Hydrazine Tank	003011_leoissttscold		12	003009_leoisstnhot		13

No additional violations

On-orbit analysis- Lunar LEO

Crew Exploration Vehicle Project Office

Orion configuration

Pressure Vessel Temperatures

- MEETS REQUIREMENTS

[redacted] Min temp case : 10002 Tail to Sun (cold)
  - No PV location below min dew point (55F)

- Max temp case : Nose Fwd (hot)
  - No PV location above max PV touch temp req (113F)
  - Max PV temp 85 F

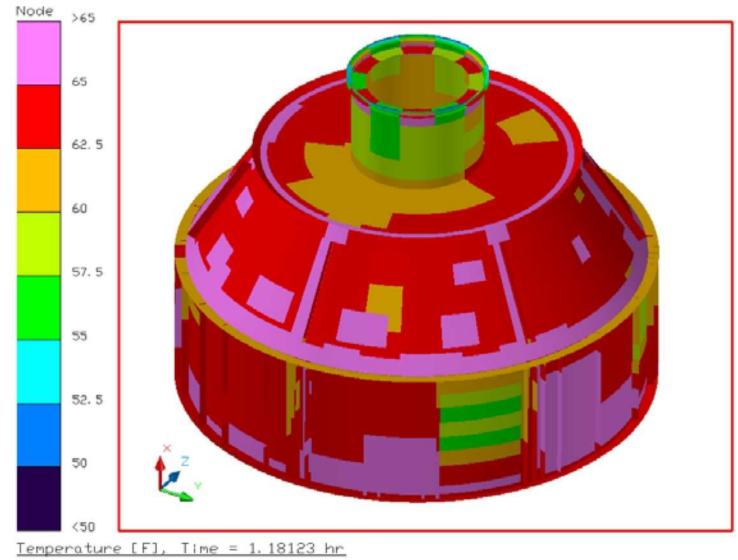
Backshell and FBC Bondline Temperatures

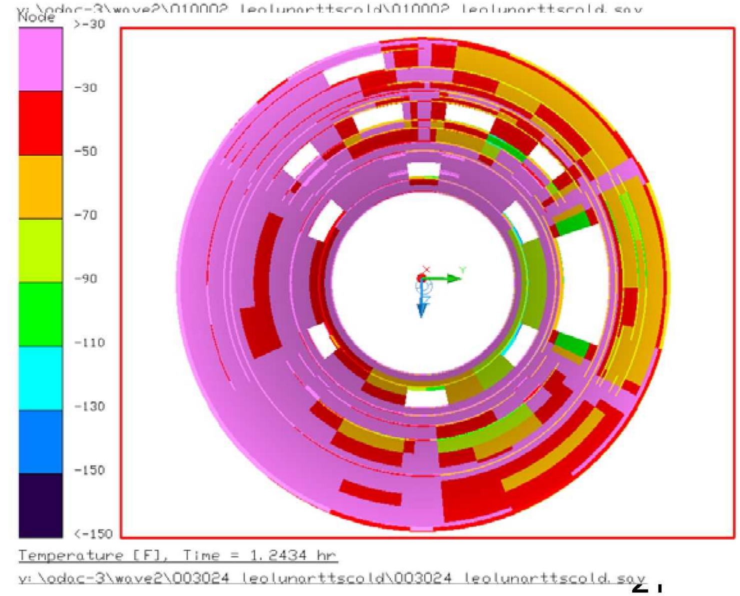
- MEETS REQUIREMENTS

- Min temp case: 3024 Tail to Sun (cold)
  - No bondline below min temp req (-150 F)
  - Min temp is -88F at FBC tile bondline

- M[redacted]x temp case: 3020 Nose Forward (hot)
  - No bondline above max temp req (550 F)
  - Max temp is 99 F at FBC tile bondline

No additional violations





On-orbit analysis- Lunar LEO

Orion/LSAM/EDS configuration

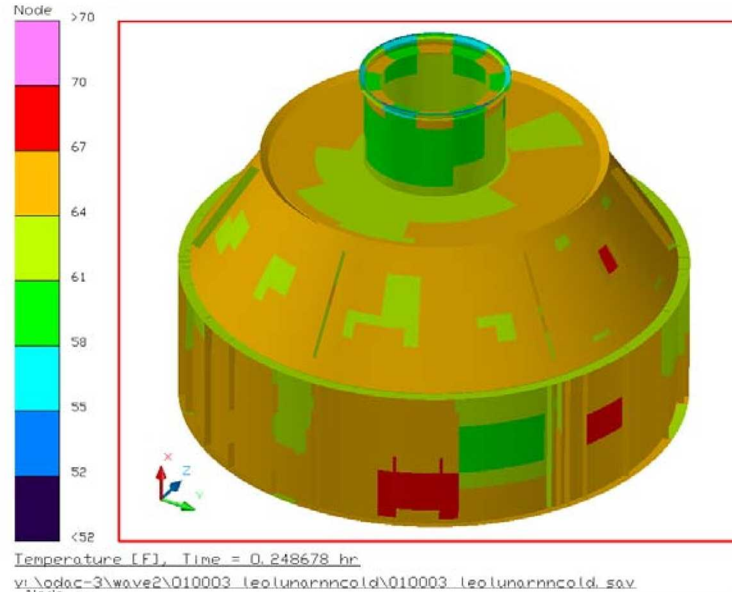
Pressure Vessel Temperatures

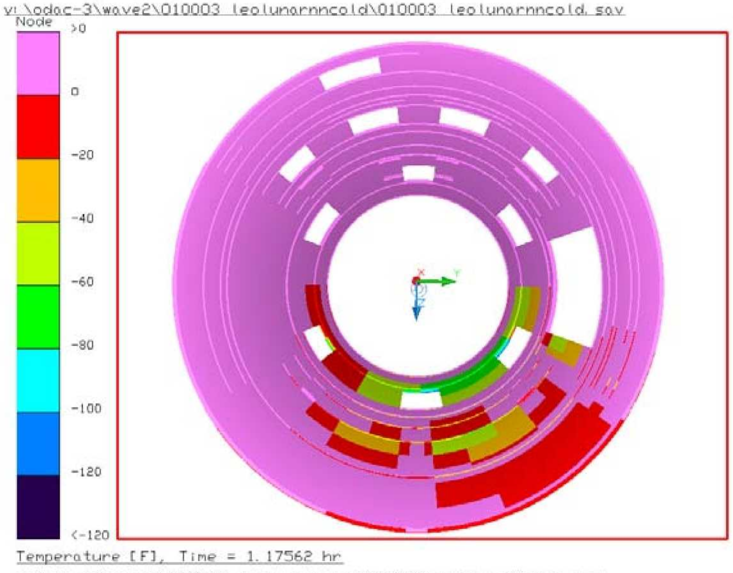
- MEETS REQUIREMENTS
- Min temp case : 10003 Nose Nadir (cold)
  - No PV location below min dew point (55 F)
- Max temp case : 3021 Tail Fwd (hot)
  - No PV locations are above max touch temp req (113 F)
  - Max PV temp 89 F

Backshell and FBC Bondline Temperatures

- MEETS REQUIREMENTS
- Min temp case: 3023 Nose Nadir (hot)
  - No bondline below min temp req (-150 F)
  - Min temp is -65 F at FBC tile bondline
- M[redacted]x temp case: 3023 Nose Nadir (hot)
  - No bondline above max temp req (550 F)
  - Max temp is 103 F at FBC tile bondline

No additional violations





On-orbit analysis- Lunar LEO

Inside of the PV
Orion Only

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VMC	003024_leolunarttscold		8	003020_leolunarnfhot		13
Port Av Wing CP BFCS	003024_leolunarttscold		0	003020_leolunarnfhot		31
CM Micro RIU	003024_leolunarttscold		8	003020_leolunarnfhot		24
PTU	003024_leolunarttscold		3	003020_leolunarnfhot		39
DU switch Panel	003024_leolunarttscold		13	003020_leolunarnfhot		0
Star Tracker Elec	003024_leolunarttscold		6	003020_leolunarnfhot		35
Ka Band Transceiver	003024_leolunarttscold		15	003020_leolunarnfhot		10
X/Ka Base Band Proc	003024_leolunarttscold		7	003020_leolunarnfhot		19
Base Band Proc's	003024_leolunarttscold		11	003020_leolunarnfhot		10
S Band Transponder	003024_leolunarttscold		11	003020_leolunarnfhot		15
S Band Swith Matrix	003024_leolunarttscold		11	003020_leolunarnfhot		18
S Band Baseline Proc	003024_leolunarttscold		11	003020_leolunarnfhot		10
S Band LNA Lo Power	003024_leolunarttscold		10	003020_leolunarnfhot		23
DV/EC/LP Radio	003024_leolunarttscold		2	003020_leolunarnfhot		40
UHF/VHF SAR Radio	003024_leolunarttscold		2	003020_leolunarnfhot		40
Sar Sat Beacon	003024_leolunarttscold		15	003020_leolunarnfhot		23
ACU 1	003024_leolunarttscold		11	003020_leolunarnfhot		12
ACU Speaker Box	003024_leolunarttscold		8	003020_leolunarnfhot		24
NH3 Boiler Controller	003024_leolunarttscold		7	003020_leolunarnfhot		21

No additional violations

On-orbit analysis- Lunar LEO

Inside of the PV

Orion + EDS + LSAM

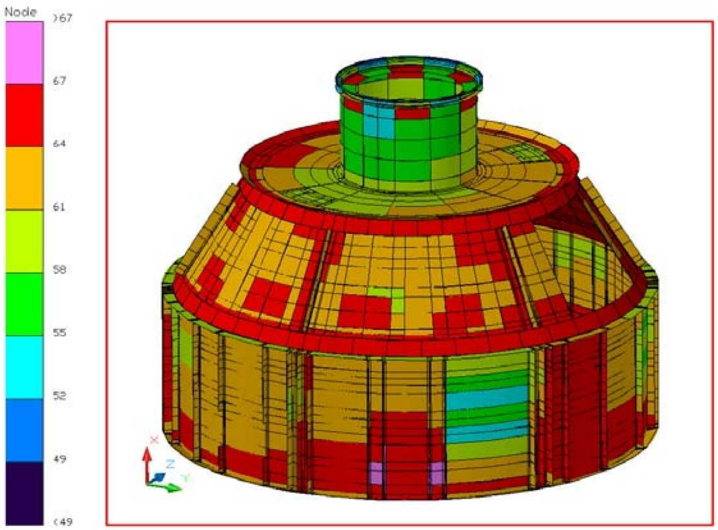
Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VMC	003028_leolunarnncold		10	003021_leolunartfhot		14
Port Av Wing CP BFCS	003028_leolunarnncold		1	003021_leolunartfhot		32
CM Micro RIU	003028_leolunarnncold		9	003022_leolunartnhot		24
PTU	003028_leolunarnncold		3	003021_leolunartfhot		40
DU switch Panel	003028_leolunarnncold		14	003021_leolunartfhot		2
Star Tracker Elec	003028_leolunarnncold		6	003021_leolunartfhot		35
Ka Band Transceiver	003028_leolunarnncold		16	003021_leolunartfhot		11
X/Ka Base Band Proc	003028_leolunarnncold		8	003021_leolunartfhot		20
Base Band Proc's	003028_leolunarnncold		13	003022_leolunartnhot		11
S Band Transponder	003028_leolunarnncold		13	003021_leolunartfhot		16
S Band Swith Matrix	003028_leolunarnncold		13	003022_leolunartnhot		19
S Band Baseline Proc	003028_leolunarnncold		13	003022_leolunartnhot		11
S Band LNA Lo Power	003028_leolunarnncold		12	003022_leolunartnhot		24
DV/EC/LP Radio	003028_leolunarnncold		2	003021_leolunartfhot		41
UHF/VHF SAR Radio	003028_leolunarnncold		2	003021_leolunartfhot		40
Sar Sat Beacon	003028_leolunarnncold		16	003021_leolunartfhot		24
ACU 1	003028_leolunarnncold		22	003021_leolunartfhot		13
ACU Speaker Box	003028_leolunarnncold		8	003021_leolunartfhot		26
NH3 Boiler Controller	003028_leolunarnncold		8	003021_leolunartfhot		22

No additional violations

On-orbit analysis- LLO

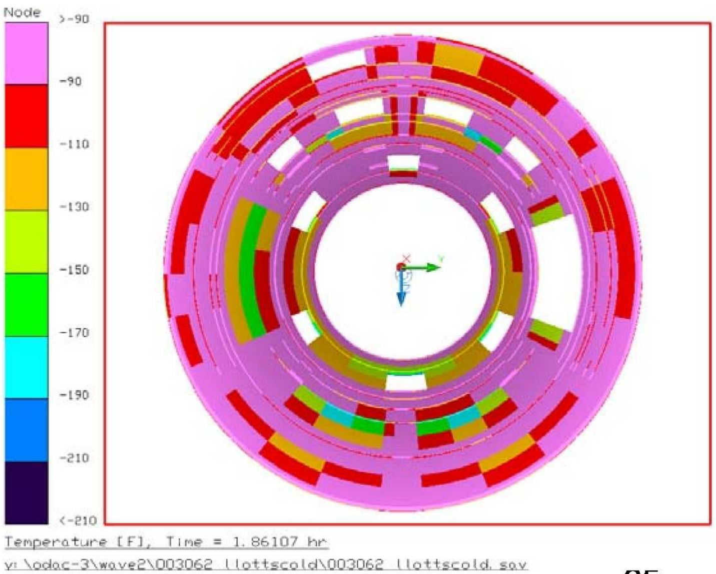
Pressure Vessel Temperatures

- Min temp case 10008: Tail to Sun, Cold
  - Min heater setpoint is 60 F
  - PV temperatures below dew point req (55F) in 3 locations
    - Minimum temperatures due to heat losses through RCS thruster brackets
    - Mitigation: isolate thruster brackets, optimize PV heaters
  - Min predicted PV temperature is 54 F
- Max temp case: Nose Forward, Hot
  - No PV location above max PV touch temp req (113F)
  - Max PV temp 83 F on cone



Backshell and FBC Bondline Temperatures

- Min temp case: Tail to Sun, Cold
  - Several locations below min temp req (-150F)
    - Bondline requirement assumed to only apply just prior to reentry
  - Backshell bondline min temp is -171 F
- Max temp case: Nose Forward, Hot
  - No bondline above max temp req (550 F)
  - Backshell bondline max temp is 103 F



CM Components Inside of PV, LLO

Crew Exploration Vehicle Project Office

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VMC-1, -2	3061_llottscold		8	3040_llottshot		15
BFCS	3061_llottscold		0	3058_llotfhot		34
mirco RIU	3061_llottscold		8	3040_llottshot		26
PTU	3061_llottscold		2	3058_llotfhot		42
DU switch Panel	3061_llottscold		8	3058_llotfhot		2
Star Tracker Electronics	3061_llottscold		5	3058_llotfhot		38
Ka Band Transceiver	3061_llottscold		14	3040_llottshot		11
X/Ka Band Processor	3061_llottscold		6	3040_llottshot		13
Base Band Processors	3061_llottscold		24	3058_llotfhot		12
S-Band Transponder	3061_llottscold		14	3058_llotfhot		18
S-Band Switch Matrix	3061_llottscold		18	3058_llotfhot		20
S-Band Processors	3061_llottscold		19	3058_llotfhot		12
S-Band LNA	3061_llottscold		12	3058_llotfhot		26
DV/EC/LP Radio	3061_llottscold		1	3058_llotfhot		42
UHF/VHF SAR Radio	3061_llottscold		1	3058_llotfhot		42
SAR Sat Beacon	3061_llottscold		14	3040_llottshot		26
ACU-1, -2	3061_llottscold		14	3036_llottshot		14
Speaker Box	3061_llottscold		7	3058_llotfhot		26
Ammonia Boiler Controller	3061_llottscold		6	3040_llottshot		22

No additional violations

CM Components Outside of PV, LLO

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
OIMU-1, -2, -3	3062_llottscold		26	3056_llotfhot		40
Star Trackers	3062_llottscold		15	3057_llotfhot		39
Phased Array Antennas	3062_llottscold		1	3058_llotfhot		60
Main Chutes	3062_llottscold		145	3058_llotfhot		28
Drogue Chutes	3062_llottscold		137	3058_llotfhot		36
Uprighting Pressurant Bottle	3062_llottscold		158	3056_llotfhot		53
LIDS Electronic Boxes	3062_llottscold		4	3044_llonnhot		88
LIDS Soft Capture Ring	3062_llottscold		0	3042_llonnhot		59
LIDS Loads Cells	3062_llottscold		19	3044_llonnhot		242
LIDS Tunnel	3062_llottscold		73	3055_llonfhot		TBD
Nitrogen Tanks	3062_llottscold		-5	3058_llotfhot		51
Ammonia Tanks	3062_llottscold		12	3058_llotfhot		48
Water Tanks	3062_llottscold		5	3058_llotfhot		41
Helium Bottles	3062_llottscold		188	3058_llotfhot		19
Hydrazine Tanks	3062_llottscold		7	3058_llotfhot		14

Mitigation Table

Component	Exceedance	Issue	Mitigation
CM Nitrogen Tank	-5°F less than minimum requirement (35°F)	Minimum Nitrogen tank temperatures are less than the minimum allowable temperature requirement during the lunar transit phase.	Work with ECLSS to re-evaluate the nitrogen tank temperature requirements. Nitrogen is only used for fire suppression. Expect minimum tank temperature requirement can be reduced.

PV & bondline temps- Lunar Transit

Pressure Vessel Temperatures

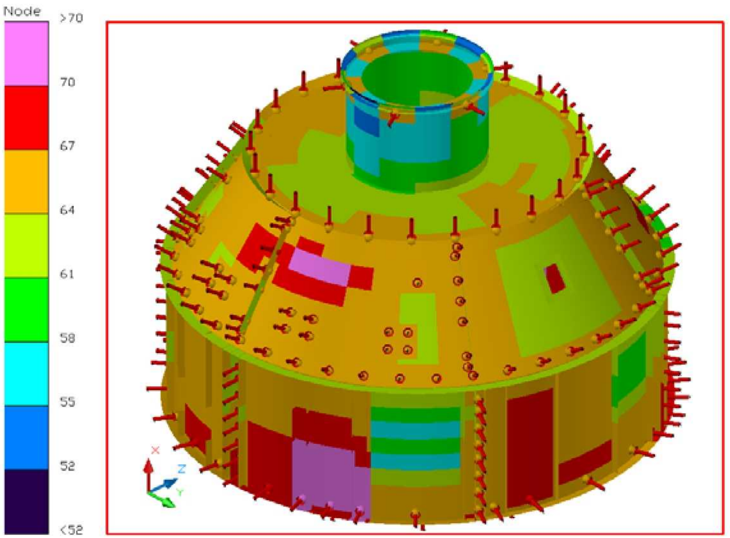
- Min temp case : 10004 Tail to Sun (cold)
  - Heater set points at 60F
  - 1 PV location below dew point (55F)
    - Confined to tunnel (54F min temp)
    - Heaters/locations need to be optimized

- Max temp case : 3032 Tail to Sun (hot)
  - No PV locations above max touch temp req (113F)
  - Max PV temp 82 F

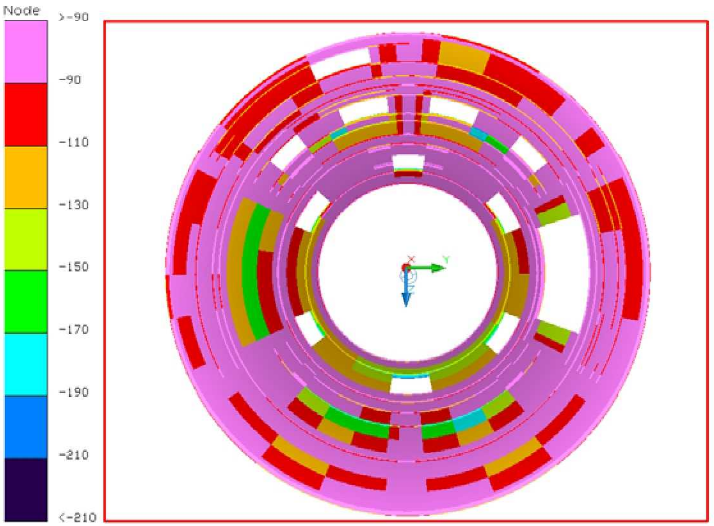
Backshell and FBC Bondline Temperatures

- Min temp case: 3031 Tail to Sun (cold)
  - Several locations below min temp req (-150F)
    - Bondline requirement assumed to only apply just prior to reentry
  - Min temp is -171 F at Backshell bondline

- M[redacted]x temp case: 3032 Tail to Sun (hot)
  - No bondline above max temp req (550 F)
  - Max temp is 33 F at Backshell bondline



Temperature [F], Time = 2 hr
v:\odac-3\wave2\010004_ltttscold\010004_ltttscold.sav



Temperature [F], Time = 2 hr
v:\odac-3\wave2\003031_ltttscold\003031_ltttscold.sav

CM Components Outside of the PV

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
OIMU-1, -2, -3	003031_Itttscold		28	003032_Itttshot		42
Star Tracker-1, -2	003031_Itttscold		17	003032_Itttshot		54
Phased Arrays	003031_Itttscold		32	003032_Itttshot		71
Main Parachute	003031_Itttscold		144	003032_Itttshot		30
Drogue Parachute	003031_Itttscold		138	003032_Itttshot		54
Uprighting Pressurant Tank	003031_Itttscold		159	003032_Itttshot		57
LIDS Electronics Boxes	003032_Itttshot		45	003032_Itttshot		175
LIDS Soft Capture Ring	003032_Itttshot		14	003032_Itttshot		181
LIDS Load Cells	003032_Itttshot		64	003032_Itttshot		340
LIDS Tunnel	003032_Itttshot		103	003032_Itttshot		TBD
GN2 Tank	003031_Itttscold		-3	003032_Itttshot		63
Ammonia Tank	003031_Itttscold		15	003032_Itttshot		48
Water Tank	003030_Itttscold		32	003032_Itttshot		41
Helium Tank	003031_Itttscold		191	003032_Itttshot		24
Hydrazine Tank	003031_Itttscold		7	003032_Itttshot		15

Note: For LIDS, only heater controlled nodes are shown.

Mitigation Table

Component	Exceedance	Issue	Mitigation
CM Nitrogen (GN2) Tank	-3°F less than minimum requirement (35°F)	Minimum Nitrogen tank temperatures are less than the minimum allowable temperature requirement during the lunar transit phase.	Work with ECLSS to re-evaluate the nitrogen tank temperature requirements. Nitrogen is only used for fire suppression. Expect minimum tank temperature requirement can be reduced.

CM Components inside of the PV

Component Description	Cold Case ID	Temperatures (°F)		Hot Case ID	Temperatures (°F)	
			Margin			Margin
VMC -1, 2	003030_Itttscold		19	003032_Itttshot		16
BFCS	003031_Itttscold		19	003032_Itttshot		35
Micro RIU	003031_Itttscold		21	003032_Itttshot		31
LPTU	003030_Itttscold		18	003032_Itttshot		-71
DU switch Panel	003031_Itttscold		21	003032_Itttshot		5
Star Tracker Electronics	003030_Itttscold		23	003032_Itttshot		-16
Ka Band Transceiver	003031_Itttscold		30	003032_Itttshot		25
X/Ka Base Band Processor	003030_Itttscold		19	003032_Itttshot		35
Base Band Processors	003031_Itttscold		35	003032_Itttshot		11
S Band Transponder	003031_Itttscold		30	003032_Itttshot		17
S Band Swith Matrix	003031_Itttscold		35	003032_Itttshot		19
S Band Baseline Processor	003031_Itttscold		35	003032_Itttshot		11
S Band LNA Lo Power	003031_Itttscold		28	003032_Itttshot		26
DV/EC/LP Radio	003030_Itttscold		18	003032_Itttshot		-13
UHF/VHF SAR Radio	003030_Itttscold		18	003032_Itttshot		-13
Sar Sat Beacon	003031_Itttscold		30	003032_Itttshot		26
Audio Control Unit-1, 2	003031_Itttscold		39	003032_Itttshot		11
Audio Comm Unit Speaker Box	003031_Itttscold		14	003032_Itttshot		28
Ammonia Boiler Controller	003030_Itttscold		19	003032_Itttshot		35

CM Components inside of the PV

Mitigation Table			
Component	**Exceedance**	**Issue**	**Mitigation**
LPTU	71°F High	LPTU dissipates 414 W of power and there are several other electronic components including Star Tracker Electronics, and Radios on the same cold plate.	Work with Power, ECLSS and Structures subsystems to determine integrated solution. Increase heat transfer between cold plate and coolant.
Star Tracker Electronics	16°F High	LPTU warms cold plate temperature above maximum requirement, causing Star tracker electronics to exceed max temperature requirement. Star Tracker Electronics dissipates 22 W of power	Fixing LPTU temperature issue will fix Star Tracker Electronics maximum temperature issue
DV/EC/LP Radio	13°F High	LPTU warms cold plate temperature above maximum requirement, causing Radio to exceed max temperature requirement.	Fixing LPTU temperature issue will fix Radio maximum temperature issue
SAR SAT Radio	13°F High	LPTU warms cold plate temperature above maximum requirement, causing Radio to exceed max temperature requirement.	Fixing LPTU temperature issue will fix Radio maximum temperature issue

CM Special Trade Studies

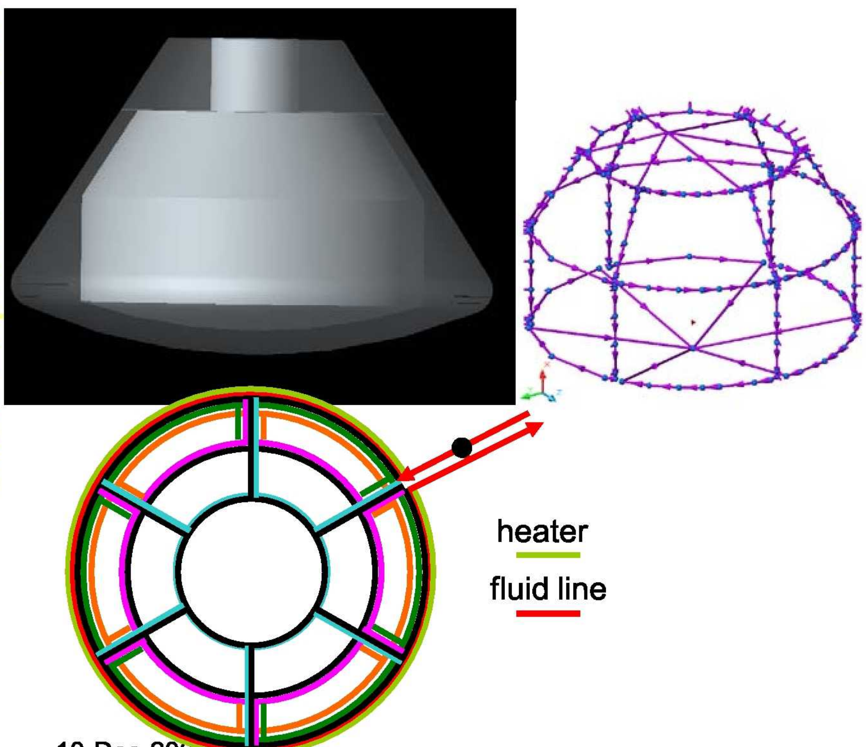
- Pressure Vessel (PV) heater power assessments and optimization studies
  - Heat Pipe Assessment (NASA JSC IDOT team)
  - Heat Pipes vs. Distributed ATCS (LM)
  - Effect of avionics box emissivity on PV heater power (LM)
  - Effect of backshell optical properties on PV heater power (LM)

- Vehicle emergency scenarios
  - Backup Emergency Capability (BEC) entry analysis (NASA)
  - Dead Spacecraft – What happens thermally during a power outage (LM)

Heat Pipe Assessment

Background

- Conventional thermal design uses local electric heaters to maintain all zones of pressure vessel above dew point (here 53ºF)
  - Some zones do not require heat in some attitudes
- Waste heat is available from warm areas and from the Active Thermal Control System (ATCS)



Approach

- Heat pipe isothermalization was studied as a means of providing condensation control for the ORION Crew Module (CM) PV.
- Heat pipes would scavenge heat from the ATCS and distribute the heat over the crew cabin external surface area;

Results

- Analysis indicated that the heat pipe network will provide sufficient heat transfer to preclude crew cabin condensation (i.e., all crew cabin temperatures will be maintained at or above the 53 F dew point while in the coldest attitude -- tail-to-sun, trans-lunar/trans-earth;
- The flexibility of the design was tested using a side-to-sun, trans-lunar/trans-earth analysis case and showed that the heat pipe network was able to distribute the heat and preclude condensation;
- Potential power savings on the order of 1+ kW are estimated for the trans-lunar/trans-earth cases

Conclusion

- The use of heat pipes for PV isothermalization looked promising and was proposed to be further evaluated.

*Backup is reconfiguration of the S loops and making them primary means of condensation control

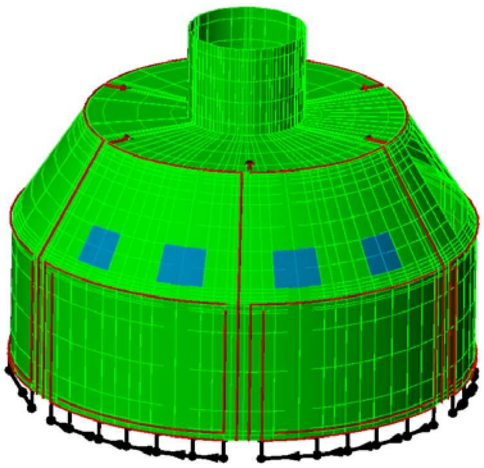
Heatpipes vs. Distributed ATCS Lines

Background

- After IDOT recommendation heatpipes were evaluated for the isothermalization method for the Crew Module PV.

Approach

- Heat pipes were incorporated to the DAC-2 Thermal Desktop (TD) model and compared to the S-Loops alternative. Lunar transit broad side/aft to sun analyzed



Results

- Both heat pipes and S-Loops are nearly equivalent delivering ATCS heat to PV
  - Especially if ATCS film coefficient is included in the heat-pipe model
  - Heat spreading potential appears marginal

	Pros	Cons
Heat Pipes	•Works without pumps •Slightly more efficient than S-Loops transferring ATCS heat (taps ATCS fluid after unpressurized coldplates) •Can be used as heater distribution network	•Relatively more difficult to test and verify •Will likely require additional structure to attach, adding mass •Current configuration only marginally effective reducing circumferential temperature gradients •Higher development costs
S-Loops	•Relatively easier to test and verify •Can be used as heater distribution network •Probably easier to implement than heat pipes.	•Requires pumps to work •Slightly less efficient than heat pipes transferring ATCS heat (taps ATCS fluid after pressurized coldplates)

- Current heat pipe configuration does not appear effective at reducing circumferential gradients
  - Heat-pipe arrangement is better at longitudinal isothermalization

Conclusion

- Determined that heat pipes show no significant heater power savings over S-Loops

Effects of avionics box emissivity on PV

Background

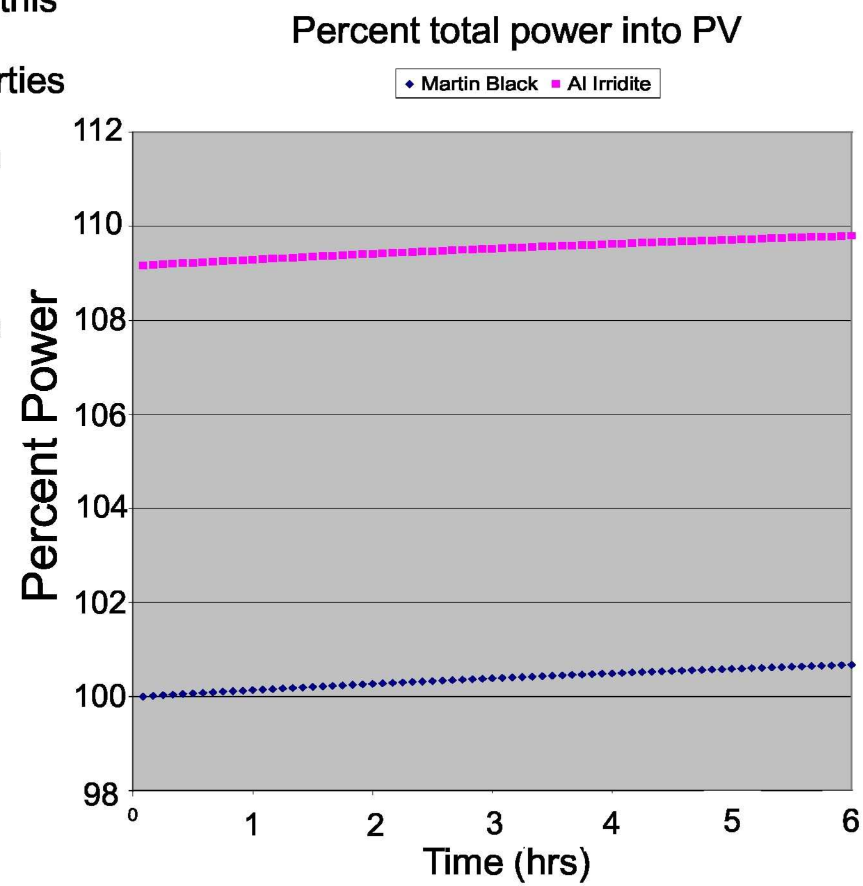
- As part of an emergency contingency where only ½ the vehicle power is available, the effects of avionics box coating emissivities on PV heater requirement was analyzed.

Approach

- DAC 2 LM Integrated thermal model updated for this analysis.
- All CM & SM avionics box coatings optical properties were changed and compared for this analysis.
- Optical properties used: black ε=.94 to irridite ε=.(
- Based on previous analysis screening two worst case mission phases wee analyzed:
  - Cold: Lunar transit Aft To Sun (ATS) Evacuated
  - Hot: Low Lunar Orbit (LLO) Nose Forward (NF) Be
- Total PV heater power required and box temperatures were scrutinized.

Results

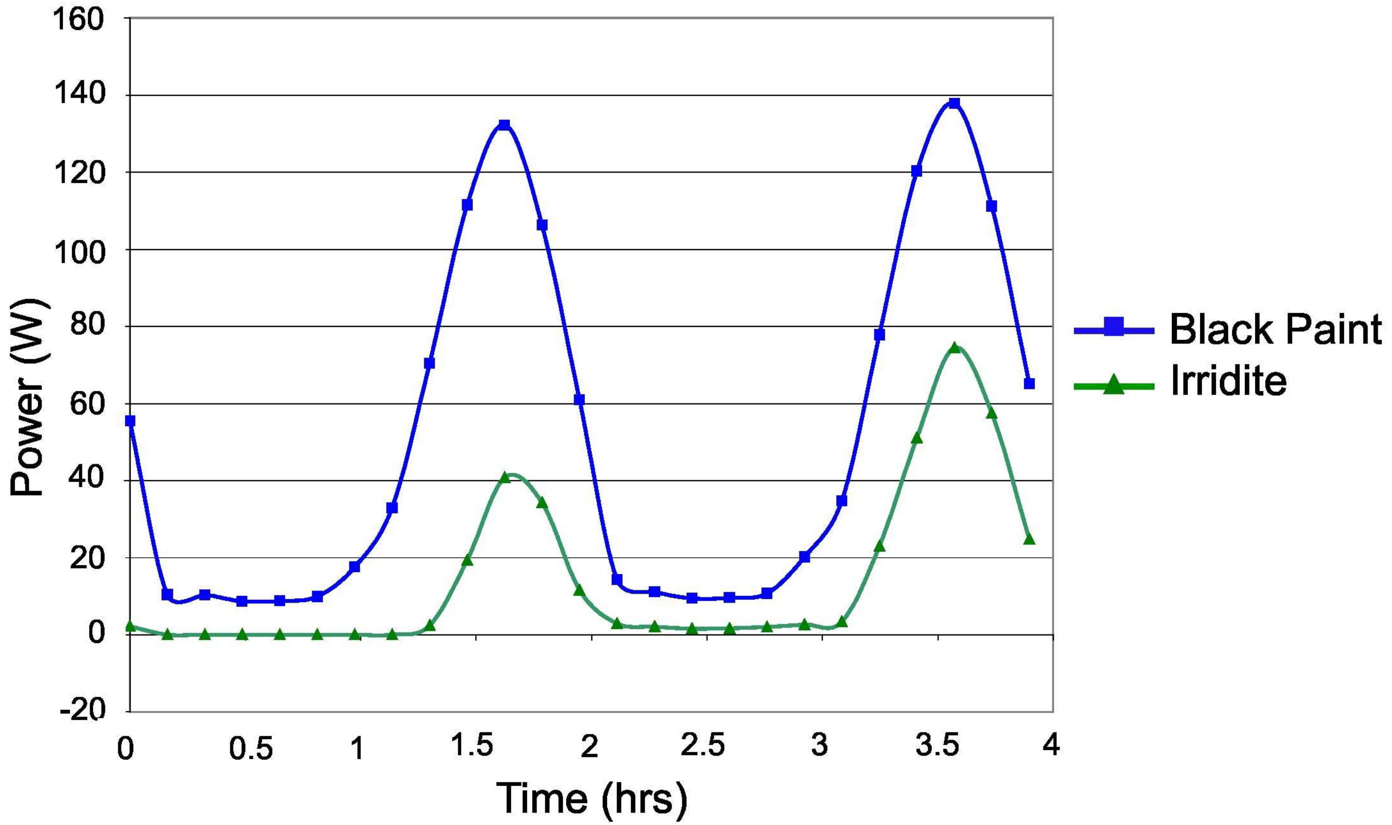
- Total heater power into the pressure vessel for cold case: lunar transit aft to sun (evacuated)
- Delta of 9% ~ 125W



Effects of avionics box emissivity on PV

Results
- Total heater power into the pressure vessel for hot case: low lunar orbit, nose forward Beta 20.
- Irridite requires less intermittent power, ~40-100 W.

Conclusion
- It was determined the PV would require 9% less heater power to be conditioned with the use of black or an equivalent high emissive coating for the avionics.



Effect of optical properties on PV heater power

<u>Background</u>

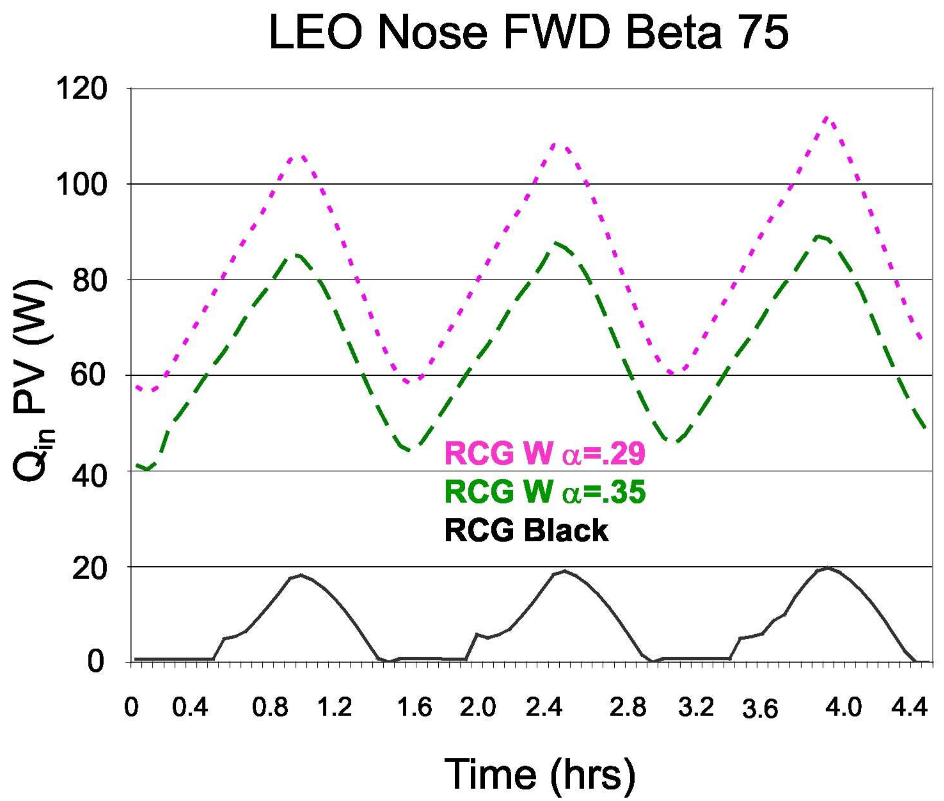
- As part of an emergency contingency where only ½ the vehicle power is available, the effects of different backshell optical properties on PV heater requirement was analyzed.

<u>Approach</u>

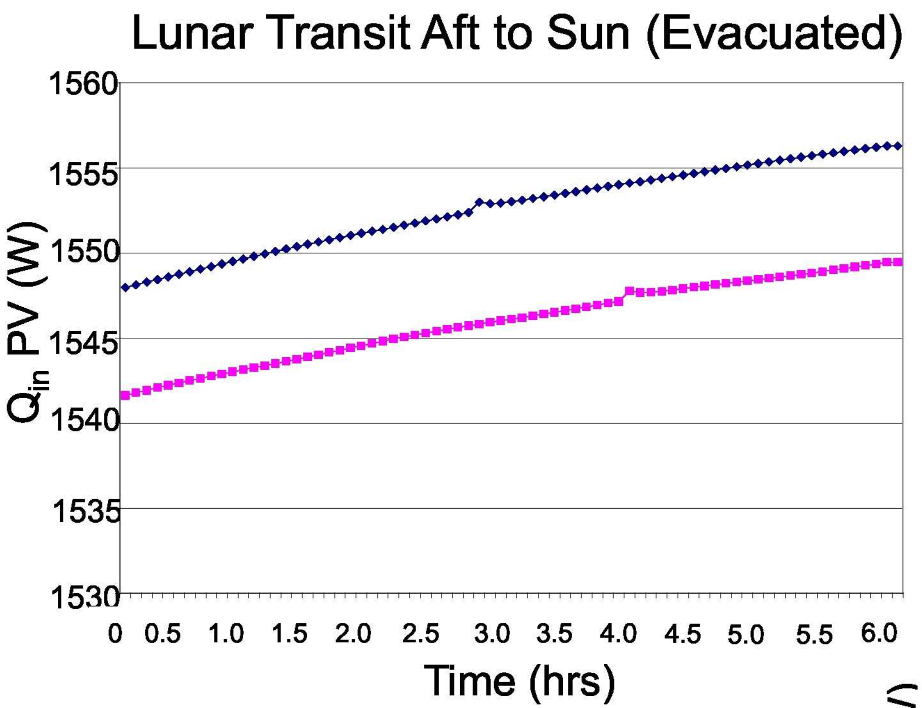
- DAC 2 LM Integrated thermal model updated for this analysis.
- Solar absorptivity sensitivity was done changing the baseline white RCG to black RCG
- Low emissive parametric study done.
- Analysis cases:
  - ATS & NTS Lunar Transit "cold" cases
  - NF LEO and LLO "hot" cases
- Total PV heater power required was scrutinized.

<u>Results</u>

White vs Black RCG

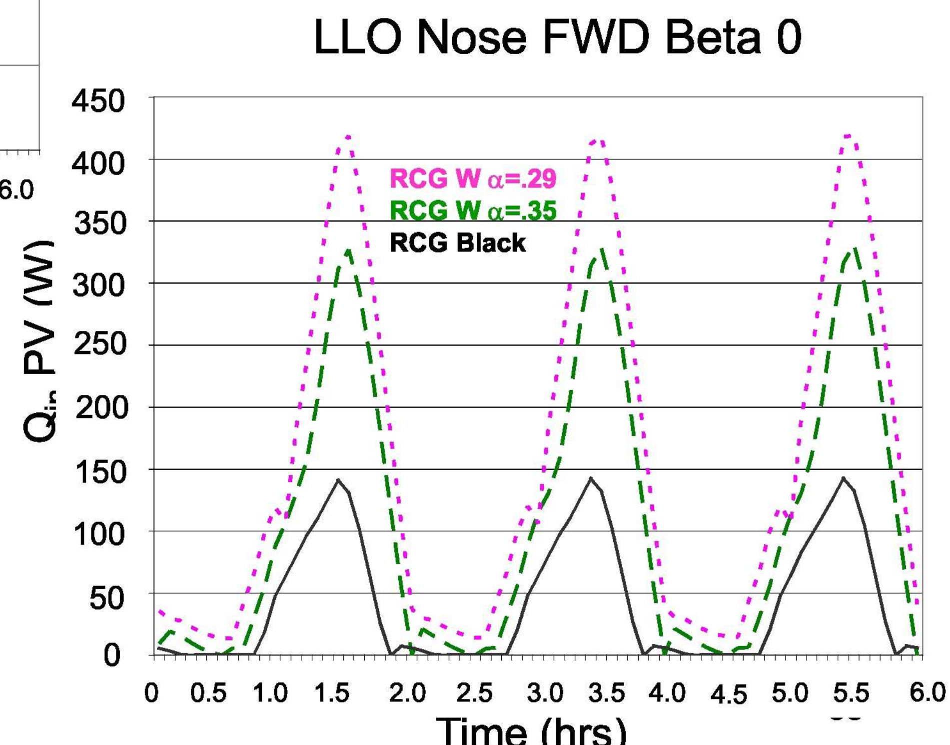


Effect of optical properties on PV heater power

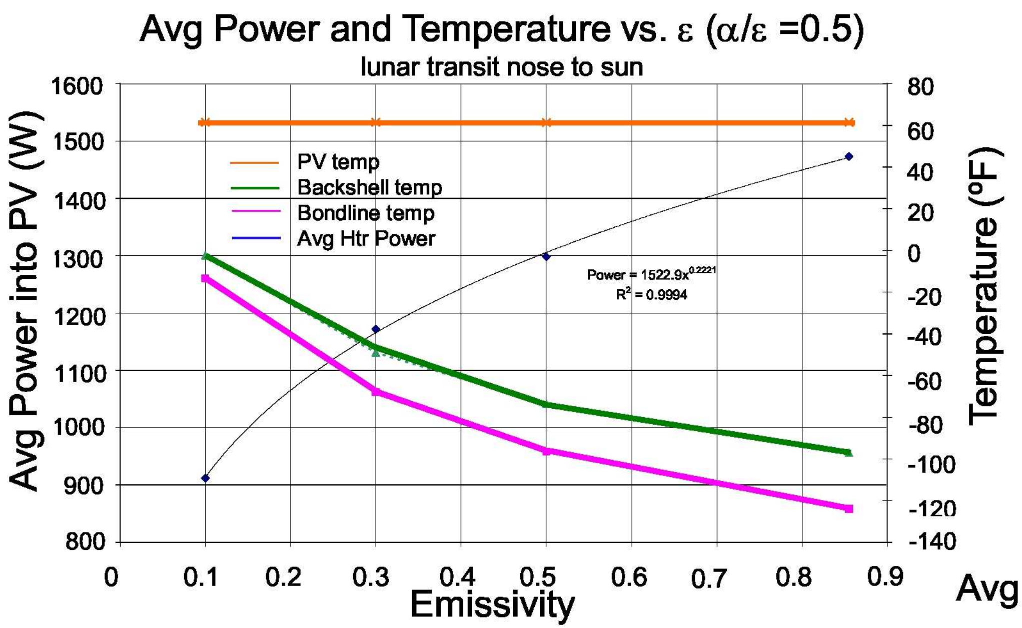


Results

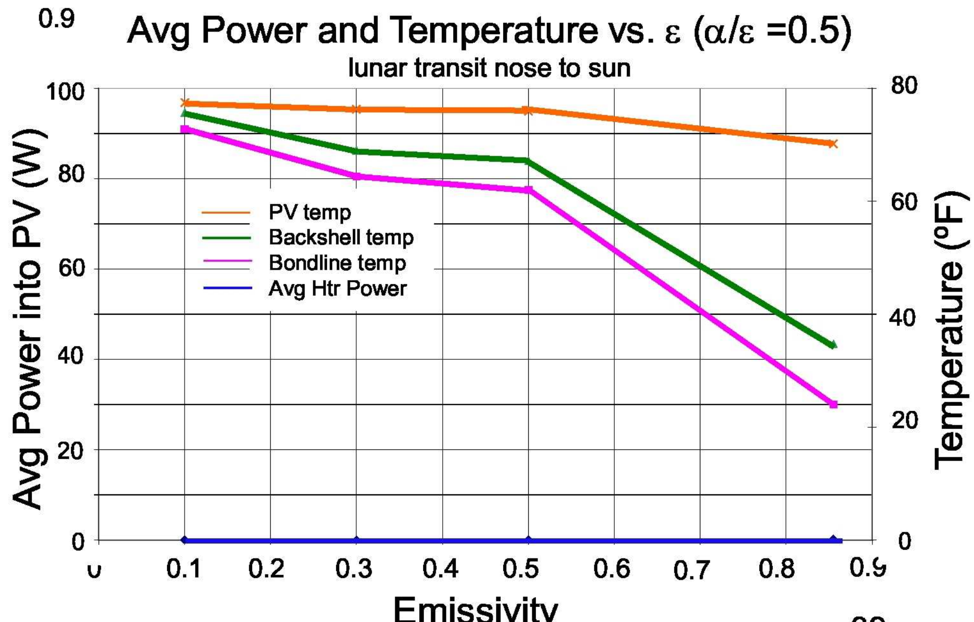
White vs Black RCG



Effect of optical properties on PV heater power



Results
Emissivity parametric analysis



Conclusion

RCG White vs. Black study:

- Black saves up to ~250 Watts for hot case LLO
- Little PV heater power effect for LT (cold case)
  - ATS: Very small change
  - NTS: PV Power results were zero for this case—PV too warm

Low e parametric studies:

- Lowering e for LT is effective for reducing heater power for PV. (up to 38% savings, theoretically @ e=0.1)

BEC entry analysis

Background

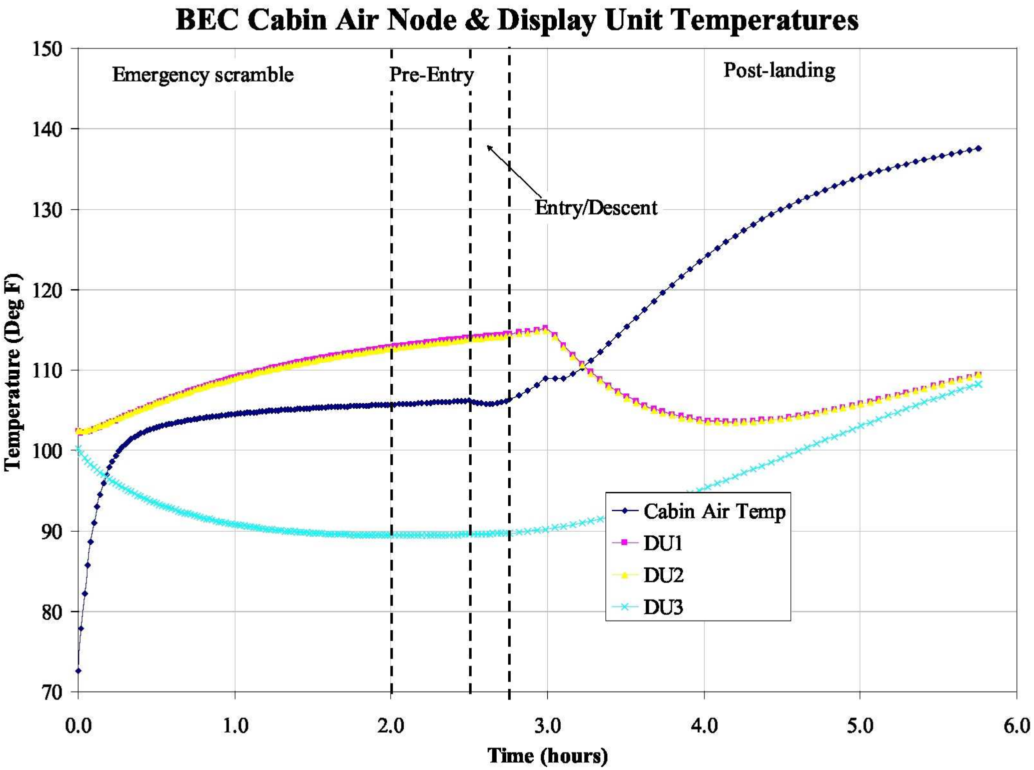
- Provide thermal assessment of the main cabin air node and internal components for an Emergency entry scenario.

Approach

- DAC 2 LM Integrated thermal model updated for this analysis.
- Assumption of ATCS complete failure
- Vehicle in reduced power mode
- 5 phase emergency entry analyzed from LEO to Post landing

Conclusion

- Main cabin air temperature reaches 106ºF at landing.
- After 3hrs post-landing the main cabin air temperature reaches a max. of 138ºF.
- Predictions show that no components exceed acceptance limits.



Dead Spacecraft Results

Background

- Purpose of the analysis was to determine cabin air temperature and the available time for power recovery.

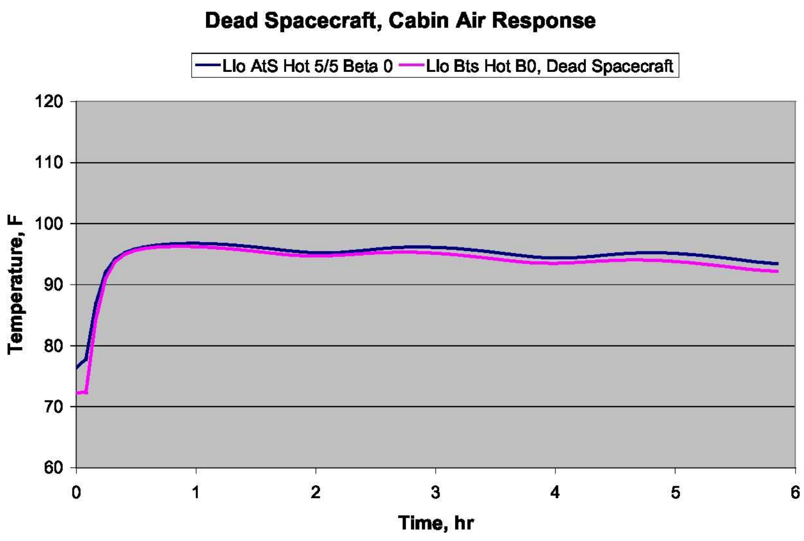
Approach

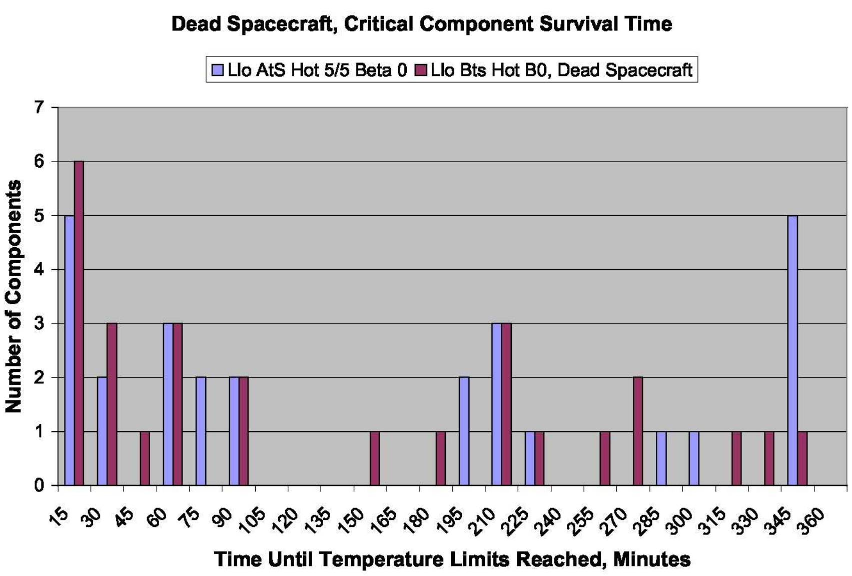
- Turn off all the heat loads associated with a box dissipation.
- Turn off all heater power.
- Low lunar orbit, aft to sun and nose forward attitudes analyzed

Conclusion

- Cabin air temperature rises quickly to ~97°F. As boxes cool and thermal gradients develop the cabin air begins to cool off slowly.
- There is a very short period time to recover from a total power loss. Propulsion components (lines and thrusters) exceed their temperature limits within the first 15 minutes.

Results

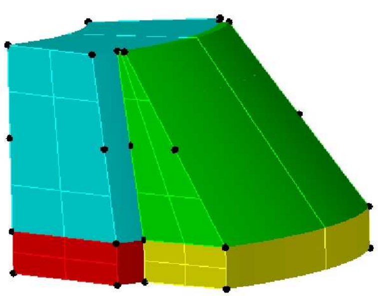




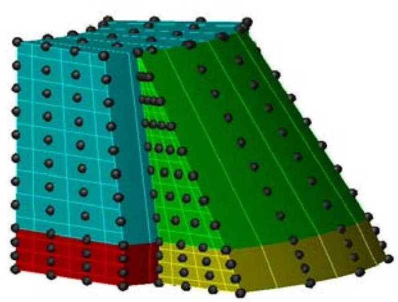
GFE CEV Parachute Assembly System (CPAS) Analysis

Background

- Lockheed Martin (LM) uses a NASA built coarse thermal model of the Crew Exploration Vehicle Parachute Assembly System (CPAS) in the integrated Orion thermal model for ODAC-3
- Analysis was needed to verify the fidelity of the CPAS thermal model
- On Orbit, Lunar Transit, Tail to Sun, No Heaters: Minimum temperature shown with LM coarse analysis: 15°F
- With CEQATR margins, limits not exceeded



Coarse Nodalization



Fine Nodalization

Approach

- NASA built a detailed thermal model of the CPAS and conducted analysis using boundary sink temperatures and conductors from LM

Results

- Same case: Minimum temperature of detailed model analysis: -23°F, is ~40°F lower than predicted in LM coarse analysis

Conclusion

- Due to averaging of the volume cell temperature, the extreme temperatures are masked in the coarse model
- With CEQATR margins, the operational temperature limits are exceeded