Thermal Performance Expectations of the Advanced Stirling Convertor Over a Range of Operating Scenarios

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OBJECTIVE

- Assist the Science Mission Directorate in developing technologies for space missions.

- Explore the capability of computational modeling to assist in the development of the **A**dvanced **S**tirling **C**onvertor.

- Baseline computational simulation with available experimental data of the ASC.

- Calculate peak external pressure vessel wall temperatures and compare them with anticipated values.

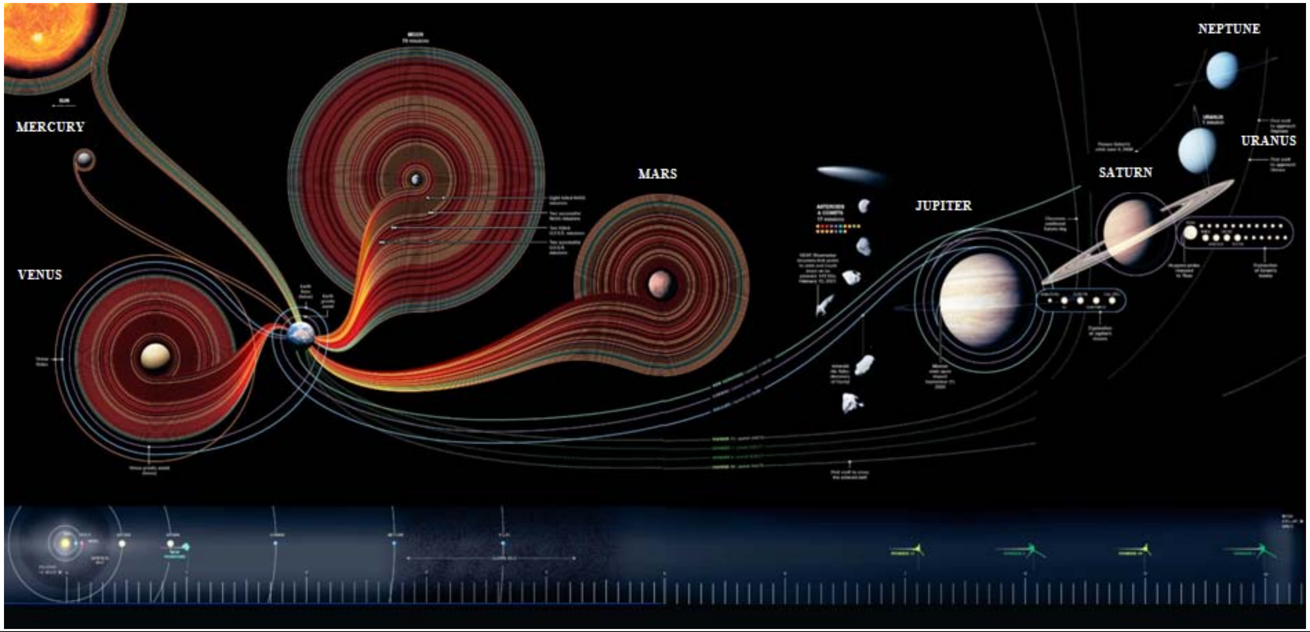
- Calculated peak magnet temperature inside the ASC over a range of operational scenarios.

BACKGROUND

- Radioisotope power system are an effective source of power for missions that are far from the sun.

- Radioisotope power systems provide on-board power for various deep space missions.

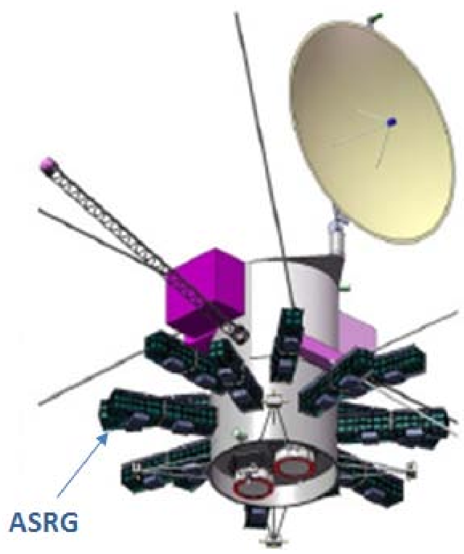
Pioneer → Includes explorations of Jupiter and Saturn
Voyager → Includes explorations of Neptune
Cassini → Includes explorations of Saturn's rings
Galileo → Includes explorations of Jupiter



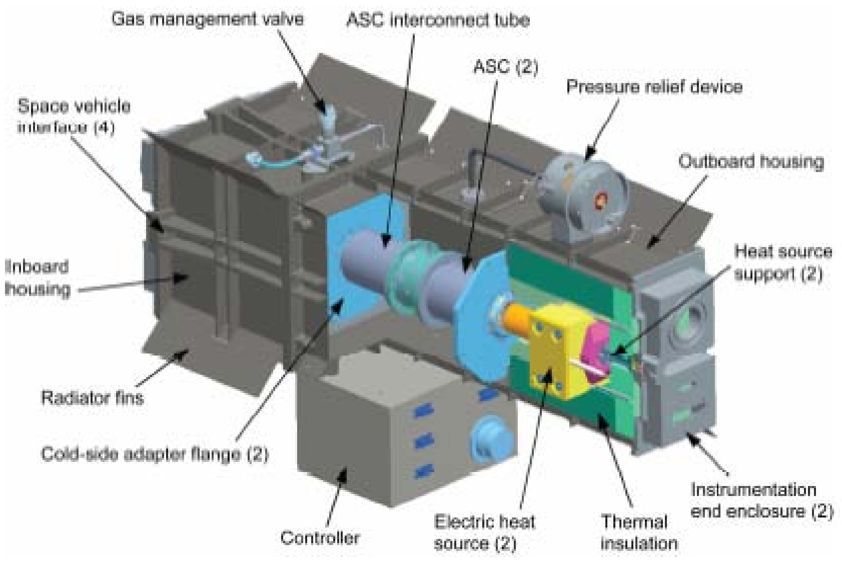
BACKGROUND

- Deep space probe configurations have been examined to explore the Kuiper Belt

- Configuration includes 140W ASRG.



Kuiper Belt Object Orbiter



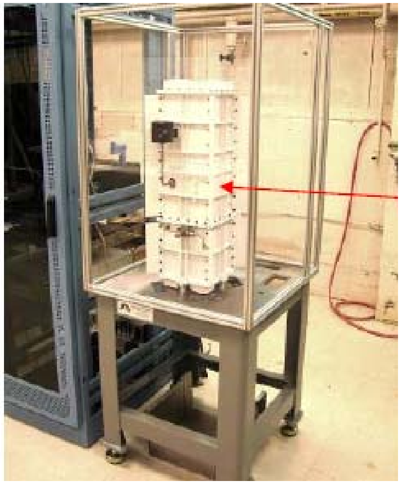
Advanced Stirling Radioisotope Generator

BACKGROUND

- 140 W ASRG currently tested at NASA GRC.

- ASRG is equipped with two ASC convertors.

- Testing includes different hardware versions of ASC



ASRG Testing at the NASA GRC Stirling Lab

Advanced Stirling Convertor

CLUSTER

- Node Count: 374 processors, 160 channel Clos network

- Fiber optic 1.28 Gb/s Bi-Directional, 600 ns latency

- Chip Design: AMD Opteron 250 & 850, 2- & 4-Way

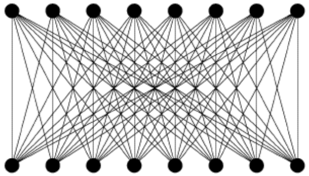
- Peak Floating Point Performance: 1.795 TeraFlops

- Total Memory: 4 Terabytes, Total Disk: 31.5 TeraBytes

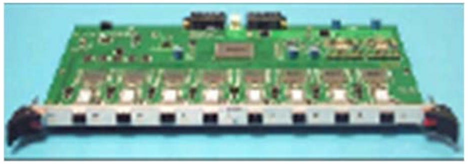
•Utilizes 75 KVA Power and 20 Ton Cooling

NASA GRC Cluster with Myrinet Fiber Optic Communications

128 port Myrinet Clos fiber Optic network switch

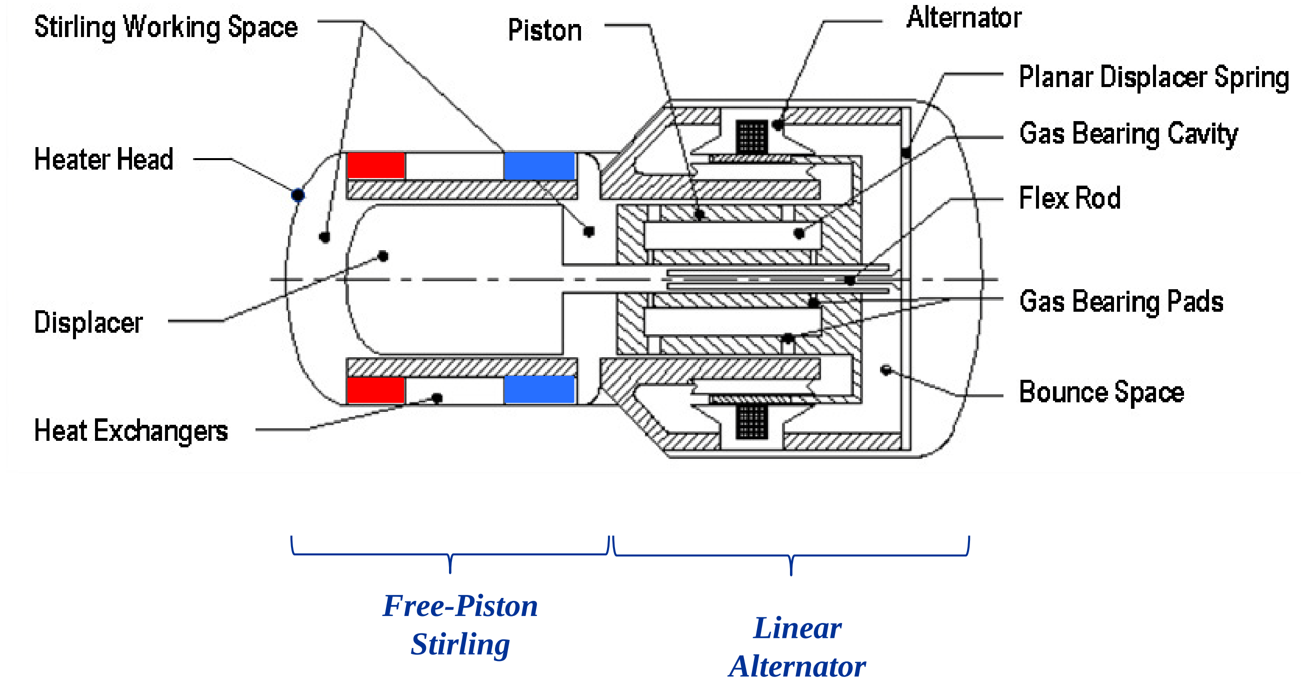


Clos Network



8-port “leaf “ level of switching in Clos network

MODEL



- Stirling cycle occupies head of the device. Hot-end temperature (from heat input → **red**) and cold-end temperature (from heat removal → **blue**) results in displacer and piston motion.

- Cyclic motion of piston moves a magnet adjacent to an alternator, creating an electric field.

- 2D (750,000 grid points); 3D (8.2 million grid points)

METHODOLOGY

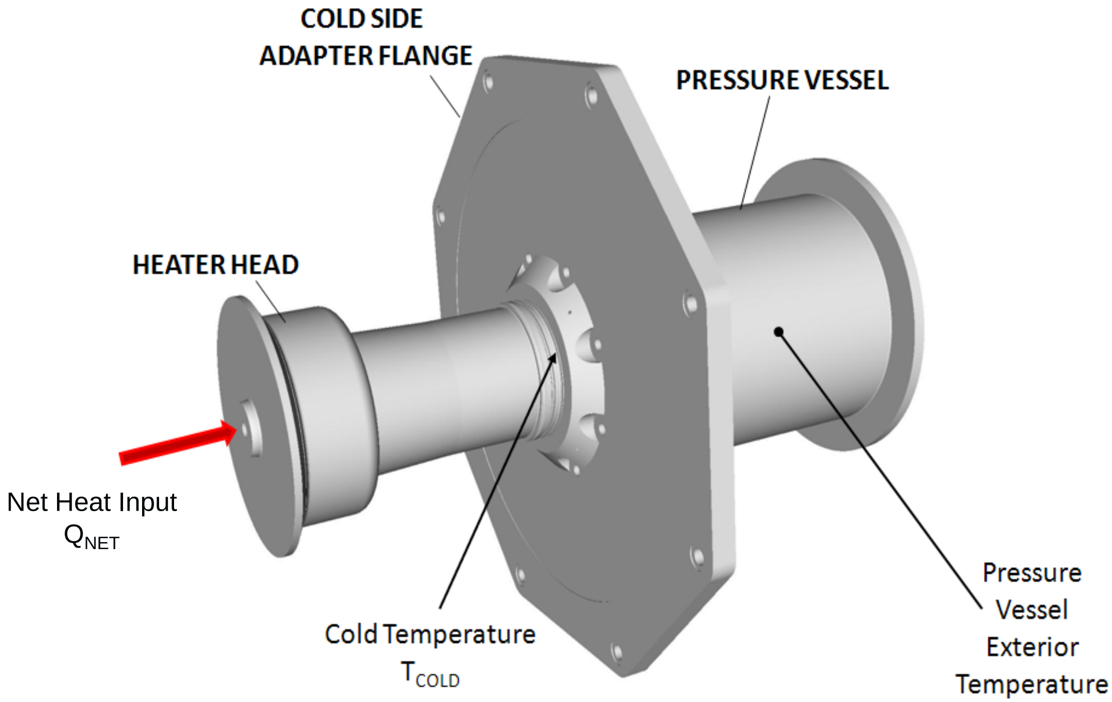
1) Run simulation using steady Navier Stokes equations until solution is converged.

Boundary conditions

- Net heat input (or hot-end temperature) on the heater head.
- Heat removal (or cold-end temperature) at the cold side adapter flange.
- Heat generation due to linear alternator losses (operating convertor).
- Radiating external wall to a remote environment at a temperature 25 C lower than the cold-end temperature.

2) Run unsteady Navier Stokes equations for 10 cycles until solution is time periodic.

BOUNDARY CONDITIONS

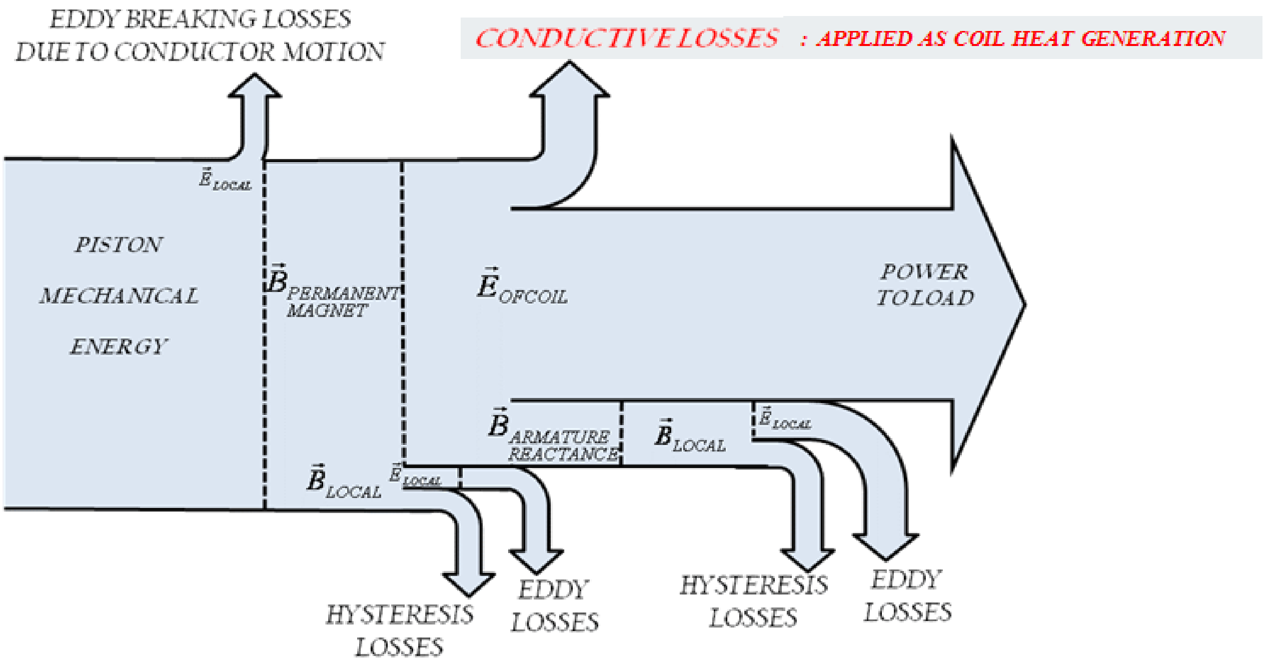


Heat input: Ranges from 180 to 208 Watts.

Heat rejection at CSAF: Removal rate up to 150 W.

Coil Heat generation: Aimed at simulating linear alternator losses during the conversion of mechanical power to electrical power.

BOUNDARY CONDITIONS



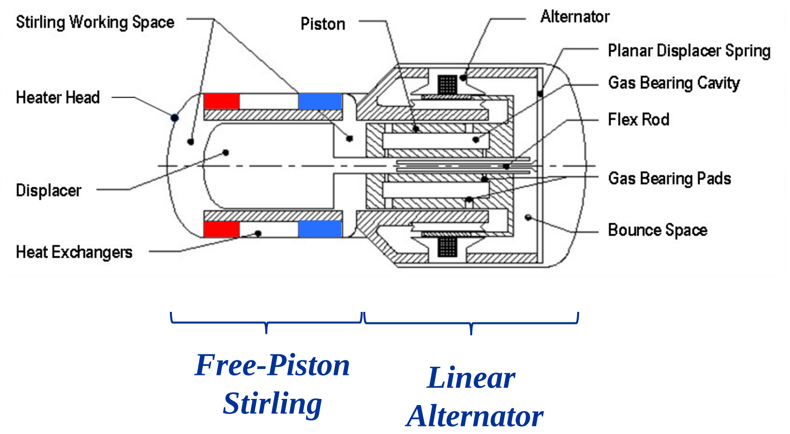
Linear Alternator Losses

Eddy Losses

Hysteresis Losses

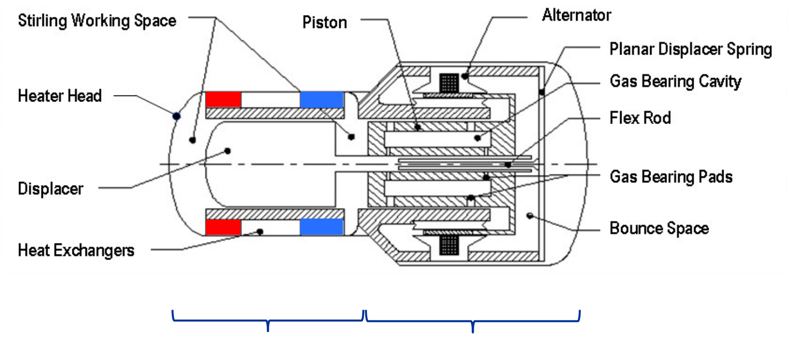
Applied all losses in computational model as heat generation terms in LA coil

RESULTS – *Comparison with lab data*



MODEL CONFIGURATION	AVAILABLE DATA	ENVIRONMENT		BOUNDARY CONDITIONS		MEASURED VALUE	CALCULATED VALUE
MODEL	TYPE	SURROUNDING MEDIUM	ENVIRONMENT TEMPERATURE	THOT °C	TCOLD °C	PV °C	PV °C
ASC-E	**Exp and Comp**	ARGON	20	624	63.2	**67.8**	69.1

RESULTS – *Varying coil heat generation*



MODEL CONFIGURATION			ENVIRONMENT	APPLIED BOUNDARY CONDITIONS		COIL HEAT GENERATION	PV External Wall
MODEL	TYPE	BEHAVIOR	TEMPERATURE	THOT °C	TCOLD °C	Watts	°C
ASC-E2	AXI	Stationary	110	850	120	7	*132.7*
	AXI	Stationary	110	850	120	8	*134.0*
	AXI	Stationary	110	850	120	**10**	***137.0***
	AXI	Stationary	110	850	120	11	*138.6*
ASC-E2	3D	Stationary	110	850	120	**10**	***135.7***

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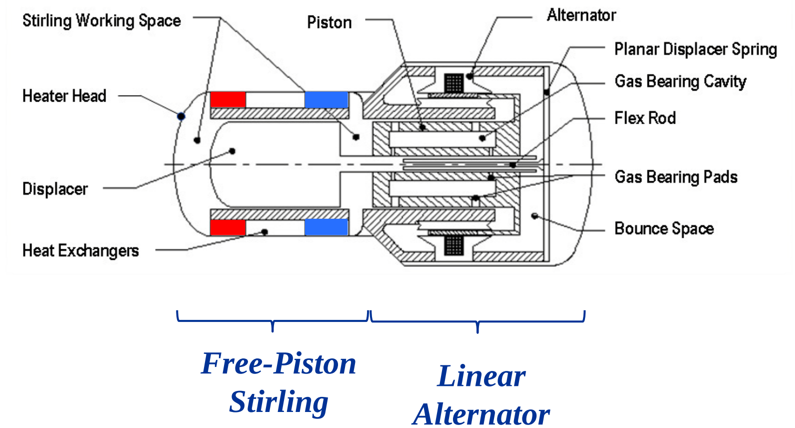
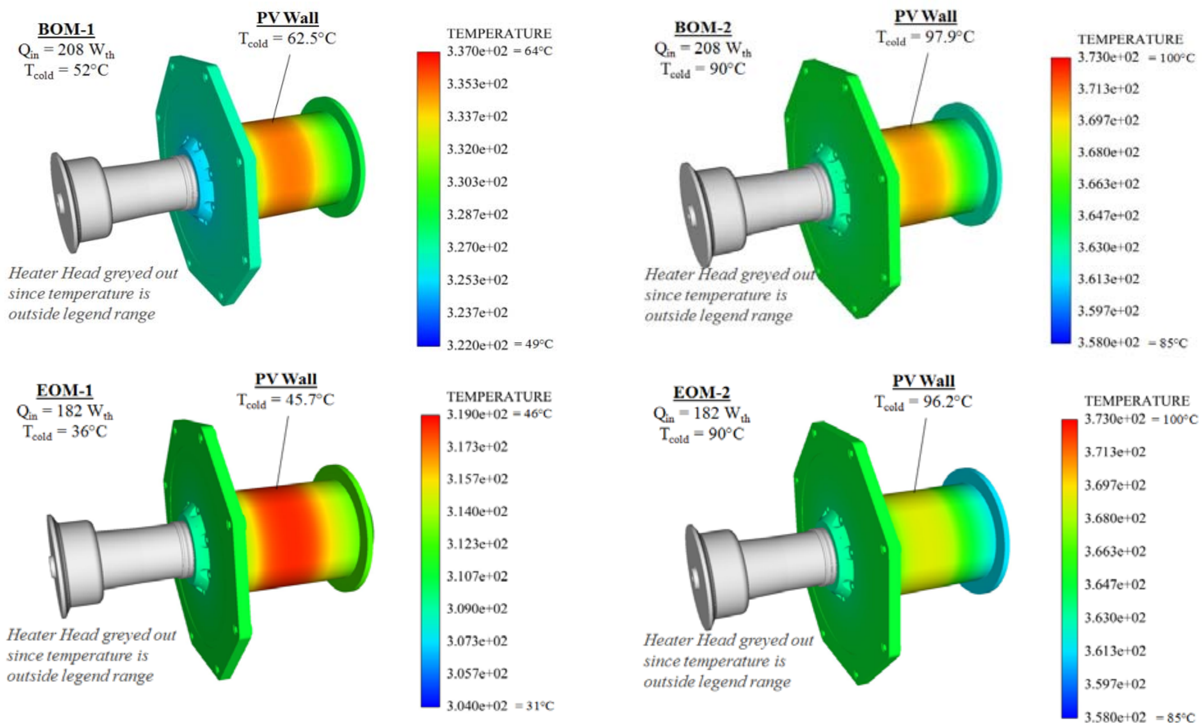
RESULTS – *Varying cold-end temperature*



MODEL CONFIGURATION			ENVIRONMENT	APPLIED BOUNDARY CONDITIONS		COIL HEAT GENERATION	PV External Wall
MODEL	TYPE	BEHAVIOR	TEMPERATURE	THOT °C	TCOLD °C	Watts	°C
ASC-E2	AXI	Stationary	110	850	120	10	*137.0*
	3D	Stationary	110	850	120	10	*135.7*
	AXI	Stationary	110	850	130	10	*142.5*
	AXI	Stationary	110	850	140	10	*147.0*
ASC-E2	AXI	Stationary	110	850	120	11	*139.6*
	AXI	Stationary	110	850	130	11	*144.2*
	AXI	Stationary	110	850	140	11	*148.8*

RESULTS – *Various operating conditions*



MISSION PHASE	CONDITION	FAR-FIELD TEMPERATURE	DESIGN INTENT VALUES			MODEL VALUES	
			THOT °C	TCOLD °C	PV °C	PV-AXI °C	PV-3D °C
BOM	**1**	27	850	52	**61**	**65.8**	**62.5**
BOM	**2**	65	850	90	**98**	**97.5**	**97.9**
EOM	**1**	11	850	36	**44**	**55**	**45.7**
EOM	**2**	65	850	90	**98**	**95.9**	**96.2**

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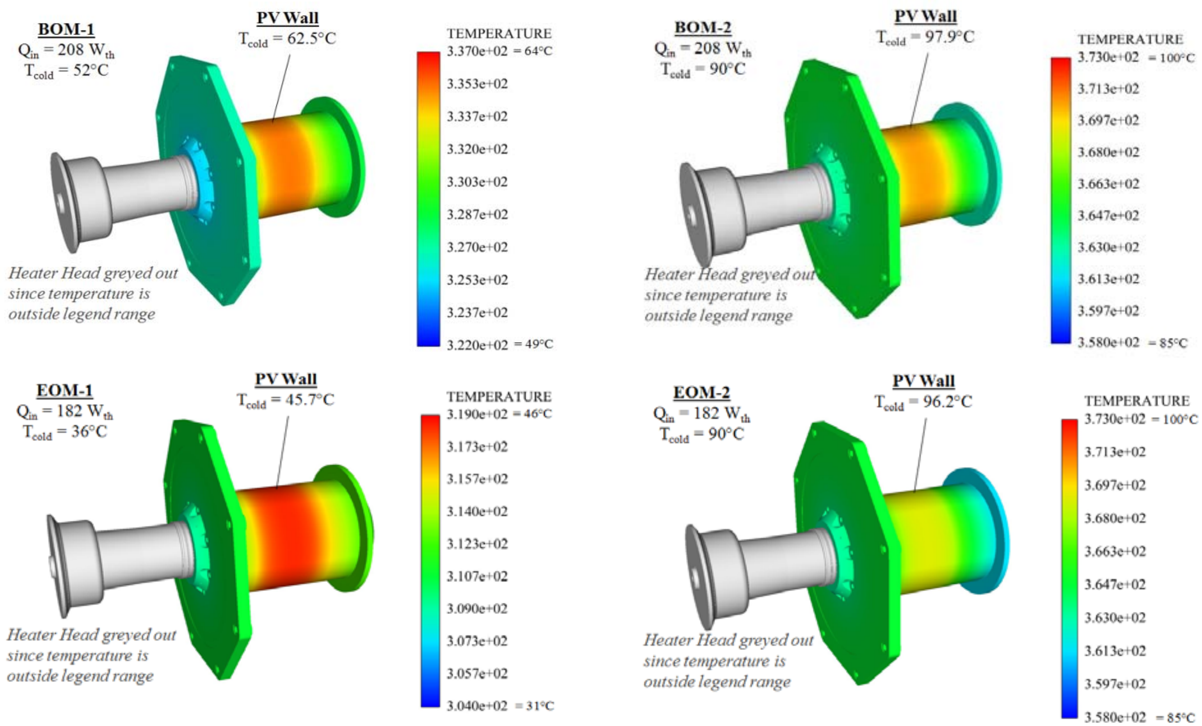
RESULTS – *Various operating conditions*



MISSION PHASE	CONDITION	FAR-FIELD TEMPERATURE	DESIGN INTENT VALUES			MODEL VALUES		
			THOT °C	TCOLD °C	PV °C	COIL °C	MAGNET °C	PV °C
BOM	**1**	27	850	52	**61**	**64.4**	**63.0**	**62.5**
BOM	**2**	65	850	90	**98**	**99.9**	**98.7**	**97.9**
EOM	**1**	11	850	36	**44**	**47.3**	**46.0**	**45.7**
EOM	**2**	65	850	90	**98**	**98.0**	**97.0**	**96.2**

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SUMMARY

- When conditions from the operating ASC-E were applied to the computational model, the calculated peak pressure vessel exterior wall temperature was within 1.5 C of the test article.

- A 1 Watt increase in coil heat generation rate resulted in a 1.4 C increase in peak temperature on the pressure vessel external surface.

- As the cold end temperature is increased, the ΔT between the peak PV wall and the cold-end decreases when coil heat generation is kept constant.

- While further enhancements are planned, the computational model should have enough fidelity to investigate the complex internal flow physics and heat transfer in the ASC-E2.

ACKNOWLEDGMENTS AND DISCLAIMER

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