Dynamic Power Convertor Validation and Verification Thermal Analysis

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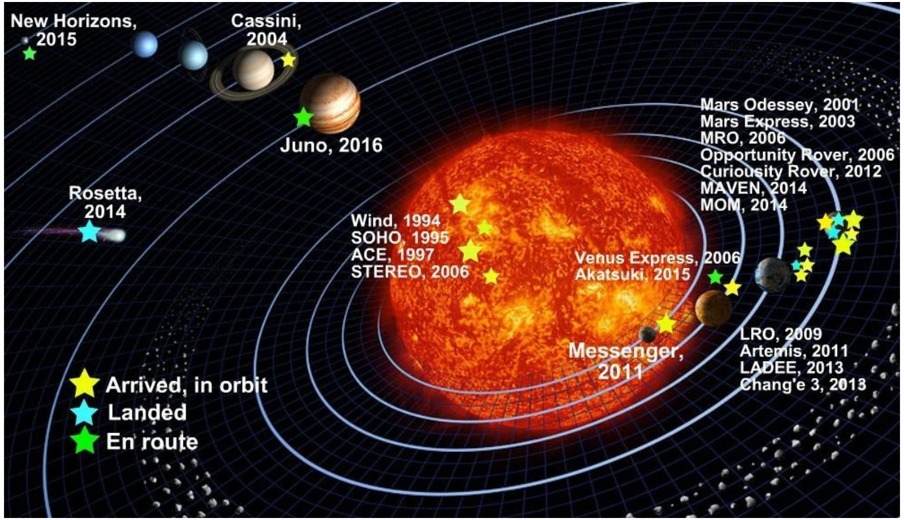
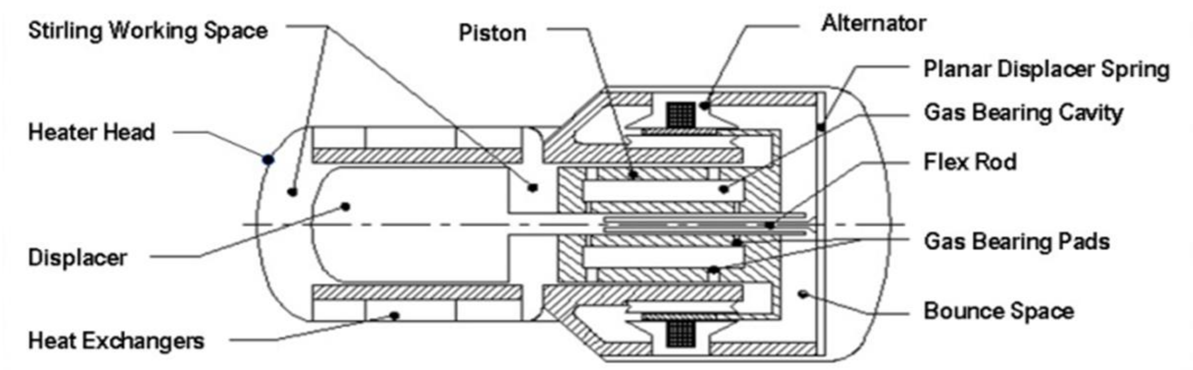
BACKGROUND

There have been numerous space missions conducted by NASA. Typically, for missions between the sun to Jupiter, batteries and solar panels can be used to generate onboard power. When the mission go to Saturn and outward, alternative power options are needed to supplement batteries.



BACKGROUND

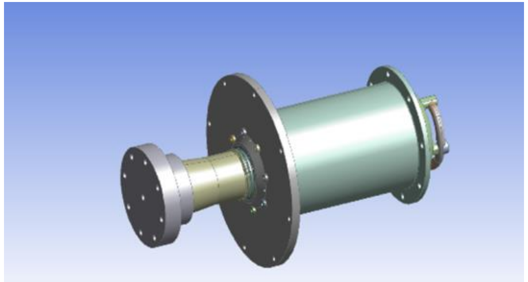
The Stirling convertor is an option for providing onboard electric power during unmanned space mission that target Saturn and beyond. If the convertor is supplied with radioactive decay heat, it can provide onboard power and recharge batteries.



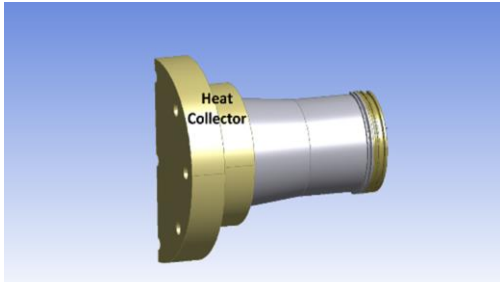
Generalized Stirling Convertor Layout

GEOMETRY

Stirling convertor (SRSC) are being tested in the Stirling Research Lab (SRL) at the NASA Glenn Research Center (GRC). To assist in understanding the performance of these convertors, numerical simulations are being run, using measured boundary conditions. To predict the behavior of the Stirling cycle, only the heater head (and its encapsulated components) are included in the CFD model.



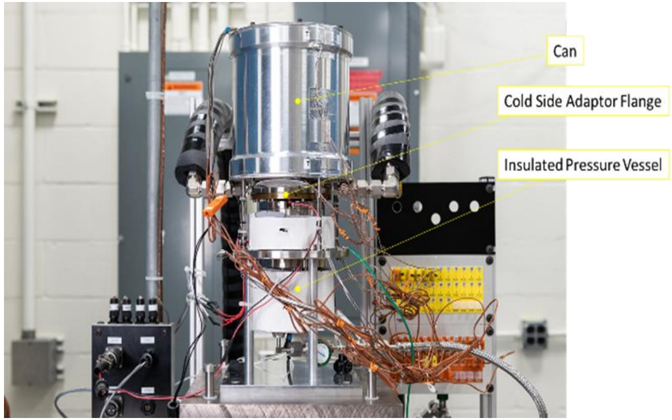
SRSC Convertor

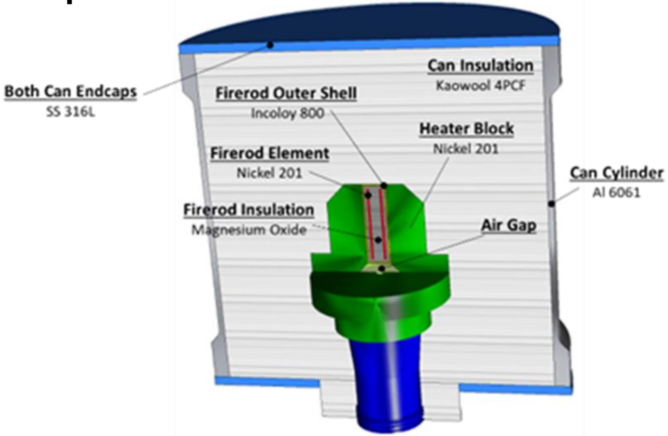


SRSC Convertor Heater Head

GEOMETRY

The SRSC was fitted with a Heating Package and an Insulation Package. Once instrumented and placed on the test stand, Insulation Loss (non-operating) and Operating tests were performed. For the CFD model, only the heater head (and its encapsulated components) were included.





SRSC Convertor in NASA GRC SRL

SRSC Convertor Heater Head

MEASURED DATA

The **Insulation Loss** data was collected over a variety of conditions. While other data was collected, only the data needed to perform the Insulation Loss simulations are shown here.

Convertor #	Point #	Ins Can Lid *C*	Ins Can Ext Fore *C*	Ins Can Ext Mid *C*	Ins Can Ext Aft *C*	Ins Can Base *C*	GHI W_{th}	Avg Hot-End *C*	Avg HS Temp *C*	Avg CE Temp *C*
SRSC-1	**S1**	*43.4*	*43.2*	*43.9*	*45.1*	*51.2*	*24.1*	*300.0*	*312.5*	*100.9*
SRSC-1	**S2**	*59.1*	*55.9*	*56.7*	*57.9*	*65.2*	*56.6*	*501.1*	*522.8*	*100.6*
SRSC-1	**S3**	***83.6***	***76.1***	***77.0***	***78.0***	***87.2***	***104.7***	***700.4***	***730.9***	***100.1***
SRSC-1	**S3L**	*79.5*	*70.4*	*70.8*	*70.7*	*76.0*	*107.9*	*700.2*	*731.4*	*20.2*
SRSC-1	**S3H**	*85.8*	*79.7*	*81.0*	*83.0*	*95.7*	*102.4*	*700.3*	*729.0*	*150.0*

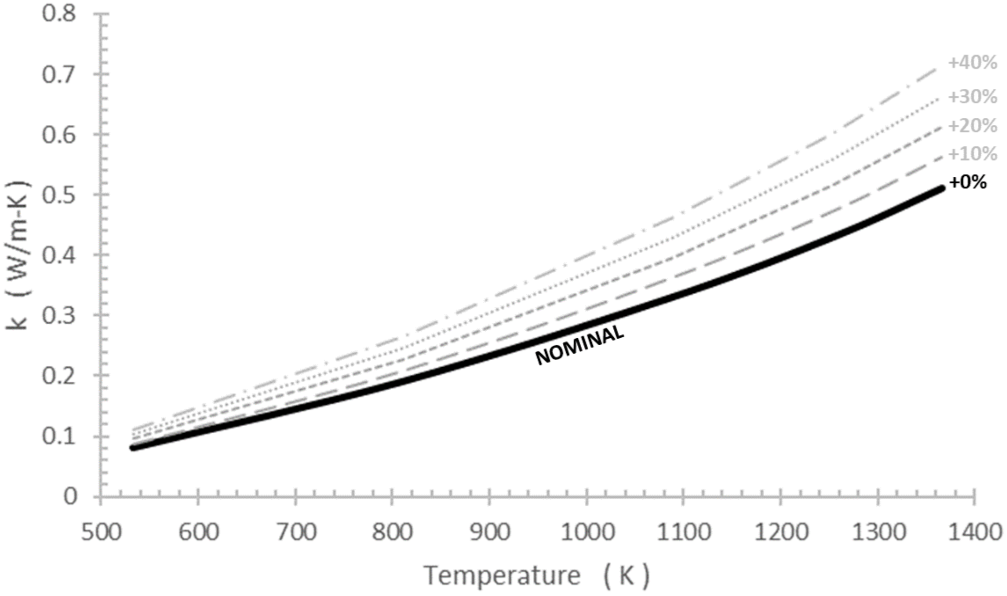
MEASURED DATA

The **Operational** data was collected over a variety of conditions. While extensive data was collected, only the data needed to perform the simulated operation simulations are shown here.

Convertor #	Point #	Ins Can Lid C	Ins Can Ext Fore C	Ins Can Ext Mid C	Ins Can Ext Aft C	Ins Can Base C	GHI W_{th}	Avg Hot-End C	Avg HS Temp C	Avg CE Temp C
SRSC-1	1a	91.4	78.1	78.0	77.0	81.3	357.0	700.4	813.9	21.1
SRSC-1	1b	93.5	79.8	79.6	78.5	82.1	381.4	700.6	822.7	20.8
SRSC-1	1c	85.9	75.8	75.9	75.4	79.9	182.4	700.7	757.6	20.1
SRSC-1	2a	**93.0**	**82.1**	**82.4**	**82.8**	**90.2**	**310.1**	**700.3**	**797.2**	**100.1**
SRSC-1	2b	94.8	82.6	83.0	83.1	90.5	357.0	700.2	813.5	99.9
SRSC-1	2c	89.6	81.0	81.6	82.1	88.2	184.3	700.7	757.6	100.2
SRSC-1	3a	99.1	90.1	91.1	92.8	105.1	331.8	699.8	804.3	175.0
SRSC-1	3b	94.9	89.9	91.3	93.9	106.6	182.7	700.1	756.1	175.2

MODELING

Once the boundary conditions and gross heat input were applied the model, the only changes were to the bulk insulation thermal conductivity.



MODELING

Insulation Loss

- Apply BCs and gross heat that was applied in lab.
- Calculate to convergence.
- Compare predicted T_{HE} to lab data.
- Adjust bulk insulation (KW) thermal conductivity and rerun
- Repeat until predicted T_{HE} matches measured T_{HE}

Result → Effective thermal conductivity for Kaowool

MODELING

Simulated Operation

- Apply BCs and gross heat that was applied in lab
- Set k_{KW} to that produced from Insulation Loss w/ similar gradients
- Calculate to convergence
- Compare predicted T_{HE} to lab data
- Sink heat via Expansion Space
- Repeat until predicted T_{HE} matches measured T_{HE}

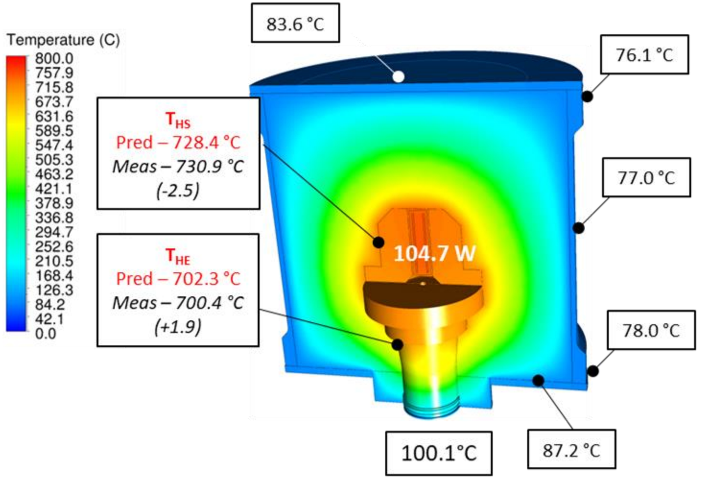
Result → Net Heat Input

MODELING

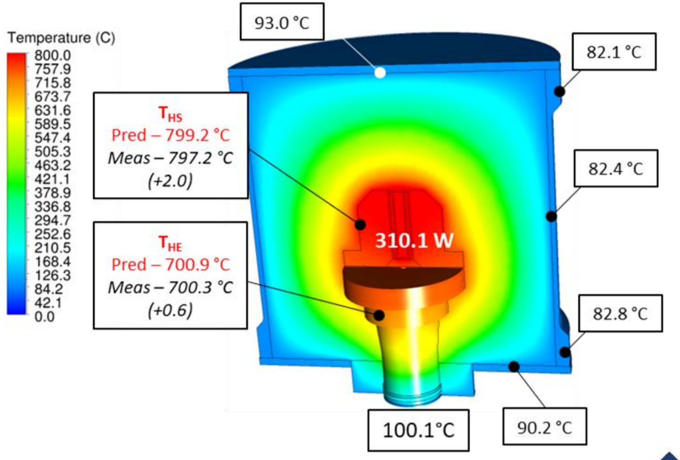
- 3D Pressure-Based coupled solver
- Compressible (ideal gas law activated)
- Specific heat, and thermal conductivity of all properties are temperature-dependent
- SIMPLE pressure-velocity coupling scheme with Green-Gauss discretization
- V-cycle algebraic multigrid solver used with BCSTAB (Bi-Conjugate Gradient Stabilized method)
- Discrete Ordinances radiation model activated

RESULTS

Below are converged solutions for Insulation Loss (S3: lower left), and an Operation Test Point (2A: Lower right). S3 was used for Insulation loss predictions because it was anticipated that it would have similar temperature gradients as Operation Test Point 2A.



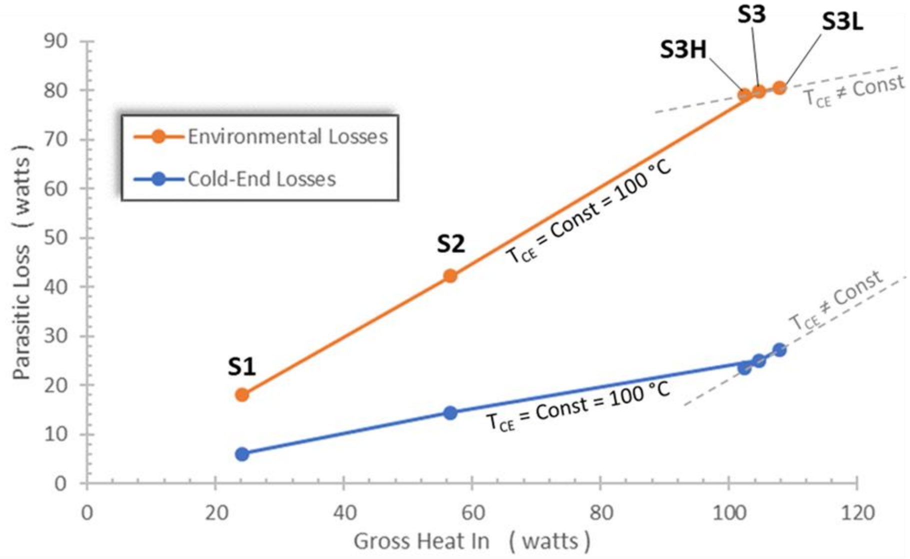
INSULATION LOSS TEST POINT S3



OPERATION TEST POINT 2A

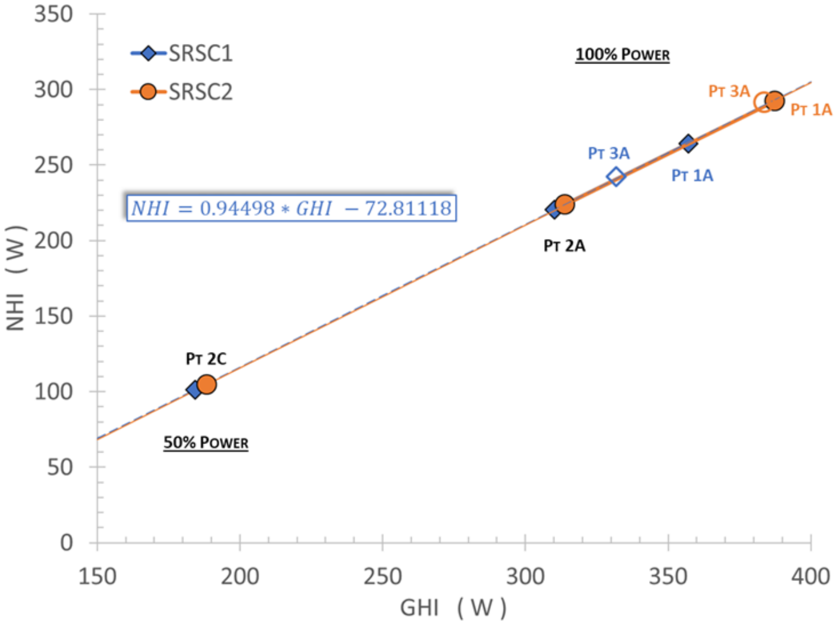
RESULTS

For the **Insulation Loss** simulations, parasitic losses increase linearly with increasing gross heat input for a constant cold-end temperature.



RESULTS

For the **Simulated Operation** simulations, Net Heat Input increases linearly with increasing Gross Heat Input for all conditions run.



SUMMARY

The table summarizes the simulated operation cases that were run. All of the cold end components that contribute to the conducted losses are available, but are not shown here.

		SRSC 1				
		1A	2A	2B	2C	3A
Target T_{HTR}	*(K)*	*1,086.9*	*1,070.2*	*1,086.5*	*1,030.6*	*1,077.3*
Target T_{HE}	*(K)*	*973.4*	*973.3*	*973.2*	*973.7*	*972.8*
Target T_{CE}	*(K)*	*294.1*	*373.1*	*372.9*	*373.2*	*448.0*
Q_{HTR}	*(W)*	**357.0**	**310.1**	**357.0**	**184.3**	**331.8**
T_{HTR}	*(K)*	1,088.1	1,072.2	1,088.7	1,030.3	1,079.2
T_{HE}	*(K)*	973.3	973.9	973.7	973.7	973.0
T_{CE}	*(K)*	294.1	373.1	372.9	373.2	448.0
Q_{CE}	*(W)*	26.2	24.2	24.0	24.6	21.6
Q_{ENV}	*(W)*	92.8	89.4	91.8	83.1	89.6
Q_{ESD}	*(W)*	238.0	196.5	241.2	76.6	220.6
Q_{TOT}	*(W)*	**357.0**	**310.1**	**357.0**	**184.3**	**331.8**
NHI	*(W)*	*264.2*	*220.7*	*265.2*	*101.2*	*242.2*

CONCLUSION

The table below shows a brief comparison of Sage and CFD results. The consistency between these results provides us with increased confidence of the extra detail that is provided by the CFD predictions.

		SRSC-1 (2a)	
		Sage	*ANSYS Fluent*
Q_{HTR}	*(W)*	311.0	310.1
Q_{CE}	*(W)*		24.2
Q_{ENV}	*(W)*	88.0	89.4
$Q_{PARASITIC}$	*(W)*		113.6
NHI	*(W)*	*223.0*	*220.7*

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