Thermal Model Correlations of Europa Clipper REASON Antennas with and without Modeling Solar Lamps in Thermal Desktop Models

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2. REASON Thermal Balance Tests
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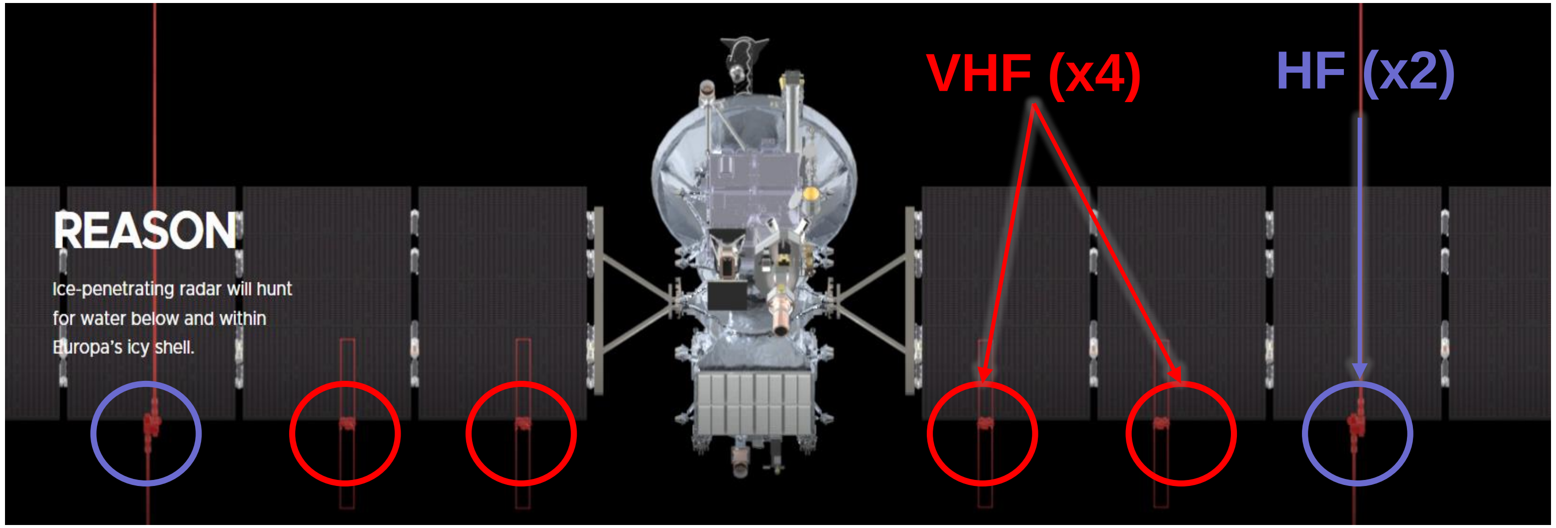
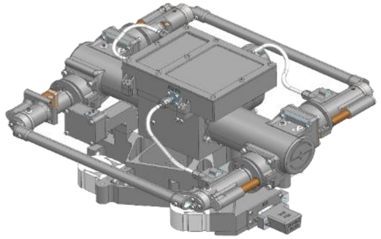
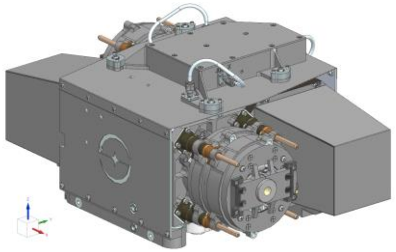
Europa Clipper REASON Antenna Overview

- Europa Clipper, planned to launch in October 2024, will determine if Jupiter's moon Europa has conditions suitable to support life
- REASON: Radar for Europa Assessment and Sounding: Ocean to Near-surface
  - Six REASON instruments installed on top of solar arrays
  - High frequency (HF) and very high frequency (VHF) radio waves will be used to penetrate Europa's ice, search for the suspected ocean, measure ice thickness, and study the ice's internal structure
  - The topography, composition, and roughness of Europa's surface will also be studied





REASON VHF Antenna Stowed



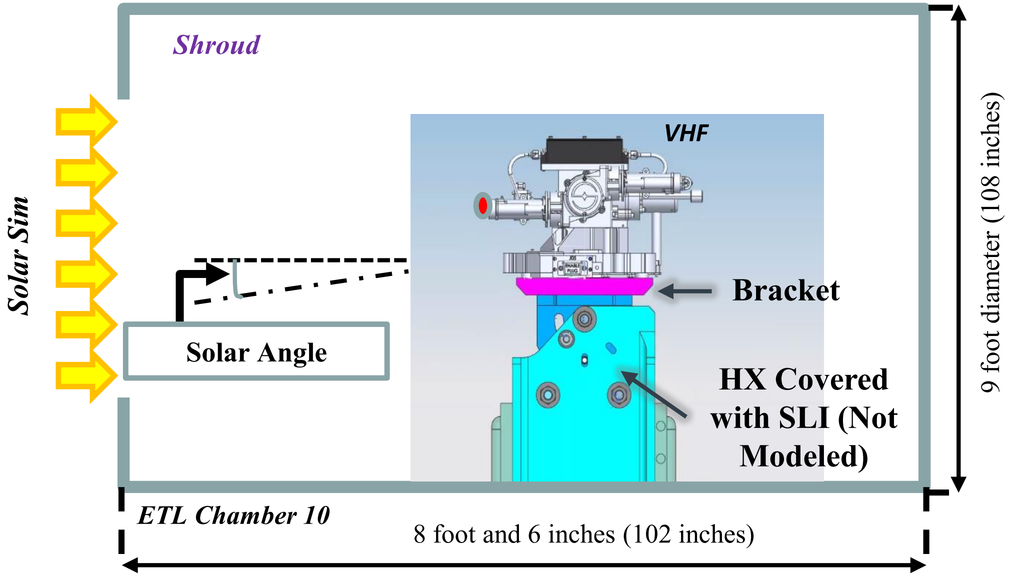
REASON HF Antenna Stowed

REASON Thermal Balance Test Overview

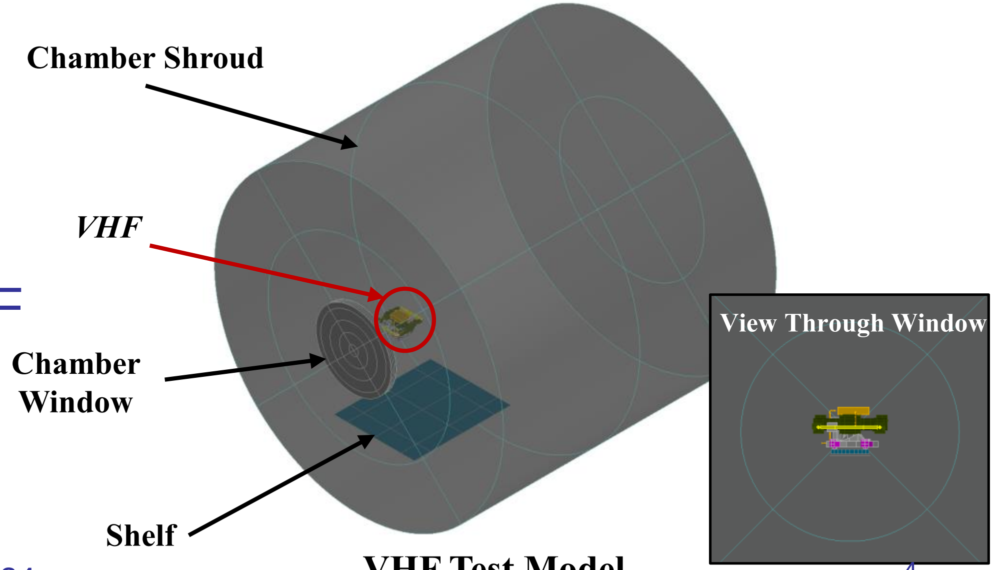
- VHF or HF is mounted on a bracket behind a window in the vacuum chamber, and a solar simulator is directed at the window so that flux is incident on the hardware
  - Bracket angle can be adjusted to tilt the hardware up to 45 degrees
  - Bracket is connected to heat exchangers to regulate the VHF/HF boundary temperature
- Thermal Balance TVAC testing of the VHF or HF hardware (stowed configuration) includes five steady-state conditions for correlation:

	Case01	Case02	Case03a	Case03b	Case04
Solar Angle [deg]	0	0	45	45	45
Interface Bracket	Cold	Hot	Cold	Cold	Hot
Lamp Power Condition	**Low**	**High**	**Low**	**High**	**High**

- Methodology and results are presented only for VHF, as HF used the same method and also achieved excellent correlation results



Thermal Balance Test Configuration

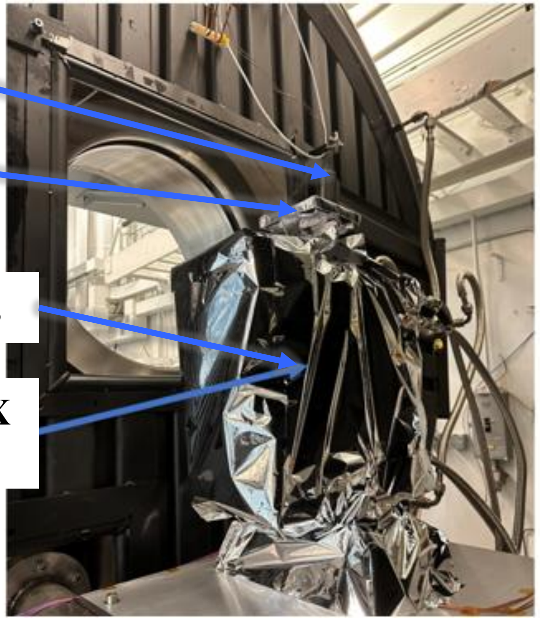


VHF Test Model

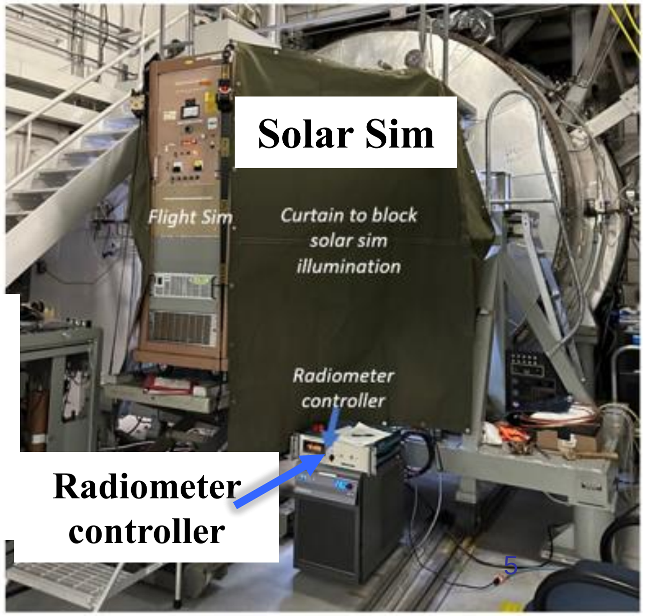
Test Configuration

- Two heat exchangers and heaters are used to fix the interface (Titanium) bracket temperatures at cold and hot AFTs, −35 ℃ and 80 ℃, respectively
- A Solar Sim is used to simulate the solar flux applied to the REASON antenna prior to deployment
- A radiometer sensor (off-centered) behind the window was used to measure the heat flux from the solar simulator

View from Shroud Rear



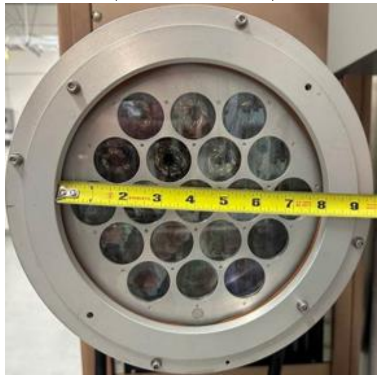
View from Shroud Front



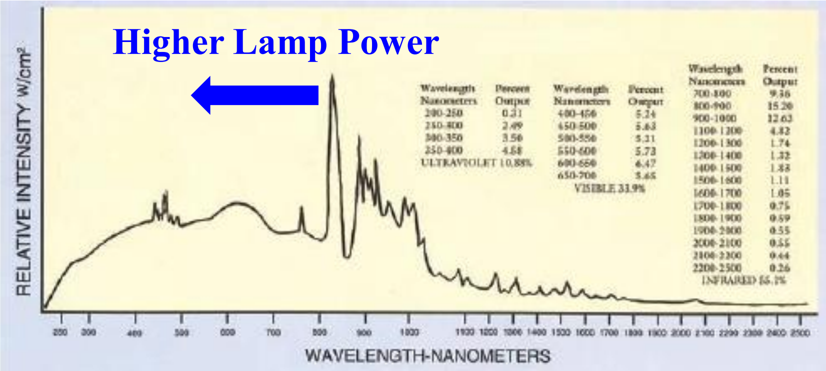
Lamp Heat Flux Characterization

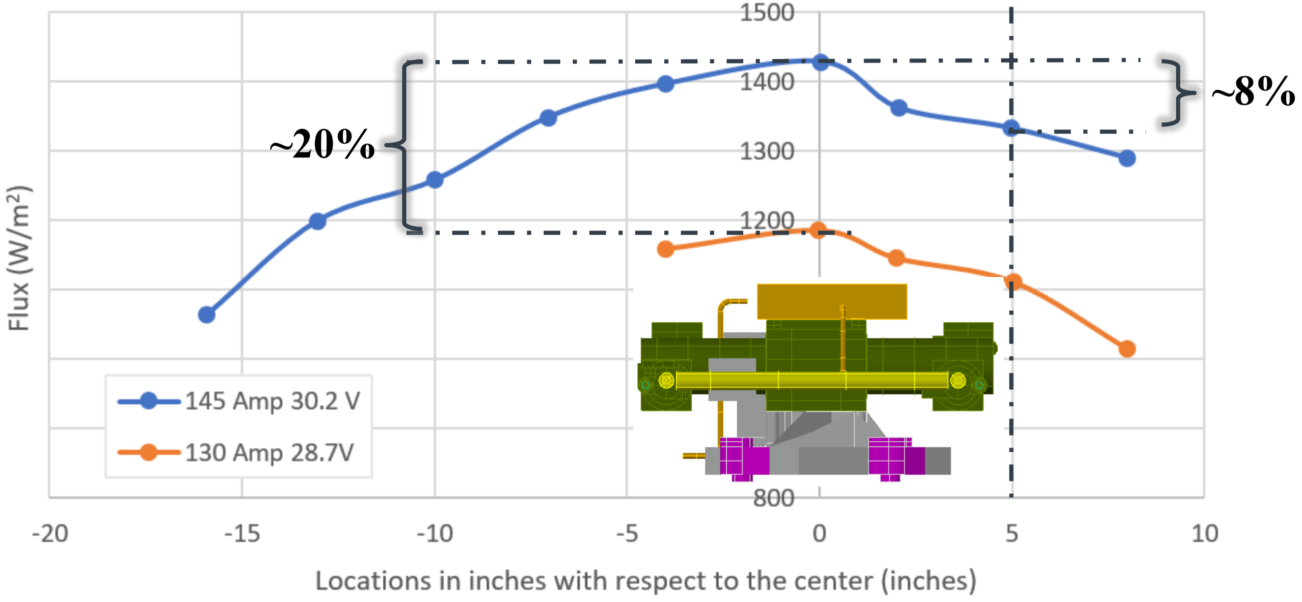
- The Xenon short arc lamp characterization test was completed to quantify the solar flux before the thermal balance test
- Heat flux increases with lamp output power (130 Amp vs. 145 Amp). Peak-to-peak difference is 20%
    - As lamp output power increases, flux peaks shift toward solar visible wavelength (or away from infrared wavelength), thus yielding higher solar content or fraction than IR
- Heat flux decreases with radial distance from the center of the lamp. An 8% reduction is observed at 5 inches away from the center
    - Expect similar spatial variation in the axial direction

Xenon Short Arc Lamp (OD = 8″)

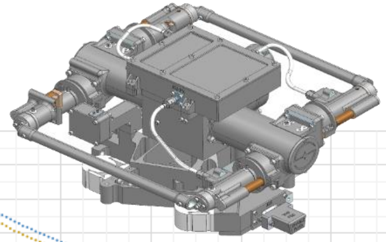


Example Xenon lamp spectrum: flux vs. wave length

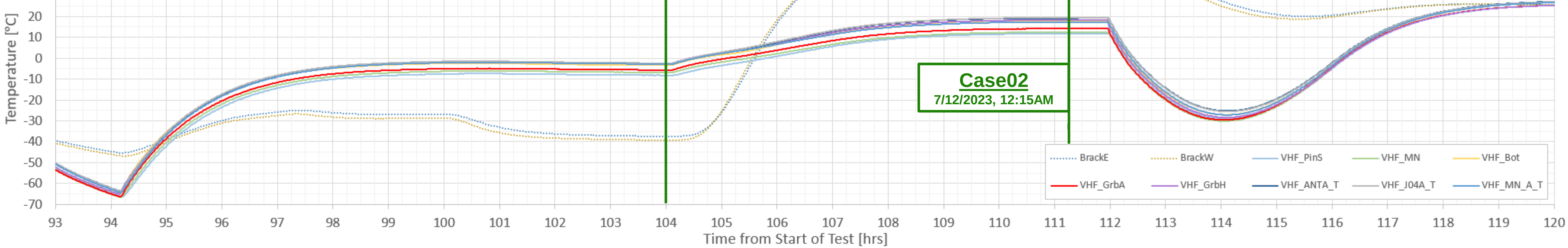


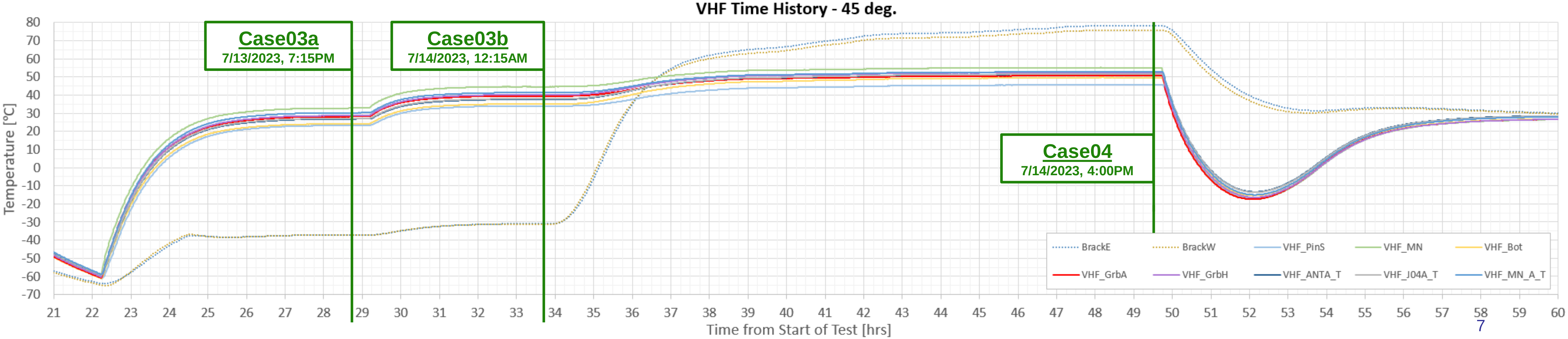


VHF TVAC Test Five Thermal Balance Points (or Cases)



REASON VHF Antenna CAD





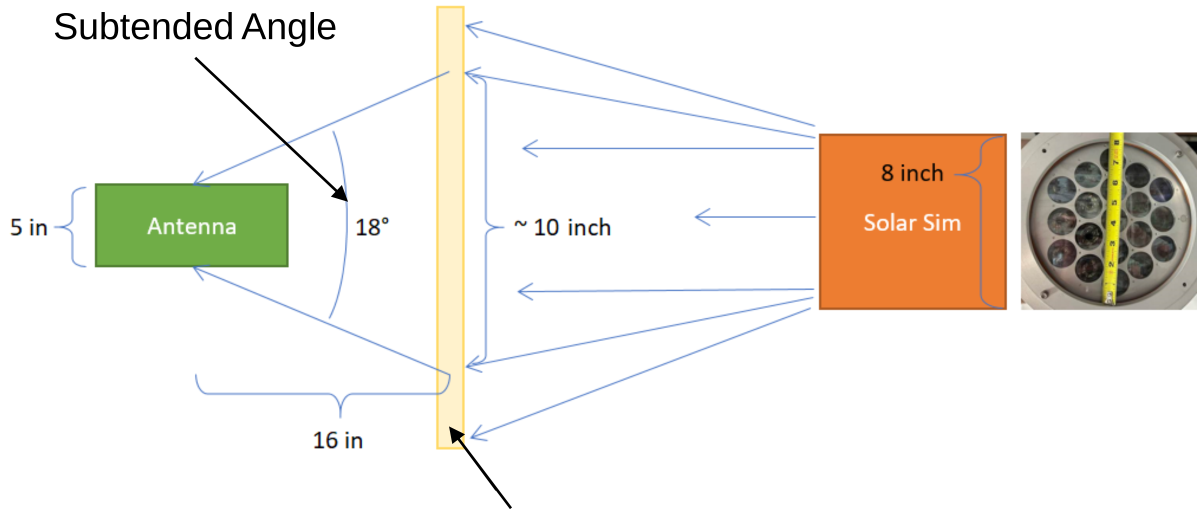
VHF Correlation without Modeling the Lamp

- Why not model the lamps?
  1) Xenon lamp solar or IR fractions at different power levels were unknown at the time of test or correlation
  2) VHF was entirely coated with black (BR127): solar absorptivity (0.94) and IR emissivity (0.86) are close. VHF absorbed heat flux barely changes due to uncertainty of solar/IR spectral content of incident flux
  3) Heat fluxes were measured by radiometer during the test (although Case04 has erroneous reading)

- Methodology used when lamp was not modeled:
  - Use an 18-degree subtended angle of a far point solar source to simulate non-collimated heat source
  - Multiple heating rates and radiation groups are considered for different parts of VHF, due to spatial variation of measured flux in radial and axial directions
  - Use of higher correlated flux than radiometer-measured flux accounts for the fact that the radiometer was not centered at the solar rays

	Case01	Case02	Case03a	Case03b	Case04
Solar Angle [deg]	0	0	45	45	45
Interface Bracket	Cold	Hot	Cold	Cold	Hot
Lamp Power Condition	**Low**	**High**	**Low**	**High**	**High**
Radiometer Measured Flux *(off center location) [W/m²]*	1034	1161	1023	1200	850
Correlated Flux* *(v042) [W/m²]*	1260	1465	1260	1465	1465

*This flux applies to the entire VHF except stacer bars, for which a 10% higher/lower flux is applied to the front/back bars, respectively, accounting for spatial variation of flux in axial direction.



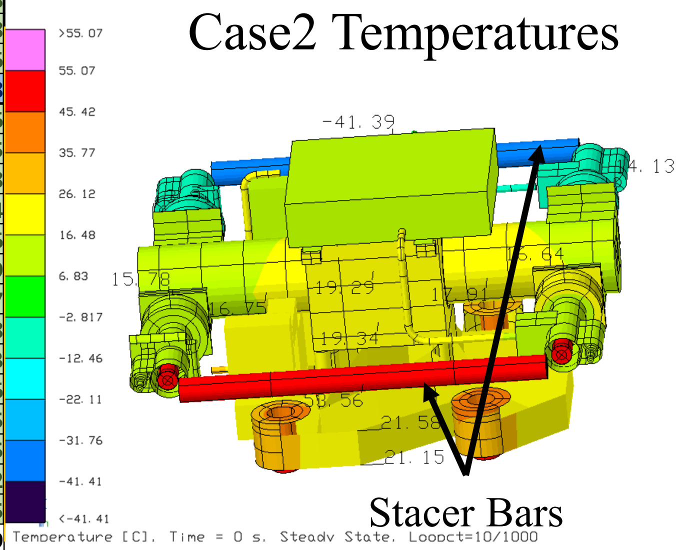
18-degree angle was agreed upon by assuming rays originated from a 10-inch diameter disk on the window surface

VHF Correlation Results without Modeling the Lamp

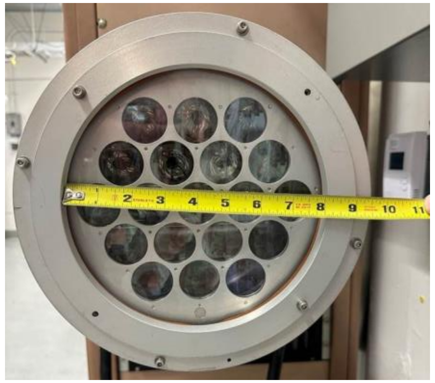
Negative Error:	Model node is cooler than test by at least 5 °C
Acceptable Error:	Model node is within +/-5 °C of test data for critical components, or within +/-10 °C less critical components
Positive Error:	Model node is warmer than test by at least 5 °C

- RMS error ranges from 2 ℃ to 4 ℃ (excellent correlation)
- Most sensors considered “correlated” within +/−5 ℃ of test data
- Stacer bars (less-critical components) considered “correlated" if within +/−10 ℃ of test data
- PRTs labeled purple; TCs labeled green

v042	case01			case02			case03a			case03b			case04		
	0° SA, Cold Bracket, Low Flux			0° SA, Hot Bracket, High Flux			45° SA, Cold Bracket, Low Flux			45° SA, Cold Bracket, High Flux			45° SA, Hot Bracket, High Flux		
CHANNEL	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]
BasShr	-5.1	-5.6	-0.5	16.8	18.0	1.2	25.3	26.8	1.5	36.3	36.8	0.6	50.4	50.5	0.2
BasWin	-2.9	-4.2	-1.3	19.7	19.6	-0.1	26.7	28.1	1.4	37.9	38.2	0.3	52.7	52.0	-0.8
Edg_GrbB	-6.6	-5.7	0.9	13.2	14.8	1.6	27.8	32.2	4.5	38.9	42.7	3.8	50.2	52.4	2.3
Shr_StcW	-20.5	-24.2	-3.7	-3.6	-8.4	-4.8	24.8	28.4	3.7	35.6	38.6	2.9	43.4	44.8	1.4
StcShE	-49.9	-50.7	-0.8	-36.3	-39.4	-3.1	25.9	35.5	9.7	37.1	46.4	9.3	40.4	49.2	8.8
StcShW	-47.3	-51.1	-3.8	-33.0	-39.8	-6.8	26.0	35.6	9.6	37.1	46.4	9.3	40.5	49.3	8.8
StcWinE	34.9	36.6	1.6	51.0	51.2	0.2	56.0	54.0	-2.0	68.1	65.2	-3.0	75.4	67.7	-7.6
StcWinW	36.3	36.4	0.1	52.2	51.0	-1.1	58.5	53.7	-4.8	70.6	64.8	-5.8	78.2	67.4	-10.8
VHF_ANTA_T	-2.8	-5.4	-2.6	19.1	18.3	-0.8	26.9	27.2	0.4	37.5	37.2	-0.3	51.7	51.0	-0.6
VHF_BEOT	-4.7	-6.1	-1.4	17.3	17.3	0.0	26.4	26.6	0.2	37.5	36.6	-0.9	51.5	50.0	-1.5
VHF_BES	-3.9	-5.6	-1.7	18.1	18.3	0.2	25.3	26.0	0.7	36.3	35.9	-0.4	50.7	49.9	-0.8
VHF_Bot	-3.4	-5.4	-2.0	18.0	18.3	0.3	24.2	27.2	3.0	35.0	37.2	2.2	49.6	51.0	1.4
VHF_GrbA	-5.7	-4.6	1.1	14.2	15.9	1.7	28.2	33.1	4.9	39.4	43.7	4.3	50.7	53.3	2.6
VHF_GrbH	-2.8	-2.7	0.1	18.2	19.4	1.2	28.8	31.6	2.8	40.1	42.0	2.0	52.5	53.4	0.9
VHF_J04A_T	-2.4	-6.1	-3.7	19.3	17.3	-2.0	27.2	26.6	-0.6	37.9	36.6	-1.4	51.7	50.0	-1.7
VHF_MN	-6.8	-4.2	2.6	12.4	16.3	3.9	32.8	35.5	2.7	44.6	46.3	1.7	55.1	56.0	0.8
VHF_MN_A_T	-2.8	-4.1	-1.3	17.3	17.5	0.3	30.2	31.2	0.9	41.3	41.6	0.3	52.9	52.5	-0.3
VHF_PinS	-8.2	-7.8	0.4	11.7	13.3	1.6	23.3	26.5	3.1	33.9	36.3	2.4	45.7	47.3	1.6
Shr_STCE	-29.1	-24.3	4.8	-13.5	-8.8	4.7	24.6	28.5	3.9	35.6	38.7	3.1	42.3	44.7	2.5
Win_GrbB	-5.9	-5.4	0.4	14.3	15.3	1.0	28.0	32.0	4.0	39.2	42.5	3.3	50.9	52.4	1.5
Win_StcE	-2.3	-1.7	0.6	15.0	15.4	0.5	37.4	41.1	3.7	49.3	52.0	2.8	58.2	57.9	-0.2
Win_StcW	-2.0	-1.9	0.1	14.8	15.2	0.4	36.6	38.5	1.9	48.0	49.2	1.2	55.8	55.3	-0.5
RMS Error			2.096			2.475			4.035			3.747			4.079

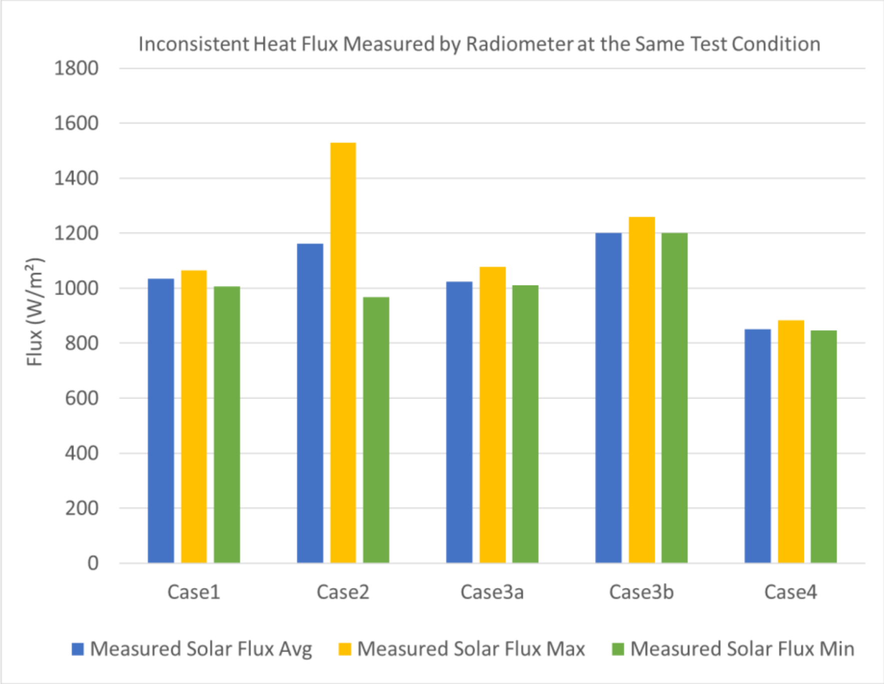


Challenges Associated with Modeling Lamps



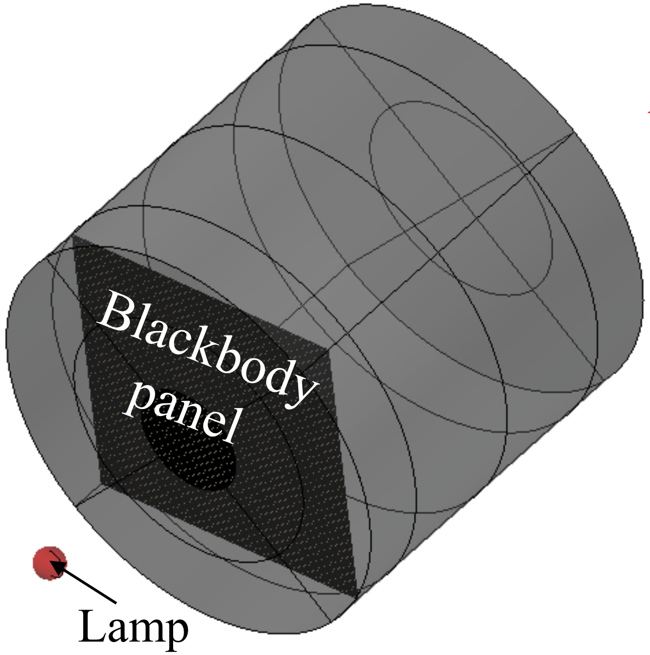
- Per NASA Passive Thermal Control Engineering Guidebook: *"If it is desired to correlate thermal models to TVAC test data, it is best to avoid the use of quartz lamps, or any lamps that have any significant solar spectrum."*

- Four major challenges associated with modeling lamps:
  - Difficulty in tuning IR or solar fraction at different lamp powers without temperature readings of a surface with known and very different solar absorptivity and IR emissivity
  - Inevitable variations in the intensity of the incident flux on the test article at different test conditions, even at the same lamp output
  - Inconsistent heat flux measured by the radiometer at the same lamp power and test condition
  - Additional effort associated with correlating the lamp's output flux to the flux measured by the radiometer before correlating temperatures

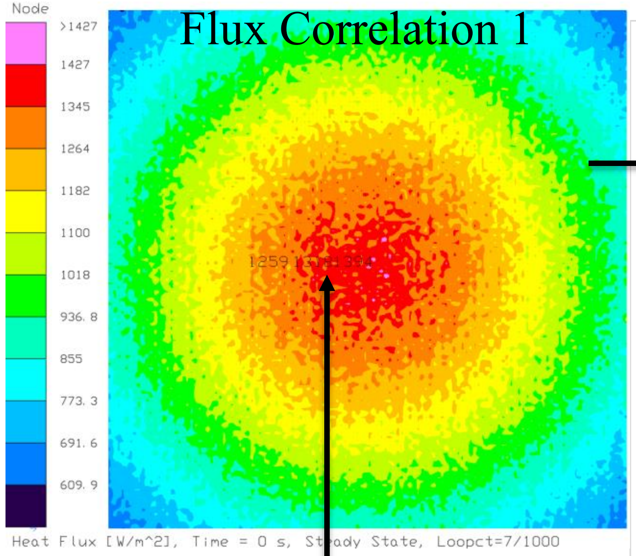


Modeling Lamp and Correlating Flux

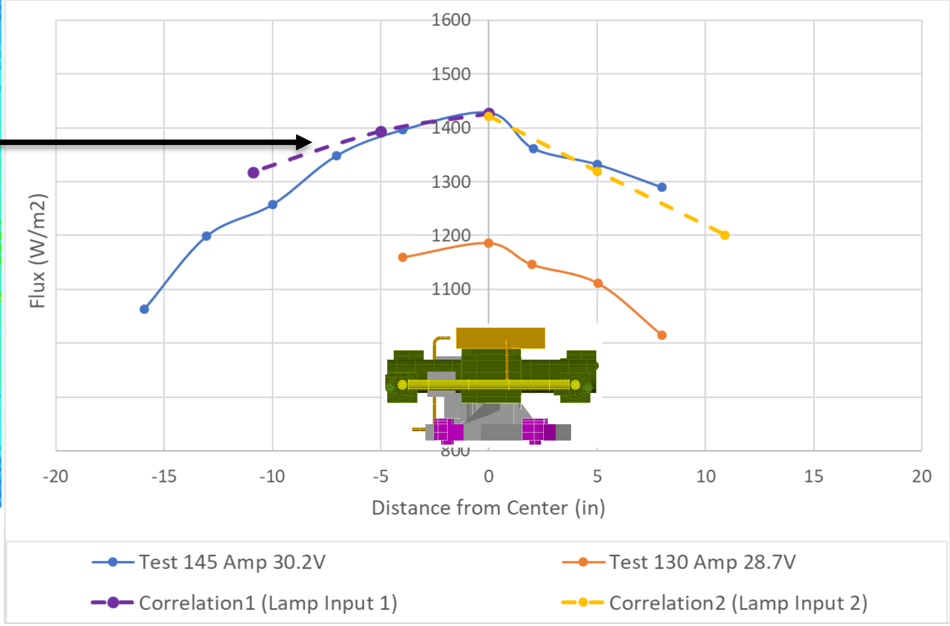
- Modeled the lamp as a sphere of 8 inches in OD
- Tuned the lamp IR/Solar fraction
  - 55% IR (45% Solar)
  - Small sensitivity on temperatures because of VHF's black coating
- Tuned lamp output flux to match the magnitude and spatial variation in the lamp characterization test
  - A blackbody panel at the radiometer location with fine mesh to correlate flux
- Lamp flux needed to be fine-tuned for each thermal balance case to better correlate temperatures
  - Different test setup or case could result in different flux measured by radiometer
- Used the same conductance, thermal material, and optical properties as the model without the lamp



Correlated Fluxes Match Characterization Test

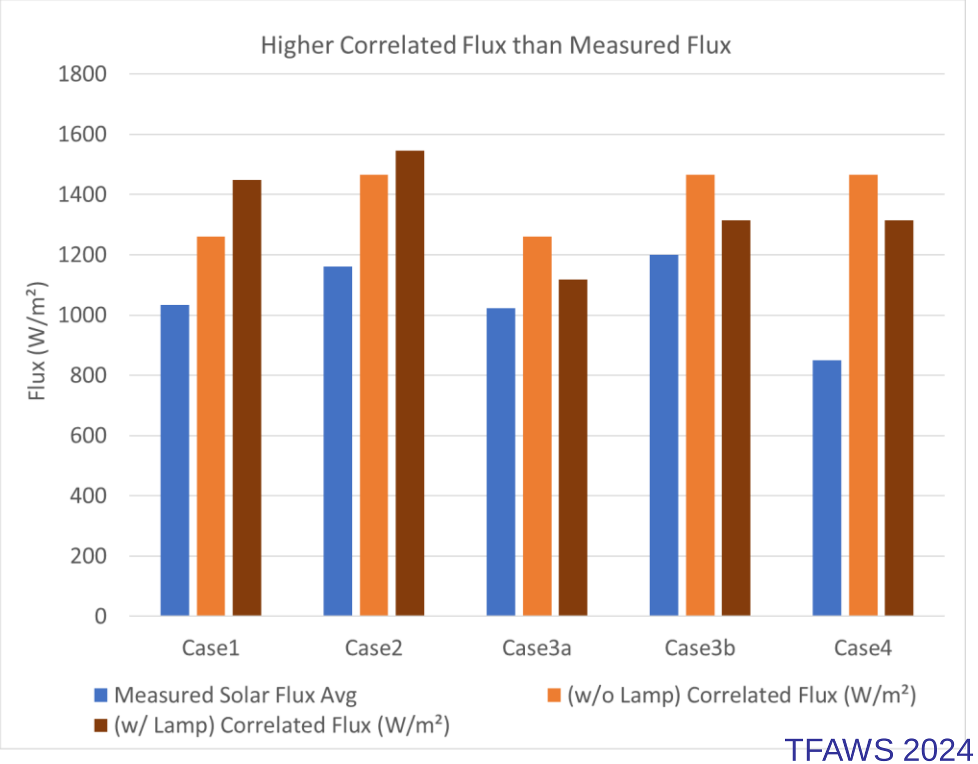


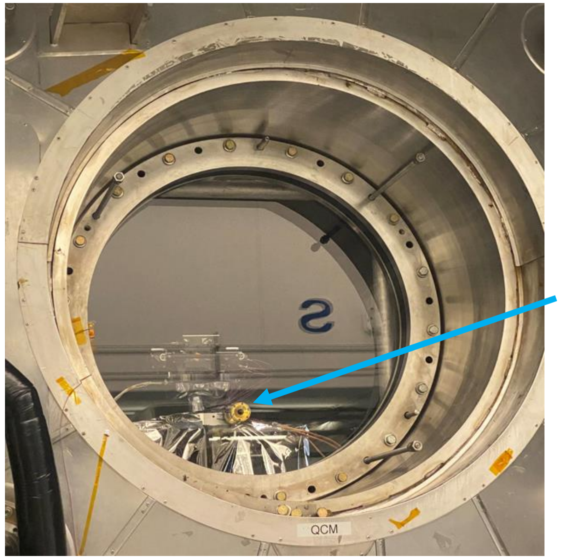
1394 W/m² (5 inches away from center)



Measured vs. Correlated Flux

- Both correlated models with and without lamps have higher correlated flux than radiometer-measured flux during the test
    - Radiometer was not centered at the flux cone and about 5 inches away from the center (10 to 20% lower flux expected)
    - Energy reflected from the (less than perfect) black shroud or other ground support equipment (GSE) not accounted for in the models
- −11 to +15% difference in correlated flux between models with and without lamps
    - Reasonable difference considering flux measurement could have +/−20% error
    - Different formulations of absorbed flux with two different heat sources (far point source vs. lamp)





Radiometer off-centered

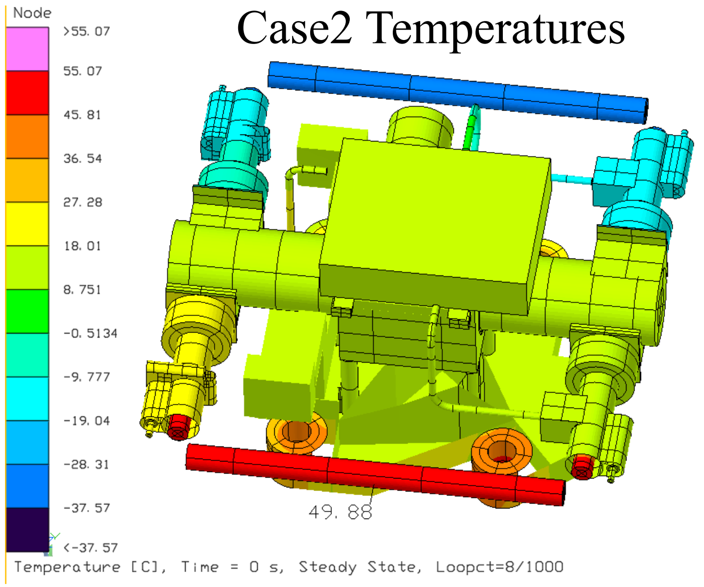
VHF Correlation Results with Lamp Modeled

- RMS error ranges from 2 °C to 3.5 °C (excellent correlation)
- Similar RMS errors are achieved in temperature correlation with and without modeling lamps
- Two outliers could be removed by further fine-tuning the lamp flux or optical properties of the shroud/GSE

Negative Error:	Model node is cooler than test by at least 5°C
Acceptable Error:	Model node is within +/-5°C of test data for critical components, or within +/-10°C less critical components
Positive Error:	Model node is warmer than test by at least 5°C

Correlation with Lamped Modeled

–	case01 0° SA, Cold Bracket, Low Flux			case02 0° SA, Hot Bracket, High Flux			case03a 45° SA, Cold Bracket, Low Flux			case03b 45° SA, Cold Bracket, High Flux			case04 45° SA, Hot Bracket, High Flux		
CHANNEL	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]	TEST [°C]	T [°C]	Err. [°C]
BasShr	-5.1	-6.1	-1.0	16.8	15.4	-1.4	25.3	23.0	-2.3	36.3	34.6	-1.7	50.4	51.7	1.3
BasWin	-2.9	-4.5	-1.6	19.7	17.1	-2.6	26.7	24.4	-2.3	37.9	36.2	-1.7	52.7	53.4	0.7
Edg_GrbB	-6.6	-5.7	0.9	13.2	12.4	-0.8	27.8	28.3	0.6	38.9	40.4	1.6	50.2	53.7	3.5
Shr_StcW	-20.5	-24.4	-3.9	-3.6	-10.1	-6.4	24.8	22.2	-2.6	35.6	33.4	-2.2	43.4	42.9	-0.5
StcShE	-49.9	-48.7	1.2	-36.3	-37.5	-1.3	25.9	23.7	-2.2	37.1	36.7	-0.3	40.4	42.7	2.2
StcShW	-47.3	-47.0	0.3	-33.0	-35.5	-2.5	26.0	24.0	-1.9	37.1	36.9	-0.2	40.5	43.1	2.6
StcWinE	34.9	39.7	4.8	51.0	49.6	-1.3	56.0	47.9	-8.2	68.1	60.8	-7.3	75.4	68.6	-6.8
StcWinW	36.3	41.8	5.5	52.2	50.9	-1.2	58.5	48.6	-9.9	70.6	61.0	-9.6	78.2	68.4	-9.8
VHF_ANTA_T	-2.8	-5.9	-3.1	19.1	15.7	-3.4	26.9	23.4	-3.5	37.5	35.0	-2.5	51.7	52.3	0.6
VHF_BEOT	-4.7	-6.7	-2.0	17.3	14.6	-2.8	26.4	22.6	-3.8	37.5	34.0	-3.5	51.5	50.9	-0.6
VHF_BES	-3.9	-6.2	-2.3	18.1	15.7	-2.4	25.3	22.5	-2.8	36.3	33.9	-2.4	50.7	51.4	0.6
VHF_Bot	-3.4	-5.9	-2.5	18.0	15.7	-2.3	24.2	23.4	-0.8	35.0	35.0	0.0	49.6	52.3	2.7
VHF_GrbA	-5.7	-6.4	-0.7	14.2	11.8	-2.3	28.2	28.8	0.6	39.4	41.3	1.9	50.7	54.2	3.5
VHF_GrbH	-2.8	-3.4	-0.6	18.2	16.3	-1.8	28.8	27.7	-1.1	40.1	39.9	-0.2	52.5	54.7	2.2
VHF_J04A_T	-2.4	-6.7	-4.3	19.3	14.6	-4.7	27.2	22.6	-4.6	37.9	34.0	-3.9	51.7	50.9	-0.7
VHF_MN	-6.8	-5.1	1.7	12.4	13.1	0.7	32.8	31.9	-0.9	44.6	44.5	-0.1	55.1	57.8	2.6
VHF_MN_A_T	-2.8	-4.9	-2.0	17.3	14.5	-2.8	30.2	27.3	-2.9	41.3	39.4	-1.9	52.9	53.9	1.0
VHF_PinS	-8.2	-8.6	-0.4	11.7	10.5	-1.2	23.3	22.5	-0.9	33.9	33.9	0.0	45.7	48.2	2.5
Shr_STCE	-29.1	-29.6	-0.5	-13.5	-15.8	-2.3	24.6	21.7	-2.9	35.6	34.0	-1.5	42.3	42.1	-0.1
Win_GrbB	-5.9	-5.5	0.3	14.3	12.8	-1.5	28.0	28.1	0.1	39.2	40.2	1.1	50.9	53.7	2.9
Win_StcE	-2.3	-3.5	-1.2	15.0	11.8	-3.2	37.4	38.2	0.8	49.3	52.0	2.7	58.2	61.5	3.4
Win_StcW	-2.0	4.4	6.4	14.8	18.6	3.8	36.6	38.1	1.5	48.0	50.3	2.3	55.8	59.9	4.1
RMS Error			2.759			2.747			3.509			3.176			3.333



Conclusions

- REASON VHF and HF antenna models were successfully correlated to the test with and without modeling the solar lamp

- The correlated thermal model with a lamp used the same conductance, thermal, and optical properties as the model without a lamp. This confirms the accuracy of the correlated models without the lamp which are independent of modeling methods

- If the test article surface finish has close solar absorptivity and IR emissivity, modeling the lamp is not necessary to achieve a good correlation
    - Subtended angles and spatial variation of the flux need to be considered in the correlation

- If possible, a heater plate instead of a lamp could be used in the test considering the challenges associated with modeling the lamp and correlating the flux

- If a solar or an IR lamp is desired in a test, a lamp characterization test needs to be done using a radiometer for heat flux measurements in conjunction with thermocouples for temperature measurements of surfaces with known and very different solar absorptivity and IR emissivity. Thus, IR or solar fraction of the incident flux can be correlated correctly, which is especially important if test article surface finish optical properties have large uncertainty

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Questions?