Thermal Performance of Starling Spacecrafts and Comparison to Thermal Model Results

Ali Kashani[1], Scott Miller[2], Terry Stevenson[2], Jeffrey Blair[2], Watson Attai[3], Jennifer Young[4], David Brasser[4], Reece Whitt[4]
[1]ASRC Federal, [2]NASA Ames Research Center, [3]MEI Company, [4]BCT

SSC24-P2-04

Starling Mission

The Starling mission consists of four 6U CubeSats launched in July 2023 to test several technologies that could enable future swarm missions. The Starling experiment payload is comprised of a Xiphos Q7S processor, a C&DH/power board called the Bus Interface Card (BIC), and CesiumAstro's CommPack radio that enables crosslink communication amongst the spacecrafts in the swarm. The CommPack radio is itself comprised of an S-band Software Defined Radio (SDR) and two Transmit Receive Modules (TRMs) with integrated patch antennas.

Also in the payload volume is the additively manufactured HAMLET cold gas propulsion system. HAMLET is comprised of a composite additively manufactured propellant main tank, plenum, and four independently controlled nozzles. When full, HAMLET carries a propellant mass of about 976 grams of R236fa. The Starling bus was developed by Blue Canyon Technologies (BCT).

Spacecraft Instrumentation

Temperature sensors located on or near key components monitor the thermal health of each spacecraft and its components in the payload and the bus volumes. Survival heaters in the bus and the payload modules provide temperature control of sensitive components. There are three manifold heaters in the HAMLET which facilitate its operation.

Mission Orbits

The Starling spacecraft were deployed into a Sun-synchronous orbit and were initially maneuvered into a "string of pearls" formation. In this formation, the spacecrafts were spaced roughly 100 km apart in the same orbit, with orbital plane, altitude, and eccentricity matched as closely as possible. In March 2024 this formation was reconfigured into a passive safety ellipse (PSE) formation, adding small eccentricity and inclination differences to produce relative motion. This reduces the risk of conjunction from in-track drift, as well as providing visual relative motion for Starling's StarFOX experiment. Due to prop system performance variability, the target PSE was not achieved, but the resulting PSE formation was sufficient to reduce conjunction risk and provide visual relative motion.

Thermal Model

A thermal model of the Starling Spacecrafts was developed in Thermal Desktop (Fig. 1) which includes both the payload and the bus components. Except for the HAMLET all other components are represented by finite difference elements. The HAMLET propulsion system is modeled using a meshed structure.

The HAMLET has two irregularly shaped internal volumes, i.e., a main tank that contains the two-phase propellant and a plenum that is filled with gaseous propellant via tubing connections to the main tank. The plenum volume feeds the HAMLET four nozzles during its operation. Both these volumes are modeled as FloCAD compartments. The fluid connections between the main tank and the plenum and those form the plenum to the prop nozzles are modeled as FloCAD pipes.

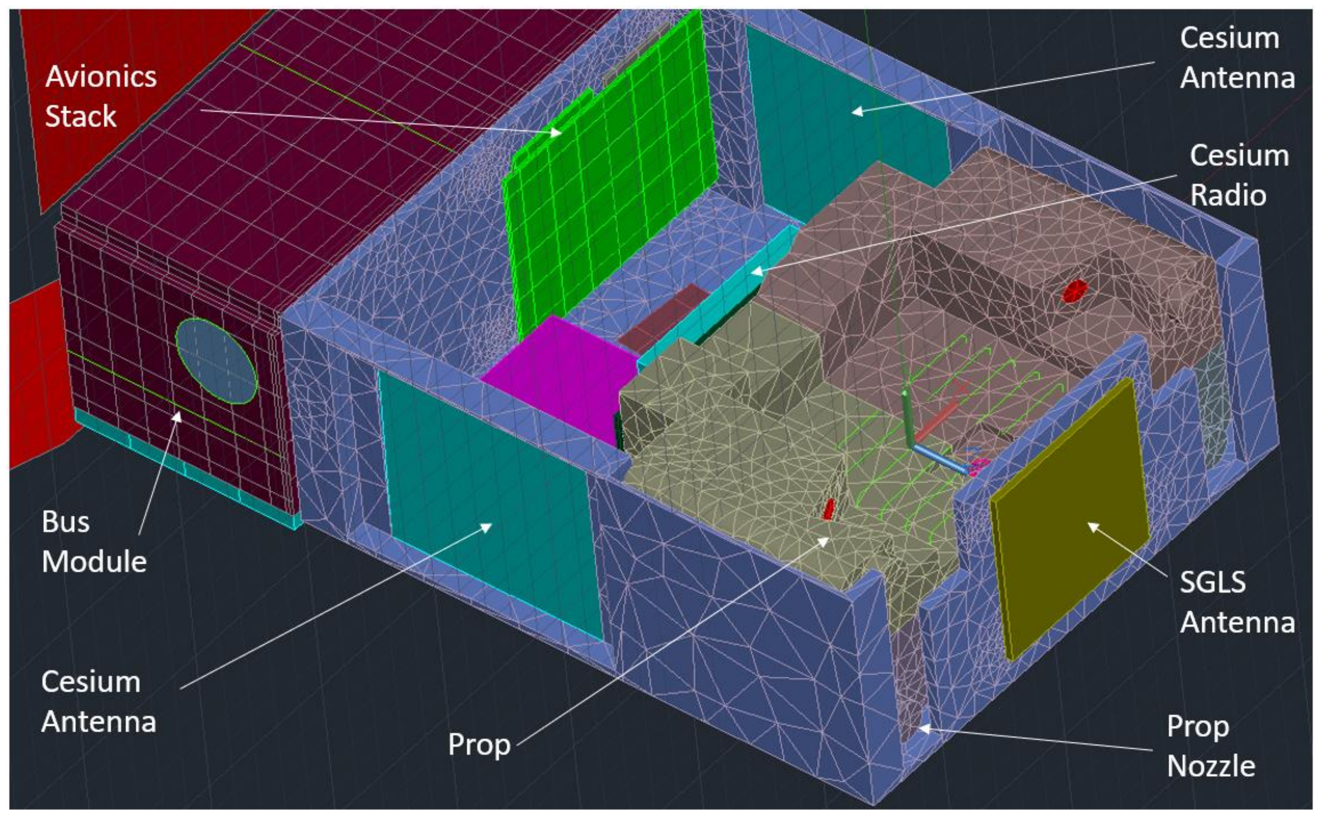
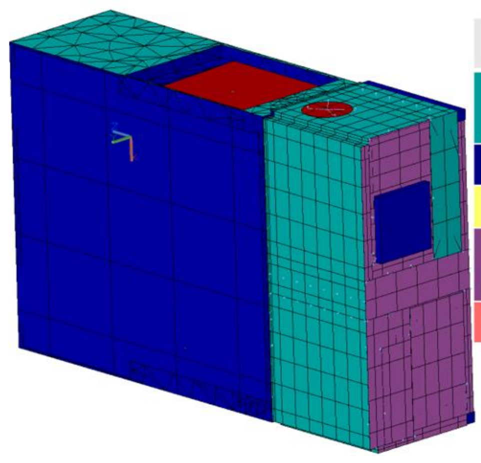


Fig. 1) Starling spacecraft Thermal Desktop model.

The spacecraft components are attached to the payload and the bus chassis using standard fasteners. Gap-pad materials are employed in the payload avionics stack to enhance thermal transfer and reduce temperatures of power components. The optical coatings of the spacecrafts outer surfaces are depicted in Fig. 2.

Thermal Model Cont.



Coating	α	ϵ
5 mil Ag Teflon	0.09	0.78
Iridite	0.25	0.06
Solar Arrays	0.60-0.63	0.80-0.81
3 mil VDA Kapton	0.43	0.79
Other	Varies	Varies

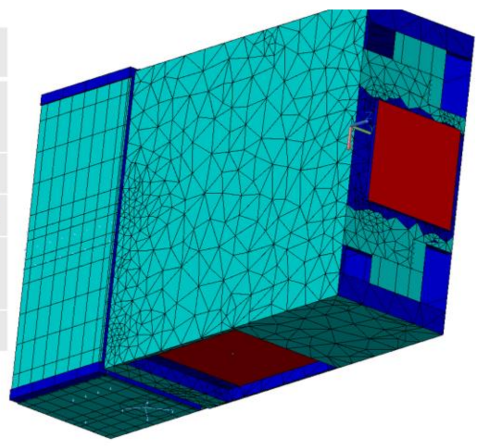


Fig. 2) Spacecrafts Optical Coatings

Thermal Performance

To date the thermal performance of the Starling spacecrafts has been nominal and no anomalies have been observed. The thermal model is employed to compare its results to the thermal performance of the spacecrafts in orbit. The first case considered is the thermal performance of spacecraft #1 on 2/26/2024 where the spacecraft is in a near-circular Sun-synchronous orbit at 567 km altitude and 99.5º inclination. The average power dissipation in the bus module is 6.2 W and that in the payload module is 15 W. The environmental heating rates assumed are listed below.

Solar	Albedo	Planetshine
1414 W/m^2	0.47	241 W/m^2

Figure 3 shows three payload temperatures and their counterparts obtained from the model results. These are temperatures of the payload chassis, the Cesium radio mounting bracket (Fig. 1), and the HAMLET. To match the model predicted temperature profiles to those obtained from the spacecraft orbit data two model parameters were adjusted. The contact conductance between the Cesium bracket and the payload chassis was lowered by a factor of 3. This reduction can be attributed to the coarse surface finish of the payload chassis where the Cesium bracket is mounted. The emissivity of the silver Teflon coating was also reduced though this change requires further investigation as to its validity.

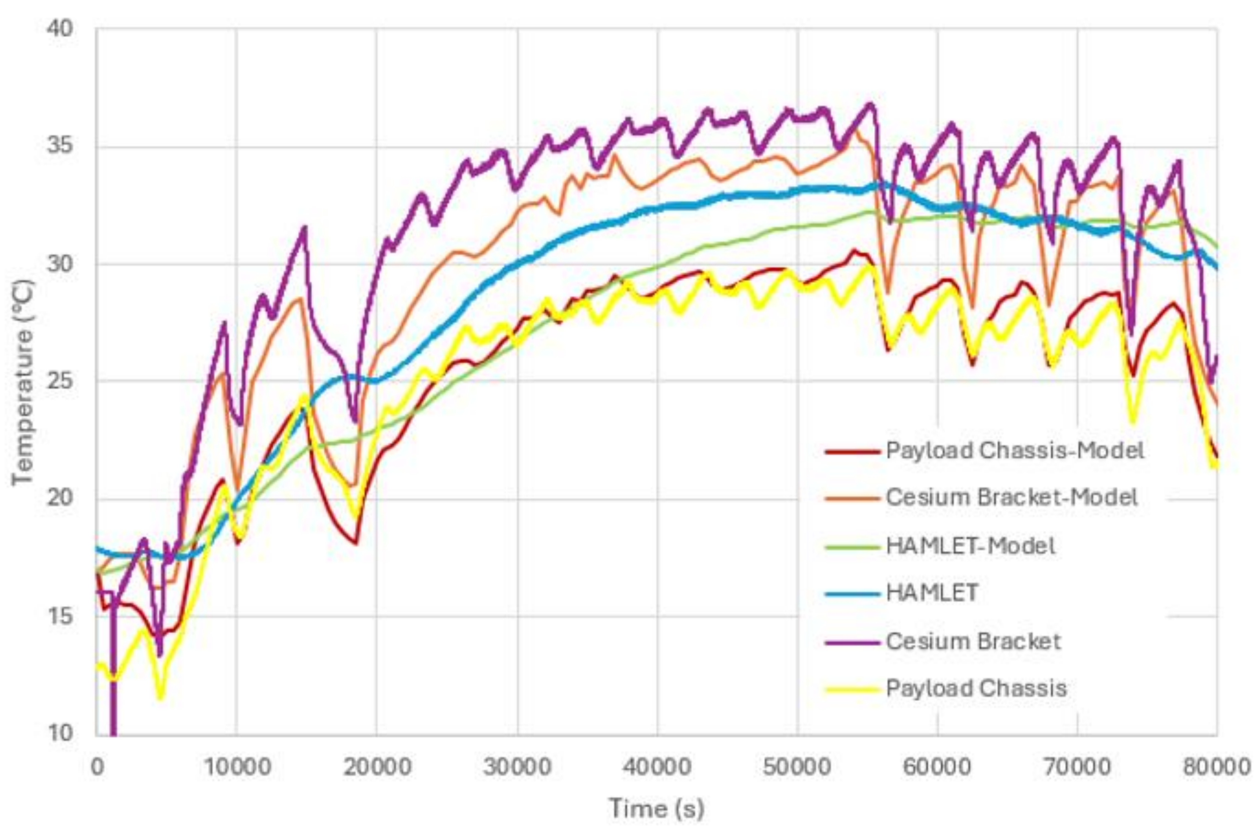


Fig. 3) Comparison of model and flight temperatures for S/C 1 on 2/26/24

The thermal performance of Spacecrafts #1 and #4 on the same date, i.e., 2/26/2024 shows that the two spacecrafts have similar thermal behavior. Temperatures of the same components on both spacecrafts are very close. The only difference is the HAMLET temperature where it is higher in spacecraft #1 than that observed in spacecraft #4. The reason for this difference is the larger volume of propellant left in spacecraft #4.

The second case modeled is Spacecraft #4 on 4/20/2024. Initially, the spacecraft is in the LVLH attitude. Its orbital altitude and inclination are the same as that in the first case. At time 14760s the spacecraft attitude is altered to maximize the exposure of its solar panels to the sun for charging its batteries. As a result, the payload module is rotated away from the sun thus cooling of its components. For this case, the bus and payload modules have the same power levels as in the first case. The orbital heating rates used are listed below.

Solar	Albedo	Planetshine
1367 W/m^2	0.20	227 W/m^2

Thermal Performance Cont.

Figure 4 shows the temperature profiles for this case. As seen all temperatures rise before the slew and begin to decrease afterwards. When the HAMLET temperature reaches below a set point temperature its survival heater turns on to maintain its temperature between 6 ºC and 11 ºC.

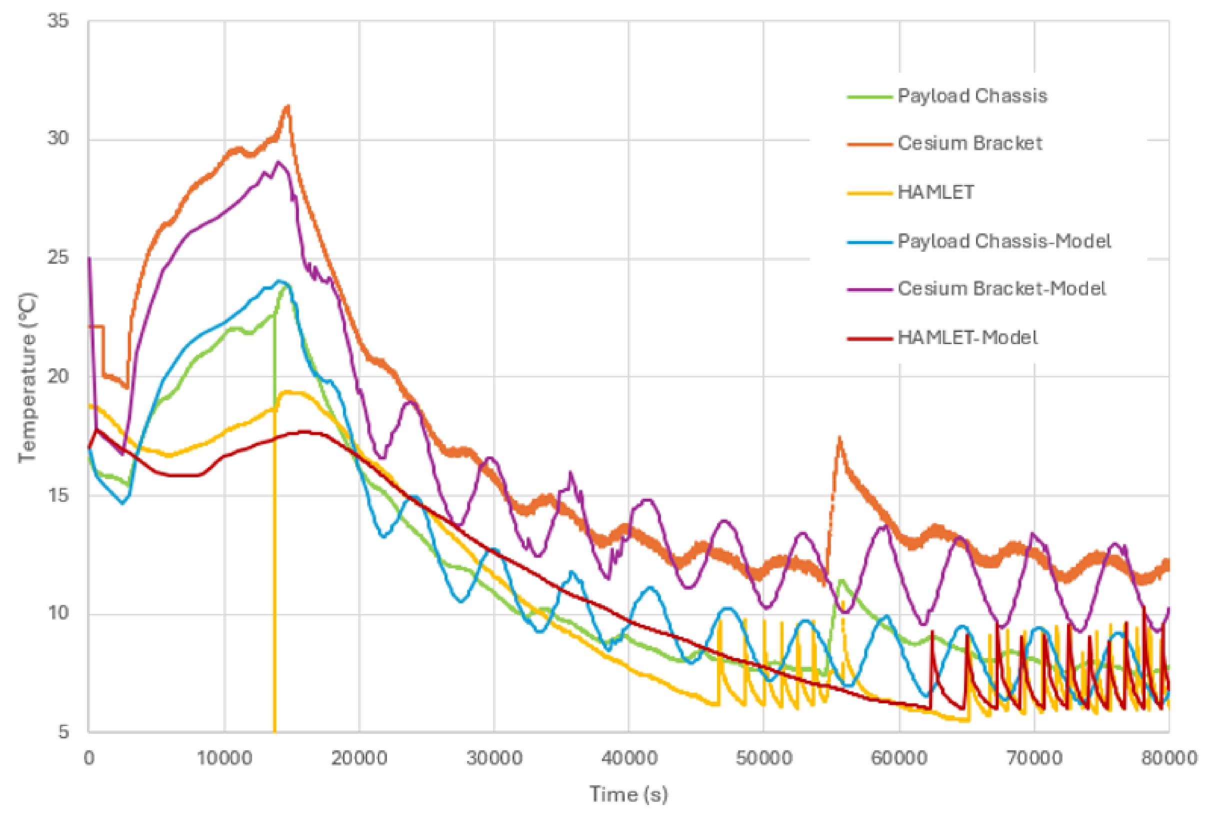


Fig. 4) Comparison of model and flight temperatures for S/C 4 on 4/20/24.

The final case considered is spacecraft #4 on 5/2/2024 where the prop system was employed to perform a maneuver. To activate the HAMLET, first its electronics are turned on. The HAMLET operational heaters are turned on next to raise the temperature of the fluid in the tank and in the plenum. The HAMLET heaters are temperature controlled. Each of the HAMLET heaters, two on the tank and one on the plenum, generates 3.9 W while its electronics generate 1.6 W. The Cesium radio is off, and the BIC dissipates 5 W. Figures 5 and 6 show the temperatures and pressures as reported by the HAMLET.

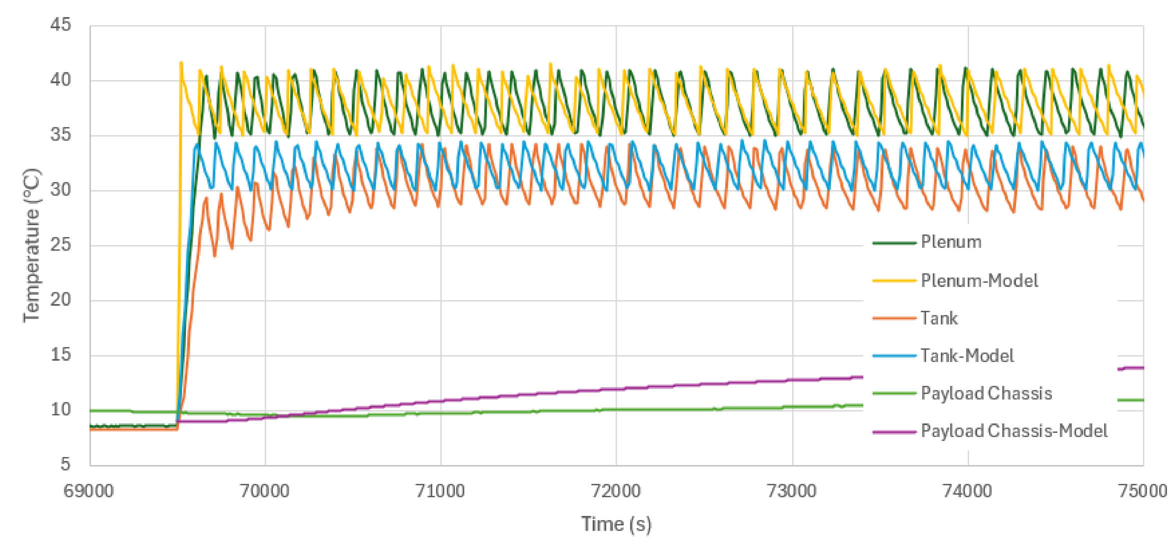


Fig. 5) Comparison of model and flight temperatures for S/C 4 on 5/2/24

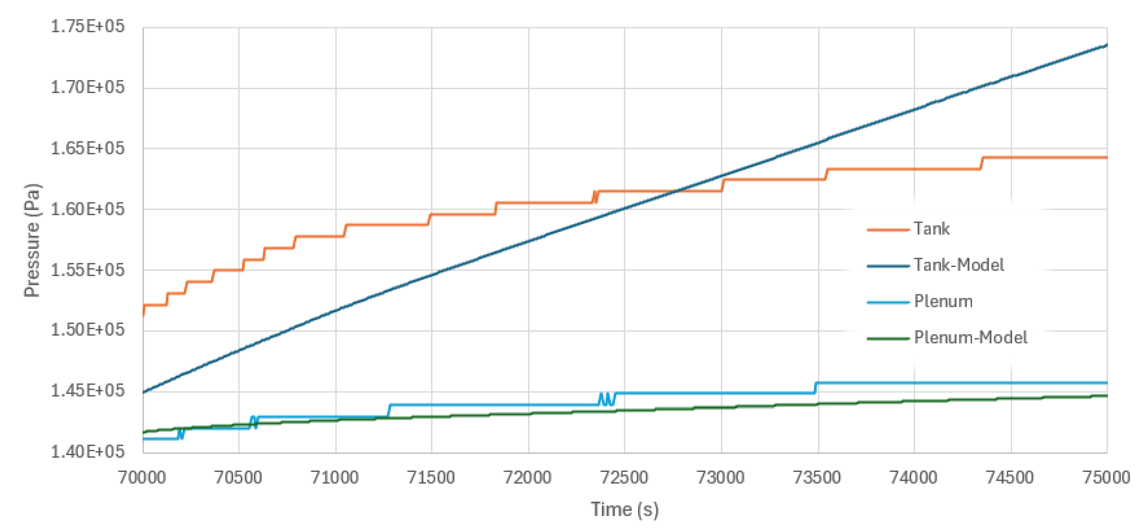


Fig. 6) Comparison of model and flight Pressures for S/C 4 on 5/2/24

Conclusions

All four Starling spacecrafts have successfully operated since their launch one year ago. Their on-orbit thermal performance has been nominal, and their components have operated well within their thermal limits. The thermal model of the Starling spacecrafts developed to facilitate their design has been employed to model their in-flight performance. Some model parameters needed to be adjusted for the model results to match the flight data. Modeling of more flight cases will be performed to further examine the suitability of the model and its assumptions.

Acknowledgements

We would like to thank James Milsk, Nahum Alem, Jose Alvarellos and Sonny Hwang at ARC and Brian Uzzle at BCT who provided invaluable technical support for this effort.