Argus-1

Camera Module Endurance
&
Jetson Thermal Management
TVAC Test Plan

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Revision	Release Notes Author	Release Date
A	Initial Release Colton Amos	4/11/2024

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1.0 Purpose and Scope

This test plan verifies the endurance capabilities of a selected camera unit and its consequent resistance to thermal distortion in its lenses and mounted PCB. Furthermore, this plan will also investigate the proficiency of a proposed thermal management system for an on board Jetson unit. The performance of a copper vs aluminum thermal sink board will be compared utilizing a copper thermal strap to the aluminum chassis. These results and their respective conductances will then be incorporated into a protoflight thermal model.

1.1 Requirements Table

Table 1: Requirements

ID	Title	Description	Information Learned in this Version
THR-01	Survival Temperature Regulation	The thermal system shall maintain temperatures in accordance with the ThEL survival temperatures during orbit without operating high-risk avionics components.	
THR-02	Operation Temperature Regulation	The thermal system shall maintain temperatures in accordance with the ThEL operating temperatures during orbit that involve high-risk components being on.	
THR-17	Thermal Model Correlation	Argus-1 shall have a thermal model that is correlated to within 5% temperature accuracy in K.	
THR-18	Thermal Vacuum Survivability	The thermal system shall use components that will survive the vacuum conditions of low Earth orbit.	

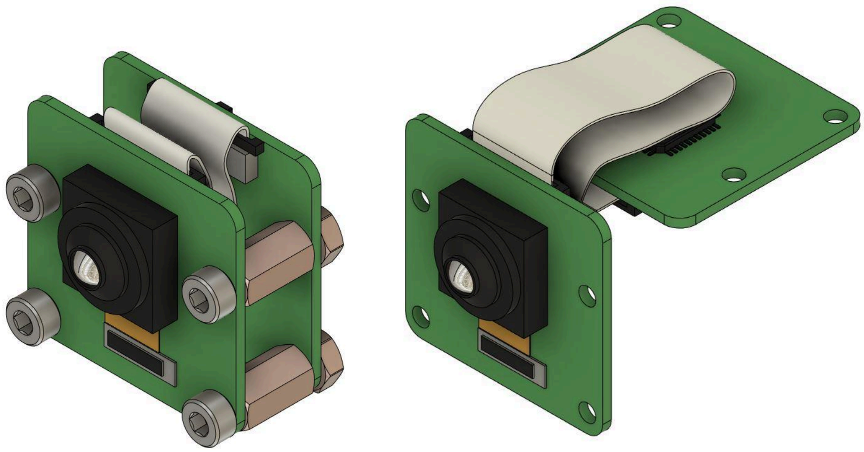
2.0 Involved Personnel

Table 2: Personnel

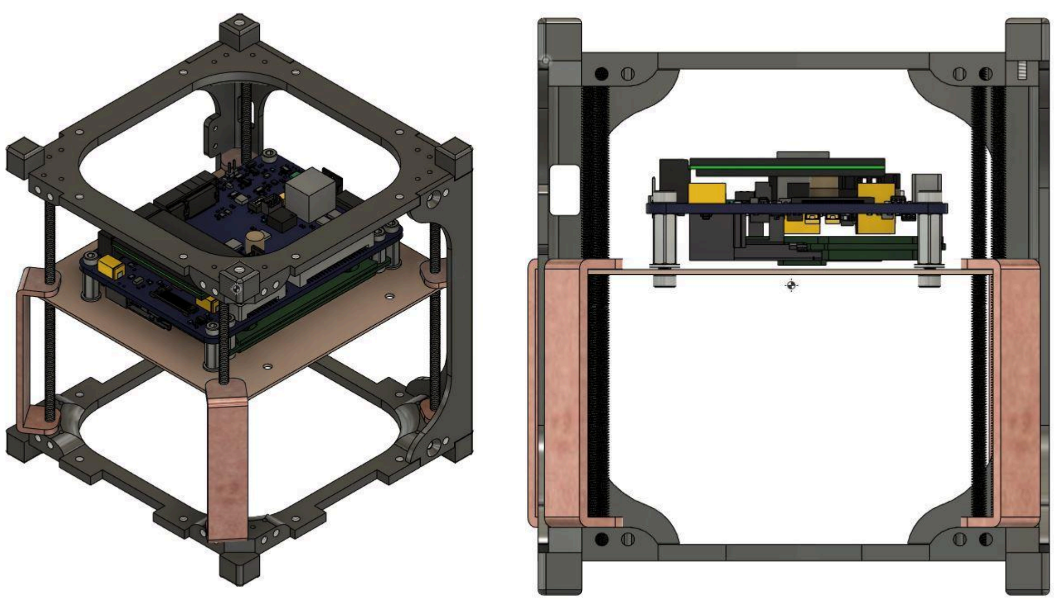
Name	Role	Contact Information
Colton Amos	Thermal Lead	camos@andrew.cmu.edu
Ashley Kline	Mechanical Engineer	ankline@andrew.cmu.edu
Allison Weller	Mechanical Engineer	ahweller@andrew.cmu.edu
Sankalp Chopkar	Mechanical Engineer	schopkar@andrew.cmu.edu
Rohit Bangal	Avionics Engineer	rbangal@andrew.cmu.edu
Elakhya Nedumaran	Payload Engineer	enedumar@andrew.cmu.edu
Paulo Fisch	Thermal/Mechanical Advisor	pfisch@andrew.cmu.edu
Zach Manchester	Professor	zmanches@andrew.cmu.edu
Brandon Lucia	Professor	blucia@andrew.cmu.edu
Chuck Whittaker	Supervisor	warrenw@andrew.cmu.edu

3.0 Test Articles

The TVAC test will be primarily testing two articles. A fully assembled Arducam camera module including its two mounted PCB's, its camera housing and its camera lens. A CAD representation of this article can be found below:

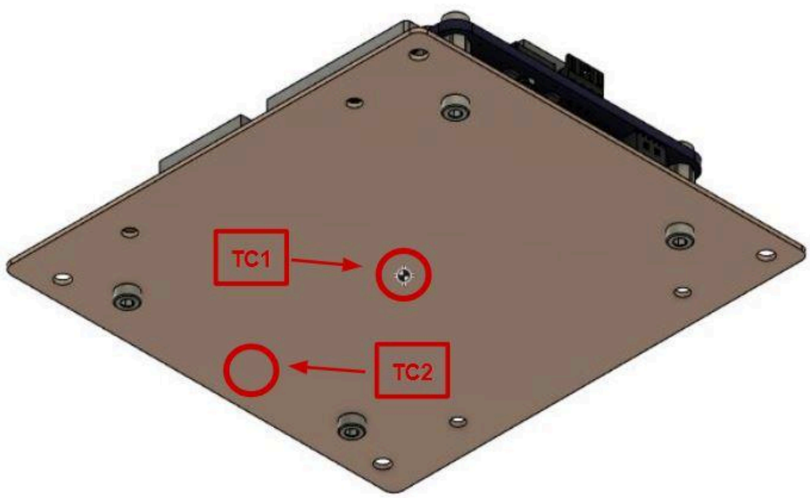


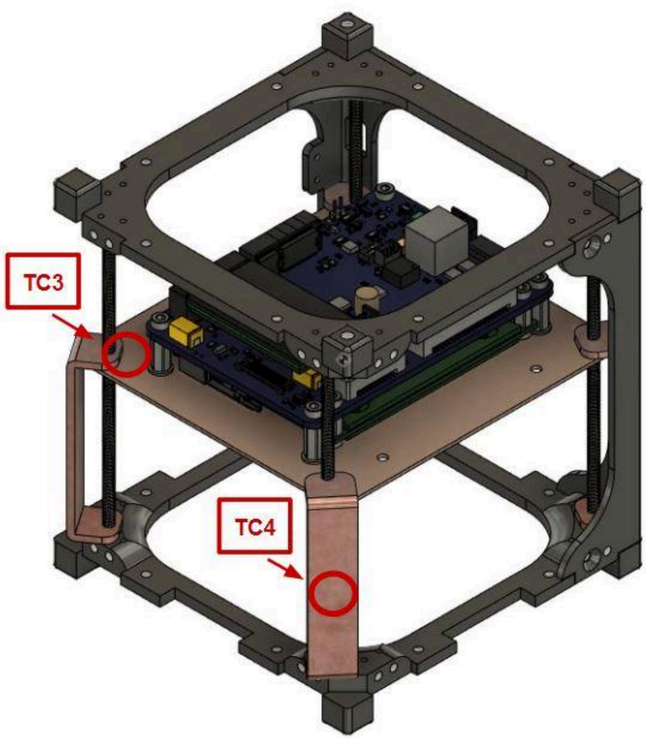
The second test article will be sub assembly of the thermal management system for the Jetson Module. This sub assembly includes: the chassis frame and legs, M3 PC104 rods, 4 copper thermal straps, a copper and aluminum thermal sink board, a Jetson Module, Jetson carrier board, thermal gap pad, and all associated M3 mounting hardware. Abbreviated assembly instructions can be found in *Table 4: Test Setup*. A CAD representation of the thermal management system can be found below:

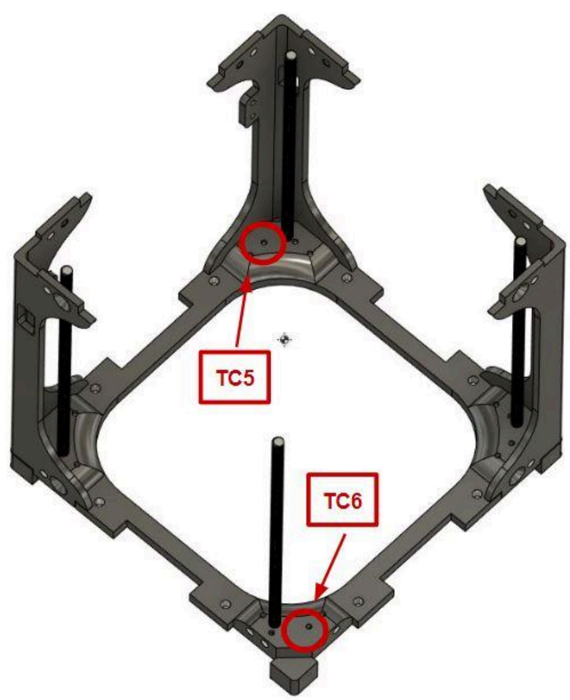


3.1 Thermistor Locations

The test will employ the use of six 10k Ohm thermistors to monitor and track the temperatures throughout the test. The thermistors will be secured to the Jetson thermal management system in six different locations with kapton tape. These positions are specified below:







4.0 Facilities

The test will happen in the Robotics Institutes's vacuum chamber, located in the Planetary Robotics Laboratory High Bay on floor 1 of Gates Center.

5.0 Test Procedures

5.1 Summary

Table 3: Summary

Description:		
This test assesses the effects of thermal dilation of a camera unit and a Jetson computing unit under TVAC conditions. The camera module's PCB and lens resistance to thermal distortion are going to be measured by placing a fully assembled camera module onto the bottom of the vacuum chamber's cryogenic shroud, which will cool the camera module to a set temperature. The temperature profile and thermal management system of a Jetson module are going to be tested by placing an assembled chassis mounted Jetson unit and thermal sink board onto the bottom of the vacuum chamber's cryogenic shroud, which will cool the chassis and Jetson unit to a set temperature. The temperature time-histories of the Jetson module will be used in simulations to back calculate its conductances with the thermal sink board. The temperature profile and power output will also be recorded to get an accurate model of Jetson operational conditions.		
Pass Criteria:		
The camera module shows minimal distortion post TVAC conditions and maintains the same image quality as pre test calibrated images. Temperature profile across the Jetson module stays within supplier specified survival and operating temperature bounds throughout the duration of the test. The proposed thermal management system shows effective heat transfer to the chassis.		
Data Products (data to be collected during test):		
Temperature time histories of the camera pcb, Jetson module, thermal sink board, chassis frame and vacuum chamber. The pressure time histories of the vacuum chamber shall be collected. The power outputs of the Jetson module during GPU burn.		
Test Articles:		
Part Number:	Description:	Revision:
B0305	Arducam 12MP IMX708 camera module	

900-13767-0000-000	Jetson Orin module	
	Jetson Orin Carrier Board	
Custom	Copper thermal sink board	
Custom	Aluminum thermal sink board	
Custom	Copper thermal straps	
2242235	Thermal Gap Pad	
a21072000ux0246	M3 PC104 threaded rods	
Custom	Aluminum Chassis (top, bottom and 4 legs)	
90592A085	M3 PC104 mounting hex nuts	
92125A125	M3 Chassis mounting hardware	
93655A093	Jetson Orin mounting standoffs	
Test Equipment:		
ID:	Description:	Calibration Date
	Vacuum Chamber	
	Agilent Thermocouple DAQ Module	
	10k Ohm Thermistors	
	Polyimide Heater	
	BD Lab Supply (for lamps and dot projectors)	
	Sorensen DCS20 Lab Supply (For Spacely)	
	Arduino Uno Microcontroller	
	MAX31855 Thermocouple Breakout	
	Sensata Crydom CMX600D10 Solid State Relay	
	HDMI Compatible Monitor (with power cable and HDMI cable)	
	USB keyboard and mouse	

5.2 Test Setup

Table 4: Test Setup

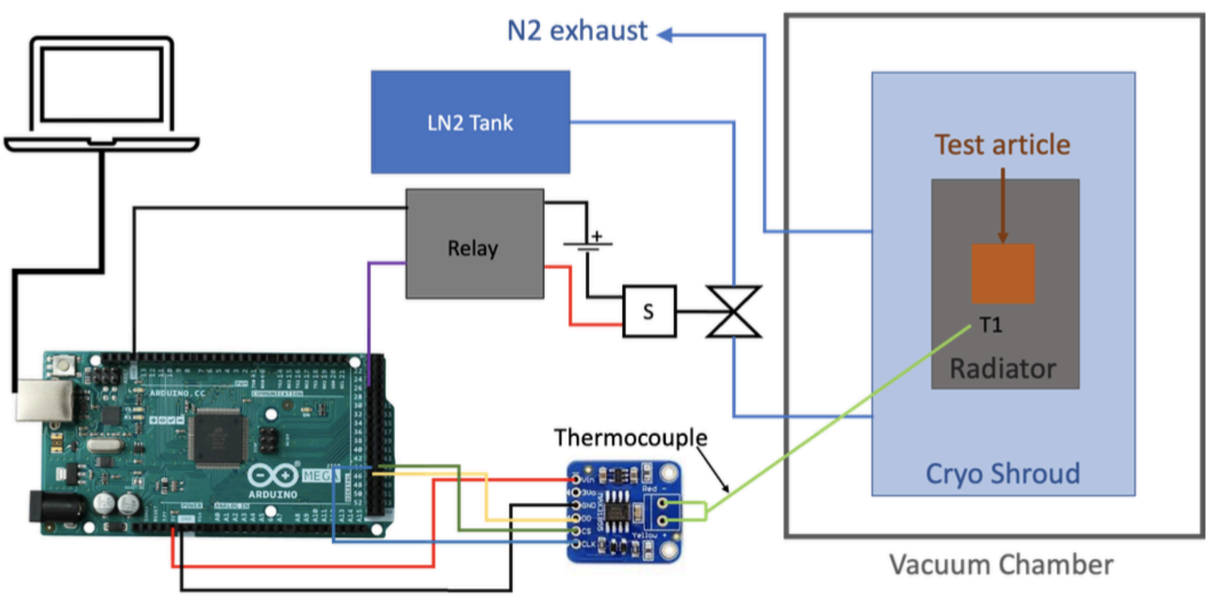
Procedure Step:	Diagrams / Descriptions:
1. Calibrate camera, record resulting camera calibration (if this was already done, no need to redo)	Confirm with Payload that the selected camera has been calibrated before the test. Points of communication are Kyle McClearly and Elakhya Nedumaran.
2. Clean PCB edges, camera housing, and camera lens	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
3. Clean chassis legs, top and bottom	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
4. Clean M3 PC104 rods threads	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
5. Clean M3 PC104 mounting hardware, Jetson Module standoffs	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
6. Clean copper thermal straps	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
7. Clean copper and aluminum thermal boards	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
8. Clean Jetson Module and corresponding carrier board	Ensure that isopropyl alcohol is used or a sufficiently sensitive cleaning solvent
9. Screws all 4 legs into lower chassis frame using M3 hardware	Ensure that all hardware is torque is manufacture specifications accurately replicating flight conditions
10. Screw all 4 PC104 rods into lower chassis	Ensure that all hardware is torque is manufacture specifications accurately replicating flight conditions
11. Place lower half of thermal strap onto each PC104 rod with corresponding M3 hex nut	Ensure full contact is made with the lower chassis frame and the thermal strap (picture for reference)
12. Place thermal sink board onto all PC104 rods with an M3 hex nut below the board	

13. Place upper half of the thermal strap onto each PC104 rod with an M3 hex nut above the strap	Ensure full contact is made with the lower thermal sink board and the thermal strap (picture for reference)
14. Secure the lower portion of the thermal strap to the lower chassis with the M3 hex nut	Ensure full contact is made with the lower chassis frame and the thermal strap (picture for reference)
15. The set the preferred Z-axis height of the thermal sink board and secure in place with the M3 hex nut below the board and the M3 hex nut above the thermal strap (This action sandwiches the thermal strap onto the thermal board while simultaneously setting the Z-axis height)	For reference the thermal sink board should be ~ 42 mm in z height from the lower chassis frame (picture for reference)
16. Align the Jetson Module and the carrier board to the thermal sink board to identified region for thermal gap pad	(picture for reference)
17. Apply thermal gap to thermal sink board ensuring full coverage of the GPU is established	Ensure the entire surface area of the GPU unit is covered by the thermal gap pad. Clean surfaces with isopropyl alcohol before applying the gap pad.
18. Use the carrier board standoffs to mount the carrier board to thermal sink board	Ensure sufficient contact is made with the thermal gap pad
19. Place the upper portion of the chassis onto the PC104 rods and align with the 4 legs	Ensure upper frame PC104 mounting holes are unthreaded for ease of installation
20. Screws all 4 legs into upper chassis frame using M3 hardware	Ensure that all hardware is torque is manufacture specifications accurately replicating flight conditions
21. Take test articles to vacuum chamber in sealed bag	
22. Open vacuum chamber lid and clamp test articles ON THE SIDE OF THE SHROUD CLOSEST TO VACUUM	

CHAMBER PLATFORM.	
23. Mount thermocouples to the chassis frame, thermal sink board, and Jetson carrier board.	Use kapton tape small piece of gap pad to firmly secure thermocouples to chassis frame, thermal sink board, and Jetson carrier board
24. Connect thermocouples to the DAQ module and to the microcontroller.	**THE THERMOCOUPLE CONNECTED TO THE CONTROL SYSTEM NEEDS TO BE MOUNTED TO THE SHROUD OR THE CONTROL SYSTEM WILL NOT FUNCTION PROPERLY. IF THIS STEP IS NOT FOLLOWED CORRECTLY, THE ENTIRE TEST WILL NOT BE VALID.** **INCORRECT THERMOCOUPLE MOUNTING WILL ALSO NEGATIVELY IMPACT PERFORMANCE. PAY SPECIAL ATTENTION TO CREATING A PROPER THERMAL BOND FOR THE THERMOCOUPLE AND THE RADIATOR**
25. Connect lamp to wires leading to BD power sources and Spacely to Sorensen power source.	Connect dot projectors **IN PARALLEL. Set Spacely power supply to 15V and limit current to 2A before connecting.** Set BD power source to 5V
26. Plug power supplies into wall socket	
27. Turn on lab supplies and check lamp functionality	
28. Connect to the Spacely	Connect a monitor, keyboard, and mouse to

	the spacely
29. Verify the correct git branch is selected for the test	~~Not sure what git branch to use
30. Verify the Jetson is powered on and connected to the correct ports	Verify commands and outputs
31. Verify that the code is compiled	Ensure code compiled with no errors
32. Confirm that sufficient disk space exists	Confirm that at least 2GB of space is free on the system (2GB will be sufficient so long as the test runs for less than 10 hours). If needed, the build directories of the other workspaces can be cleared to make space **check with the workspace owners first to make sure they don’t need any files stored in build** (especially images in /cf)
33. Start Jetson GPU burn operation cycle	
34. Verify Jetson is running and performing test functions	Check power output and outputs of GPU burn to ensure results are what is expected
35. Disconnect the monitor, mouse and keyboard from the Spacely	**Do not disconnect the power or the cameras from the spacely.** NOT REQUIRED IF USING SSH
36. Connect chamber shroud line to Liquid Nitrogen Tank. Open tank valve.	**FOLLOW SAFETY PROCEDURES FOR LIQUID NITROGEN. WEAR GLOVES AND A FACE SHIELD. ENSURE NO UNPROTECTED PERSONNEL IS CLOSE TO LN2 TANK BEFORE CONNECTING LINES AND**

	OPERATING VALVES
37. Turn on thermocouple and DAQ modules. Verify temperature readings. Input desired temperature profile.	**Do not set temperature drop ramps to inclinations steeper than 2min/oC**
38. Close the vacuum chamber lid	



5.3.1 Test Procedures

Table 5: Test Procedures

Procedure Step:	Expected Result:	Actual Result:
1. Record the current time as "post closing TVAC Chamber lid"	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
2. Wait 15 minutes, allowing the Jetson to continually operate in a normal state with the GPU burn activated.	Check expected outputs of GPU burn, confirm with Payload liaison	___ Pass ___ Other

		Explain:
3. Continually record the wattage of the Jetson Module during the entire test. First data collection shall begin must the GPU has begun.	Wattage noted in spreadsheet (link here)	___ Pass ___ Other Explain:
4. Record the current time as “pre activating vacuum chamber pumps”	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
5. Activate vacuum chamber pumps.	Pressure should be less than 10e-2 Torr	___ Pass ___ Other Explain:
6. Wait for the vacuum chamber to get to hard vacuum (pressures lower than 10^-2 Torr)	Pressure should be less than 10e-2 Torr	___ Pass ___ Other Explain:
7. Record the current time as “post hard vacuum achieved”	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
8. Wait 15 minutes, allowing the Jetson to continually operate in a normal state.	Check expected outputs of GPU burn, confirm with Payload liaison	___ Pass ___ Other Explain:
9. Record the current time as “pre activating dot projectors and shroud thermal control”	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
10. Record the wattage of the Jetson	Wattage noted in	___ Pass

during the GPU burn.	spreadsheet (link here)	___ Other Explain:
11. Turn on dot projectors. If possible, confirm via thermocouple readings that the dot projectors are indeed active.	Dot projectors active	___ Pass ___ Other Explain:
12. Activate shroud thermal control system.	Temperatures follow the specified temperature curve to 10% divergence	___ Pass ___ Other Explain:
13. Record the current time as “post shroud activation”	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
14. Record the wattage of the Jetson during the GPU burn.	Wattage noted in spreadsheet (link here)	___ Pass ___ Other Explain:
15. Perform inspections of the test articles for damage every 30 minutes. Overshoots larger than 15°C are expected when ramping down.	Thermocouples, Jetson module, and shroud temperature control system functioning normally	___ Pass ___ Other Explain:
16. Check data every 10 to 15 minutes. Allow the shroud system to oscillate slowly around the reference temperature. Look for big jumps in temperature or current readings that might indicate some sort of thermocouple joint failure or test article failure.	Thermocouples, Jetson module, and shroud temperature control system functioning normally	___ Pass ___ Other Explain:

17. Deactivate the solenoid after two to three hours or if temperatures get close to -40°C.	**DEACTIVATE SOLENOID IF TEMPERATURES DROP TOO MUCH TO AVOID COMPONENT FAILURE**	___ Pass ___ Other Explain:
18. Let the test articles cool until temperature readings stabilize and oscillate with the shroud temperature.	Jetson module shall follow desired temperature profile	___ Pass ___ Other Explain:
19. Record the current time as "start of desired thermal state for test"	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
20. When the camera module and Jetson module is at desired equilibrium temperature, maintain this state for 30 minutes to fully capture thermal management capabilities of the system. Continue checking data.	Jetson module functional. Temperature data and wattage data is continually being recorded	___ Pass ___ Other Explain:
21. Record the current time as "end of desired thermal state for test"	Time noted in spreadsheet (link here)	___ Pass ___ Other Explain:
22. Record the wattage of the Jetson during the GPU burn.	Wattage noted in spreadsheet (link here)	___ Pass ___ Other Explain:
23. Remove solenoid power cord from socket and close LN2 tank valve. DO NOT TOUCH THE LN2 TANK VALVE UNTIL SOLENOID IS PROPERLY POWERED OFF	**FOLLOW SAFETY PROCEDURES FOR LIQUID NITROGEN. WEAR GLOVES AND**	___ Pass ___ Other Explain:

	A FACE SHIELD. ENSURE NO UNPROTECTED PERSONNEL IS CLOSE TO LN2 TANK BEFORE CONNECTING LINES AND OPERATING VALVES.	
24. Vent the vacuum chamber to the atmospheric pressure following MEC-0275 procedures.	Vacuum chamber vented to atmospheric pressure	___ Pass ___ Other Explain:
25. Deactivate the Jetson Module and ensure the entire system is powered down.		___ Pass ___ Other Explain:
26. Open the vacuum chamber lid.		___ Pass ___ Other Explain:
27. Remove the thermocouples from the test articles. Unplug heaters from the power supply. Check for integrity of full data acquisition.		___ Pass ___ Other Explain:
28. Take the test articles out of the vacuum chamber in sealed bags.		___ Pass ___ Other Explain:

Test Completed By:	Date:

5.3.2 Data Analysis Procedures

Table 6: Post Test Data Analysis

Procedure Step:	Expected Result:	Actual Result:
1. Process and compile all recorded temperatures from thermocouples and Jetson module. Separate based on test article and temperature reading location.	Data compiled in test spreadsheet (link here)	___ Pass ___ Other Explain:
2. Align all recorded temperatures with their respective time stamps.	Align and clean data in spreadsheet	___ Pass ___ Other Explain:
3. Align recorded wattages with the indicated time stamps.	Align and clean data in spreadsheet	
4. Highlight the following milestone timestamps as recorded during the test: “post closing TVAC Chamber lid”, “pre activating vacuum chamber pumps”, “post hard vacuum achieved”, “pre activating dot projectors and shroud thermal control”, “post shroud activation”, “start of desired thermal state for test”, and “end of desired thermal state for test”.	Align and clean data in spreadsheet	___ Pass ___ Other Explain:
Date Compile Completed By:	Date:	

5.4 Safety Concerns

- Only trained personnel are authorized to operate the vacuum chamber
- Exposure to electricity from heaters and lab power supplies
- Exposure to LN2. Only trained and authorized personnel can operate the LN2 shroud
- Be cautious and aware of extreme temperatures present on the test articles

6.0 Results & Conclusions

6.1 Special Test Information

This test requires the use of a control system to regulate mock radiator temperatures by activating the shroud LN2 line. Contact Paulo Fisch (pfisch@andrew.cmu.edu) or Chuck Whittaker (warrenw@andrew.cmu.edu) if you have any questions. Each board will require specific ports for communication in the chamber. Verify with Avionics, Payload, and Mechanical teams

6.2 Test Failures & Corrective Actions

6.3 Unaccomplished Tasks & Recommended Retests

7.0 Literature & Relevant Documents

MR-MEC-0275: Vacuum Chamber Operation Guidelines