Thermal Vacuum Testing of a Modified COTS Camera for use in Lunar Environments

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COTS Testing for Lunar Environments

Why COTS?

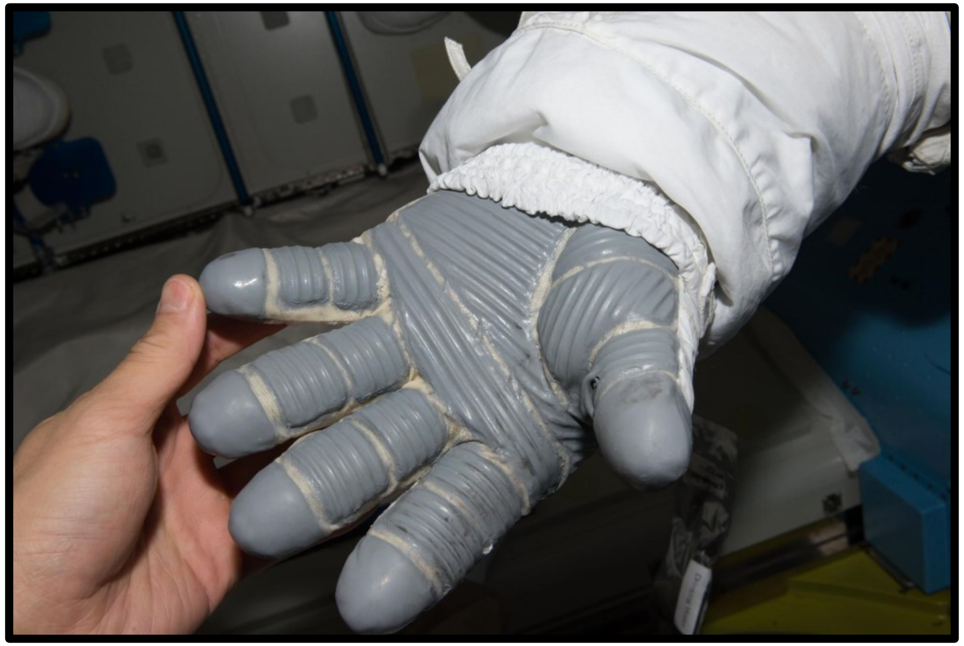
- Cost of hardware
- Availability
- Established user base
- Modified COTS sparked much attention during Gemini missions

Credit: nasa.gov

Credit: nssdc.fsfc.nasa.gov

Study Objectives

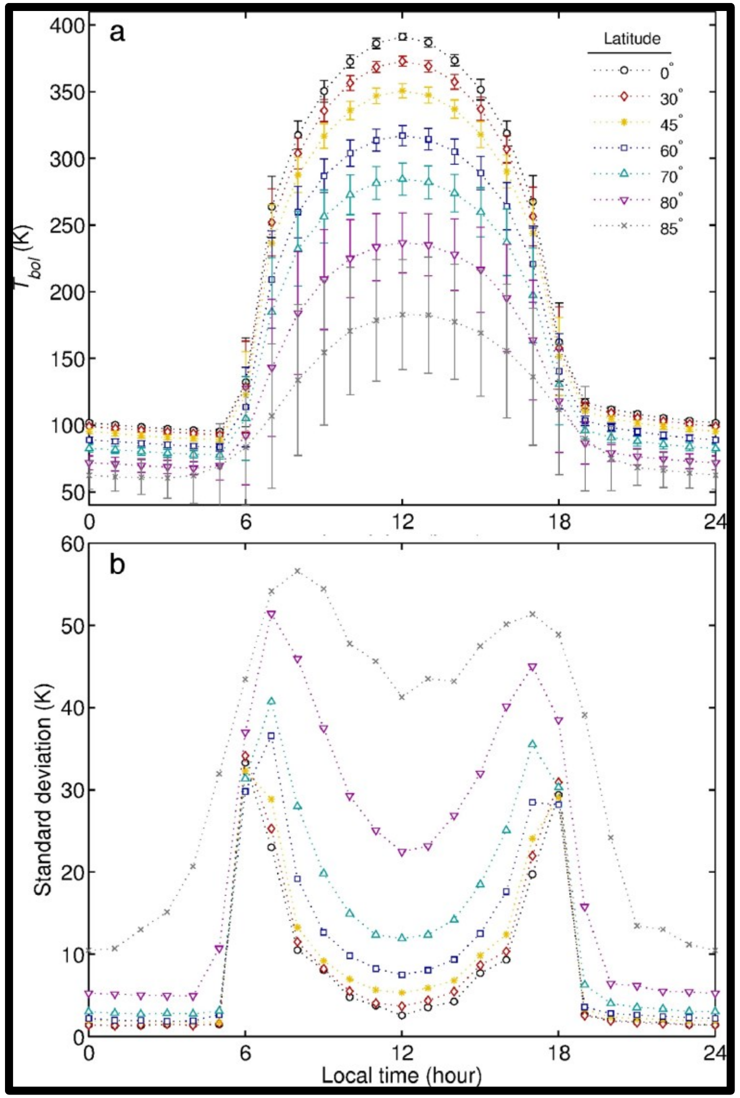
- Analysis and test to ensure the HULC and its TPS will survive the lunar environments
  - Simulate use cases, thermal loads
  - Dust mitigation
  - Astronaut hands
- Characterization of the thermal response of the HULC to expected use cases
  - Time to failure
  - How usage affects survivability
  - How environment affects operation



Credit: nasa.gov

Lunar Considerations

- Temperature
  - Highly transient, especially during morning and evening
  - Variability increases near poles
  - Delta between surface and deep space
- Environment
  - Lack of natural convection
  - Regolith
  - Radiation
  - Astronauts

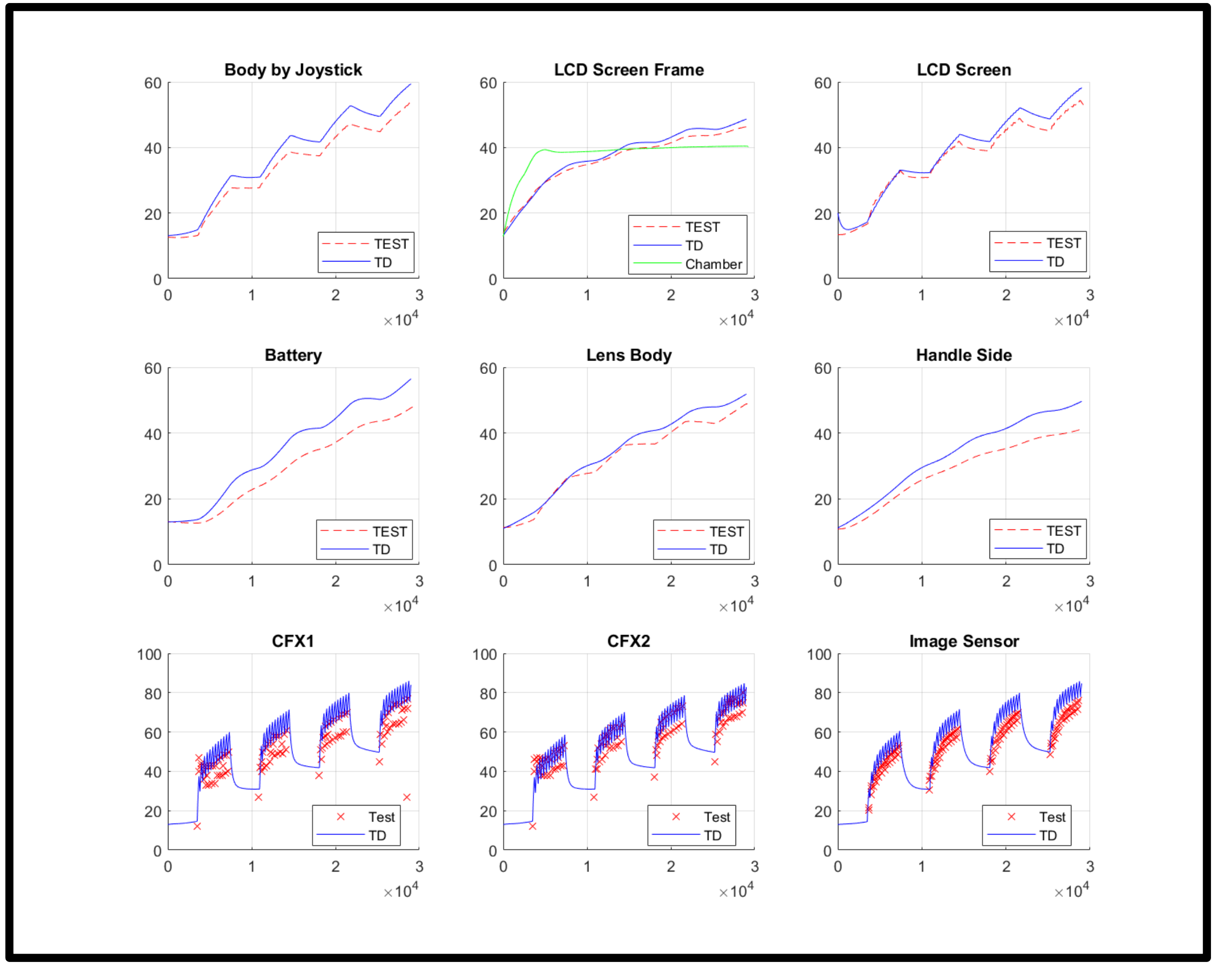


Williams et al. 2017

Thermal Vacuum Testing

- Many benefits from substantial TVAC testing
  - Corollary data for model
  - Identify issues not displayed during benchtop testing or analysis
  - Qualification of hardware
  - Characterization of operations

Credit: esa.int



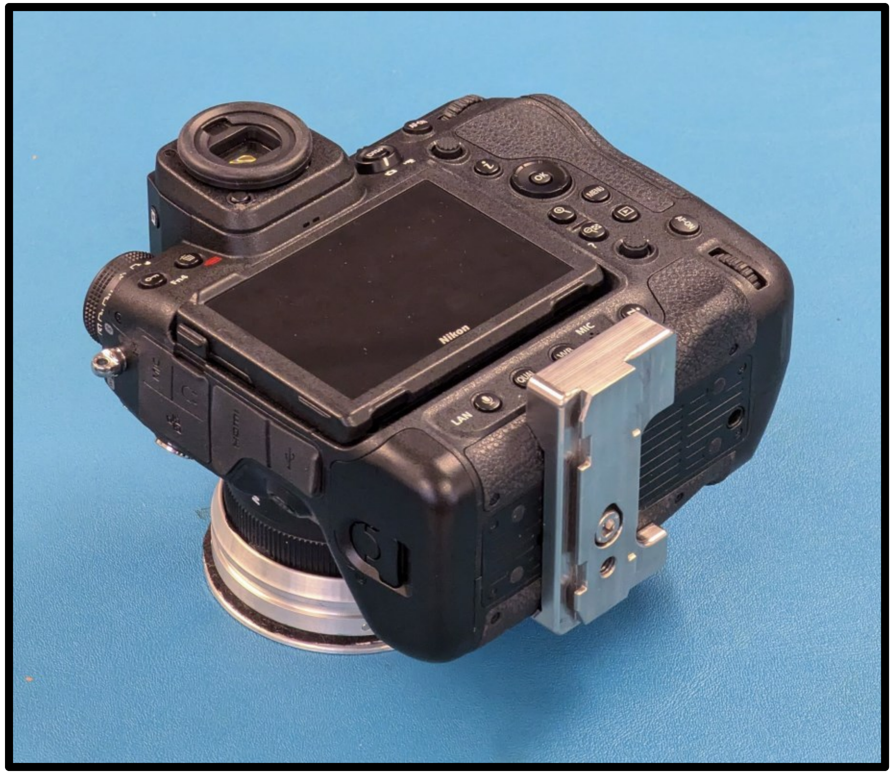
Camera Modifications

- **Camera Modifications (Hardware)**
  - Thermal blanket
    - 7 layer MLI with Orthofabric shells
    - Custom fit for camera
    - Designed with regolith protection in mind
  - Component selection
    - Lens(es)
    - Storage card

Credit: esa.int

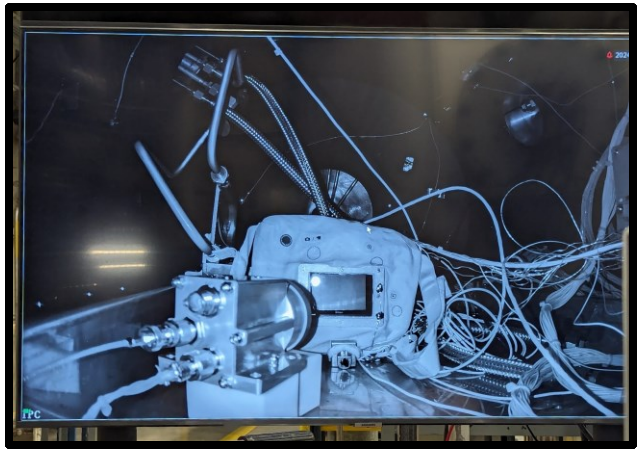
Camera Modifications

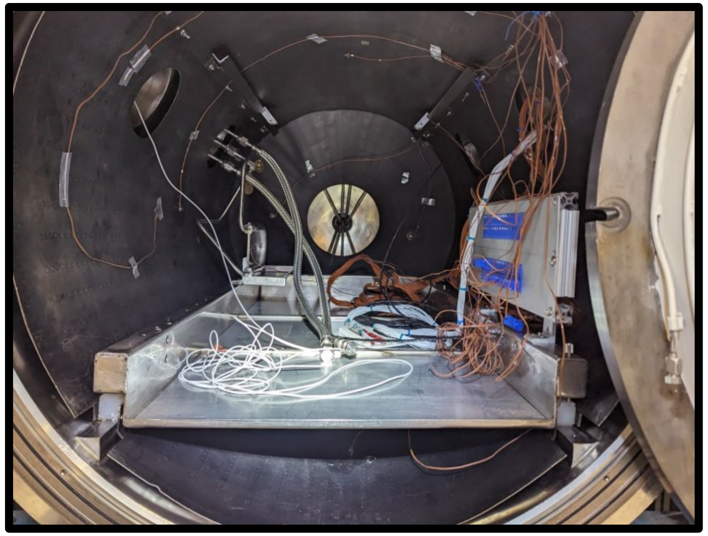
- **Camera Modifications (Hardware)**
  - Mechanical mounts
    - Handle mount
      - Aluminum, to attach to carrying handle
    - Lens mount
      - Reduce dust ingress



Vacuum Testing

- **Thermal Vacuum Chamber Setup**
  - VAC
    - HI-TTeMP Lab at MSFC
      - 1E-4 Torr
      - Ambient thermal control
  - TVAC
    - ETF at MSFC
      - Temperature control by LN2 shroud
      - Thermally isolated from floor
      - Secondary camera to watch HULC LCD screen
  - Thermocouples attached using Stycast at predetermined points
  - Blanket present for EVA tests, absent for IVA tests
  - Control provided through ’10-pin’





TVAC Testing Procedures

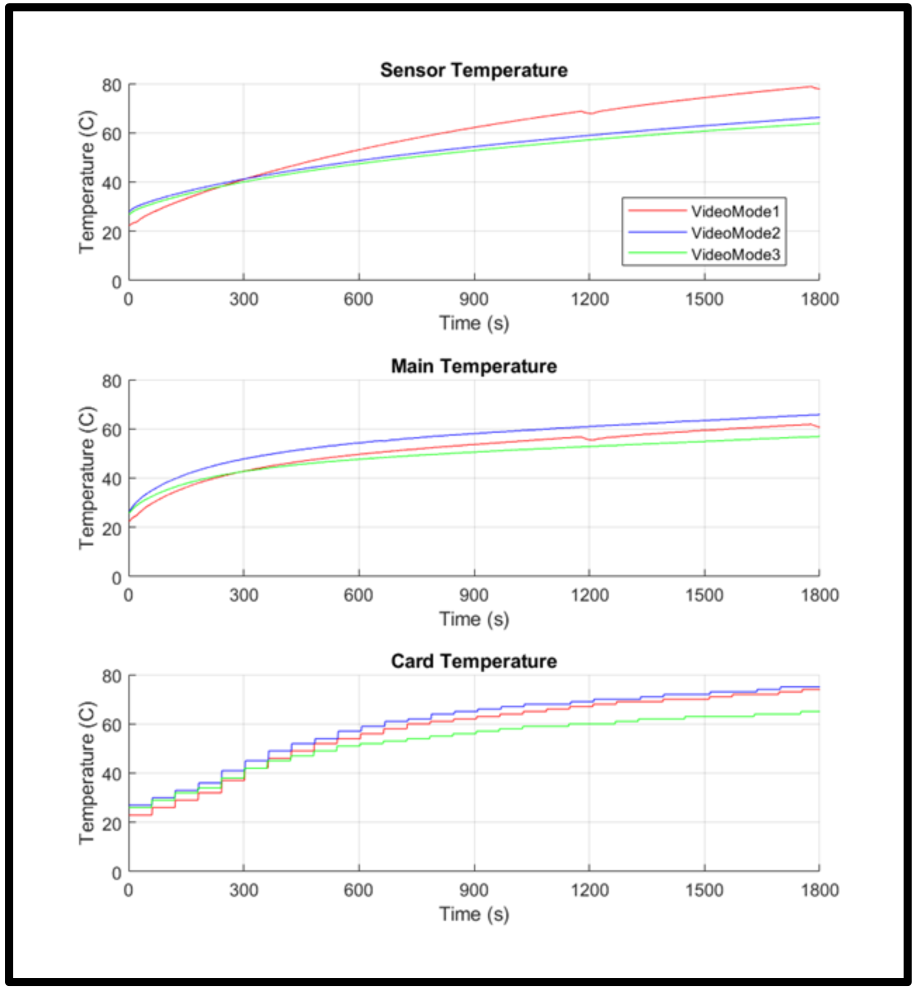
- Both operational and non-operational conditions tested
  - Non-operational was to verify survivability over an EVA duration
  - Operational conditions ensured that a simulated use case would not damage camera
- Major Assumptions for testing
  - Begin at ambient temperature
  - 50% duty cycle
  - Level orientation with view of lunar surface and deep-space (no astronaut)
  - BOL optical properties (not soiled by regolith)

Timestamp (s)	Operation(s)
0 – 30	- Power on/awake
30 – 90	- Panoramic shot - 10 x 3 shot burst - Pause
90 – 150	- 3 x 3 frame burst - Pause
150 – 270	- Powered off

Case	Lat	Solar Flux [W/m2]	Hours post lunar sunrise	'Time' of lunar day	Equivalent Sink	Chamber Temp	Test Duration [hours]
Hot	84S	1414	212	Early afternoon	6°C	40°C	8+1
Cold	84S	1323	330	Late evening	-80°C	-120°C	8+1
PSR	84S	0	576	NA	-203°C	-190°C	2+1

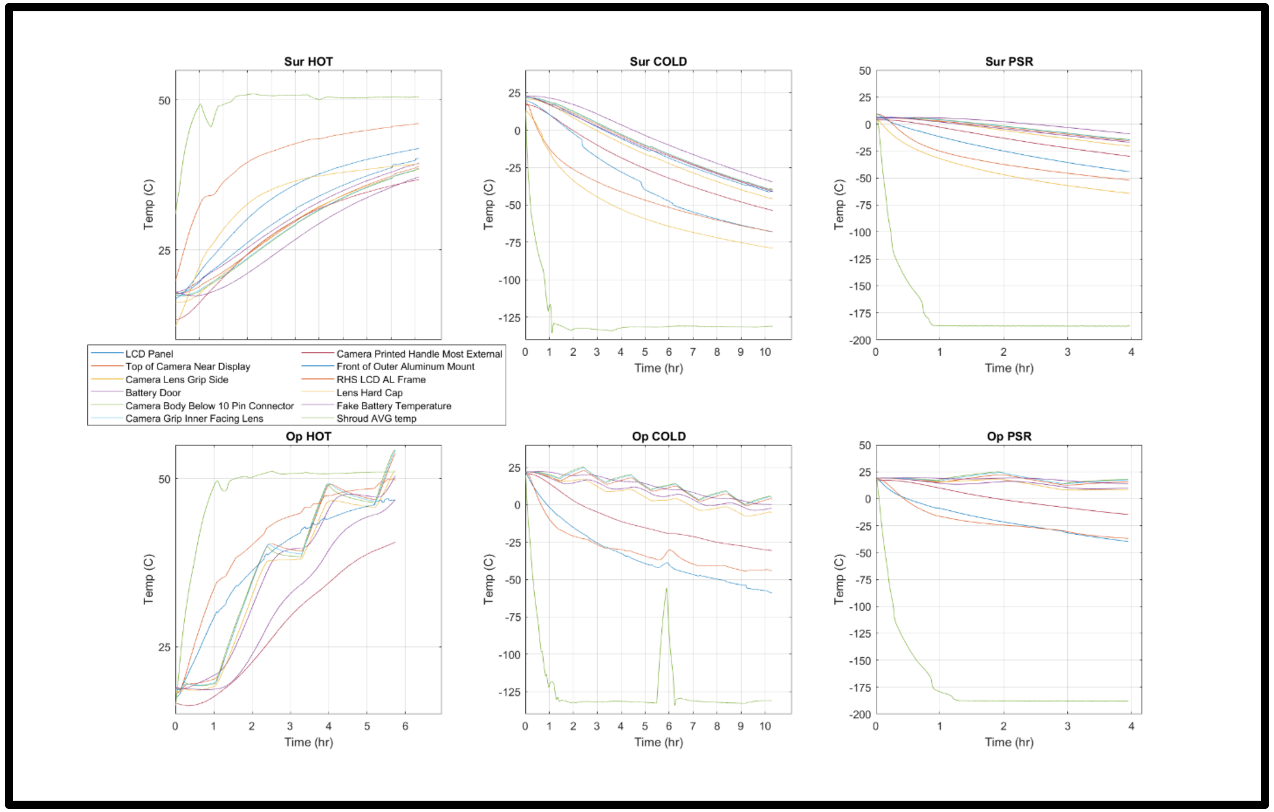
Results

- **Temperature Profiles – Video mode operations**
  - Plot shows temperature profiles during video mode tests
  - Consistent storage cards across tests
  - Simulation of IVA environment
    - Microgravity (no natural convection)
    - No blanket
    - Battery powered operation



Results

- **Temperature Profiles – Simulated Surface Environments**
  - Consistent configuration (blanket on, battery stand-in, firmware settings
  - Survival – HULC in standby
  - Operational – 50% duty cycle
  - 8+1 hour test cycle for hot and cold cases
  - 2+1 hour test cycle for PSR
  - Hot operational shut down early in this test due to temperature limits being reached



Operational Lessons Learned

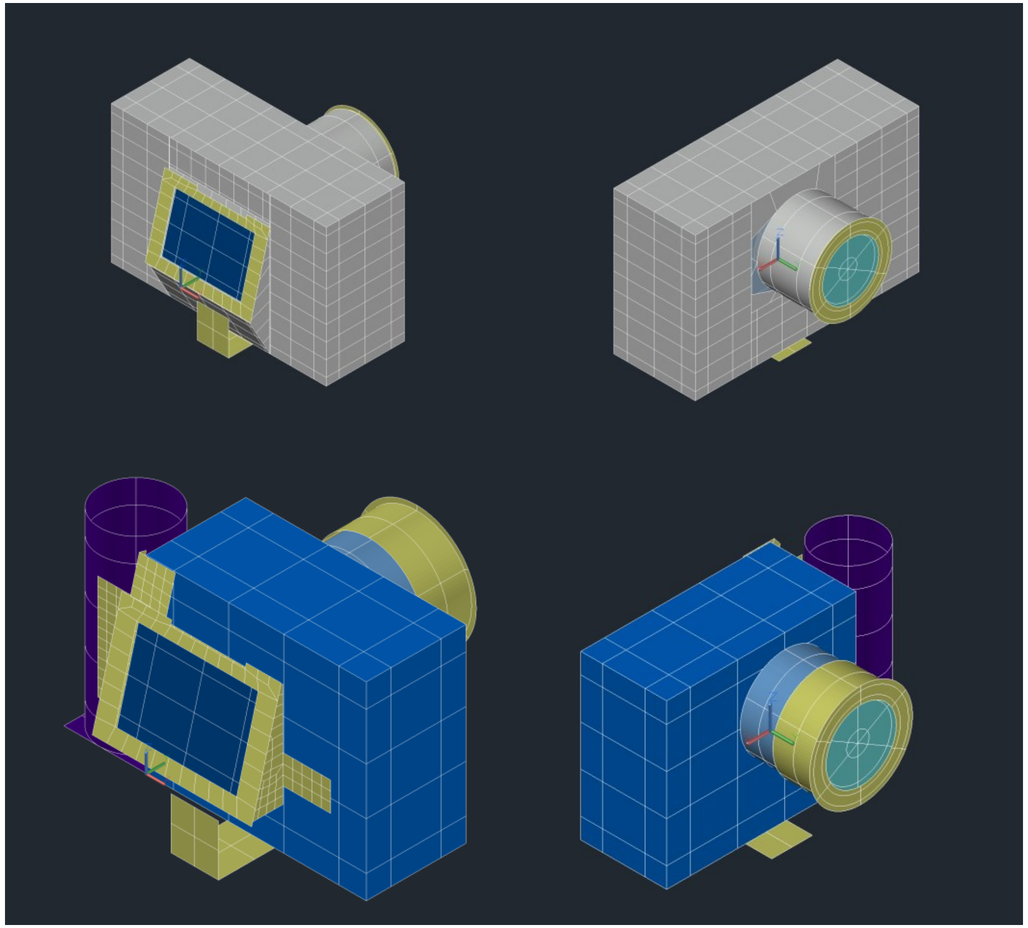
- **Impact of Environmental Extremes**
  - LCD screen ‘ghosting’
    - Occurred after long periods of LCD off at colder temperatures
    - Typically experienced when LCD temperatures were below -15 degC
    - Difficult to characterize quantitatively (duration and severity)
    - Never resulted in the camera unable to perform photography
  - Overtemperature warnings and camera shutdowns
    - Occurred during hot cycles due to HULC internals not able to shed heat
    - Mirrorless camera live view uses main sensor
      - Extra heat generated, even if data is not being recorded
    - Camera has built in overtemperature protections
      - Alert icon, shutdown countdown, auto shutdown

Lessons Learned

- **Effectiveness of Thermal Protection System**
  - Thermal blanket is effective at protecting HULC from lunar surface temperatures
  - Further insulation/protection from environment may lead to further problems
    - Camera maintains operation in cold environments and increased usage raises internal temperatures to more suitable temperatures
    - If camera failed due to under-temp conditions, unlikely to self recover
    - Due to built in firmware temperature shutdowns, battery is unlikely to reach temperatures that would cause thermal breakdown (18650s)
  - Blanket is also suitable for protection from regolith
  - Astronauts approved of design and are able to use easily

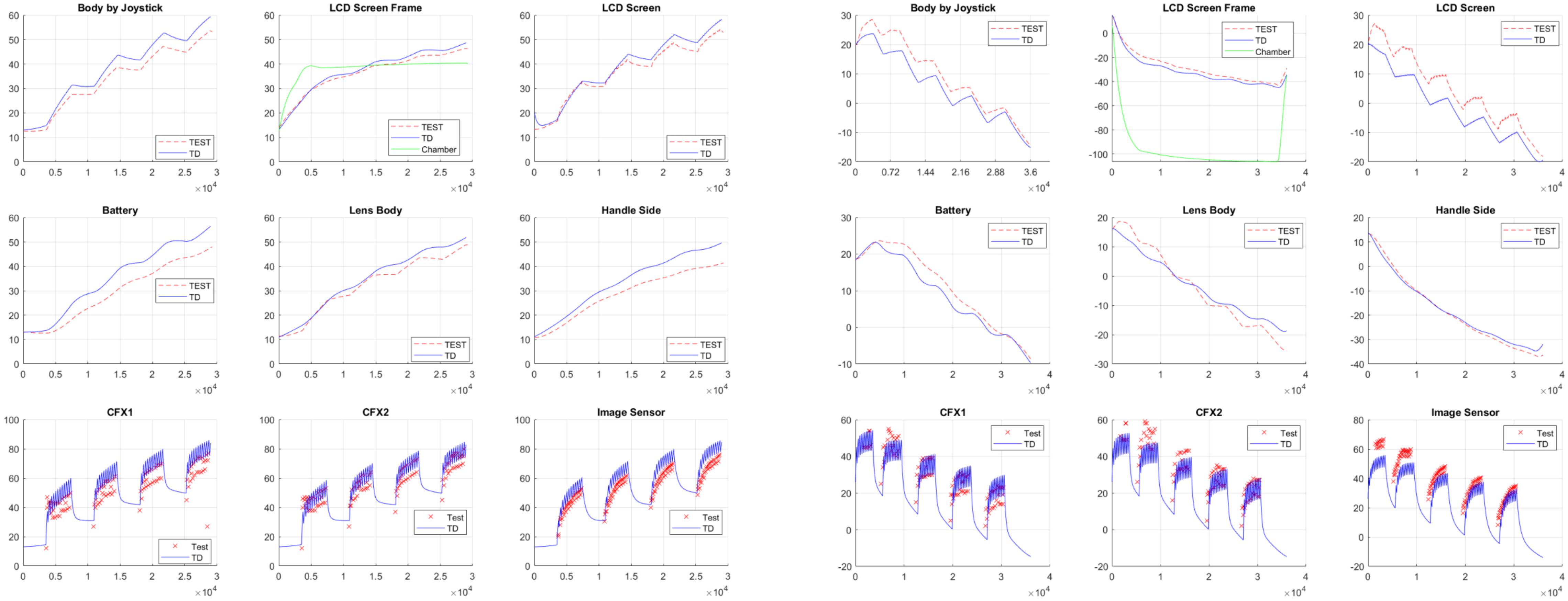
Credit: nasa.gov

- ## Thermal Desktop Model
  - Comprised of FD surfaces and solids
  - MLI uses combination of e* and stack manager to simulate different layers at bottom of blanket
  - Heat loads controlled by symbol manager and logic
    - Allows for different duty cycles, cyclical or interrupted cycles
    - Heat loads spread across surface, not nodal based



TD Model

- **Thermal Desktop model correlation results**



Comparison with Expected Lunar Conditions

- Current TVAC testing was done with a large amount of margin on expected temperatures
  - Validation that blanket provides adequate protection
  - Provides certainty to unknown usage cases
- Future TVAC testing will more closely simulate lunar cases
  - TVAC temperatures closer to SLS surface temperature data
  - Operational timelines compiled from field tests

Conclusions

- **Takeaways**
  - Thermal blanket provides sufficient protection for EVAs
    - Both from external thermal loads and regolith
  - HULC survives lunar environmental conditions
  - HULC is suitable for use in IVA environments (microgravity)
  - Astronauts are capable of using camera even with limited mobility and dexterity of gloves
  - Thermal model is capable of capturing trends of current hardware build

Credit: nasa.gov

Forward Work

- Further TVAC testing or analysis to assess impacts of the following:
  - Duty Cycle / useage
  - Regolith fouling
  - Orientation of HULC relative to spacecraft and astronaut
  - Orientation of HULC relative to sun and horizon
  - Variability in thermal blanket installation
  - Lens selection
- Capture changes due to changes in firmware and handle material

Acknowledgments

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Credit: nasa.gov

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