

# **Analysis and Design of Phase Change Thermal Control for Light Emitting Diode (LED) Spacesuit Helmet Lights**

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## **ABSTRACT**

LED Helmet Extravehicular Activity Helmet Interchangeable Portable (LEHIP) lights for the Extravehicular Mobility Unit (EMU) have been built and tested and are currently being used on the International Space Station. A design is presented of the passive thermal control system consisting of a chamber filled with aluminum foam and wax. A thermal math model of LEHIP was built and correlated by test to show that the thermal design maintains electronic components within hot and cold limits for a 7 hour spacewalk in the most extreme EVA average environments, and do not pose a hazard to the crew or to components of the EMU.



## Analysis and Design of Phase Change Thermal Control for Light Emitting Diode (LED) Spacesuit Helmet Lights

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# Purpose/Agenda



- Purpose
  - Present the thermal analysis and design of phase change thermal control for Light Emitting Diode (LED) helmet lights.
  
- Agenda
  - Background
  - Description of the Existing Hardware
  - Proposed Modifications to Existing Hardware
    - Temperature Design Limits of the LEDs/Electronics
  - Analysis Methods and Results
    - Modeling Methods
    - Environment Definition
  - Final Design of the LED Helmet Lights
  - Final Summary, Conclusions and Recommendations.



# Background - History



- The Extravehicular (EVA) Visor Assembly (EVVA) lights, also known as the EMU helmet lights, provide the astronaut with portable lighting while performing an EVA.
- Helmet lights have been used on all space shuttle related EVA since the first EVA conducted on STS-6.
- Over the years, the helmet lights have been modified several times, with the last significant modification occurring in late 1999. These helmet lights were used on the STS-103 mission.
- For the STS-97 mission (November 2000), the Wireless Video System (WVS) was added to the EVVA. The helmet lights served as a mounting location for the system's camera lenses and motor control.



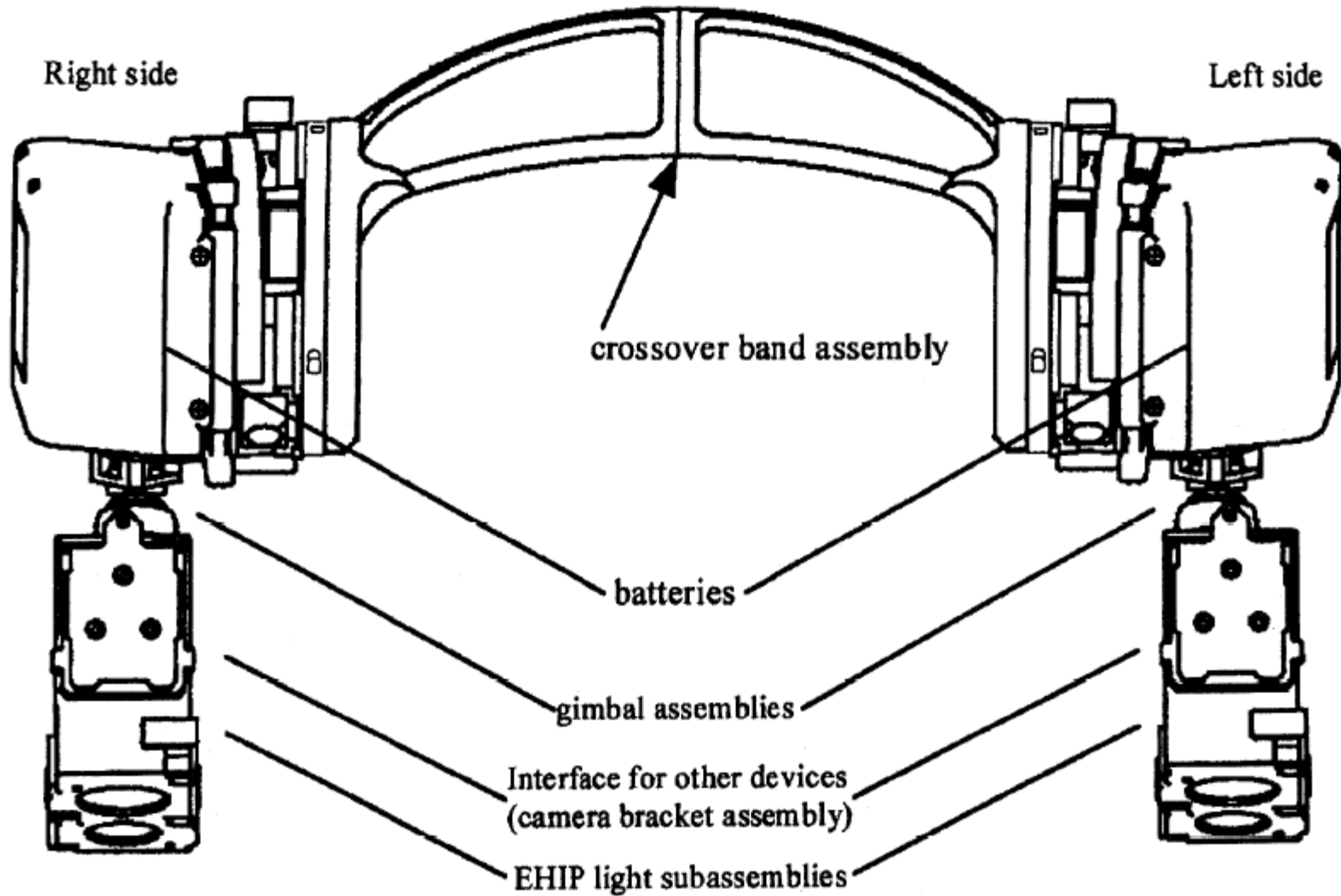
# Overview of the Helmet Light Design



- The helmet lights are two functionally independent lamp modules (bulbs) that are connected by a cross member that fits around and attaches to the back of the astronaut's space helmet.
- Each helmet light set consists of a narrow light beam and a wide light beam. The EVA crew member can choose which type of beam to use by pushing a simple switch. Both beams can be on simultaneously.
- To ensure redundancy, each helmet light set is powered by an independent battery pack (EHIP battery).
- Each light assembly is mounted to a gimbal assembly which allows the EVA crew member to direct the light beam to its desired location.
- Additional design drawings and photographs can be found in the Back-Up Charts.

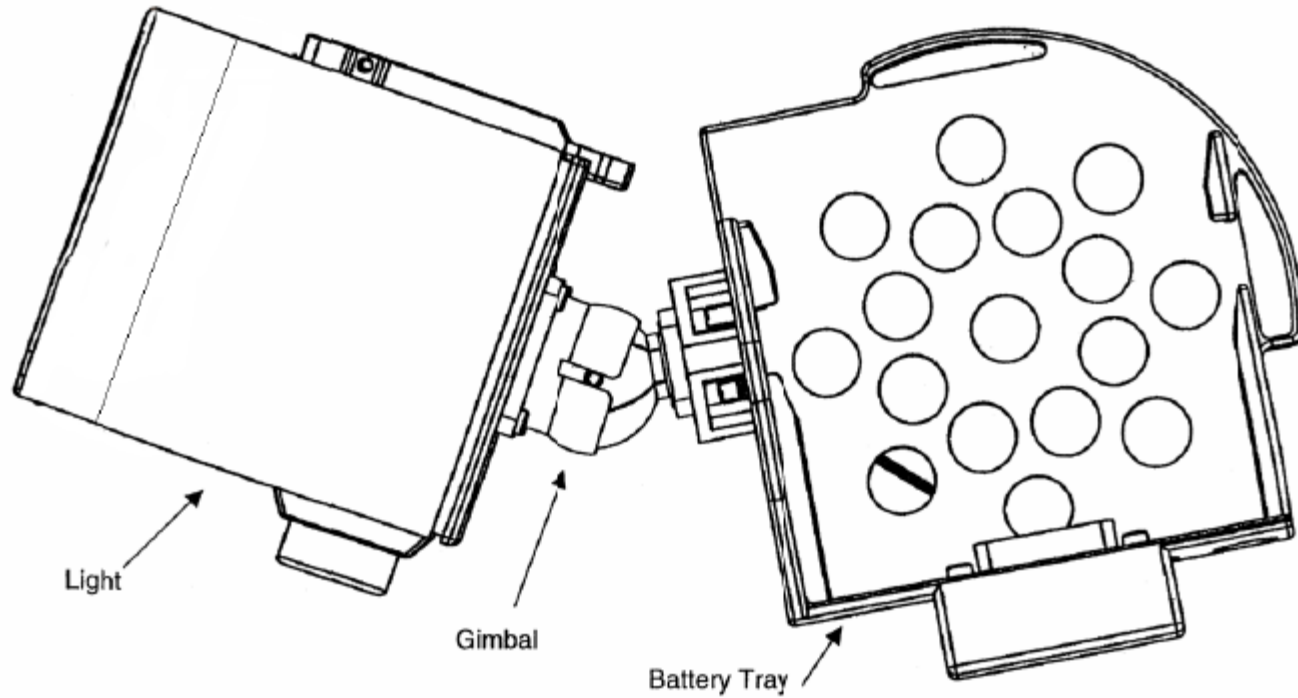


# Overview of the Helmet Light Design



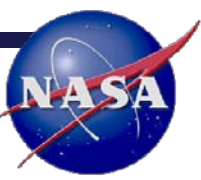


# Overview of the Helmet Light Design





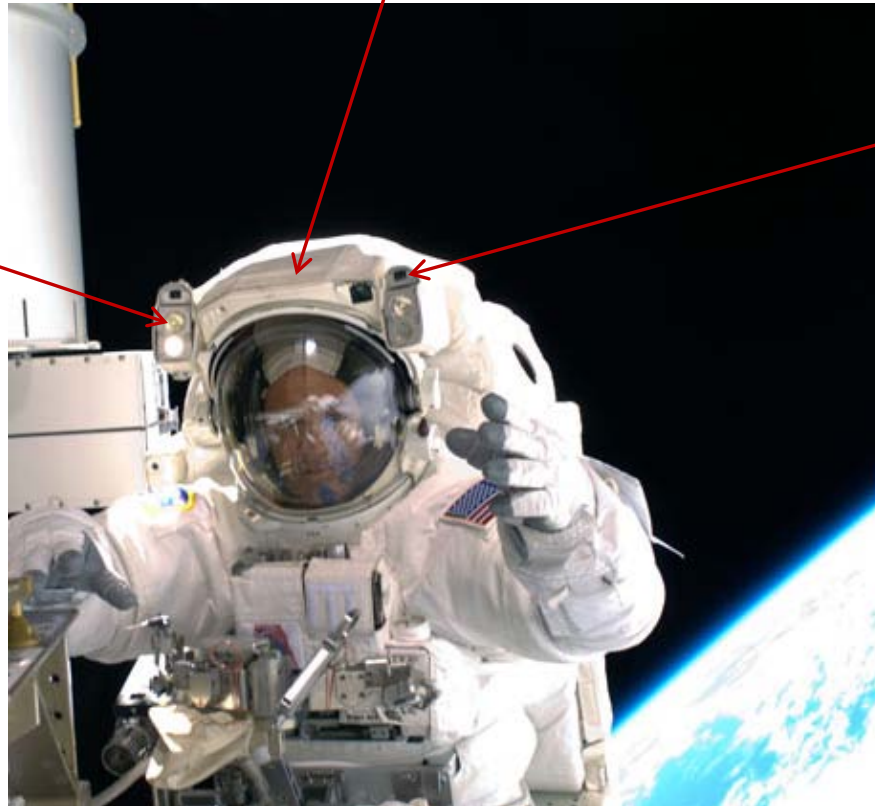
# Helmet Lights and the Wireless Video System



**WVS Helmet and Electronics**

**WVS Lens and Motor Assembly**

**Helmet Lights**







# Modifications to Existing Hardware



- Within 18 months, each incandescent light bulb module of the current helmet light design will be replaced with a module containing two Light Emitting Diodes (LEDs). The advantages of using LEDs are:
  - Longer lifetime
  - More shock resistant
  - They produce more light in the visible spectrum than bulbs which produce significant infrared radiation
  - If designed properly, they use less power.
  - They also produce less heat, which may be a problem for cold case operations.



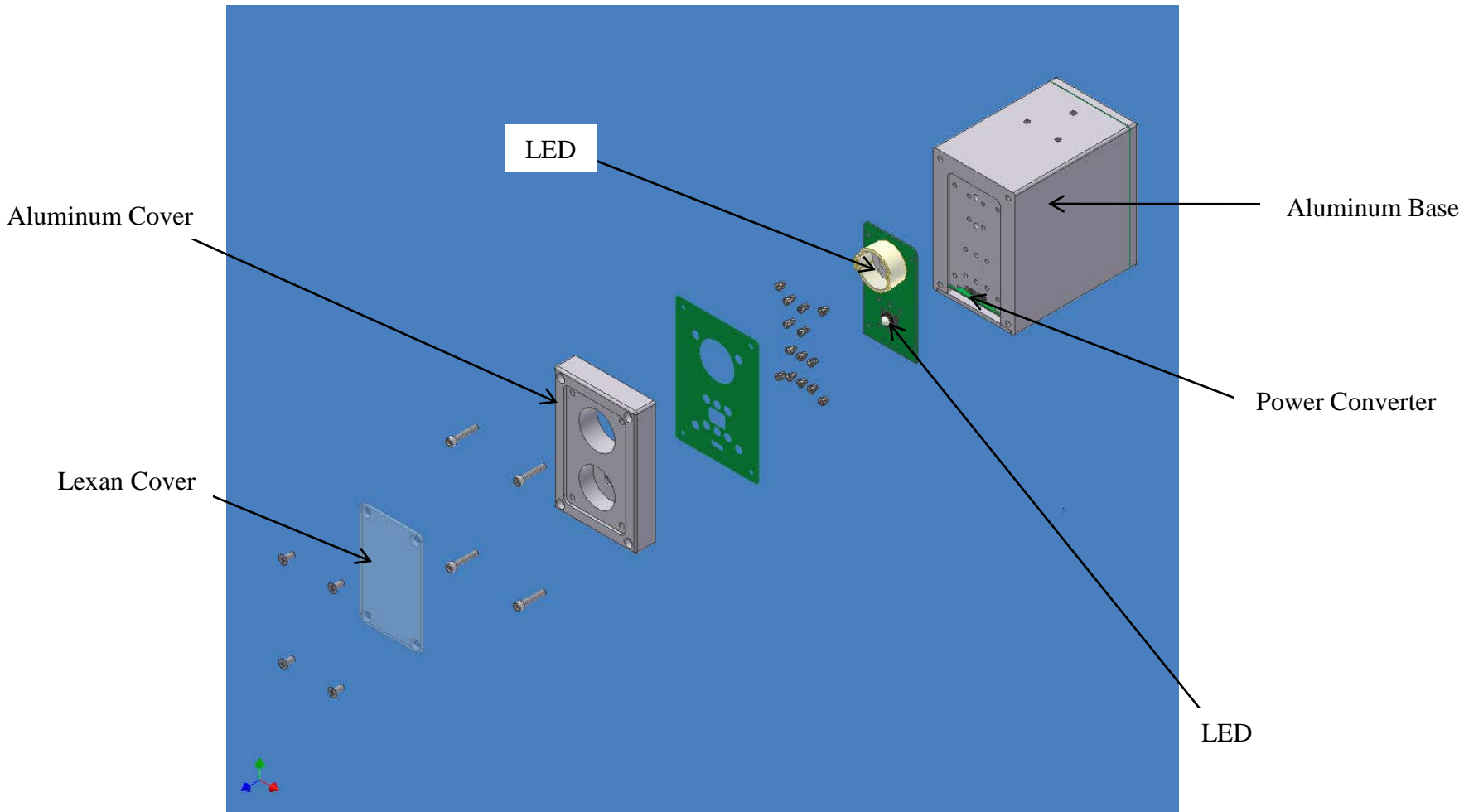
# Modifications to Existing Hardware (Cont)



- The disadvantages to using LEDs are:
  - The non-operational and operational temperature limits for LEDs are much smaller than the incandescent light bulb.
    - Usual temperature range is  $-25^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
  - Unlike bulbs, LEDs need supporting electronics. For example, a power converter may be required.
    - These supporting electronics will also have their non-operational and operational temperature limits.
  - LEDs cost significantly more than incandescent light bulbs; however, for EVA operations, this cost is minimal compared the certification costs.



# Preliminary Design of the LED Light Module





# Temperature Limits of LEDs/Electronics



- A survey of manufacturer literature showed that both the operational and non-operational temperature limits (ranges) of LEDs are significantly narrower than for incandescent light bulbs.
  - The non-operational and operational temperature limits for LEDs are more restrictive than for incandescent light bulbs. The typical temperature range of LEDs is  $-25\text{ }^{\circ}\text{C}$  to  $+125\text{ }^{\circ}\text{C}$ .
  - The supporting electronics, such as the power supply have an upper temperature limit of  $+80\text{ }^{\circ}\text{C}$ ; however, to increase operational life, it is desired to operate these electronics at approximately  $60\text{ }^{\circ}\text{C}$ .
  - Solder melts at approximately  $200\text{ }^{\circ}\text{C}$ .



# Analysis Methods and Results



- Due to the complex geometry associated with the Helmet, WVS, and the helmet lights, a Geometric Math Model (GMM) of these components was developed. An existing Thermal Synthesizer System (TSS) model of the WVS, the helmet and the lights was modified to simulate this new design.
- To predict the transient thermal response of the system components, an existing Thermal Math Model (TMM) developed using the Systems Improved Numerical Differencing Analyzer (SINDA) was modified in a similar fashion to the TSS model.

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# Thermal Modeling Assumptions



- The following assumptions were used in the development of the basic (non-phase change) LED helmet lights.
  - The dimensions of the components were based on manufacturer data, design drawings, and hardware.
  - The heat loads of the LEDs and the DC/DC Converter were obtained from manufacturer specification sheets.
  - The temperature-dependant power consumption for them was also based on manufacturer supplied data.
  - For the LEDs, 80% of the power consumed is in the form of heat while the remaining 20% is emitted as light.
  - Variable specific heat and thermal conductivity were used.
  - Because the EHIP batteries are no longer used, their heat generation was removed from the model.
  - For the hot case, both LEDs were assumed to be operating, while for the cold case only one LED was assumed to be on.



# Environmental Test Cases



- The extreme thermal environments for the helmet lights were obtained using flux cube data from the EVA Thermal Environments Database.
- ISS and Space Shuttle Payload EVA work sites were considered.
- Solar beta angles ranged from  $-75^{\circ}$  to  $+75^{\circ}$ .
- A screening analysis used the optical properties of the anodized aluminum and orthofabric to search for extreme operating temperatures.
- This search yielded two extreme hot and two extreme cold thermal environments.
- These flux cube locations, the flux cube number and the ISS attitudes for these extreme environments are listed in the Back-Up Charts.



# Preliminary Results

- Using the flux cube thermal environments and the applying the previously mentioned assumptions, the predictions showed that for the worst case hot conditions, the LEDs and the DC/DC converter reached approximately 90°C. This is above the limit of 80 °C and well above the desired limit of 60°C.
- Therefore two options were considered
  - 1) Scrap the idea.
  - 2) Find a method to reduce the operation temperature, without reducing operational capability (beta angles restrictions) and that is safe and does not EVA operations.

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# Possible Design Ideas



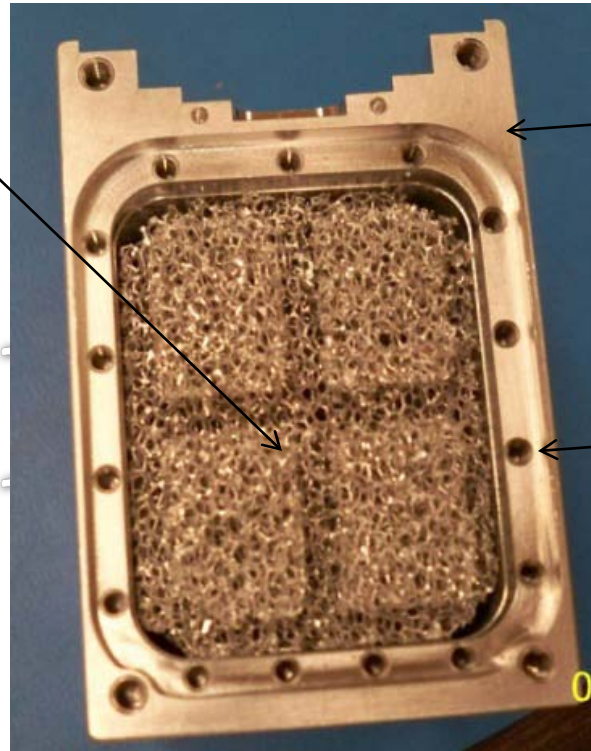
- Remove the MLI.
  - Created cold case problems for the WVS lenses and the LED.
- Add a heat pipe
  - Physically difficult. Also creates additional EVA concerns
- Add a phase change material (PCM) within the housing of the helmet light assembly.
  - The PCM is contained within a metal (Aluminum) foam matrix to ensure conduction deep into the material.



# PCM Cavity with Aluminum Foam



Metal Foam

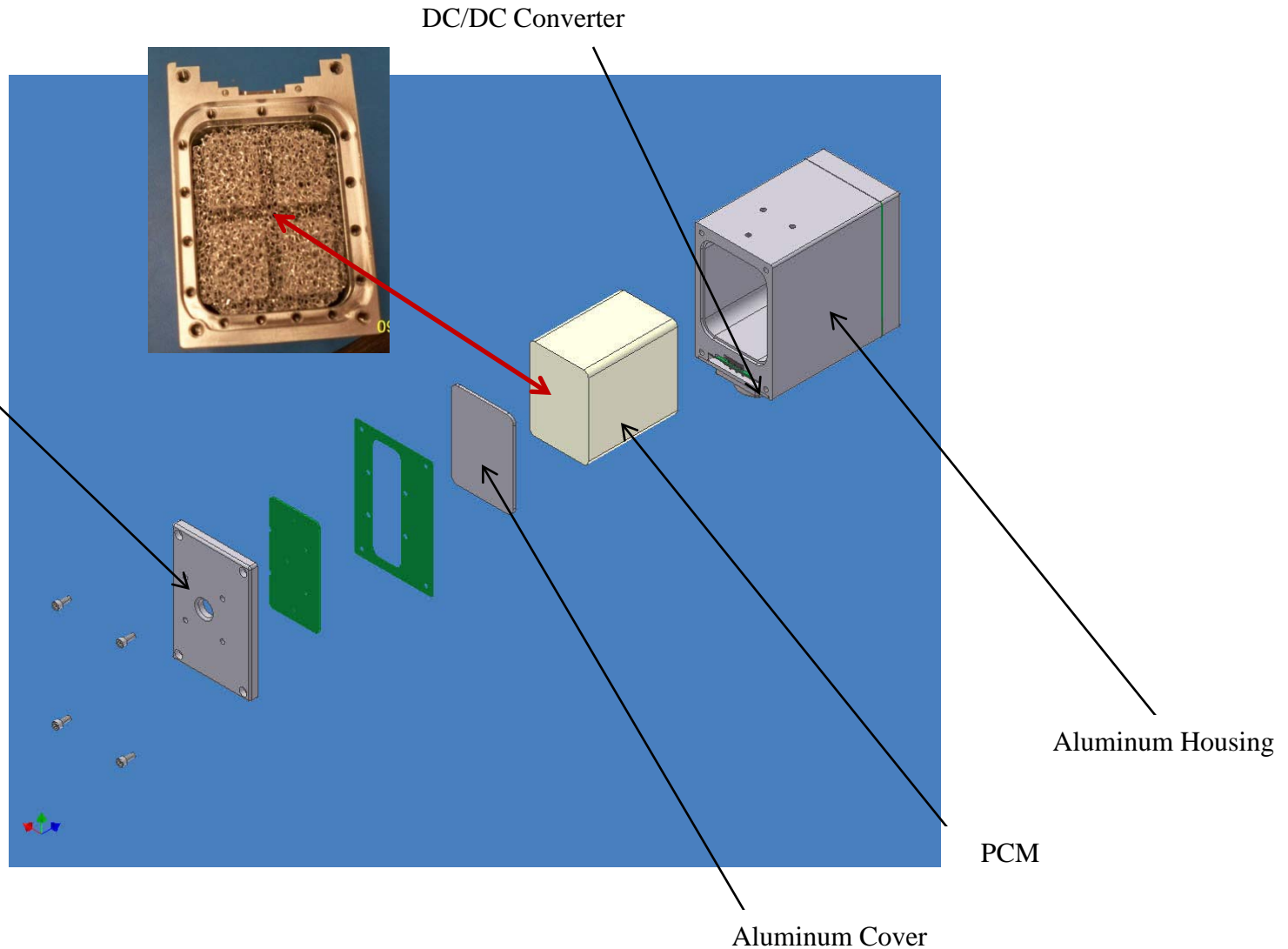


Cavity Walls

Seal Location



# Helmet Light Design with PCM





# Analysis Method

- Add nodes that represent a generic phase change material.
  - The Volume of the PCM cavity was determined by designers.
- Conduct a literature search of PCMs with emphasis on the following.
  - High heat of fusion/melting
  - Fusion/Melt temperature near 40°C.
    - Using boundary nodes for the PCM, a parametric study showed that this was the optimum temperature to keep the electrical components near their desired temperature.
  - Non- or Low Toxicity
  - High Density
  - High Thermal Conductivity and Specific Heat
  - Compatible with Aluminum and other metals

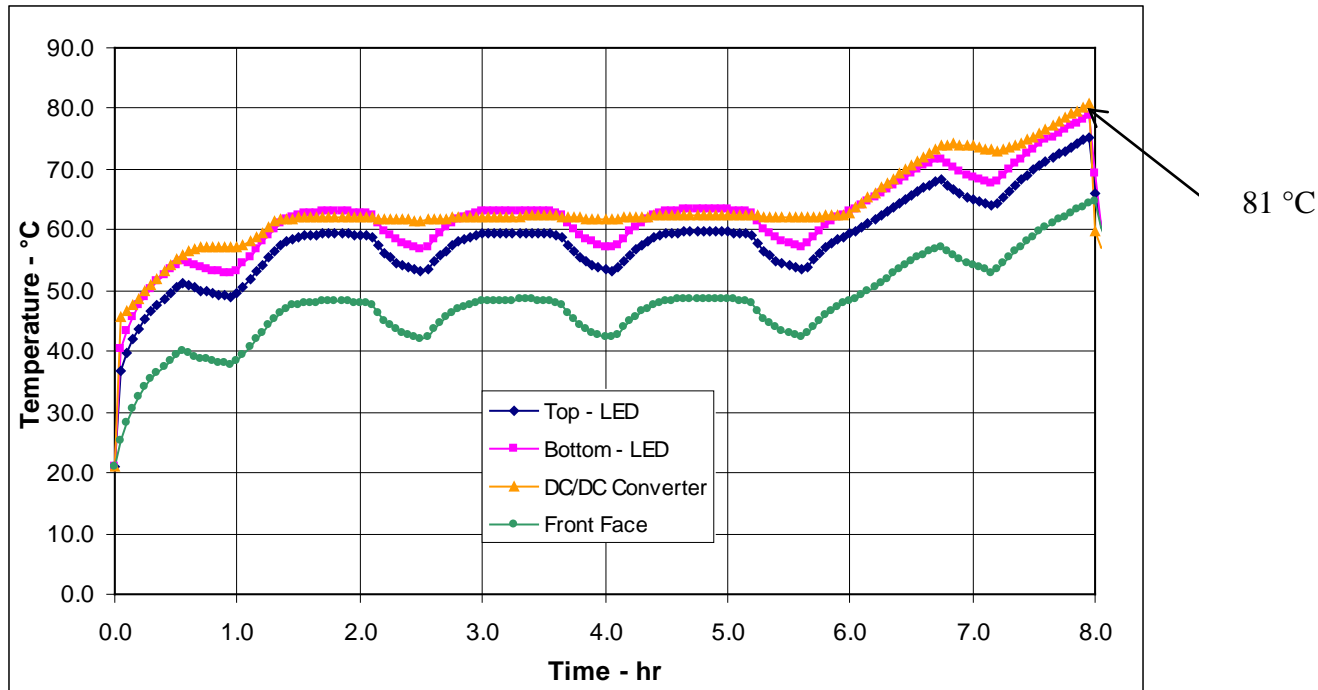


# PCM Results

- After the literature search was completed, several candidate materials of the straight-chain alkane hydrocarbon family were examined.
  - Paraffin Wax is one example from this family
- Thermophysical property data was added to the SINDA model.
- Predictions were then made for the specific PCMs.
- The predictions showed that using n-eicosane achieved the desired hot case operating temperatures.
  - The mass of n-eicosane for the PCM volume was 0.27 lbm.
- There were no cold case problems.



# Predicted Temperatures- Hot Case





# Summary and Conclusions



- Previously developed SINDA and TSS models of the WVS were modified to incorporate a proposed design change to upgrade helmet lights to use LEDs and PCMs.
- The worst hot case showed that the hottest component was the DC/DC Converter which reached a temperature of 81 °C (178 °F).
- The predictions also showed that the PCM was able to maintain the electrical components near the desired 60 °C temperature limit for six hours.



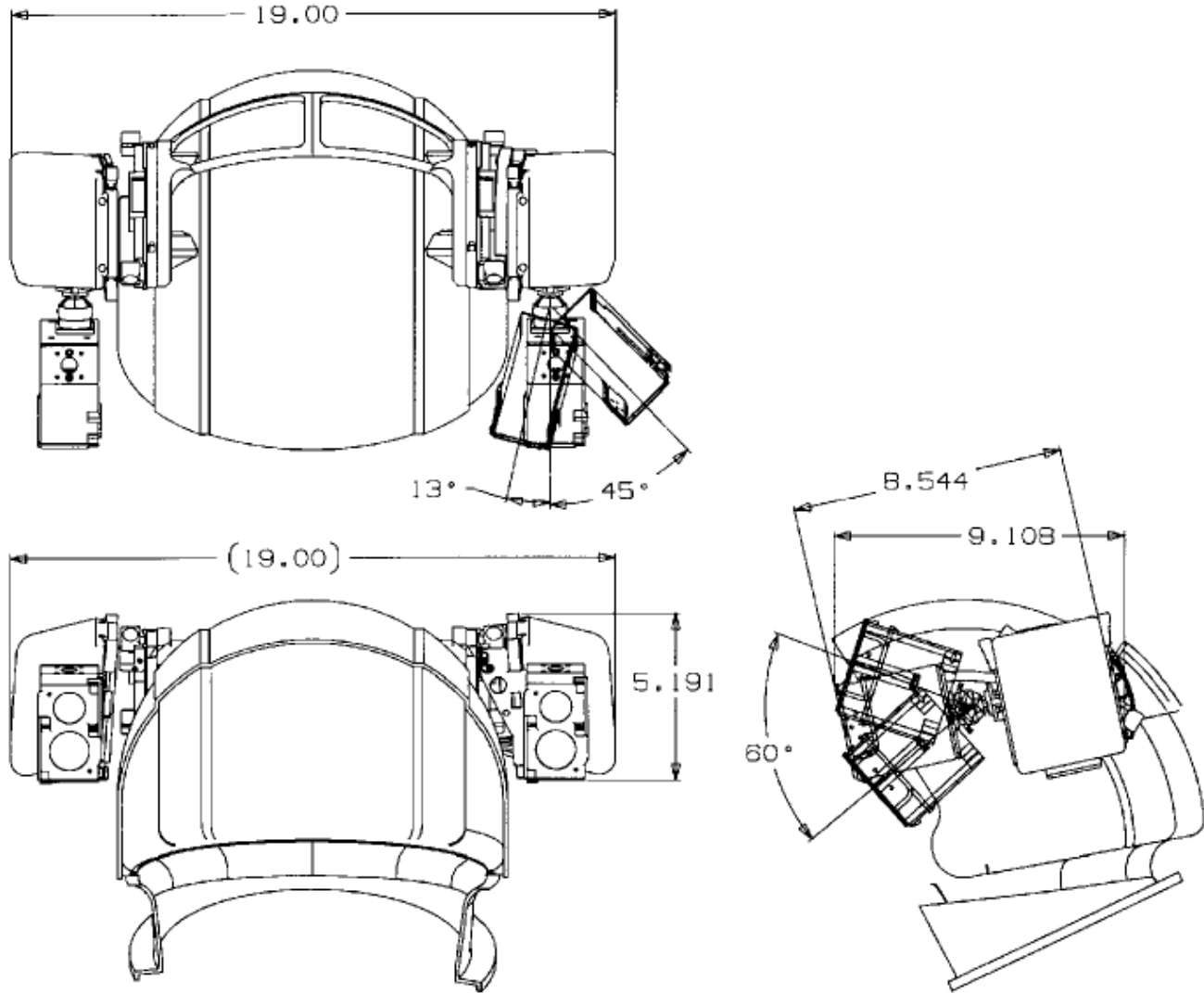
# BACK-UP CHARTS

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# Helmet Light Design





# Helmet Light Photographs





# Flux Cube Thermal Environments



Cases	Environment	Configuration	Beta Angle	ISS LVLH (Yaw, Pitch, Roll)	Flux Cube Number	Location
Case 1	Hot-Orbit Average Max (Orthofabric)	3R	75	(15,15,-15)	17	PMA-3, Zenith
Case 2	Hot-Orbit Average Max (Anodized Aluminum)	1J	-75	(15,15,-15)	22	Lab, Stbd, Aft
Case 3	Cold-Orbit Average Min (Orthofabric)	1J	-75	(-15,-0,-15)	142	JEM ELM PS,Zenith
Case 4	Cold-Orbit Average Min (Anodized Aluminum)	1J	-75	(-15,-0,-15)	63	S0,Fwd,Port, Zenith