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THERMAL ANALYSIS OF A POWER CONDITIONING UNIT FOR A HOWITZER

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14. ABSTRACT

This report describes a thermal analysis for a power conditioning unit for the M119 A1 howitzer. The analysis includes conduction, convection, and radiation as described by the Army's rigorous environmental standards. The analysis was completed using computational fluid dynamics in the STAR-CCM+ software package. The analysis estimated the maximum temperature of various components. Most components are predicted to exceed their allowable operating temperature. Some components are predicted to fail with conduction alone. A redesign could include additional heat sinks.

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Heat transfer, Conduction, Convection, Heat, Thermal, and Solar radiation

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INTRODUCTION

The M119 A1 howitzer is a lightweight howitzer used by the U.S. Army. Since its introduction to the U.S. Army in 1987, the M119 howitzer has undergone numerous design changes to improve maintainability, functionality, and compatibility. It is currently being used in the Middle East by regular Army and by the National Guard (fig. 1).

Figure 1
Soldiers train on firing points with an M119 howitzer (ref. 1)

This report describes modeling and simulation of the thermal effects of a new power enclosure for the M119 howitzer. The power enclosure will increase functionality of the mobile unit. The enclosure consists of a sealed box containing batteries, power control circuitry, and other assorted electronics. The enclosure regulates and supplies power to electronics. To maintain reliability of the power supply unit, each component must remain below its design temperature during expected operating conditions. For this initial study, it was assumed that the gun vibration and temperature rise in the gun tube would not affect the power enclosure (refs. 2 through 4).

The thermal analysis was done on the enclosure using the extreme operating conditions. The operating conditions account for extreme solar radiation, elevated ambient temperature, and heat generation of components. The system was modeled using Computational Fluid Dynamics (CFD). This computer model was used to solve the heat transfer problem including conduction, convection, and radiation. This approach allows for changes to the parameters of the model as needed for redesign or upgrades.

Two thermal load cases were evaluated. First, the enclosure and the parts inside the enclosure were modeled using conduction with a prescribed convection on the outside of the enclosure. The second analysis was built upon the first analysis. Free convection on the outer surfaces of the enclosure and solar radiation were added to the thermal loads. The goal of both of these analyses was to find the temperature of various components once the system reached a steady state thermal condition during operation.

METHODS ASSUMPTIONS AND PROCEDURES

Geometry

For this analysis, geometry was imported from Pro/E (ref. 5) part files for the enclosure and the internal components. The model as provided had details that would not affect the results and make the model overly complex. To simplify the model, only major components were considered. The analysis included the box, battery, main relay, heat sink, circuit card board, charger board, burst board, and the DC filter board. The inside of the enclosure was cluttered with wires and cables. None of these were included in this simplified model. ProE files were converted to CFD files using the software package Gambit (ref 6). Figure 2 shows the Pro/E assembly.

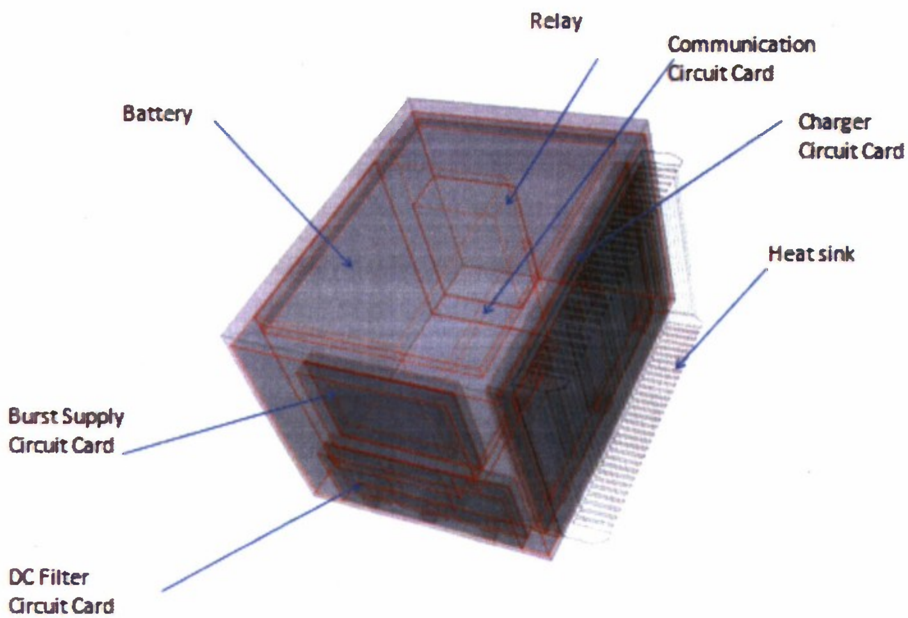

Figure 2
Pro/E geometry of power supply package

Model Setup and Assumptions

The geometry files were imported to the CFD software package, STAR-CCM+ v 3.06.006 (ref 7). The imported model included the enclosure box, battery, main relay, heat sink, circuit card board, charger board, burst board, and the DC filter board.

Once the geometry was in the software package STAR-CCM+, it was further refined. This refinement reduced the number of contact interfaces without any adverse impact on the results of the simulation. To model the transfer of heat from one body to another, contact interfaces needed to be defined between surface faces that were touching each other.

All of the components were modeled as 3-D stationary solids using the coupled solid energy solver and having constant density. This included the air within the enclosure. It was assumed that the wire, cables, and other internal blockages would allow little natural convection within the enclosure. The air was modeled as a stationary solid that could only conduct heat.

Materials

This analysis consisted of many different parts each with their own thermal properties. For simplicity and due to lack of data, everything was assumed to be one of seven possible materials. For each material the density, thermal conductivity, and heat capacity were needed. Some material parameters were found in the open literature and others were estimated from available references (refs. 8 and 9).

The components were assumed to be in one of seven material groups. Table 1 shows the material properties for air, printed circuit board (PCB), aluminum, battery, electronics, large power chips (power converters), and small power chips (power filters).

Table 1
Material assumptions

Material	Density (kg/m^3)	Thermal conductivity (W/m K)	Heat capacity (W/m-K)
Air	1.18415	0.0257	0.026
PCB	1900	23	1200
Aluminum	2800	193	880
Battery	534	84.7	3582
Electronics	3600	17.17	795.5
Large power chips	950	165	120
Small power chips	950	100	83

Interfaces

The areas where two parts touch are defined as contact interfaces; STAR requires a thermal contact resistance between two contact surfaces. Contact resistance is a function of surface finish, contact pressure, and interface material (ref. 8). Since this data was not available for the components, an equivalent thermal contact resistance was found using an air gap size associated with standard surface finishes. For the interfaces where thermal compound was applied, that compound's thermal conductivity was used in place of air's. These values were compared with the available data in literature and found to be within the correct ranges (ref. 8). Interface assumptions are listed in table 2.

Table 2
Calculated contact interface resistance

Interface	Thermal contact resistance (m^2-K / W)
AL-PCB	0.000389
AL-AL (thermal grease)	0.000083
AL-power chips	0.003891
AL-power chips (thermal grease)	0.000033
AL-electronics	0.0389
PCB-power chips	0.019
PCB-electronics	0.019

Operating Conditions

The system is designed to operate reliably in an area with an ambient temperature of 130°F (327.6 K). In addition to the ambient requirement, the power supply unit must operate with a solar load of 1120 W/m^2. Figure 3 shows the view of the box that the source of the solar radiation sees. The inside of the box is cluttered with cables, wiring, and other small parts that were not modeled. This clutter may block airflow at critical locations within the box. To take this blockage and lack of internal air flow into account, the air inside the box was modeled such that it only factored into the heat transfer calculations as allowing heat transfer through conduction only.

Figure 3
Solar radiation view of the enclosure

The heat generation for the various components was modeled as a constant value in time. These values were calculated from the known or estimated heat production rates and are expressed in W/m^3. Table 3 shows heat production and heat produced per unit volume for each component.

Table 3
Heat generation by internal components in the power supply unit

Component	Q (W)	W/m^3
Burst chip	23	277108
DC filter big chips	7	176322
DC filter small chips	8	390224
Relay	0.5	714
Battery	1	131
Circuit card	2	6779
Charger main chip	33	397590
Charger chip A	0.85	798122
Charger chip B	2.6	1150442
Charger chip C	2.6	1135371
Charger chip D	0.4	197044
Charger chip E	2.5	1288660

Conduction only, Analysis 1

The first simulation was done without solar radiation or natural convection. However, since natural convection would be an important method of heat transfer out of the system, it had to be taken into account. This was accomplished by specifying an ambient temperature (130°F) and a conservative convective heat transfer coefficient (5 W/m^2) to all of the outer surfaces. These outer surfaces would normally be in 'contact' with the atmosphere. This provided a relatively quick analysis that formed the ground work and a bench mark for further analyses.

Solar Radiation and Natural Convection, Analysis 2

The model was improved by including solar radiation and natural convection. The convection analysis included some updated heat production rates (table 4).

Table 4
Updated heat production rates for selected components, analysis 2

Component	Q (W)	W/m^3
DC filter small chips	9.25	4512195
Charger chip D	0.63	310345
Charger chip E	3.85	1984536

The power enclosure was designed to withstand relatively high solar loads (ref. 10). The direct solar load was modeled as 1120 W/m^2 and the diffuse solar load as 840 W/m^2 (75% of the direct solar load). These values assumed that the sun was in the "worst" position in the sky. The direct solar load was applied to the sides of the box with the components of interest. The direct solar load was also applied to the top of the box. The diffuse solar load was applied to the rest of the exterior surfaces, modeling the scatting effect of the atmosphere and the reflections from objects that could be nearby.

Since natural convection is a buoyancy-driven flow, the gravity model in STAR also had to be activated. The outer surfaces of the box and heat sink had their boundary conditions modified to be compatible with the natural convection. To be able to model the natural convection, it was necessary to add a volume of air around the box. This did not change the internal components.

RESULTS

Conduction Only

Figure 4 shows the results of the conduction-only analysis. With conduction only, Diode B and Relay 2 exceeded failure temperatures. Other component temperatures neared the failure condition, but did not exceed design values.

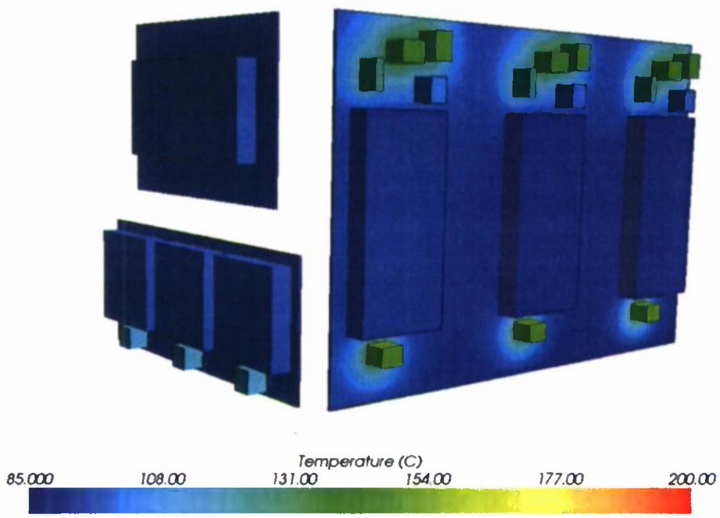

Figure 4
Temperature results, conduction only

Conduction, Solar Radiation, and Natural Convection

Figure 5 shows the result with radiation and convection included. Figure 6 shows the components that exceed their design temperature values. With solar radiation and natural convection, more than half of the components would be expected to exceed their design temperatures at extreme conditions.

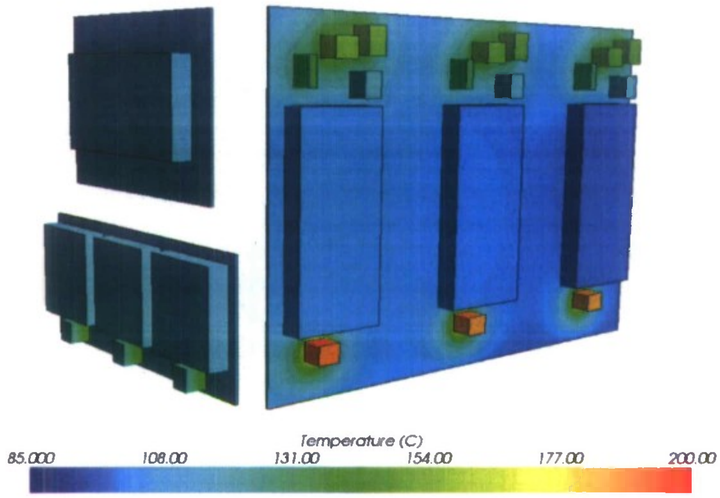

Figure 5
Temperature distribution with convection, conduction and radiation included

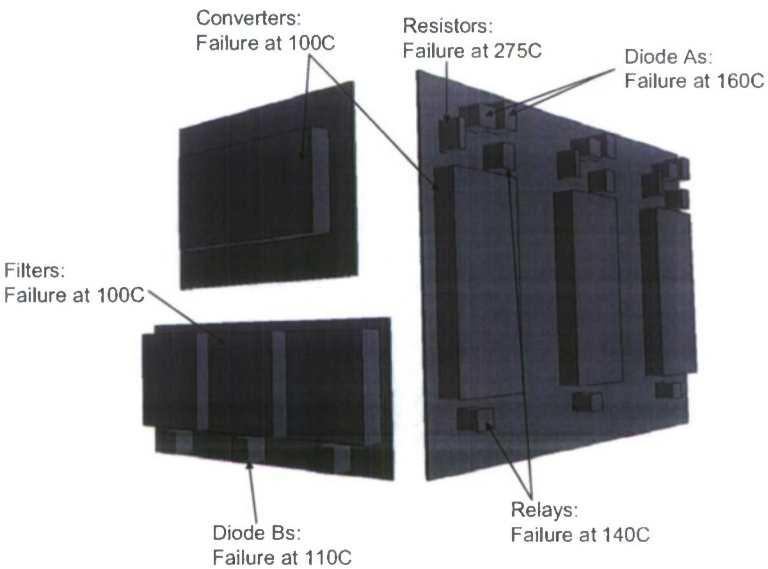

Figure 6
Summary of failed components based on thermal analysis

Table 5 compares the results with and without solar radiation and convection. Solar radiation and convection increased the temperature in key components by about 20%.

Table 5
Component temperatures

	Failure temperature (°C)	Conduction only (°C)	w/Solar radiation and natural convection (°C)
Converter - burst	100	98.4	112.2
Converter - charger	100	94.1	105.5
Filter	100	97.9	117.1
Diode A	160	149.1	159.7
Diode A 2	160	147.7	158.1
Diode B	110	113.1	140.7
Resistor	275	129.3	140.1
Relay 1	140	103.1	119.1
Relay 2	140	153.9	198.1

CONCLUSIONS

The current design is unable to keep the components within the allowable operating temperature. As expected, the added solar load in the second simulation resulted in higher temperatures and additional failed components.

Several design improvements could be suggested. The system does have an external heat sink to help dissipate the heat that was included in this model. This heat sink could be optimized to provide greater heat dissipation. In addition, it may be possible to install an additional heat sink to dissipate heat from the side with the filter and burst chips. A third suggestion is to replace components with similar components that generate less heat and/or function at higher temperatures.

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