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OPTIMIZATION of COMPREHENSIVE THERMAL MODEL and HEAT TRANSFER OPTIMIZATION for ½ CONDUCTION COOLED ATR CHASSIS

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ABSTRACT

In this paper, validation of a comprehensive thermal model for design of conduction cooled Air Transport Rack (ATR) chassis is represented. An ATR chassis is an avionic box which is located in avionic bay on civil aircrafts. They consist of power supply, electronic cards, SSD cards etc. Overheating conditions could significantly affect the performances and durability of electronic devices. Design of a chassis with the given geometrical and thermal constraints starts generation of the three dimensional (3D) model. Then, thermal analysis of 3D model is conducted to determine if the given heat loads can be dissipated. According to results, geometry and material of 3D modal is updated to reach optimum cooling solution. Validation of thermal model reduces the cost of prototype for similar chassis design projects and also reduces certification process by using analysis results to compliance D0-160 and MIL-STD-810 temperature test without any real test systems.

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INTRODUCTION

Commercial off-the-shelf (COTS) components are recent trend of military electronics design. Especially for military requirements, system thermal and mechanical reliability must be carefully considered due to stringent of military standards. Correct cooling method can reduce thermal stresses and provide the capability to system reliability. Also, it improves performance of electronic components which is directly related to temperature as seen on component. In ruggedized avionics systems, each electronics modules are often cooled by conduction method by application of correct conduction packaging. Heat dissipates packaging to the side walls of a chassis, which have a finned surface area to maximize the amount of heat that can be dissipated from a conduction-cooled chassis. Conduction-cooled methodology can provide a sealed compartment to protect the electronic components from various environmental factors (moisture, dust, sand, salt, etc.) as a means of black box description. Aeronautical Radio, Inc.'s (ARINC) "Austin Trumbull Radio" or "Air Transport Rack" (ATR) chassis and racking system has been a leading commercial avionics standard since 1940. [Geisler K., Van Engelenhoven J., Solbrekken G.L., 2007]

ATR Chassis

ATR chassis are military enclosures working environment to the electronic equipment to protect them against the environmental factors. ARINC 404A, Air Transport Equipment Cases and Racking military standards describe the specific dimensions and interfaces. [Aeronautical Radio, Inc., 1974] Interface compatibility between the manufacturers is provided by application of standards.

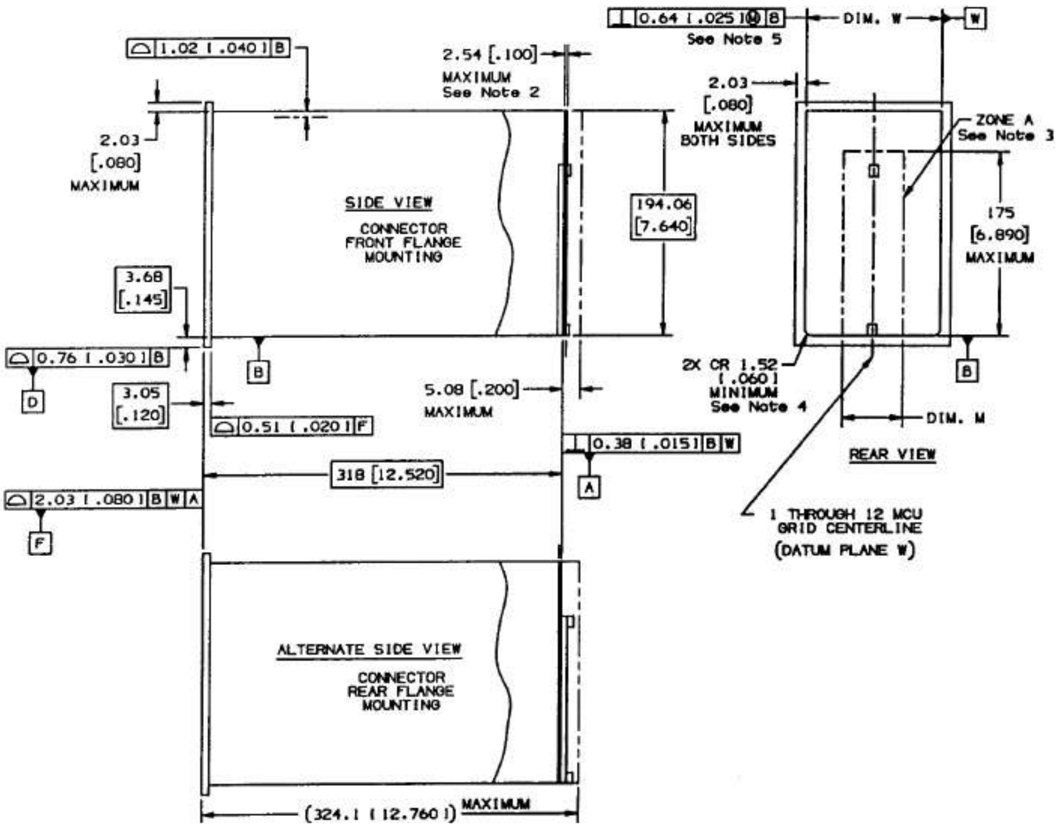

Figure 1: Standard LRU Case Size [VITA Standards Organization, 2005]

All dimensions and tolerances are in millimeters of the chassis are described in ARINC 404A [Aeronautical Radio, Inc., 1974] and ARINC 600 [VITA Standards Organization, 2005]. Case dimension can be seen in Figure 1 and Table 1.

Table 1: Standard ATR Case Dimensions [Aeronautical Radio, Inc., 1974]

ATR Size	Approx. Volume	Width(W)	Length(L1)	Length(L2)	Height(H)
	[liter]	[±0.76mm]	[±1mm]	[mm]	[mm]
1/4 Short	3.52	57.15	318	320.5	193.5
1/4 Long	5.49	57.15	495.8	498.3	193.5
3/8 Short	5.57	90.41	318	320.5	193.5
3/8 Long	8.69	90.41	495.8	498.3	193.5
1/2 Short	7.7	123.95	318	320.5	193.5
1/2 Long	11.88	123.95	495.8	498.3	193.5
3/4 Short	11.8	190.5	318	320.5	193.5
3/4 Long	18.36	190.5	495.8	498.3	193.5
1 Short	15.96	257.05	318	320.5	193.5
1 Long	24.75	257.05	495.8	498.3	193.5
1 1/2 Long	37.62	390.65	495.8	498.3	193.5
Notes: Per ARINC characteristic 561 INS. the standard dimension 'H' = 193.5 mm may be increased to a maximum 'H' dimension of 269.88 mm when necessary for equipment reasons.					

For avionic applications, minimize weight and maximize reliability are most common limitations when overcome thermal challenges. Avionics applications have two different areas as military and civilian applications. Currently, COTS electronic components which are designed for computers, consumer, and telecommunications applications etc. are cooled by heatsink which is cooled fan. Fan cooling solution is sufficient for stationary components that are not exposed to high vibratory loads but especially for military application, this thermal solution is not feasible because of weight, vibration, and dimension limitations. At this point, heat conduction optimization and reducing contact resistance become important topics.

Heat dissipation problem for military enclosure systems affects the performance of these systems. Especially, for mission critical equipment, failure of thermal problems causes catastrophic results. Thus, thermal simulations are playing an essential role in the design of ATR Box. To success in thermal design of systems, operation temperature of the internal electronic components must be maintained. By application of recent technologies, there are so many cooling method used in cooling of chassis such as direct forced convection cooling inside the chassis, forced convection cooling via cooling channels, liquid cooling chassis, conduction-cooled chassis etc.

In this paper, ½ ATR short case dimensions are used for design data. 3U card packaging system simulates to generate conduction bases. Secondary and primary side cover which is named as cold plates in this paper are designed based on VITA 48.2 as seen in Figure 2.

Before starts the design, maximum weight of chassis determined as 10 kg according to ARINC 404A [Aeronautical Radio, Inc., 1974]. Materials are selected to meet required weight, vibration, shock, and acceleration load limits. Al 6061-T6 series are used in chassis wall and cold plate. Copper plates are applied some cold plate surface to increase heat dissipation. Total heat dissipation of electronic cards is 70 W. The main problem in this design is dissipation of heat from small volumes. Especially, thermal management is a potentially significant for integrated processor and memory stacks due to limited space for cooling solution.

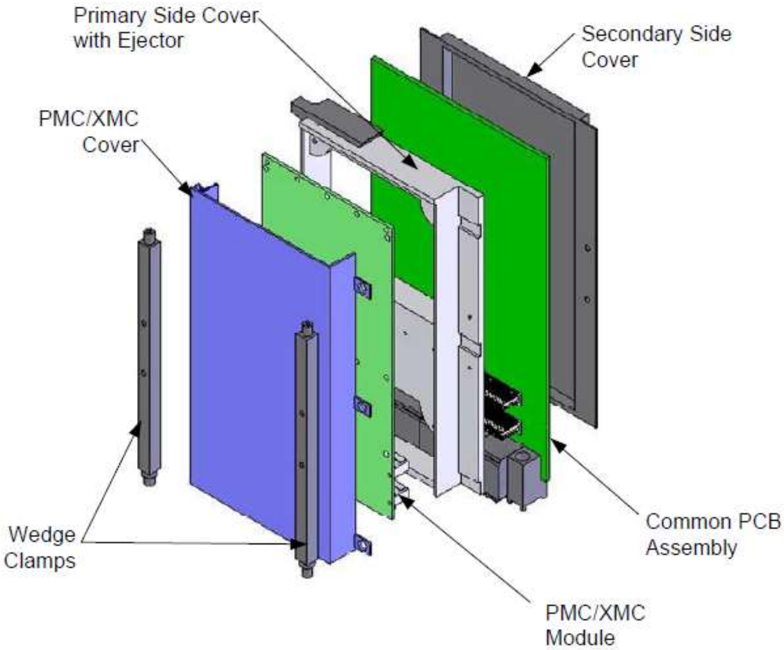

Figure 2: General configuration of 3U conduction-cooled plug-in units on 1.00 in centers [VITA Standards Organization, 2005]

METHOD

Thermal Management of Avionic Equipment

'*Heat transfer (or heat) is thermal energy in transit due to a spatial temperature difference. Whenever a temperature difference exists in a medium or between media, heat transfer must occur*.' [BERGMAN L., ADRIENNE A., FRANK I., DAVID D., (2002)] There are different heat transfer modes which are called as conduction, convection, and radiation. *Conduction* is used the term form temperature gradient for existing in a stationary medium. Temperature is transferred from high temperature region to low temperature region and the basic calculation for one dimensional heat flow is given following:

$$q''_x = -k\frac{T_2 - T_1}{L}$$

Where k is known as thermal conductivity, L indicates the length of the conducting path.

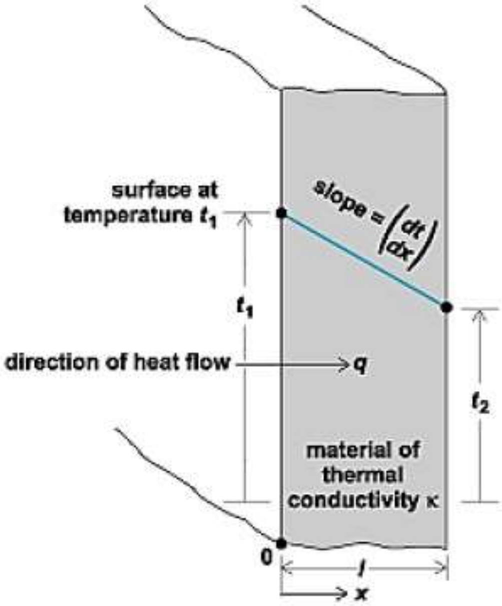

Figure 4: One-dimensional conduction heat transfer [http://www.accessscience.com, 2013]

Formula for three dimensional conduction heat flows explained with energy balance for cartesian coordinates:

$$\frac{\partial}{\partial x}\left(\kappa\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\kappa\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\kappa\frac{\partial T}{\partial z}\right)+\dot{q}=\rho c_p\frac{\partial T}{\partial t}$$

The right side of the equation gives the change in thermal energy storage in element and left side of the equation represents energy generated within the infinitesimal element and thermal energy for control volume.

Formula to show the relationship between thermal conductivity and temperature difference according to first law of the thermodynamics is given following:

$$Q=\frac{1}{R_{\text{thermal}}}\Delta T$$

where the thermal resistance for conduction and contact interface is expressed by

$$R_{\text{thermal}}=R_{\text{contact}}+R_{\text{conduction}}=\frac{1}{h_{\text{contact}}}+\frac{x}{kA}$$

Thermal Analysıs Method:

To simulate the heat dissipation of chassis and see the temperature on electronic components, analysis model is created. The results are obtained by using different materials and fin optimization to reach optimum cooling solution. These arrangements and analyses performed using ANSYS® (workbench) program. Analyses are conducted for 55 C^0 and 70^0 C operational temperature tests.

The draft model of the ATR chassis with side plate fins is shown in Figure 3. Enclosure of the ATR chassis measures by 193 mm by 127 mm by 319 mm which is between the 1.72 ATR box standard limits. Overall en-closure consists of eight sub-models in a staggered configuration. All models which dissipate heats are cooled by conduction method and each module has special cold plate mechanism. Whole case and cold plates are designed by using AL 6061 series. For high heat dissipates components, small copper parts are used. Thermal conductivity for Aluminum equals to 200 W/m-K and copper have k = 400 W/m-K.

Figure 3: Draft design model of ½ atr chassis

The maximum operational junction temperature for electronic components in our design is 105 C. Figure 4 shows the thermal model of ATR design.

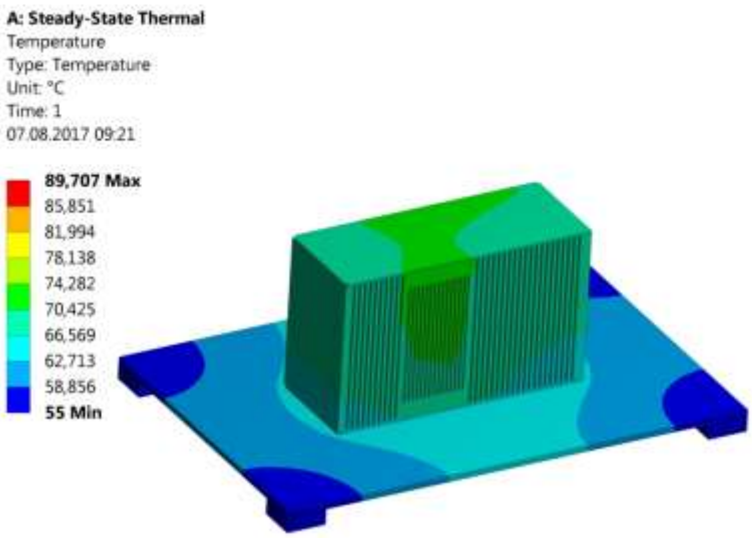

Figure 4: Thermal analysis model of atr Design

Thermal analysis are conducted according to DO-160 section 4.5.3 Ground Survival High Temperature Test and section 4.5.5 Operating High Temperature Test. For operating high temperature test, surrounding temperature is assumed 55 C^o and for Ground Survival High Temperature Test, surrounding temperature equals to 70 C^o. For both case, the junction temperature of any avionic component don’t exceed 105 C^o. This ATR box is installed in Avionic Bay which has conditioned air and cooling system to inhibit excessive heating of electronic cases. To simulate in flight cooling system, a big table is used to convect heat box to table by helping of conduction.

Assumptions which are applied to simplify analysis method are given as following:
1. Steady and laminar flow;
2. No thermo-physical properties variation with temperature;

3. Fluid is incompressible, Newtonian and viscous;
4. No velocity-slip at the walls.

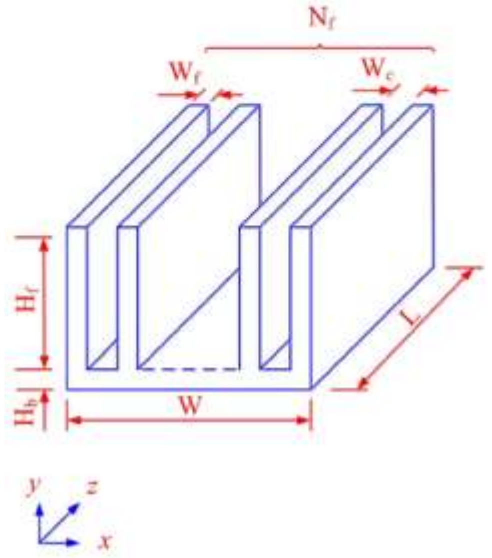

Figure 5: Geometric parameters of fin heat sink

According to figure 5, design parameters are given:

W	298.25 mm
L	198.5 mm
N_f	Change between 37 and 70
H_f	Change between 3 mm and 9,5 mm
W_c	Change between 3 mm and 4,5 mm
W_f	Change between 2,5 mm to 4 mm
H_b	Change between 0,25 mm to 12 mm

Some of the results for optimization study by using Ansys parameterization tool are shown as below:

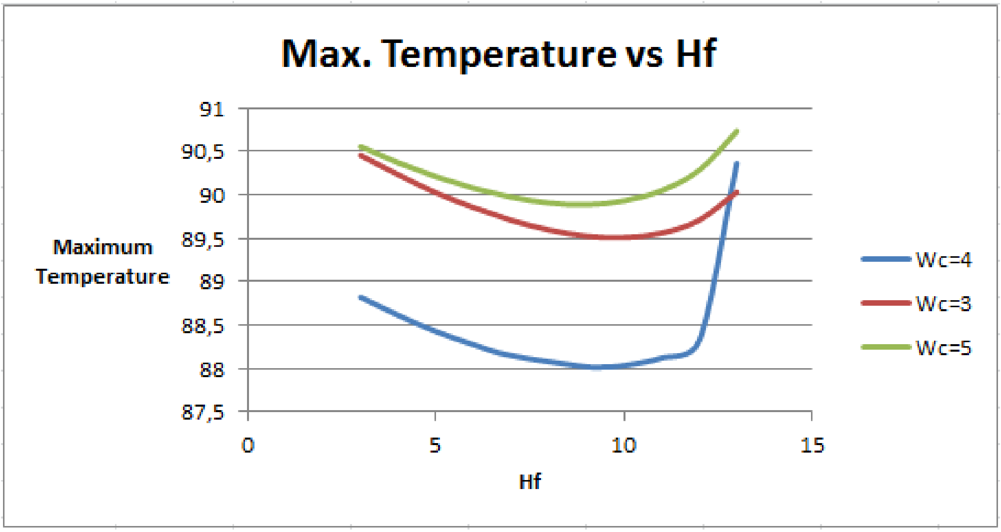

Figure 5: Maximum Temperature vs hf

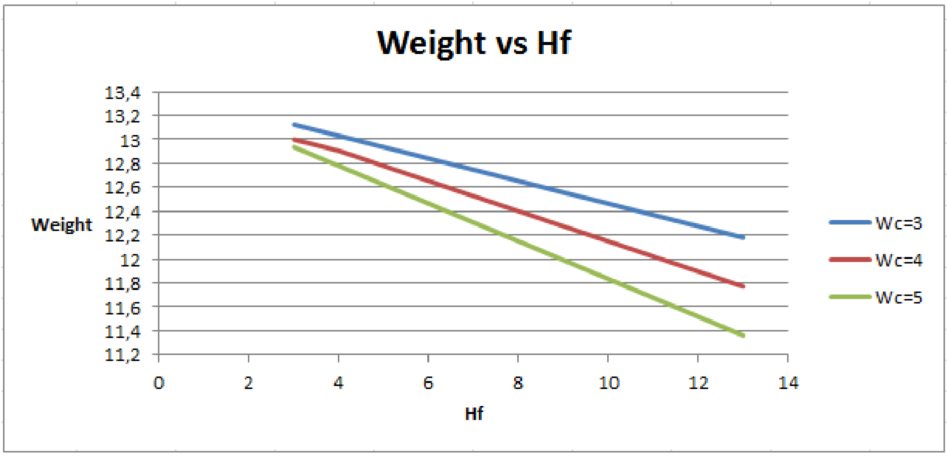

Figure 6: Weight vs hf

Although, weight decreases with increasing H_f, decreasing in temperature is more important parameter to mission of the design. Therefore, the minimum value for maximum temperature is obtained when H_f equals to 4 mm. Also, by using H_f = 4 mm, optimal maximum temperature is indicted at W_c = 9 mm.

For optimization process, Ansys parameter set option is used to help create design of experiment and morphing geometry according to optimization variables. In addition, response surface which are an efficient way to get the variation of a given performance with respect to input parameters and provide a continuous variation of the performance over a given variation of the input can be applied by using parameter set. Figure 7 shows that parameter set in used as design variables.

Table of Design Points

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Name	Update Order	P1 - P1@DS_... 12.Part	P2 - P2@DS_... 12.Part	P3 - P3@... 12.Part	P4 - P4@DS... 12.Part										P5 - Temperature Maximum	P6 - Geometry Mass	Retain
2	Units															C	kg	
9	DP 6	7	11	4	4	11	5000	5	50	33	33	332	3325	50	5000	88,121	12,023	
10	DP 7	8	12	4	4	12	5000	5	50	33	33	332	3325	50	5000	88,321	11,897	
11	DP 8	9	10	4	4	10	5000	5	50	33	33	332	3325	50	5000	88,034	12,149	
12	DP 9	10	3	5	5	3	5000	5	50	33	33	332	3325	50	5000	89,867	12,937	
13	DP 10	11	3	6	6	3	5000	5	50	33	33	332	3325	50	5000	88,929	12,842	
14	DP 11	12	8	5	5	8	5000	5	50	33	33	332	3325	50	5000	88,21	11,982	
15	DP 12	13	2	2	2	2	5000	5	50	33	33	332	3325	50	5000	88,704	13,22	
16	DP 13	14	2	3	3	2	5000	5	50	33	33	332	3325	50	5000	88,762	13,128	
17	DP 14	15	5,5	3	3	5,5	5000	5	50	33	33	332	3325	50	5000	87,829	12,511	
18	DP 15	16	5,5	4	4	5,5	5000	5	50	33	33	332	3325	50	5000	88,017	12,212	
19	DP 16	17	5,5	5	5	5,5	5000	5	50	33	33	332	3325	50	5000	88,221	11,913	
20	DP 17	18	9	4,5	4,5	9	5000	5	50	33	33	332	3325	50	5000	88,108	12,134	
21	DP 18	19	3	3	3	3	5000	5	50	33	33	332	3325	50	5000	88,587	13,126	
22	DP 19	20	4	3	3	4	5000	5	50	33	33	332	3325	50	5000	90,21	13,031	
23	DP 20	21	5	3	3	5	5000	5	50	33	33	332	3325	50	5000	90,023	12,937	
24	DP 21	22	9	4,5	4,5	9	5000	5	50	33	33	332	3325	50	5000	89,787	12,134	
25	DP 22	23	6	3	3	6	5000	5	50	33	33	332	3325	50	5000	89,852	12,842	
26	DP 23	24	7	3	3	7	5000	5	50	33	33	332	3325	50	5000	89,707	12,748	☑
27	DP 24	25	8	3	3	8	5000	5	50	33	33	332	3325	50	5000	89,595	12,653	☑
28	DP 25	26	9	3	3	9	5000	5	50	33	33	332	3325	50	5000	89,525	12,559	☑
29	DP 26	27	10	3	3	10	5000	5	50	33	33	332	3325	50	5000	89,508	12,464	☑
30	DP 27	28	11	3	3	11	5000	5	50	33	33	332	3325	50	5000	89,539	12,37	☑
31	DP 28	29	12	3	3	12	5000	5	50	33	33	332	3325	50	5000	89,708	12,275	☑
32	DP 29	30	13	3	3	13	5000	5	50	33	33	332	3325	50	5000	90,03	12,181	
33	DP 30	31	13	4	4	13	5000	5	50	33	33	332	3325	50	5000	90,361	11,771	
34	DP 31	32	3	5	5	3	5000	5	50	33	33	332	3325	50	5000	90,555	12,937	
35	DP 32	33	4	5	5	4	5000	5	50	33	33	332	3325	50	5000	90,369	12,779	
36	DP 33	34	5	5	5	5	5000	5	50	33	33	332	3325	50	5000	90,308	12,622	
37	DP 34	35	6	5	5	6	5000	5	50	33	33	332	3325	50	5000	90,075	12,464	
38	DP 35	36	7	5	5	7	5000	5	50	33	33	332	3325	50	5000	89,972	12,307	
39	DP 36	37	8	5	5	8	5000	5	50	33	33	332	3325	50	5000	89,905	12,149	☑
40	DP 37	38	9	5	5	9	5000	5	50	33	33	332	3325	50	5000	89,885	11,992	☑
41	DP 38	39	10	5	5	10	5000	5	50	33	33	332	3325	50	5000	89,929	11,834	☑
42	DP 39	40	11	5	5	11	5000	5	50	33	33	332	3325	50	5000	90,049	11,677	☑
43	DP 40	41	12	5	5	12	5000	5	50	33	33	332	3325	50	5000	90,283	11,519	☑

Figure 7: Parameter set

Figure 8 indicates the temperature distribution of CPU cold plate mechanism in 55 C. Cpu which can be seen most heat dissipation and power supply modes are most critical components to functionality of avionic box. Although maximum temperature seems equal to 89,707 C, this temperature doesn't mean temperature on CPU component. Thermal pad is used between CPU component and copper plate.

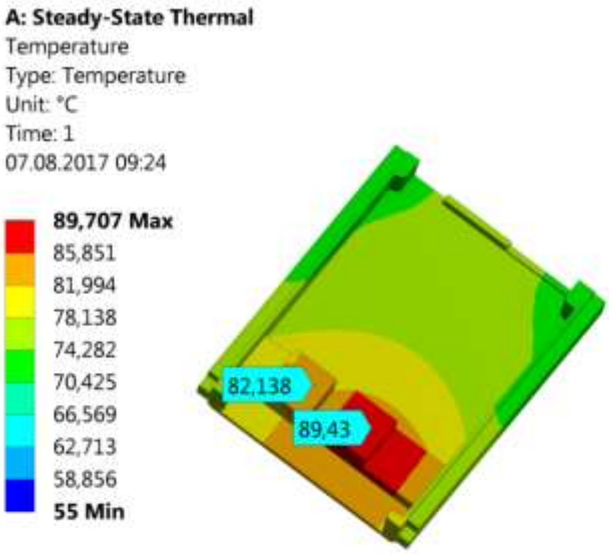

Figure 8: Temperature distribution in cpu cold plate

RESULTS

Electronic equipments are cooled to keep the component maximum temperature on limit. The main of this numerical study is to optimize thermal performance characteristic of ½ ATR chassis. The effects of different sizes, numbers, orientations of fin on maximum temperature and weight are investigated. By using optimization technique, weight decreases about 1 kg and maximum temperature reduces about 8 C^0. Results show that maximum temperature decreases by decreasing H_f, but at some point it starts to increase. Therefore, optimum H_f and W_c values must be determined according to optimization results. Finally, it is strictly encouraged that this design must be tested with same conditions in analysis.

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