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Thermal Management Study of Avionics Equipment Cooling

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ABSTRACT

Generally, thermal challenges that emerge from the compactness of electronics or electrical are common to most electronic or electrical equipment. For avionic applications, the measures to overcome these challenges are however constrained by the obvious and strong driving forces to minimize weight, and maximize reliability. Power Distribution Panels installed in Avionics Equipment bay on a civilian aircraft for thermal. The thermal characteristic changes owing to abrupt changes in pressure and temperature as aircraft moves quickly from a lower altitude to higher altitude. The altitude changes the heat transfer processes in power distribution Boxes. This is being investigated to examine the compatibility of thermal design. At various altitude, to evaluation of the effects of optimized vent holes size and shape for natural air convective cooling will be studied numerically using commercial software like ANYSY ICEPAK. The evolution of the more electric aircraft has led to the adoption of high power electronics for flight critical systems and the need to mitigate their thermal loads. The changes in altitude affect properties that govern heat transfer, such as air pressure, density, and temperature. The numerical investigation will serve to provide a greater confidence for predictive methods of heat transfer at high altitude, which can lead to better optimized thermal management solutions for avionics equipment.

INTRODUCTION

All electronic devices and circuitry generate excess heat and thus require thermal management to improve reliability and prevent premature failure. The amount of heat output is equal to the power input, if there are no other energy interactions. There are several techniques for cooling including various styles of heat sinks, thermoelectric coolers, forced air systems and fans, heat pipes, and others. In cases of extreme low environmental temperatures, it may actually be necessary to heat the electronic components to achieve satisfactory operation.

THERMAL CHALLENGES FOR AVIONIC EQUIPMENT

The thermal challenges that emerge from the downsizing of electronics are common to most electronic equipment. For avionic applications, the measures to overcome these challenges are however constrained by the obvious and strong driving forces to minimize weight, and maximize reliability. Avionics applications can be divided into military and civilian applications, where military applications have historically represented the driving force in the evolution of avionics. In the past, design of military electronic equipment embodied the cutting edge in technology, as military applications represented more than 50% of the total semiconductor market in the 1960´s [7]. Currently, ADHP applications represent approximately 2% of the semiconductor market [8] and thus render no interest of major semiconductor manufacturers to make such parts. Therefore, COTS electronic components designed for computers, consumer, and telecommunications applications, which

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today represent more than 75% of the semiconductor market, are used to a growing extent in ADHP applications. From a thermal perspective, high-performance COTS components are often cooled by adding a fan-cooled heatsink with spring-loaded attachment to the top surface. This is adequate for stationary computers that are subjected to insignificant vibration loads during its lifetime. However, for military and/or avionic applications, this would not be a feasible design due to multiple reasons such as weight, volume, and vibration levels. Instead, focus might be set on minimizing contact resistance to a cooling surface, optimizing heat conduction, and affecting the power distribution on the printed circuit board assembly (PBA) in collaboration with electronic design engineers. For avionic applications, the trend of more electric aircraft (MEA) generates additional thermal management challenges, as an increasing amount of avionic systems are employed in harsh environments, subject to large variations in ambient temperatures, external thermal loads generated by nearby high-power dissipating equipment, and inherently transient internal power dissipation.

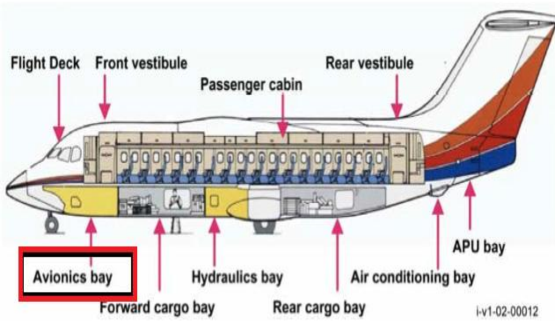

Fig: Avionics

OBJECTIVE AND SCOPE

The objective of this thesis is to, consider one of the Power Distribution Panel (PDP) installed in Avionics equipment (E-E bay) and by forced convective cooling mechanism using appropriate fan, conduct Numerical investigation of thermal behaviour of the PDP at various altitudes. To investigate compatibility of thermal design. In addition, the Forced air convective cooling will be studied numerically using commercial software like ANSYS ICEPAK.

APPROACH TO THE PROBLEM

- Analyzing the given problem statement(basic CAD model)
- Selection of cooling technique
- Building the basic model in ICEPAK tool and giving inputs
- Analyzing the model at sea level conditions and also at various altitudes

LITERATURE REVIEW

As the number of electrical and electronics systems increases, their physical sizes decrease, and the spacing between electrical components decreases, both the total amount of heat generated (hence to be dissipated) and the power density (the heat generated per unit volume) increase significantly. There is a general agreement in the scientific community that current air-cooling technologies are asymptotically approaching their limits imposed by available cooling area, available airflow rate, fan power, and noise [1–3].

This scenario is even more critical in the new full fly-by-wire generation of more electric aircrafts and helicopters, where the heat dissipation loads are constantly increasing, pushing the air cooling scheme towards its intrinsic limitations [4–7]. However, air forced convection still represents the standard heat transfer mechanism used in the aeronautical industry for electronic devices cooling because it is considered by the aircraft manufacturers the most robust and reliable by virtue of its long history. In these systems, in order to maintain the equipment below the maximum temperature requested by manufacturer's specifications, air flow is supplied by fans to actively remove the heat from the electronics [8].

HEAT TRANSFER FUNDAMENTALS

Heat transfer is the science that seeks to predict the transfer of energy that takes place between material bodies as a resultof a temperature difference. There are three modes of heat transfer: conduction, convection, and radiation.

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Conduction is the transfer of energy within a body due to a temperature gradient. The energy is conducted from the high-temperature region to the low-temperature region (see Figure 1). In its simplest form, one-dimensional heat flow by conduction is calculated as:

$$q_{cond} = \frac{\Delta t A \kappa}{l}, \qquad (1)$$

Where l is the length of the conducting path, A is the area of the conducting path, N is the thermal conductivity of the body, and it is the temperature difference.

For the three-dimensional case, conduction heat transfer is expressed as an energybalance for aninfinitesimal element, such that (in Cartesian coordinates):

$$\frac{\partial}{\partial x}\left(\kappa\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\kappa\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\kappa\frac{\partial T}{\partial z}\right)+\dot{q}=\rho c_p\frac{\partial T}{\partial t} \qquad (2)$$

Where the left hand side describes the net transfer of thermal energy into the control volume and the energy generated within the infinitesimal element, and the right hand side is the change in thermal energy storage in the element.

Convection is the energy transfer from a body to a fluid, which might be gas or liquid. A difference is noted between forced convection, where the fluid is propelled by a fluid accelerating device such as a fan, and natural convection, where the motion of the fluid is initiated by a change of density due to heating of the fluid. The force that arises from this phenomenon is called buoyancy force. The energy transferred by convection is calculated as:

$$q_{conv} = hA(T_s - T_{amb}) \qquad (3)$$

Where h is the convection heat transfer coefficient that depends on the properties and velocity of the fluid, A is the area of the heat-dissipating surface, Ts is the temperature of the surface, and Tamb is the temperature of the ambient air.

Thermal radiation is when a surface emits electromagnetic radiation as a result of its temperature. The frequency of the radiation depends on the absolute temperature of the radiating device; however for the temperature range possible for electronics to operate within, thermal radiation mainly occurs in the infrared frequency range. The energy transferred between two bodies by radiation can be calculated as:

$$q_{rad} = F_\varepsilon F_G \sigma A(T_s^{\ 4} - T_{amb}^{\ \ 4}) \qquad (4)$$

WhereF_ε is an emissivity function, F_G is a geometric “view factor” function, σ is the Stefan-Boltzmann constant (5.669×10^{-8} W/m^2K^4), A is the area of the radiating surface, T_s is the radiating surface temperature, and T_{amb} is the temperature of the receiving surface. Depending on the application, any of the three energy transfer modes can be the dominant mode for removing the energy, and thus the heat, from the electronic equipment. In Table 1, a coarse estimation of thermal conductivity and convective heat transfer coefficient values is provided.

Table 1. Approximate values of conductivity and convection heat transfer coefficients for different heat transfer modes.

Heat transfer mode	Thermal Conductivity (W/(m·K))	Heat transfer coefficient (W/(m²K))	Reference
Conduction in solids	0.13-2000		[32]
Natural convection in gases		5-15	[33]
Forced convection in gases		15-250	[33]
Natural convection in liquids		50-100	[33]
Forced convection in liquids		100-2000	[33]
Boiling liquids		2500-35000	[29]

In ground applications, e.g. stationary computers, the critical components may be cooled by conduction to a heatsink, which is in turn cooled by forced convection. Other options exist for removing the heat dissipated by current high-performance processors, but ultimately the heat is transferred to the surrounding air by forced or natural convection. Ground applications can of course be divided into a vast number of categories, ranging from the automotive industry, through military equipment, to handheld devices, such as mobile phones, but the general principle of conduction plus convection cooling remains.

Avionics applications may utilize the same cooling principles as ground equipment. In avionics, however, constraints are posed on the cooling solutions in terms of e.g. minimized weight, extreme reliability requirements,

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and environmental requirements such as harsh temperature levels, high levels of vibration, and lowdensity cooling air at high altitudes.

In space, the main principle for cooling of electronic equipment differs completely from the previously mentioned applications, due to the absence of air. Radiation is the only mechanism that transports heat to and from a spaceship or a satellite. Therefore, control of the temperature of the electronics is realized by carefully utilizing radiating and reflecting surfaces on the hull of the vehicle.

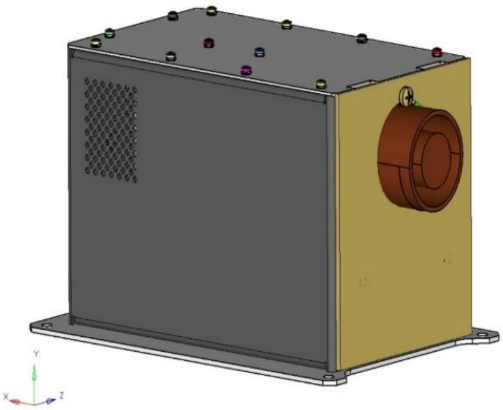
GEOMETRY OF PDP

Dimensions:

Length: 210mm

Width: 125mm

Height: 140mm



TOTAL POWER: 121W

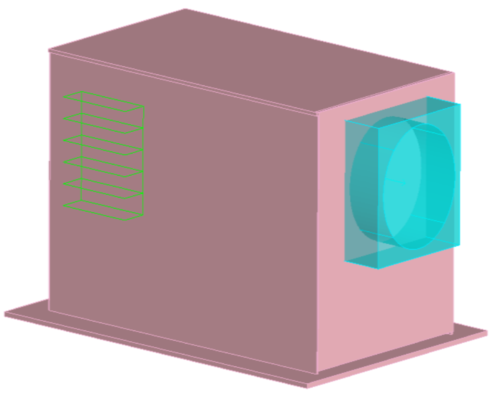


Fig 3.2: ICEPAK Geometry

ELECTRICAL COMPONENT PACKAGING DETAILS

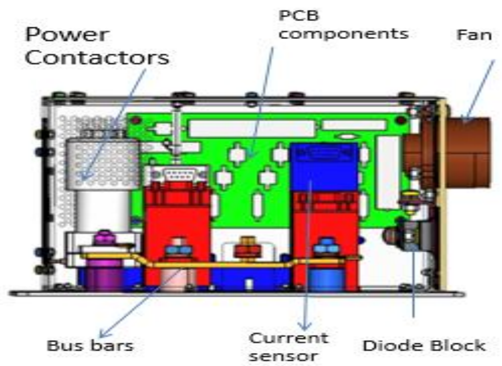


Fig 3.3: Input CAD Geometry

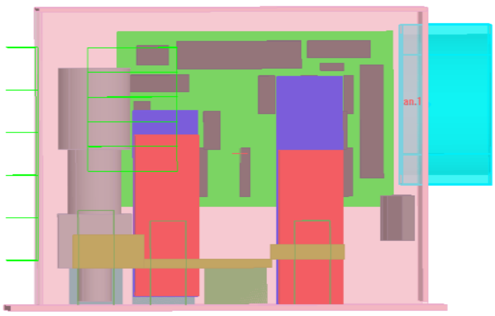


Fig 3.4: components ICEPAK Geometry

ASSUMPTIONS & BOUNDARY CONDITIONS

Several assumptions must be made about the system for thermal analysis. Examples of some of these assumptions include modes of heat transfer involved at different locations in the system, the contact resistances between different solid surfaces and heat transfer coefficients at the surfaces where the mode of heat transfer is not completely known. Even under the best of circumstances, there will be some errors in these types of assumptions. All these sources of error are in addition to the lack of complete knowledge about the physics of heat and mass transfer and the numerical imprecision of any computer model.

ASSUMPTIONS

- Steady state condition.
- Considered operating conditions at sea level & various altitudes.
- Radiation Heat Mechanism will be neglected.

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- Two equation (k-€) turbulence model will be considered.

BOUNDARY CONDITIONS

The difficulties in predicting the actual boundary conditions can add error to thermal analysis results. Fluid dynamics-based thermal analysis methodologies require well-defined boundary conditions for fluid flows and temperatures.

For modeling system-level heat transfer, the heat transfer coefficient at the boundaries can introduce significant errors. For example, in natural convection heat transfer mode, the Nusselt number relationships are different for vertical and horizontal walls. Thus, the use of a constant heat transfer coefficient for all walls of a rectangular enclosure will not be appropriate. Boundary conditions are as follows

- Cabinet boundaries are treated as Wall BCs(Convective walls)in all directions.
- Joule heating for Cable, Bus bars & Leads.
- Environmental fluid domain considered approximately 2 times of PDP unit size

Table 5.INPUTS

Part Name	Comp Rating (Amps)	Voltage	Actual Current (Amps)	EOL Voltage drop (Volts)	Resistance (ohm)	Power Loss (Watts)
Power input Contactor	500	28 Vdc	400	0.18	0.00036	25
		28Vdc	0.2	28	140	5.6
Power Transfer contactor-1	400	28 Vdc	82	0.18	0.00045	3.0258
		28Vdc	0.2	28	140	5.6
Power Transfer contactor-2	400	28 Vdc	249	0.18	0.00045	18
		28Vdc	0.2	28	140	5.6
Backup Contactor	200	28Vdc	0	0.18	0.0009	0
			0	28	140	0
Diode 320A	320	400Vr	0	1		40
Backup RCCB	100	28 Vdc	0			0
		28Vdc	0.065			0
Current Sensor	800		249			0
		28Vdc	0.065			1.7
		28Vdc	0.07		400	0
PCB & Components						[illegible]
Total Power Losses						121.5258

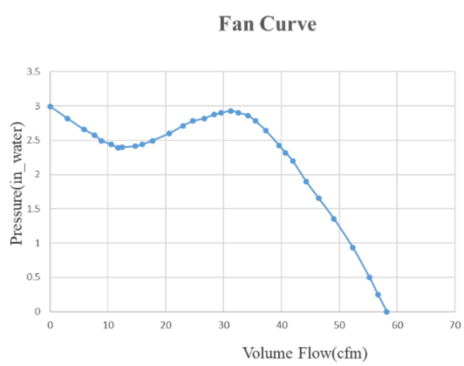
Components	Materials		Properties	
		Density	Conductivity	Specific heat
		(kg/m^3)	(W/m-K)	(J/kg-K)
Chassis	Aluminium	2700	167	896
Contactors,CB leads,Bus bars,Cables	Copper	1250	0.35	1300
Terminal blocks	FR4	7817	14.4	461
Contactors	Polycarbonate	7700	14.4	461
PCB&	FR4(Epoxy glass)	1250	0.35	1300
Components	Silicon	2330	180	700

Power loss =	Actual Current^2 * Resistance
Resistance =	(Voltage drop / Rated Current)
Power loss per lead =	(Actual Current^2 * Resistance)/2

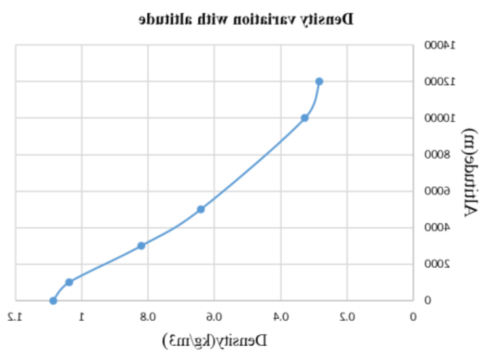
FAN DETAILS

For this procedure, we preferred Small Vane axial Fans with 10000 RPM

Fig 4.1: Operating Speed: 10,000 RPM



Graph 1: Fan Performance curve Input



Graph 2: Graph represents density

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4.2. COMPUTATIONAL DOMAIN & BOUNDARY CONDITIONS

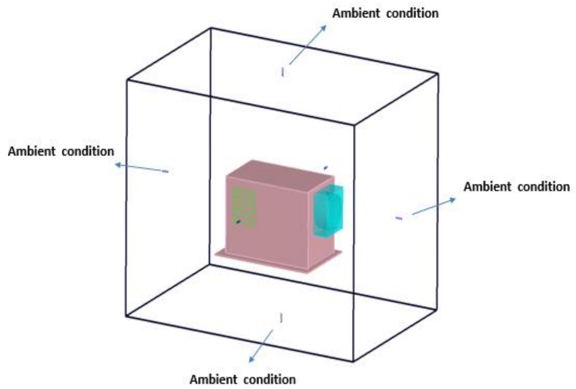


Fig 4.2: Boundary conditions

4.3. Mesh Details

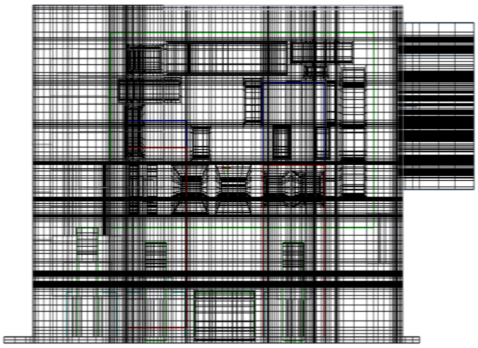


Fig 4.3: Surface Mesh-Pattern

4.4. Grid Details:

Type of Elements: Hexahedral
Number of elements: 3016940
Number of nodes: 3077546

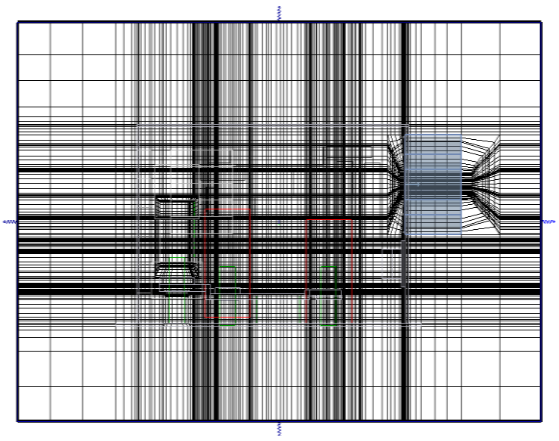
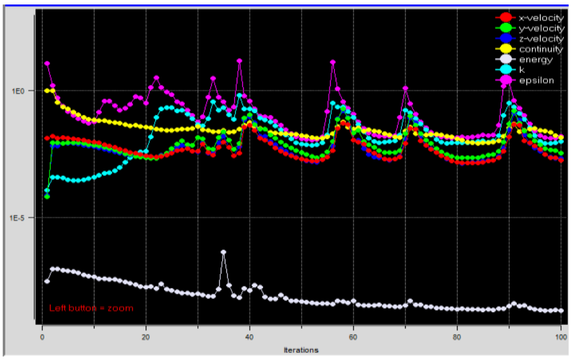


Fig 4.4: Z-axis Mid Sectional View mesh-Pattern

4.5. Residual Plots



Solution Convergence Criteria:

Continuity : 1e-3
Momentum : 1e-3
Turbulence : 1e-3
Energy : 1e-5

6. RESULTS

6.1 TEMPERATURE CONTOURS @ SEA LEVEL

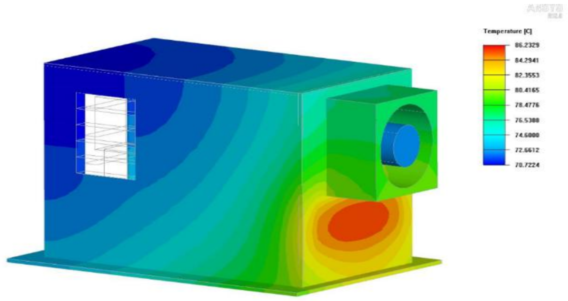


Fig 6.1: Temperature contours of Chassis at sea level

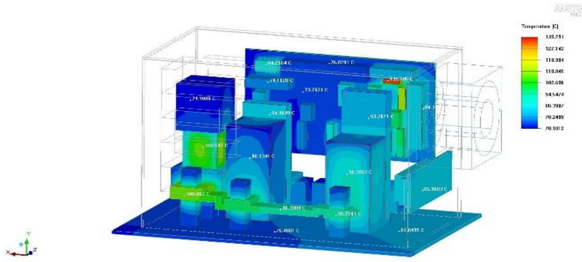


Fig 6.2: Temperature contours of Components at sea level

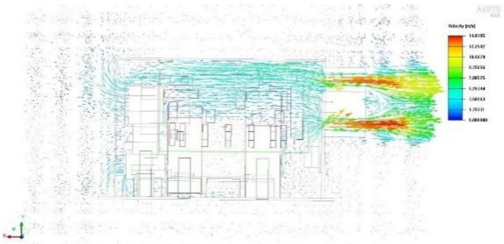


Fig 6.3: Temperature contours of Velocity at sea level

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6.2 ALTITUDE EFFECTS

Temperature contours @ 1000 m

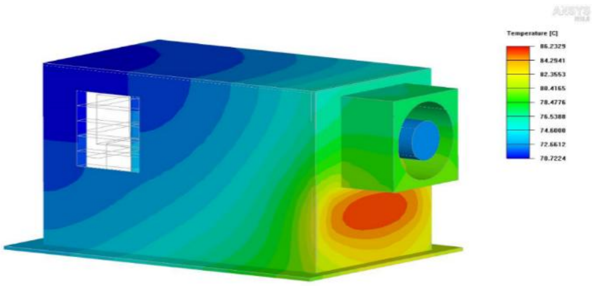

Fig 6.4: Temperature contours of Chassis at 1000 m

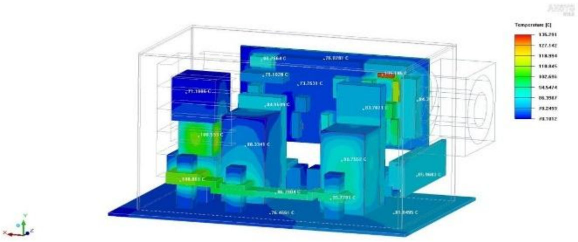

Fig 6.5: Temperature contours of Components at 1000 m

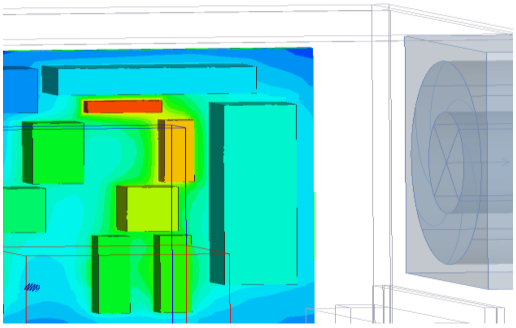

Fig 6.6: Temperature contours of Velocity at 1000 m

6.3 TEMPERATURE CONTOURS @ 3000 M

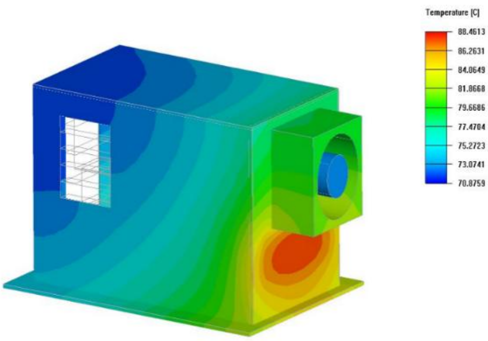

Fig 6.7: Temperature contours of Chassis at 3000 m

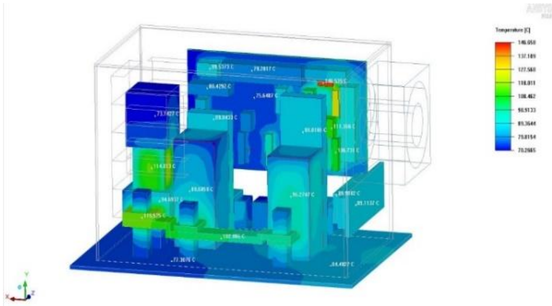

Fig 6.8: Temperature contours of Components at 3000 m

6.4 TEMPERATURE CONTOURS @ 5000 M

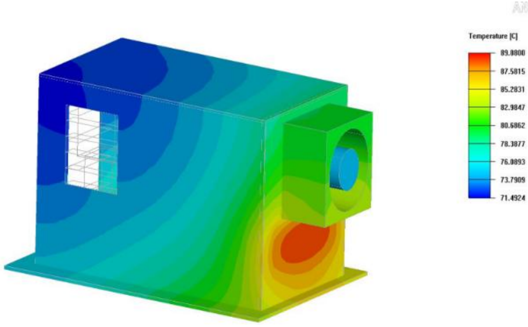

Fig 6.9: Temperature contours of Chassis at 5000 m

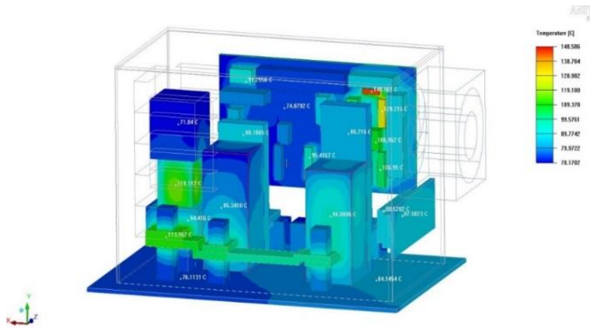

Fig 6.10: Temperature contours of Components at 3000m

6.5 TEMPEATURE CONTOURS @ 10000 M

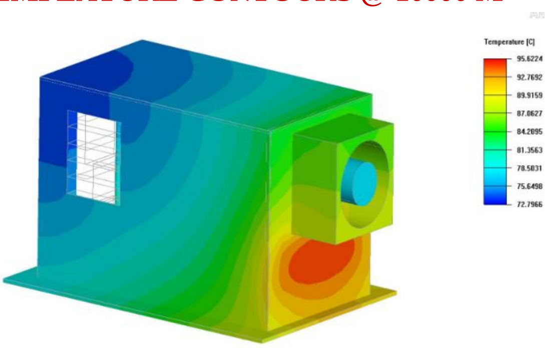

Fig 6.11: Temperature contours of Chassis at 5000 m

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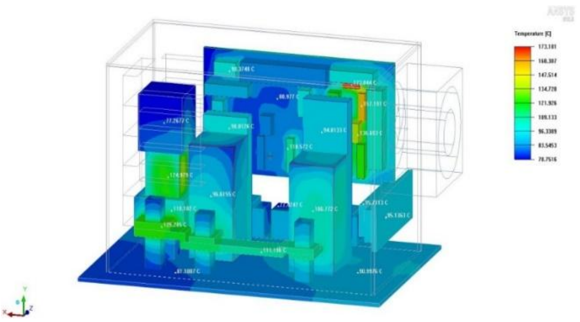


Fig 6.12: Temperature contours of Components at 3000 m

6.6 TEMPERATURE CONTOURS @ 12000 M

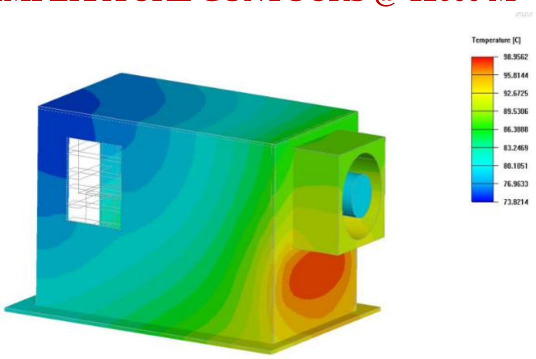


Fig 6.13: Temperature contours of Chassis at 5000 m

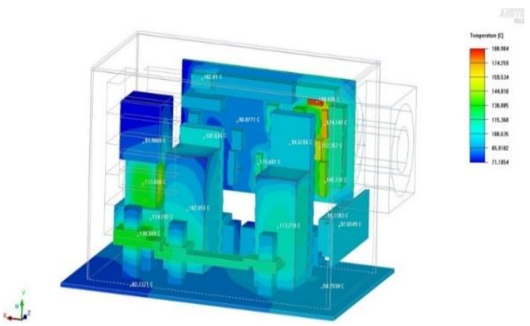


Fig 6.14: Temperature contours of Components at 3000 m

6.7 STREAM LINES

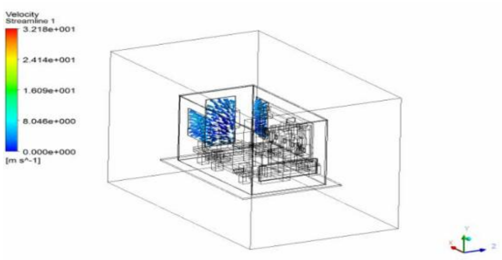


Fig: Velocity streamline 1

STREAM LINES

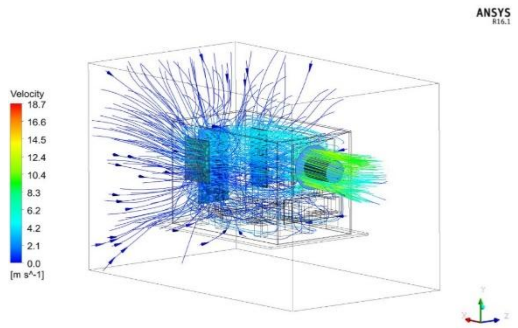
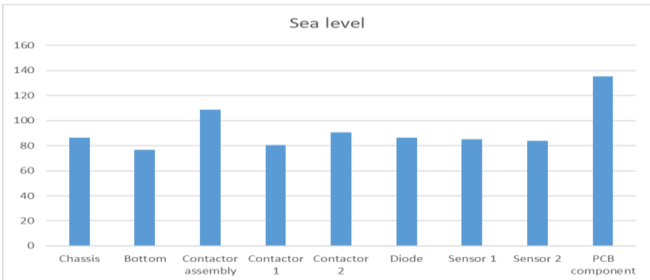


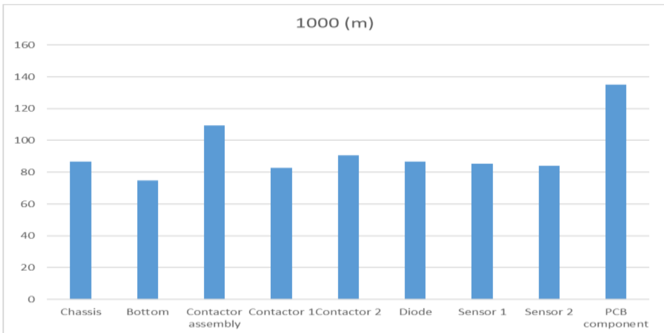
Fig: velocity

Table 6: Temperature of components (in °C) at various altitudes

	Sea level	1000 (m)	3000(m)	5000(m)	10,000(m)	12,000(m)	Allowable limit
Chassis	86.23	86.56	88.46	89.88	95.62	98.73	85
Bottom	76.466	74.88	76.11	77.3	81.1	82.73	125
Contactor assembly	108.59	109.5	114.81	118.11	124.97	133.65	150
Contactor 1	80.33	82.70	85.34	88.68	96.61	102.05	125
Contactor 2	90.755	90.7	96.08	96.27	106.77	113.21	125
Diode	86.39	86.7	88.52	89.98	95.71	99.110	125
Sensor 1	84.96	85.33	88.18	89.84	98.01	102.63	125
Sensor 2	83.70	83.98	86.21	88.01	94.81	98.67	125
PCB component	135.18	135.2	146.53	148.56	173.00	188.9	150



GRAPH: Graph Represents Temperature of Components (In °c) At Sea Level



Graph 4:Graph Represents Temperature Of Components (In °c) At 1000 (M) Above Sea Level

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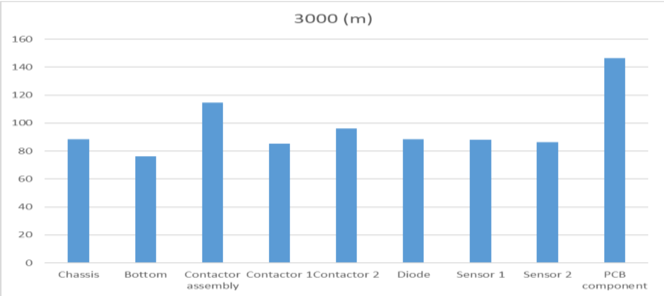
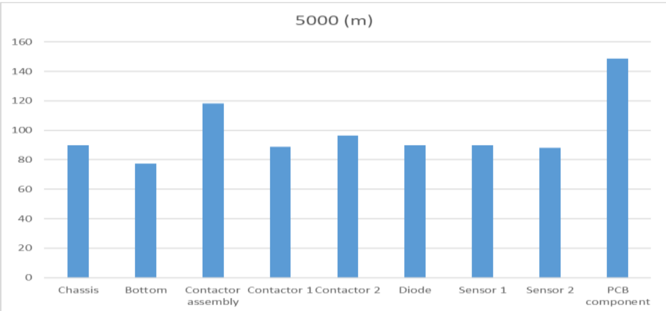
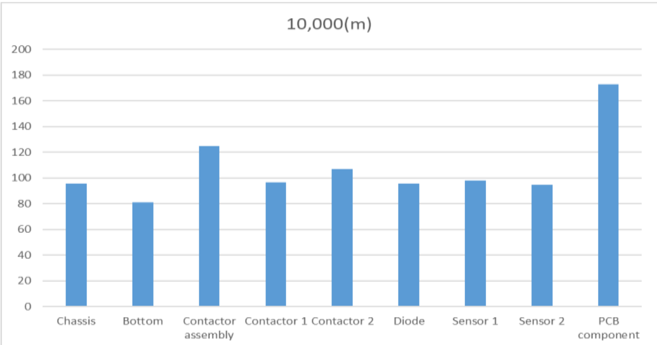


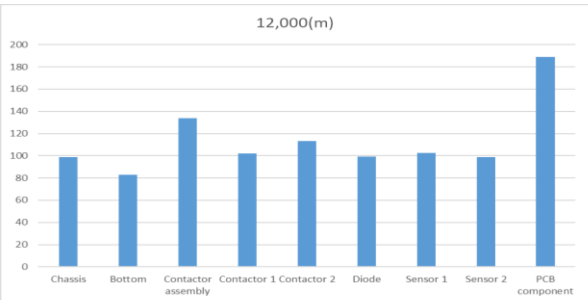
Graph 5: Graph Represents Temperature Of Components (In °c) At 3000 (M) Above Sea Level



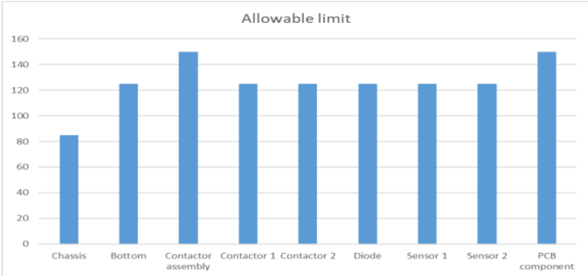
Graph 6: Graph represents Temperature of components (in °C) at 5000 (m) above sea level



Graph 7: Graph represents Temperature of components (in °C) at 10000 (m) above sea level



Graph 8: Graph represents Temperature of components (in °C) at 12000 (m) above sea level



Graph 9: Graph represents Temperature of components (in °C) at Allowable limit

6.8: ATTEMPT TO OPTIMIZE DESIGN

Considering a heat sink with cross cut fin

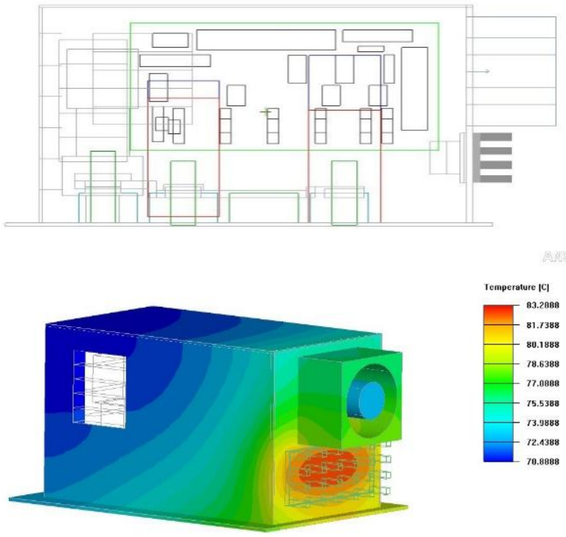


Fig 17: Slight reduction in temperature is observed

CONCLUSION

Numerical simulation has been carried out for avionic equipment at various altitude conditions like sea level, 1000m, 3000m, 5000m, 10000m and 12000m. Find out maximum temperature from simulation for all components (see above table). Component temperature value increase with altitude due to density and pressure factors.

Optimised system of the cooling to PDP addition the FINs to PDP chassis.

FUTURE SCOPE

- Considering a heat sink (with fins) at the place where maximum temperature is observed.

- Selection of an appropriate fan with higher mass flow rate.
- Detailed PCB board simulation can be carried out.
- Providing Heat spreaders & Thermal Pads.
- Optimization of fan location.
- Repackaging of electrical components
- Placing the PDP in E-E bay region where external cooling air is available.
- Providing vent holes to enhance the free flow of air.

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