THERMAL PHENOMENA MODELING OF AIRCRAFT ELECTRONIC UNIT

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The aim of this paper is to show the complex thermal analyses used to design of aircraft electronic control unit, Control Power Supply for Jet (CPSJ). The goal is to examine thermal conditions of power and control electronics components. With respect to aircraft application a computational fluid dynamics (CFD) method is used for heat transfer coefficient determination. This method is compared to analytic solution based on Petuchov equation of Nusselt number. The temperature conditions inside the CPSJ unit are presented as results.

Keywords : *thermal analyses, computational modelling, CFD, control electronic unit, cooling systems*

1. Introduction

Thermal processes play an important role in the design of electrical devices. Technical characteristics and properties such as reliability and life-time significantly depend on ambient temperature [1], [2], [3]. A size minimization, high performance requirements, complexity and integration of electrical devices make the thermal processes much more important issue in the present time. Material selection, design and further development of electrical devices are evolved with respect to thermal conditions. Quick development of high performance computers and new computational software enable to implement aerodynamics and hydrodynamics phenomena into the thermal analyses. Understanding of theoretical background of these additional sciences is necessary for correct computation and result evaluation. An unprofessional work with computational software is today's problem. Some parties of thermal analyses are made automatically by sophisticated computational algorithms integrated into the software and inexperienced users lose overview and judgement. Therefore the thermal analysis of electrical devices becomes independent branch and experts are specially trained.

2. The present trends of thermal and cooling process in electronic devices

The design of electronic devices is highly limited by their thermal properties. The most of electrical phenomena like electric conductivity, resistance, etc. are dependent on temperature level. Consequently the operating properties and characteristics of all electrical systems especially functionality, lifetime and reliability are affected. As examples the temperature stress test called accelerating ageing test (AAT) is used to determine devices life-time in levels of year decades. Another example is correlation between reliability and temperature of integrated circuits (see Fig. 1).

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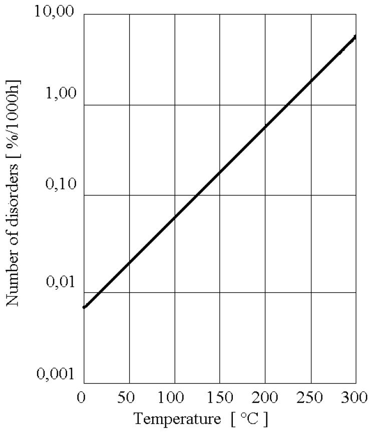

Fig.1: Correlation between reliability and temperature of integrated circuits [10]

According to [10] electronic development was mostly focused on following ways in the past:

– Decrease of own power dissipation of electric devices. The great progress in this process was made in the last decades. The electron tubes were replaced by transistors. Development and application of integrated circuits, microprocessor technology and optoelectronics decrease the own power dissipation in places of value.

– Increase of operating temperature range. For example silicium was substituted by germanium in semiconductor technology. The temperature limits were increased from the range 60–70 °C to the range 150–200 °C.

The further development in this direction is very difficult and expensive. Therefore the sophisticated cooling systems are evolved and implemented in the present time. This makes the thermal analysis more complex and interdisciplinary. The main focus in systems cooling is following:

– Natural convection is the cheapest and the most common way. The ribbed heat sinks are more carefully designed. Size of cooling surface, distance between ribcage, material properties and fixing methods are the main characteristics. Special thermal pastes and washers are used for ideal connection of cooled object and heat sink.

– Forced convection uses computational aerodynamics methods. The hot air is moved by ventilator from electrical device to the ambient environment and cool ambient air is sucked inside.

– Liquid cooling system is designed on the basis of hydrodynamic theories. The cooling liquid transfers heat from cooling object to the heat sink. The type, velocity and amount of liquid are the main factors affecting the cooling efficiency.

– Phase transition method. The thermal energy is absorbed by substance during the phase transition.

– Bubbling evaporation is special type of phase transition method. The liquid is evaporated from the surface of cooled object and condensed back in the heat sink.

– Heat-pipe is advanced technology. It is based on phase transition method. The high reliability is reached, because there are no moving parts. The heat transfer is performed by capillary action.

– Liquefied gas cooling is used in very special cases. The object temperature can be kept on −196 °C by liquid nitrogen. It is used for electrical noise reduction in spectrometric measurement devices.

3. Computational modeling

Quick progress in computer's performance and computational software allows complex thermal analysis and optimal design of cooling systems. In this context the word complex means interdisciplinary approach where thermal, aerodynamic and hydrodynamic methods are consolidated. The solvers using in software are based on finite element method (FEM) theories [4], [5], [6]. The new computational algorithms implemented into the software make the analyses more accurate and decrease computational time. Common computational software enables creation of geometry, settings of material characteristics, and application of thermal load. Special software for thermal analyses of electronic devices is developed. The electric component library and models of cooling devices are included. A lot of computational platforms are developed all over the world. Computational possibilities in most of the commercial software are very similar. It is difficult to objectively compare their quality without deep practical experience. Following is a short list of the most known software:

– [14] 'C&R Technologies provides software for heat transfer analysis and fluid flow design, training, and consulting.'
– [15] 'FloTHERM is powerful 3D computational fluid dynamics (CFD) software that predicts airflow and heat transfer in and around electronic equipment, from components and boards up to complete systems. FloTHERM PCB is new collaboration tool for product marketing, electrical and mechanical engineers that accelerates the conceptual thermal design of printed-circuit boards.'
– [16] 'COMSOL Heat Transfer Module solves any problems that include combination of conduction, convection and radiation. It finds extensive use in systems that involve the generation and flow of heat in any form.'
– [17] 'STAR-CAD Series specifically created to enable design and professional engineers to undertake flow and thermal analyses.'
– [18] 'ANSYS 12, Icepak module provides robust and powerful computational fluid dynamics (CFD) software for electronics thermal management. Based on the state-of-the-art ANSYS FLUENT CFD solver. ANSYS Icepak software has a streamlined user interface that speaks the language of electronics design engineers, enabling the rapid creation of models of complex electronic assemblies.'

4. The device specifications

The aircraft electronic devices are characterized by a wide range of thermal operating conditions, strict safety rules and complicated certification. Special equipment essential to safe aircraft operation must be subjected to very strict and expensive testing under real operating conditions. An examination and simulation of thermal phenomena can lead to savings in money and time during the development and certification process. In this case the thermal analyses are used in development process of the aircraft electronic control unit CPSJ. The purpose of this device is to control aircraft turbine engine TJ100. The CPSJ unit is integrated into the turbine engine case. There are several thermally significant parties:

- Heat sources – printed circuit boards, inductors, transistors and diodes.
- Heat removals – thermal pads and air flow inside turbine channel.

Aim of these analyses is to examine the temperature conditions inside CPSJ control unit for different ambient temperatures.

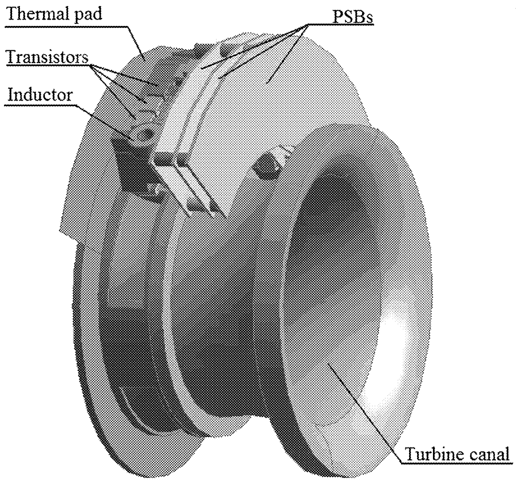

Fig.2: The thermally significant parties

5. The computational modelling of thermal phenomena

5.1. Geometry creation

The Steady-state thermal toolbox is used for analyses. Real geometry of CPSJ needs to be modified suitable for thermal analysis. The reason for modification is creation of uniform meshwork. This is important for results convergency and accuracy. The thermal significant bodies and masses need to be considered in thermal model. The thermally significant bodies contain internal heat generation e.g. transistors, diodes and inductors. The thermal significant masses play important role in thermal transfer phenomena e.g. heat pads, cases, and connection elements. The real model geometry consists of 280 bodies including screws, nuts, washers and connectors. The geometry for thermal analysis is reduced to 57 bodies.

5.2. Material properties

The most important and difficult part of the thermal analysis is the identification of optimal thermal properties of materials and components [8], [9]. The values of these parameters are determined by experimental data or physical equations. For common materials as a duralumin, air etc. the true values of thermal properties are defined. The components composed of many subsections with different materials are much more complicated issue. Moreover these parameters vary with temperature, pressure and other quantity. For steady state analysis only the isotropic behavior is considered.

The input values (material parameters and thermal load) for the computation model are summarized in the following Table 1.

Body	Material	Heat conductivity $[\mathrm{W\,m^{-1}\,K^{-1}}]$	Thermal load $[\mathrm{W\,mm^{-3}}]$
air	air	0.0314	—
case	duralumin	165	—
carrier	duralumin	165	—
thermal isolation	8810 3M	2	—
pillar	plastic	0.5	—
printed circuit power	composite	3	1.88×10^{-4}
printed circuit control	composite	3	8.8×10^{-5}
printed circuit small	composite	3	6.8×10^{-4}
inductor small	composite	250	1.65×10^{-3}
inductor big	composite	250	4.27×10^{-4}
transistor FDP right	composite	5	3.65×10^{-3}
transistor FDP left	composite	5	3.35×10^{-3}
transistor PH	composite	5	1.965×10^{-2}
diode	composite	5	7.05×10^{-3}

Tab.1: Material parameters and thermal load

6. Heat transfer coefficient of air flow through the turbine channel

The airflow into the turbine is $Q = 0.02\,\mathrm{m^3\,s^{-1}}$. This mass of air has significant effect on temperature condition. The analytic and numeric methods of the heat transfer coefficient calculation are presented in this article. The analytic method is based on Petuchov equation of Nusselt number.

$$Nu = \frac{\frac{f}{8}\,Re\,Pr}{1.07 + 12.7\sqrt{\frac{f}{8}}\left(Pr^{\frac{2}{3}} - 1\right)}\,, \tag{1}$$

$$f = [1.82\,\log(Re) - 1.64]^{-2}\,, \tag{2}$$

$$\alpha = \frac{Nu\,\lambda_{\mathrm{Air}}}{d} \tag{3}$$

where:
- Nu – Nusselt number,
- Re – Reynolds number,
- Pr – Prandtl number,
- α – heat transfer coefficient,
- λ_{Air} – heat conductivity of air,
- d – diameter of turbine channel,
- f – Darcy friction factor.

This equation is derived for values of Reynolds number in range ($10^4 < Re < 5\times10^6$) and Prandtl number ($0.5 < Pr < 200$). The value of heat transfer coefficient is represented by one number applied to interface of air and turbine channel as shown in Fig. 3.

The numeric solution is based on computational fluid dynamics (CFD)[7]. The air flow is modelled by CFX toolbox according to aerodynamics principles. The turbulences and boundary layer are considered. The heat transfer coefficient shown in Fig. 4a is computed in dependence on velocity profile shown in Fig. 4b.

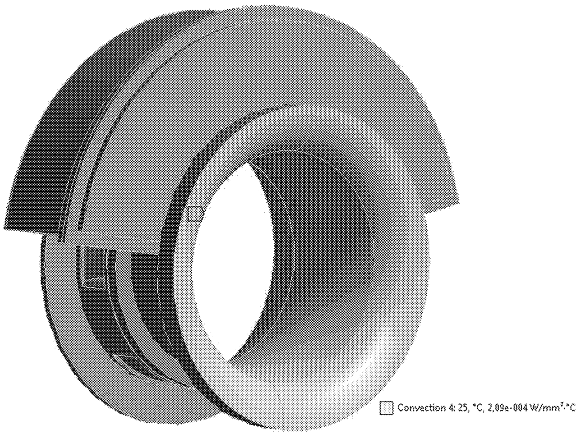

Fig.3: Transfer heat coefficient applied to the air and turbine interface

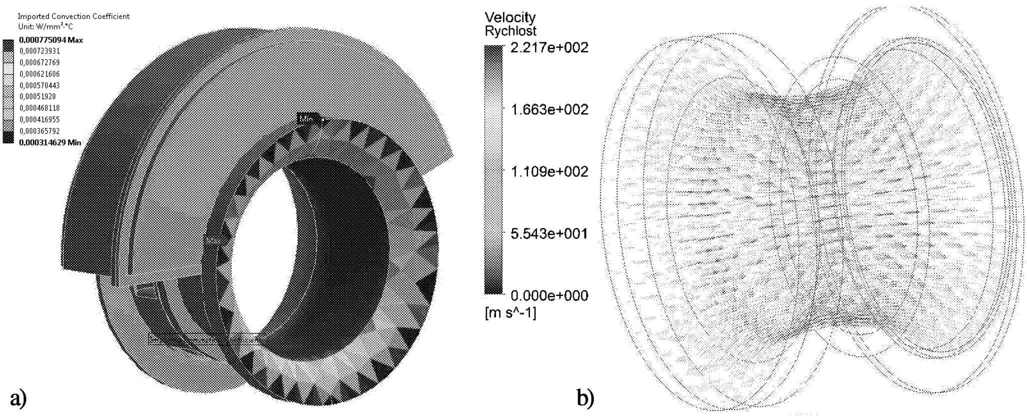

Fig.4: a) Heat transfer coefficient; b) Velocity profile

The heat transfer coefficient is directly imported from CFX toolbox to the Steady-state thermal toolbox and both analyses are computed together.

7. Results

The temperature conditions of CPSJ are presented as results. Both approaches of heat transfer coefficient computation are shown in Fig. 5 and Fig. 6.

The values of temperatures are summarized and compare in the following Table 2.

The both approaches give comparable results. The numerical solution based on CFD methods should ensure higher accuracy. For result verification the experimental measurement should be performed.

	Steady-state thermal toolbox	CFX and Stead-state thermal toolbox
Maximal	74 °C	73 °C
Minimal	27 °C	24 °C
Inlet of air	27 °C	24 °C
Outlet of air	44 °C	40 °C

Tab.2: Temperature values

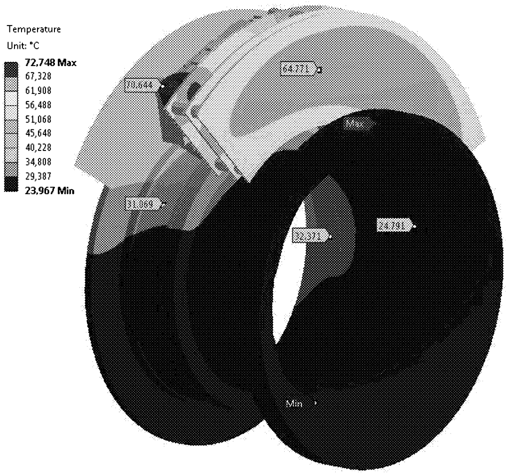

Fig.5: Temperature profile of CFX and Steady-state thermal analysis

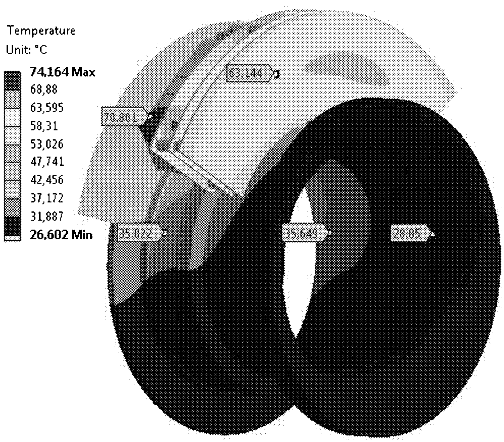

Fig.6: Temperature profile of Steady-state thermal analysis

The values of temperature inside the CPSJ are within the range of operating conditions of electrical devices. According to the level of CPSJ development when the real operation and initial conditions of computational model are estimated this thermal analysis brings useful information about thermal distribution.

8. Conclusion

Thanks to the quick progress in computer's performance and computational software the complex thermal analyses can be used in the common engineering work. The results of these analyses are necessary for optimal design of electric devices and their cooling systems.

The two methods of heat transfer coefficient computation are used in the thermal analyses. The CFD approach is of high complexity and interdisciplinary where aerodynamics phenomena is applied. This is good advantage especially in the field of aircraft applications. The analytic method based on Petuchov equation of Nusselt number is also applicable in this case. The results determined by both methods correspond very well.

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