Simulation Study of the Effect of Anti-Icing on the Nacelle Lip-skin Material

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Abstract. One of the key concerns in aircraft flight is the accumulation of ice on the wing leading edge and nacelle lip-skin. It is well known that ice accretion may dangerous to the aircraft since it severely degrades the aerodynamic performance of aircraft. As a consequence, the piccolo tube anti-icing system is installed by the aircraft manufacturer inside wing leading edge and nacelle lip-skin in order to prevent ice accumulation. However, the hotspots from piccolo tube anti-icing system potentially defect or destroy material of nacelle lip-skin. Therefore, in present work, the numerical investigation with one-way fluid-structure interaction (FSI) has been carried out to study the effect of Reynolds number based on effective-impingement-surface of piccolo tube anti-icing system on the maximum thermal stress and strain of nacelle lip-skin for several aluminum series. The simulation results reveal that the maximum strain increases with the Reynolds number. For the stress analysis, the maximum stress increases to the peak value, then it gradually decreases with Reynolds number. Among the materials have been studied, aluminium 7 series shows the highest maximum stress and maximum strain for all Reynolds number and hotspot temperature, however, aluminium 1 series produces the lowest maximum stress and maximum strain.

1. Introduction

Aircraft icing is the accretion of supercooled liquid which forms on the aircraft during flight. Accretion of ice onto vital parts of the aircraft components can bring severe effect to the flight performance and aircraft conditions [1]. This accumulation of ice on the inner part surface of the lip-skin can be hazardous to flying aircraft. The ice will break and hit the compressor. As a result, the compressor was broken and aircraft might happen. Therefore, it is very important for any aircraft to be installed with anti-icing system. Besides, ice accumulation on nacelle lip-skin can possess a major problem on any flying aircraft as it greatly alters the aerodynamic properties of the aircraft which in turn can lead to higher fuel consumption due to increased drag force generated by the non-aerodynamic shape present on the lip skin [2].

There are many types of aircraft anti-icing system which is now commercially used [3]. One of a good example and most used anti-icing system is the Piccolo Tube Anti Icing (PTAI) [4]. Piccolo tube is a series of in line and staggered holes, is placed inside the wing leading edge and near to its surface. Besides PTAI system, some researchers studied alternative anti-icing system. In 2015, Ismail et al. [12] studied temperature distribution of nacelle lip-skin by using swirl anti-icing (SAI) system. According to their result, SAI system provides much better temperature distribution than PTAI. Besides, SAI system has several advantages including fewer components, simple plumbing, is

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light and inexpensive compared to PTAI [13-15]. In addition, BAL may possibly be installed on the inner skin of the nacelle lip, SAI system has the potential to be used together with BAL since it does not produce hotspots with the same level of temperature as the hotspots of PTAI system along the inner skin.

In PTAI system, hot air is bled from the engine compressor at high pressure and temperature and is conducted forward to the fixed leading edge [5]. The high pressure and temperature of air from the tube flow out through the holes/nozzles at a high-velocity jet, then it impinges on the inner surface of the wing and nacelle leading edge. This heat transfer by conduction from the inner part surface to the outer part surface then results in maintaining the temperature of the outer part surface leading edge in order to avoid ice formation on the surface [6]. Most of the anti-icing study focuses on the thermal performance only [4], meanwhile the damage study of nacelle lip-skin only focus on the external object like a bird strike or debris strikes during flight [7]. Therefore, the presented study of the effect of hotspot temperature on the thermal strain and thermal stress on the nacelle lip-skin.

2. Methodology

2.1 Geometry

First of all, the geometry was drawn using ANSYS workbench. The geometry used in this study is as shown in Figure 1. Note the diameter, d in this study is 2mm.

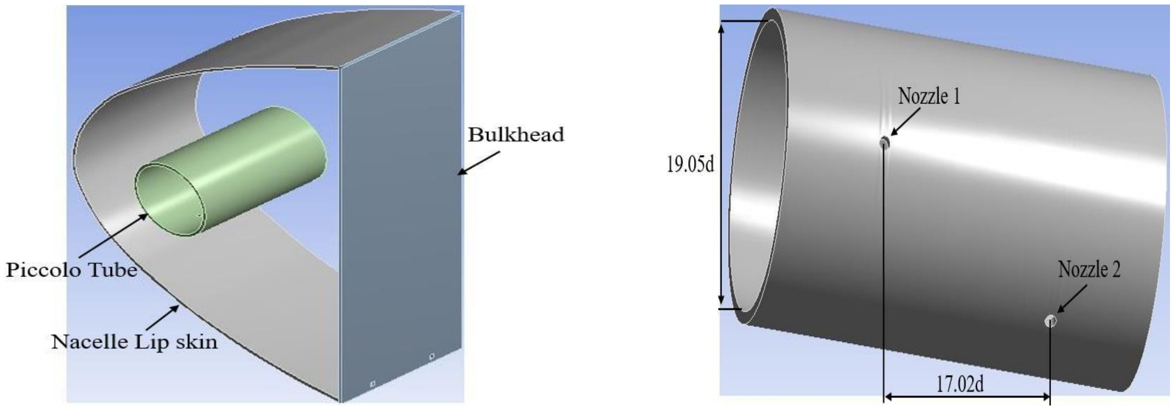

Figure 1. The Overall geometry of nacelle lip skin and Details of piccolo tube showing nozzle 1 and nozzle 2.

2.2 Meshing and Boundary Conditions

Using ANSYS workbench, the mesh was created which includes naming the surface and boundary conditions for the faces. 3 million hexahedron elements were used in the present study.

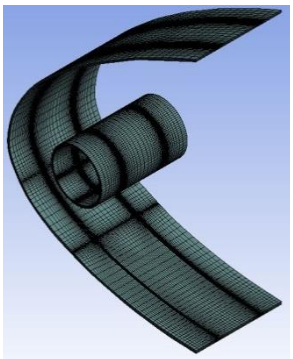

Figure 2. Meshing of nacelle lip-skin

For boundary condition as shown in Figures 3 and 4, pressure far field with 0.1 Mach number was used on the outer surface of the nacelle lip skin. Other boundary condition includes the inlet for hot gas which is called hot gas in and a pressure outlet for the hot gas which is called exhausted hot gas.

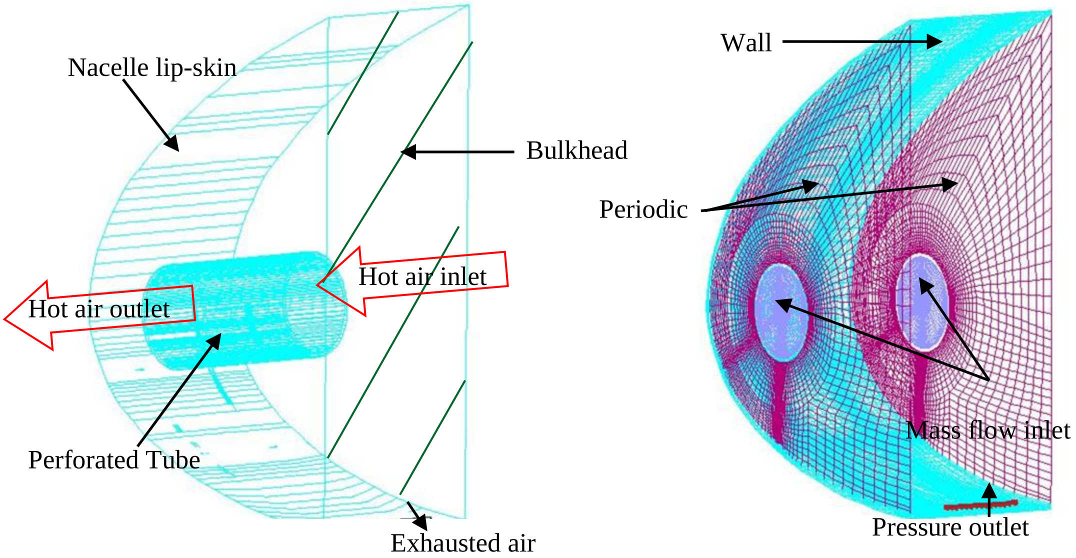

Figure 3. Boundary condition for PTAI inside D-chamber

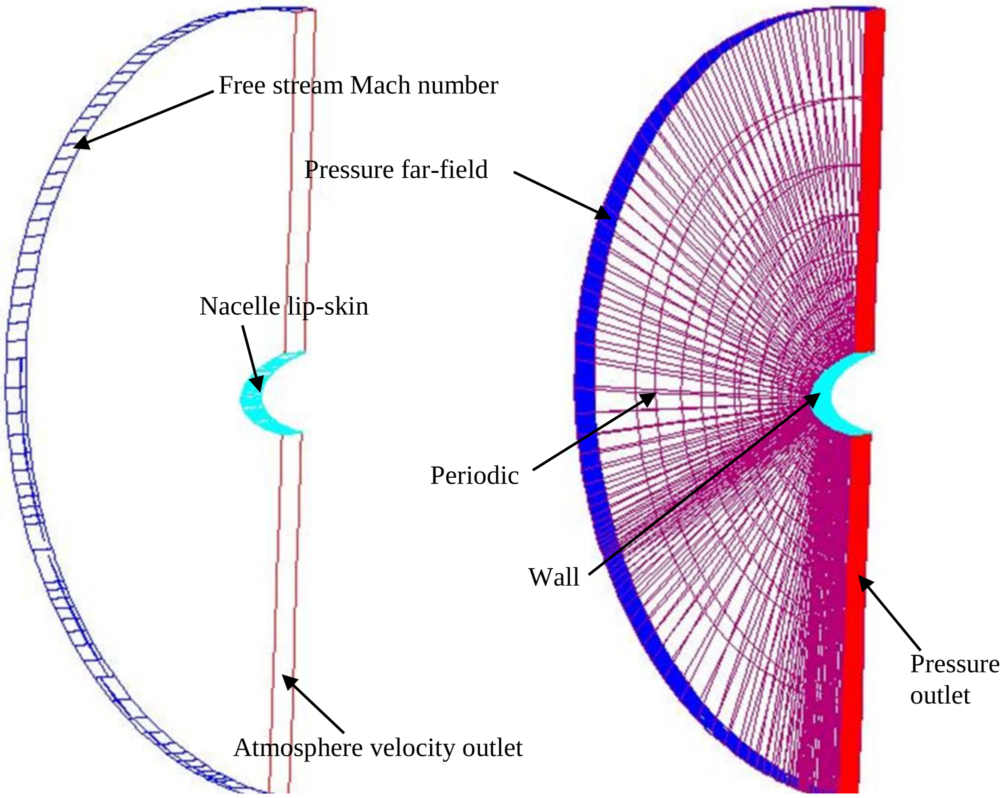

Figure 4. Boundary condition for PTAI inside D-chamber

2.3 ANSYS FLUENT Simulation

The simulation uses a turbulent model which is the shear-stress transport (SST) k-ω model and also the energy equation. SST k-ω model is an effective and accurate formulation of the k-ω model in the far field. The SST model incorporates a damped cross diffusion derivative term in the ω equation. Hence SST k-ω is able to provide a better accuracy of simulation result [8].

The boundary values are then inserted, operating condition in this simulation is 68050 Pa [9-11]. As for hot gas in and hot gas out the boundary. Next, the value of the parameter to be studied, the Reynolds number based on effective-impingement-surface (Re_G) of the hot air varies from 60 to 380. The ambient temperature and hot gas temperature of the study are 3°C and 272°C respectively. Re_G in present work is calculated by the following equation:

$$Re_G = \left(\frac{4Gd}{\pi\mu}\right) \tag{1}$$

Where

G	=	Hot air mass flow per unit area of effective-impingement-Surface
d	=	Diameter of Hole
μ	=	Air dynamic viscosity

2.4 Static Structural

In static structural, nacelle lip-skin was set as a solid domain. Since present work using FSI, the CFD results especially pressure and temperature were automatically exported to the Static structural software. After that, only one mechanical boundary conditions applied. Imported temperature data from CFD was applied on the nacelle lip-skin. For present work, one-way FSI is enough to predict stress and strain of nacelle lip-skin.

For this project, the material used and their composition are as follows:
AL 1100-O: 99% Al, 0.12 Cu, Aluminium 1st series
AL 2024-T4: 93.5% Al, Cu 4.4, Mn 0.6, Mg 1.5, Aluminium 2nd series
AL 7075-T6: 90% Al, Zn 5.6, Mg 2.5, Cu 1.6, Cr 0.23, Aluminium 7th series

3. Stress And Strain Analysis for Different Temperature on the Impingement Area

The temperature contour obtained from CFD simulation is shown in Figure 5 and the thermal stress and thermal strain contours on the nacelle lip-skin are shown in Figure 6. In Figure 5, the hotspot temperature occurs on the lower part of nacelle lip-skin, and the upper part of nacelle lip-skin has a lower temperature than the lower part of nacelle lip-skin. Figure 6 reveals that the highest strain and high stress occur on the hotspot area.

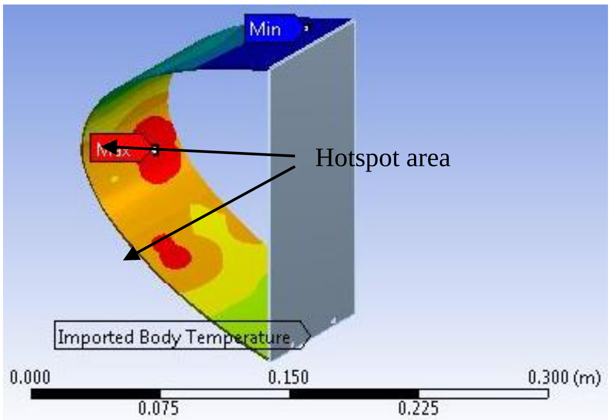

Figure 5. Temperature contour of nacelle lip-skin at ReG = 0.01362944

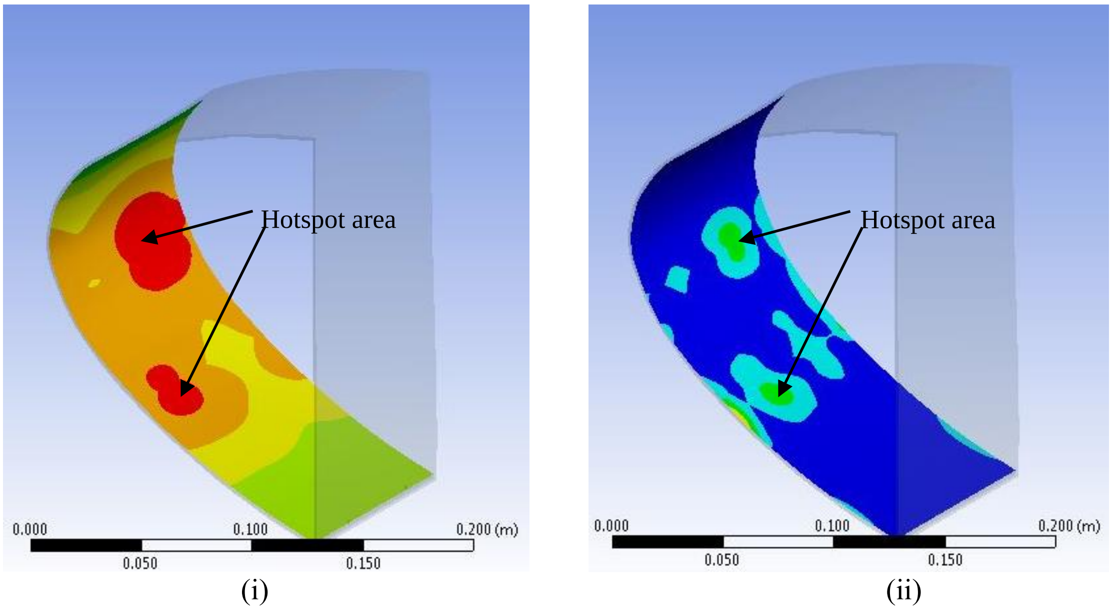

Figure 6. (i) Thermal strain contour and (ii) Thermal stress contour on nacelle lip-skin at Re_G = 0.013629447

Figure 7 shows the relationship between maximum stress and Re_G. As shown in Figure 7, the maximum stress increases tremendously with Re_G until it reaches peak value for all materials. Afterwards, the maximum stress decreases with Re_G. The figure also shows that the Aluminium 7 series has the highest maximum stress along Re_G, followed by Aluminium 2 series and Aluminium 1 series.

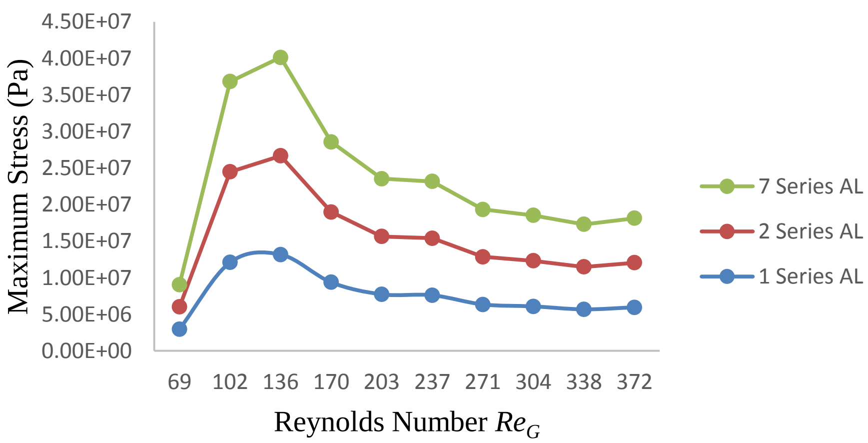

Figure 7. Graph of maximum stress against Reynolds number Re_G for all Aluminum series

The effect of Re_G on the maximum strain is shown in Figure 8. According to the figure, the maximum strain increases along Re_G for all materials studied. Similar to Figure 7, Aluminium 7 series shows the highest maximum strain and the lowest maximum strain is produced by Aluminium 1 series.

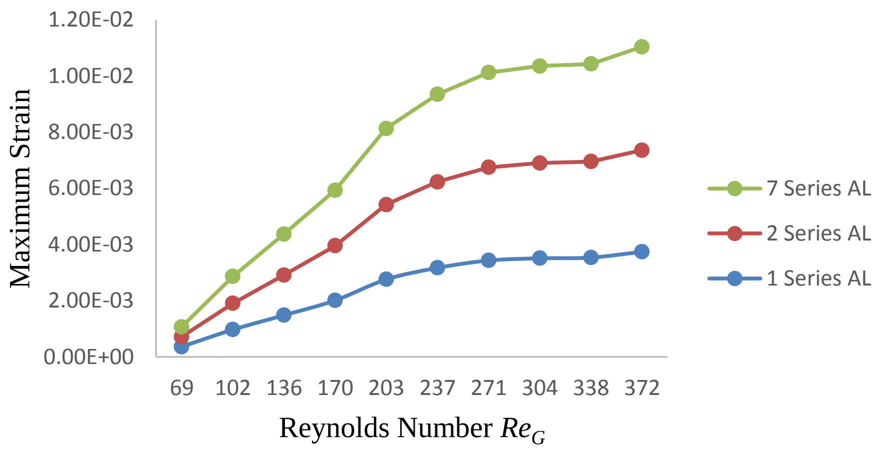

Figure 8. Graph of maximum strain against Reynold Number ReG for all Aluminum series

4. Conclusion

This present work studies the effect of hotspot temperature on the maximum thermal stress and thermal strain of nacelle lip-skin. The simulation has been done by the one-way fluid-structure interaction of ANSYS software. CFD part has been conducted by FLUENT and Mechanical ANSYS is used to predict maximum stress and strain. According to the results, maximum stress increases with Re_G until peak value, then it decreases with Re_G. Meanwhile, maximum strain continuously increases with Re_G. The simulation results show that Aluminium 1 series has the lowest maximum stress and maximum strain and the highest maximum stress and strain is produced by Aluminium 7 series. The lowest thermal stress and strain in present work are 40Mpa and 0.011 respectively.

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References

[1] J. W. Moe, J. J. Wunsch, and M. S. Sperling 2009 *Method and apparatus for noise abatement and ice protection of an aircraft engine nacelle inlet lip* ed: Google Patents.
[2] Q. Azam, M. A. Ismail, N. M. Mazlan, and M. Bashir 2016 *International Review of Mechanical Engineering (IREME)* **10** 390
[3] R. B. Rutherford 2001 *De-ice and anti-ice system and method for aircraft surfaces* ed: Google Patents.
[4] M. Ismail and M. Abdullah 2015 *Indian Journal of Science and Technology* **8**
[5] T. C. Currie, P. M. Struk, J.-C. Tsao, D. Fuleki, and D. C. Knezevici 2012 *4th AIAA Atmospheric and Space Environments Conference* 6.2012
[6] S. K. Thomas, R. P. Cassoni, and C. D. MacArthur 1996 **33** 841
[7] J. Thorpe, "100 Years of fatalities and destroyed civil aircraft due to bird strikes 2012 *International Bird Strike Committee, Stavanger* 1
[8] S. H. Park and J. H. Kwon 2004 *AIAA journal* **42** 1348
[9] M. Pascotto, A. Armellini, L. Casarsa, P. Giannatasio, and C. Mucignat 2012, *Effects of rotation and channel orientation on the flow field inside a trailing edge internal cooling channel* ASME Paper No. GT2012-68050
[10] E. D. Holstein *PEH: Reservoir Simulation*
[11] B. Srinivasan, A. Dhamarla, C. Jayamurugan, and A. B. Rajan 2014 *Numerical studies on effect of channel orientation in a rotating smooth wedge-shaped cooling channel* in ASME Turbo Expo 2014: Turbine