THE EFFECTS OF ICE FORMATION ON AIRFOIL PERFORMANCE

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

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This report was completed in dedication to both my beloved parents, Che Aziz bin Ramly and Mardziyah binti Muhammad Nasir

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ABSTRACT

Ice formation on airfoil due to two main factors, the first factor is by leaving the aircraft vulnerable towards snow and ice formation on land. The second factor is when the aircraft flies into cloud that contains supercooled droplets, as reported by Shields (2011). The ice formation will affect aircraft performance in terms of its ability to fly and manoeuvre. Past studies about ice formation on airfoil had only discussed about basic parameters of airfoil characteristics such as drag force and lift force. The objective of this study was to simulate and analyze the airflow around a two dimensional (2D) airfoil with and without ice formation on the leading edge. Three types of airfoil configurations were constructed using SOLIDWORKS 2010 software based on airfoil coordinates published by Addy (2000). The airfoil models was exported into CFD software in order to be simulated with specified boundary conditions and the results was analyzed. The obtained result shows that clean airfoil generates more lift and less drag compared to rime and glaze ice. At different altitudes, the result shows that as the aircraft ascend to higher altitude, the airfoil's lift and drag tends to drop. In conclusion, ice formation will decrease the performance of airfoil because the overall shape of the airfoil had changed from normal shape. It was also found that airfoil performance will be affected when the aircraft is at higher altitude because of the change in air properties at high altitude, in terms of density and viscosity.

ABSTRAK

Pembentukan ais pada airfoil terjadi atas dua faktor utama, yang pertama ialah dengan meninggalkan kapal terbang terdedah kepada salji dan pembentukan ais di atas darat. Faktor kedua ialah apabila kapal terbang melalui awan yang mengandungi titisan sangat sejuk, seperti yang telah dilaporkan oleh Shields (2011). Pembentukan ais pada airfoil akan mempengaruhi prestasi kapal terbang dari segi keupayaan untuk terbang dan bergerak. Kajian lalu tentang pembentukan ais di atas airfil hanya membincangkan tentang parameter asas pada ciri-ciri airfoil seperti daya angkat serta daya seret. Objektif kajian ini ialah untuk menjalankan simulasi dan menganalisa aliran angin melalui airfoil dua matra (2D) dengan dan tanpa pembentukan ais pada hujung hadapan airfoil. Tiga jenis konfigurasi airfoil telah dibina menggunakan perisian SOLIDWORKS 2010 berdasarkan koordinat airfoil yang telah diterbitkan Addy (2000). Model-model airfoil tersebut telah dieksport ke dalam perisian CFD untuk disimulasikan menggunakan keadaan sempadan dan keputusan telah dianalisa. Keputusan yang telah didapati menunjukkan bahawa airfoil bersih menjana lebih daya angkat dan kurang daya seret jika dibandingkan dengan ais "rime" dan "glaze".Pada altitud berbeza, keputusan menunjukkan bahawa apabila kapal terbang naik ke altitud lebih tinggi, daya angkat dan daya seret telah menurun. Pada konklusinya, pembentukan ais akan mengurangkan prestasi airfoil kerana bentuk asal airfoil telah berubah. Telah didapati juga bahawa prestasi airfoil akan terpengaruh apabila kapal terbang berada pada altitud lebih tinggi kerana perubahan ciri-ciri udara pada altitud tinggi, dari segi ketumpatan dan kelikatan.

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C_D	=	Coefficient of Drag
C_L	=	Coefficient of Lift
Re	=	Reynolds Number
U	=	Relative velocity
V	=	Viscosity of air
L	=	Length
kPa	=	kilo Pascal

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CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Airfoil will experience ice formation on the leading edge when the aircraft flies into bad weather condition. According to Shields (2011), leading edge will struck the super cooled droplets first and immediately freezes and this is why it occurs more on the leading edge. There are two types of ice formation on airfoil which are rime ice and glaze ice. According to Shields (2011), rime ice exhibits milky or white appearance while glaze ice is clear and smooth surface. In terms of structure, glaze ice is much more rigid compared to rime ice; hence it is harder to break. Research on airfoil could be done using two methods, which are experimental and CFD method. Experimental research involves two methods which are flight test and also wind tunnel test. According to Chi et al (2004), flight testing is the oldest and provides the most realistic simulation; however it is the costliest among the three methods. A controlled environment could be simulated in wind tunnel tests; however the downfall of wind tunnel tests is that it cannot obtain all the dimensionless parameters of actual flight conditions. Among the three methods, CFD is the cheapest method and is able to simulate the actual geometrical and flight characteristics. Hence, this fact shows that CFD simulation is a good tool in order to provide flow predictions for researchers. However, Chi states that the accuracy of the simulation depends on the grid quality and also turbulence model that were used in order to reproduce all flow characteristics that are needed.

Previous studies had shown several significant findings that are very important for flight safety. Based on simulation by Chi et al (2005) using CFD software, stall angle had drop for as much as 30% when ice formation was formed on the airfoil. Hence, the objective of this study is to simulate and analyze the airflow around a 2D airfoil with and without ice formation on the leading edge. In this study, the result will further elaborated from previous studies because there will also be analysis on airfoil performance due to change of altitudes.

1.1 PROBLEM STATEMENT

Past aviation history had seen numerous flight accidents due to ice formation on the aircraft body, particularly the airfoil. When ice was formed on the airfoil surface, the integrity of the overall shape of the airfoil will be disturbed. This is because the flow around the airfoil will not be as desired, resulting in loss of performance of the airfoil itself. Such airfoil characteristics that will be disturbed are the lift coefficient, drag coefficient and also pitching moment coefficient. Hence, further study needs to be done in order to understand the characteristics of ice formation on airfoil performance.

There are a lot accidents had been reported as a result of ice formation on the aircraft body. Moshansky V. P. Reported (1992) on an inquiry that on 10th of March 1989, Flight 1363 of Air Ontario was about to take off before the weather condition deteriorates, causing the flight to be postponed several hours. While waiting for the weather to be back in normal condition, ice starts to accumulate on the Fokker F28-1000 aircraft body especially at the wing. The pilot realizes this condition but continues the flight without any action. After 15 seconds of takeoff, the aircraft crashes to the nearby forest, killing 24 of 69 people onboard the flight. Further investigations by Commission of Inquiry into the Air Ontario Crash at Dryden, Ontario (Canada) revealed that the aircraft failed to generate enough lift force because of the ice formation on the wing.

1.2 OBJECTIVE

The objectives of this study are to simulate and analyze the airflow around 2D airfoil with and without ice formation on the leading edge.

1.3 SCOPE OF STUDY

There are three scopes of this study which are:-

a) Construct three types of airfoil models which are clean airfoil, airfoil with rime ice shape and airfoil with glaze ice shape.

b) Simulate the airflow around the three models using CFD.

c) Analyze the fluid flow characteristics around clean, rime ice and also glaze ice airfoil.

CHAPTER 2

LITERATURE REVIEW

2.0 LITERATURE REVIEW

The terms ‘ice formation’ and ‘airfoil performance’ are the two main priorities of this study. They are of two different perspectives but when combined together, it leads to a hazardous situation where flight accidents might occur. A study by Marwitz et al (1997) had revealed a catastrophic accident involving an ATR72 aircraft that involves ice formation as the potential cause. He suggested that the icing condition occurs at the crash area could be gained from pilot reports documentation (PIREPS). The PIREPS shows that more intense icing types were reported near the crash and the icing types were mostly mixed and clear. This occurrence is an indication that icing conditions (supercooled liquid water) were present at altitude where the aircraft was flying.

2.1 ICE FORMATION

2.1.1 TYPES OF ICE FORMATION

Ice formation properties differ from one condition to another. According to Shields (2011), ice formation occurs whenever there is an occurrence of supercooled drops at the area where the aircraft travels. Upon contact to the airfoil, the supercooled drops freezes and begins to form ice accretion. The study also proposes that there are two types of ice formation that normally occurs on an aircraft airfoil which are rime ice and glaze ice.

Rime ice as can be seen on Figure 2.1 occurs at a very cold temperature which is -9°C and below, where the supercooled drops will freeze almost immediately upon contact to the airfoil. It results in smaller ice accretions on the airfoil. The characteristics of a rime ice are that it exhibits a milky or white appearance because there is a lot of air that is trapped in the crystalline structure. The ice structure that contains trapped air will result in feathered edges with low density. Different from rime ice, glaze ice basically formed at warmer temperatures. The structure of glaze ice is generally clear and smooth surface and it occurs when supercooled droplets did not freeze quickly upon contact to the airfoil, hence the water drops will flow along the airfoil surface and forms a larger and more rigid ice structure. As it could be seen from Figure 2.1, the shape of glaze ice is a double horn or mushroom shapes. It was also stated by Shields that there is a possibility that both types of ice could also form at the same time.

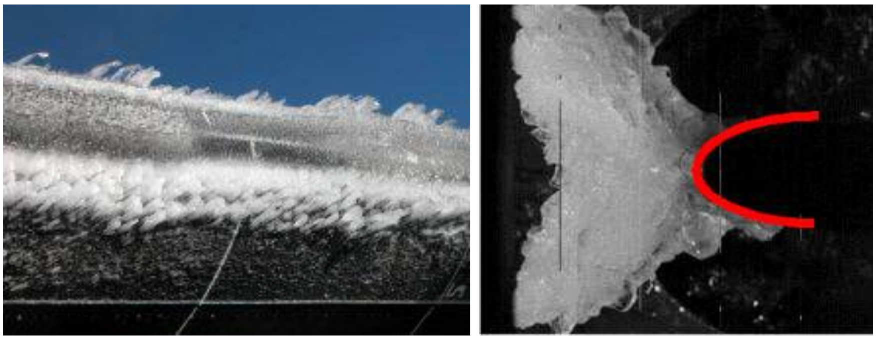

Figure 2.1: Rime ice (left) and glaze ice (right) formation (Source: Shields, 2011)

2.1.2 CONDITIONS FOR ICE FORMATION

Apart from ice that is formed during flight at icing conditions, it must be made aware that there are also several other conditions that could contribute towards ice formation of aircraft airfoil. Lynch and Khodadoust (2001) had come up with several causes of ice formation on airfoil, without having to go through flight icing conditions. One of the most significant condition and that had also claims lives from flight accidents is by leaving the aircraft and its components in a bad weather conditions unprotected by ice protection systems such as shown in Figure 2.2.

Another significant factor that had been suggested by Lynch is ice formation on both lower and upper surfaces of the wings which is close to the fuel tanks. This condition occurs when an aircraft is parked in a high atmospheric humidity conditions and the fuels that has been cooled in flight remains in the tank and forms the ice. The delay or ignorance in implementing anti-icing procedure could also be the factor in ice formation on an aircraft airfoil. These findings shows that ice formation on airfoil will not just depends on icing conditions during flight, it also indicates that pre and post flight conditions could also be a contributing factor towards ice formation on airfoil.

Figure 2.2: Aircraft with ice formation on land (Source: Meteorology-Part II [Active Weather] Website, Retrieved on 30th November 2012)

2.1.3 COUNTERMEASURES FOR ICING CONDITIONS

For any icing conditions, the way the pilot approaches the problem is very important in order to ensure that the aircraft is not vulnerable to any danger regarding icing condition risks on the aircraft itself. There are several key countermeasures that need to be done carefully because any miscalculation could prove to be too risky to the safety of all the people onboard the plane. In this case, the experience and wise judgement of the pilot are very important because they are the one that will make any decision regarding the situation. Past accidents had shown that pilots sometimes tend to make ill judgement about icing condition that had resulted in accident. On 10th of March 1989, the pilot of Flight 1362 Air Ontario had decided to take off despite the fact that snow had accumulated rapidly on the wings of the plane. What happens next is history; the plane had crashed to nearby forest because the wing could not generate enough lift for the take off and crashes, claiming 24 lives. This is one of many other examples where bad decision had lead to fatal plane accident.

Hence, in order to face icing conditions, the pilot needs to take several countermeasures in order to ensure the plane will not be affected by any risks. According to Thomas (1999), the best decision if a fatal icing condition is present is not to fly at all, however this is not a very popular step to be taken. The pilot needs to be briefed of the incoming weather situation that will be encountered in order to ensure that are well prepared for the icing condition. When icing condition is present, the pilot could decide to adjust his or her cruising altitude in order to prevent from running into clouds that are potentially to create icing condition. Hence, this step is more to evasive action rather than reactive action.

The second countermeasure to eliminate icing condition risk is actually to run away from the cloud that could create ice on the plane. This is a more reactive measure due to the fact that the step is taken only when the plane had already run into clouds that could potentially accretes ice on the plane. From an article written by Thomas (1999), there are two ways to run away from the icing conditions which are to descend to lower altitude and also to ascend to higher altitude. However, this countermeasure comes with a risk where the pilot needs to make sure that the plane has enough power in order to climb to higher altitude, otherwise it could crash due to insufficient thrust and lift on the plane.

For most of modern planes, one of the most important instruments that need to be fitted to the aircraft is the de-icing boot which is a device that will eliminate any ice accretion for certain part of the plane especially the wing and the tail. According to Steve Ells (2004), there two types of active device to shake off ice accretions which are de-icing and also anti-icing. Anti icing is a more towards preventive measure where the device is turned on before the plane runs into any icing conditions. It is different to de-icing device (Figure 2.3) where it is more towards reactive measure because the device will only be turned on when there is ice formation on any part of the plane that is equipped with the device.

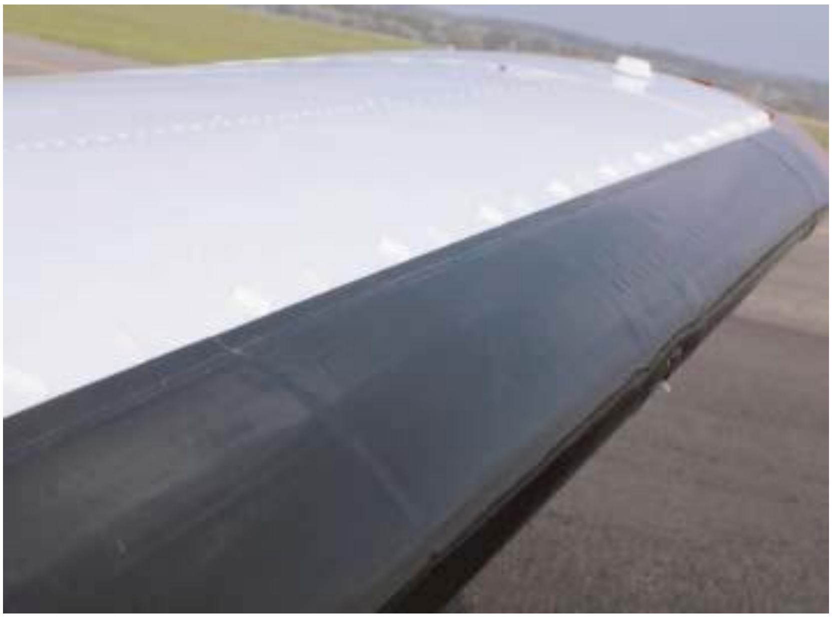

Figure 2.3: Pneumatic De-icing Boot (Source: Murphy and Bell (2004)