EXPERIMENTAL STUDY OF HEAT TRANSFER RATE ON ACOUSTIC LINER

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LIST OF SYMBOLS

A	Surface area of aluminum plate (m^2)
h	Heat transfer coefficient (W/m^2 K)
$\dot{k}$	Thermal conductivity
Nu	Nusselt number
$\dot{Q}$	Heat transfer rate (W)
q	Heat flux (W/m^2)
Re	Reynolds number
r	Radial distance
ΔT	Change in Temperature
u	Velocity of fluid
μ	Viscosity of fluid (Ns/m^2)
ρ	Density of fluid (kg/m^3)
θ	Dimensionless Temperature
^{0}C	Degree Celcius

LIST OF ABBREVIATIONS

3D	Three-Dimensional
A	Heat transfer area
AL	Acoustic Liner
BAL	Bias Acoustic Liner
SDOF	Single degree of freedom
EIDI	Electromagnetic Impulse De-icing
ETEDS	Electro-Thermal De-icing System
$\bar{h}$	Convection heat transfer coefficient over entire area
k	Air thermal conductivity
SLW	Supercooled Liquid Water
FPD	Freezing Point Depressant
m/s	meter per second, SI unit of velocity
MEDS	Mechanical Expulsion De-icing System
mm	Millimeter, SI unit of length in the metric system
Nu	Nusselt Number
Nu_{max}	Maximum Nusselt Number
NTSB	National Transport Safety Board
P	Absolute Pressure
PETDS	Pulse Electro-Thermal De-icing Systems
PIB	Pneumatic Inflatable Boot
PTAI	Piccolo Tube Anti Icing
q	local heat flux density
Re	Reynolds Number
r/D	dimensionless radial distance from centre of plate
Re	Reynolds number
SAI	Swirl anti-icing
$\check{T}$	Dimensionless temperature
$T\infty$	Ambiance Temperature
$T_{ambient}$	Temperature ambient

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ABSTRAK

Pada asalnya dipercayai bahawa ais di permukaan pesawat menimbulkan masalah aerodinamik dan mekanik penerbangan utama yang boleh menjejaskan keselamatan penerbangan. Hentakan jet udara panas adalah satu kaedah untuk menghapuskan aising dari permukaan pesawat yang penting, seperti kulit bibir nacelle. Walau bagaimanapun, kadar pemindahan haba garisan akustik yang merupakan bahan yang digunakan terutamanya berhampiran kulit bibir nacelle tidak mempunyai keputusan eksperimen setakat ini. Kajian eksperimen tentang kadar pemindahan haba bagi talian akustik dilakukan untuk menentukan pekali pemindahan haba bagi pelapik akustik untuk melihat dengan lebih baik proses yang berlaku apabila haba diletakkan di bawah pelapik akustik dan aliran udara dengan halaju yang berbeza diberikan. 5 nilai perolakan haba yang berbeza diberikan untuk setiap set data yang juga mempunyai 7 nilai halaju kipas yang berbeza untuk setiap nilai perolakan haba. Pelapik akustik diletakkan pada pad pemanas dan diletakkan ke dalam ruang. Termokopel diletakkan di pelbagai tempat untuk mengukur suhu ambien, suhu dinding pelapik akustik dan suhu pemanas. Selepas memanaskan pad pemanas untuk seketika, kipas dihidupkan dan kelajuan ditukar setiap 30 minit. Ini diulang untuk 7 kelajuan kipas dan 5 nilai perolakan haba. Semua keputusan ujian agak serupa antara satu sama lain. Graf pekali haba vs nombor Reynolds dan graf nombor nusselt melawan nombor Reynolds darab dengan nombor Prandtl diplotkan. Kedua-dua graf menunjukkan sedikit penurunan sebelum meningkat dengan nombor Reynolds turut meningkat. Penurunan sedikit ini disebabkan oleh aliran laminar iaitu di bawah 2000 nombor reynolds dan aliran peralihan iaitu sekitar 2000-4000 nombor reynolds. Selepas mencapai aliran bergelora melebihi 4000 nombor reynolds, pemindahan haba meningkat secara beransur-ansur dengan nombor Reynolds. Kesimpulannya, pelapik akustik berfungsi sebagai bahan yang baik untuk pemindahan haba kerana ia boleh berfungsi dengan baik untuk mengurangkan pembentukan ais pada kulit bibir nacelle. Kadar pemindahan haba pelapik akustik meningkat dengan aliran nombor Reynolds yang lebih tinggi.

ABSTRACT

It was originally believed that ice on an aircraft's surface posed a major aerodynamic and flight mechanics problem that could compromise the flight's safety. Hot air jet impingement is one method for eliminating icing from crucial aircraft surfaces, such as the nacelle lip skin. However, the heat transfer rate of the acoustic line which is the material used mainly near the nacelle lip skin has no experimental results so far. The experimental study on the heat transfer rate of the acoustic line is done to determine the heat transfer coefficient of the acoustic liner to better see the process that happens when heat is placed under the acoustic liner and air flow with different velocity is given. 5 different value of heat convection is given for each data set which also has 7 different values of fan velocity for each heat convection value. The acoustic liner is placed on the heater pad and set into a chamber. Thermocouples are place in various spots to measure the ambient temperature, acoustic liner wall temperature and heater temperature. After heating the heater pad for awhile, the fan is switched on and the speed is change every 30 minutes. This is repeated for 7 fan speeds and 5 heat convection values. All test result are somewhat similar to each other. The graph of heat coefficient vs Reynolds number and the graph of nusselts number against Reynolds number multiply by Prandtl number is plotted. Both the graph shows a slight drop before increasing with the Reynolds number also increasing. The slight drop is due to the flow being laminar which is under 2000 reynolds number and transition flow which is around 2000-4000 reynolds number. After reaching a turbulent flow above 4000 reynolds number, the heat transfer increases gradually with the Reynolds number. In conclusion, the acoustic liner serves as a good material for heat transfers as it can work well to reduce ice formation on the nacelle lip skin. The heat transfer rate of the acoustic liner increases with the higher Reynolds number flow.

CHAPTER 1

INTRODUCTION

1.1 Overview of the project

The risk of aircraft icing continues to be a significant threat to the aviation industry despite the ongoing expansion of the global fleets of commercial airlines, regional business jets, and general aviation aircraft. Most aviation freezing incidents result from ice building up on the aircraft's aerodynamic surfaces, like the tail's leading edges and the nacelle lip-skin surface (Authority, C. A. 2000). The ice buildup on the lipskins' inner surface can be dangerous to aircraft in flight as it will shatter and collide with the compressor. As a result, the compressor blade will be damaged, and an aircraft accident is highly possible (Syed *et al*., 2018). To guarantee that the aircraft's performance and operation are not jeopardized, ice on aircraft components must be removed or prevented at all feasible. Even little amounts of ice might cause problems. As a result, numerous ways for preventing and eradicating ice have been devised.

The two most common forms of ice control treatments are anti-icing and de-icing. Having an anti-icing system installed on any aircraft is critical because aircraft's aerodynamic properties can be significantly altered by the accumulation of ice on the lip-skin. In addition to this, it may result in an increase in the amount of fuel consumed because of the higher drag force caused by the non-aerodynamic shape that is present on the lip skin (Syed *et al*., 2018). Heat is used as the most frequent anti-icing technology to prevent ice from forming on the aircraft's surface. Hot air from the engine heats the leading edge's inner. After then, conduction allows heat to go from the inner surface of the leading edge to the outer surface of the edge. When liquid water comes into contact with the aircraft's surface, the heat from the hot air evaporates it. Evaporation of water droplets will not be achieved if the heat provided is insufficient. It causes water droplets to return back to the unheated area of the aircraft and freeze (Hassaani *et al*., 2020).

De-icing methods are used to remove ice that has accumulated on the outside surface after and during ice build-up. There are two types of ice protection systems that make use of de-icing technology. These are the Pneumatic Inflatable Boot and the Electro Magnetic Expulsion. Anti-icing devices are meant to drastically decrease or eliminate an ice buildup on protected surfaces. In order to achieve this, anti-icing fluids such as thermal and chemical fluids are routinely used (Ismail *et al*., 2015). Aside from the formation of ice on aircraft, aviation engine noise is becoming a major concern as a result of strict noise control regulations. To remedy this, the Federal Aviation Administration set aircraft noise limits that must be followed by all aircraft manufacturers. Installing an acoustic liner (AL) in a loud cowl zone, for example, is one approach for reducing engine and turbine noise (Lucas, 2017).

Lucas (2017) suggested placing a noise abatement system on the leading edge of nacelle because nose cowl zones have a restricted amount of space available. However, when an acoustic liner and anti-icing were combined on the leading edge of a nacelle, it was not able to successfully minimize the forward radiated noise while also boosting the thermal performance of the anti-icing system. As a consequence of this, a bias acoustic liner, also known as a BAL, is fitted in that specific area so that the non-uniform heat transmission to the nacelle lip cowl zone can be compensated (Ives *et al*., 2011, Ismail & Wang 2018).

Piccolo Tube Anti Icing, often known as PTAI, is the primary technology that has been used to prevent the accumulation of ice on the nacelle lip skin of contemporary commercial transport aircraft (Ismail *et al*., 2015). Ice formation can be prevented with the use of PTAI, however it generates an uneven temperature distribution along the lip of each of the engine nacelles. As a result, a hotspot is created. Even if the Bias Acoustic Liner may be placed on the critical area which is the nacelle lip, high-temperature and velocity PTAI impinging jets may cause damage or destruction to the material of the nacelle lip-skin material if they are concentrated at one point on the nacelle lip-skin (Ismail, 2014). Hence, this project is performed to study the heat transfer on an acoustic liner.

1.2 Problem Statement

When it comes to aircraft, aerodynamic is one of the most significant characteristics. An aircraft's aerodynamic performance can be adversely affected by a natural ice buildup on the nacelle lip skin and leading age of the wing, which can lead to fatal aviation accidents. To combat this, a piccolo tube anti-icing system was added to the nacelle lip skin to improve the aircraft's noise abatement system. However, the addition of acoustic liner and bias acoustic liner has created an issue because it prevents enough heat from passing through. Heat from the anti-icing system isn't properly dispersed, resulting in hot spots and damaging the bias acoustic liner, which was previously recommended. To investigate this, an experimental setup is needed to measure the rate of heat transmission on the acoustic liner and the thermal distributions of heat objectives.

1.3 Objectives

This research aims

1) To develop an experimental setup to determine the heat transfer rate on an acoustic liner.
2) To study the thermal characteristics on an acoustic liner.

1.4 Outline Scope of the Project

This study needs to be done on an experimental setup to get an experimental data because previously most of the data were retrieved from simulation. To setup experiment, we need an acoustic liner, a heater, thermocouples, thermal glue insulated jig, an air pressure regulator and compressed air. Firstly, an acoustic liner need to be 3d printed according to the size of the heater. The insulator jig, preferably wood, is designed to hold the heater and an acoustic liner. Then some thermocouples are connected randomly on the acoustic liner to read the change in temperature. Compressed air is then passed through the regulator and then through a nozzle before it is released to hit the surface of the acoustic liner. Velocity will be controlled by the regulator. The outlet nozzle is placed vertically above the acoustic liner. When the heater is switched on and air is allowed to hit the surface of the acoustic liner, the rate of heat transfer will be collected through the thermocouples which will be connected to a data logger to compile the results.

CHAPTER 2

LITERATURE REVIEW

2.1 Aircraft Icing

An atmospheric phenomenon known as "aircraft icing" causes ice to accumulate on an aircraft. Two atmospheric conditions required for the icing to occur are visible moisture, and fixed air temperature at or the below freezing point (0°C). Supercooled liquid water (SLW) is a water droplet that present in a liquid state below the freezing point. SLW droplets can persist at -40°C temperature and often do not become ice until they are disturbed. The accumulation of supercooled liquid water (SLW) on an aircraft whose skin temperature is below freezing is known as in-flight icing. The impact of supercooled water droplets on an aircraft's vital surfaces, such as the wing and nacelle leading edge, causes ice to accumulate on the surface of the aircraft. Depending on its size and temperature, a portion of supercooled water will either quickly freeze and stick to the surface or run back and re-freeze downstream (Vukits, 2002).

Accretion of ice on the sensitive aircraft’s components can have a serious impact on flight performance and aircraft conditions. The formation of ice on the inner surface of the lipskin poses a risk to flying vehicles if it continues to buildup (Moe *et al*., 2009). There are three categories of ice formation on an aircraft. The types of ice are rime ice, glazed ice and mixed ice. Rime ice is obtained at temperature lower than 10^0C. It often freezes immediately upon impact due to rime’s ice natural brittle physical state and less dense properties. When the droplets are big and the surrounding air is relatively warm, glaze ice forms. The supercooled liquid will run back to the surface and freeze there instead of immediately freezing upon impact. When compared to rime rice, glaze ice with a larger liquid water content has a higher rate of accretion and more dangerous. The type of ice that frequently developed is mixed ice. It has both the qualities of glaze ice and rime ice (Vukits, 2002).

Table 2.1: Rime ice versus Glaze ice generalized differences. Source: Vukits (2002)

Condition	**Rime Ice**	**Glaze Ice**
Temperature	Cold; Less than -10^0C	Warm; 0--10^0C
Liquid Water Content	Low	High
Density	Low	High
Airspeed	Low	High
Colour	Milky / Opaque	Glossy / Clear
Texture	Rough	Smooth
Runback	No	Yes
Fragility	Brittle	Hard
Water Droplet Size	Small	Large
Airfoil Ice Shape	Streamlined / Spearheaded	Single or double horn

2.2 Ice Protection System

Performance criteria for an ice protection system varies significantly based on aircraft's lifting surfaces as it determines the sensitivity of ice contamination and requires ice protection on a different level. For instance, airfoils used in the design of a particular lift surfaces may have varying degrees of resistance to the effects of ice contaminations and as a result, optimizations of multiple ice protection system are possible. The available energy for ice protection is only used when it is absolutely necessary to address the specific sensitivity of a given airfoil segment. On the other hand, some aircraft may have enough power supply to run an electric de-icing system, whereas for others, the heat generated by the electrical power is not enough for the ice protection system. Failure of the system to generate sufficient heat to keep the ice off leads to unwanted aircraft accidents (Al-Khalil & Kamel, 2007). According to the National Transport Safety Board (NTSB) (2014), an Embraer EMB-500 Phenom's aircraft that crashed into a neighbourhood in Gaithersburg, Maryland on December 8, 2014 is an illustration of an air catastrophe brought on by ice accumulation.

The pilot's failure to activate the anti-icing system and horizontal stabilizer de-icing equipment during an in-flight icing event caused ice to build up on those surfaces and contributed to the tragedy. The aircraft had been in icing conditions for about 15 minutes when it was about 2.8 nautical miles from Gaithersburg-Montgomery County Airport. When the airspeed started to decline, the aircraft roll to the right and left and resulted in an aerodynamic stall at an altitude at which a recovery was not possible. With regards to accident prevention, ice protection system such as anti-icing and deicing are excessively studied to ensure an aircraft’s safety. The general operation of ice protection systems are by lowering the freezing point below the ambient air temperature. Two techniques that are absolutely necessary for the safety of aircraft are anti-icing and de-icing. Deicing is the process of removing ice that has accumulated on an aircraft surface, whereas anti-icing is the technique of preventing ice from forming while in flight (Yongqiang *et al*., 2018).

According to Bin (2012), the freezing point depressant, thermal and mechanical approaches are the three fundamental kinds of anti-icing and de-icing procedure that are utilized. It is common practice for the freezing point depressant to make use of anti-icing or deicing chemicals such as propylene glycol and ethylene glycol to lower the freezing point of supercooled water droplets and melt down the ice formation that has already formed. This method's drawbacks include environmental pollution and low efficiency (Pourbagian & Habashi, 2013). On the other hand, Mohseni & Amirfazli (2013) stated that, the delivery of heat flux to the surface of the aircraft is required for the thermal approach. It generates a heated boundary layer at that location in order to prevent supercooled water droplets from freezing into ice crystals or dissolve the ice that has already crystallised. Moreover, utilizing hot electrical energy, hot oil, hot exhaust gases, or hot compressor gases are some examples of the methods that fall under this category of approach ((Pourbagian & Habashi, 2013). In contrast, the mechanical ice protection method destroys the bond of ice formation on aircraft surfaces by using air flow and gravity. Through that, it helps to clear the surface of any remaining fragments of the ice.

Pneumatic boots, electromagnetic expulsive boots, and electromagnetic impulse deicing (EIDI) are examples of this type of technique (Sommerwerk *et al*., 2016).

2.2.1 De-icing

Soviet scientists were the ones who first proposed the Electro Impulse De-Icing (EIDI) technology. The basic principle behind using a pulse coil and the instantaneous discharge approach is to generate an electromagnetic eddy current field on the metal skin. Through that, a transitory electromagnetic force is produced and under the presence of inertial and aerodynamic forces, the skin immediately vibrates and deforms, thus it helps in the breakage of ice layers. The advantages of the EIDI are it requires low energy intakes, easy installation and maintenance while the disadvantages are due to the vibrations of excessive frequency it easily causes skin fatigue damage (Jun *et al*., 2020).

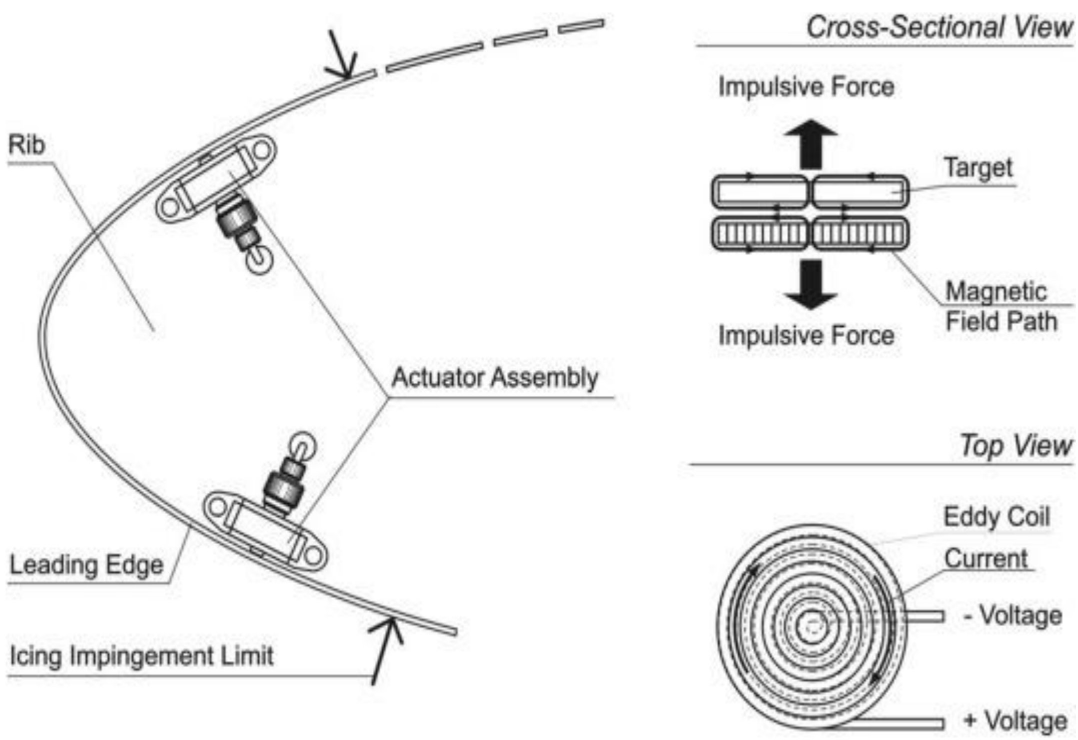

Figure 2.1: Impulsive force in a leading edge (Eddy Current). Source: Huang *et al*., (2019).

A resistive heater is used in Electro-Thermal De-Icing Systems, and it is attached to the area of the airfoil that needs to be protected from icing. There are many individual heaters that make up each segment. Common practice is to install one or two heaters directly towards the downstream on the upper and the lower surface of the parting strip, during a de-icing procedure, they are turned on one at a time and run for a duration just long enough to melt the thin coating of ice that forms at the aircraft's surface. It lets the current aerodynamic forces to control any ice that forms on the interface (Al-Khalil & Kamel, 2007).

In order to accomplish the deicing effect, hybrid deicing technique combines both electro-thermal and electro-impulse deicing technologies. The ice covering on the skin's surface is loosened using an electric heating device. Moreover, it is more convenient in terms of energy consumption and electro impulse deicing helps to reduce the damage at the skin (Jun *et al*., 2020). On the other hand, according to Goodrich, Pulse Electro-Thermal De-icing Systems (PETDS) uses an electro thermal pulse approach. Strips and shedding zones serve as the heating elements in PETDS. The shedding zones melt the ice contact at the leading-edge surface while the partition strips keep the surface temperature above freezing.

Finally, a pneumatic inflatable boot (PIB) is also used as a de-icing system for fixed aircraft's wing applications. The usage of PIB is simple and only calls for bonding a rubber boot to the lifting surface's leading edge. This boot inflates when exposed to wind, deboning any existing ice and stopping new ice from forming on the expanded surface (Dury *et al*., 2017).

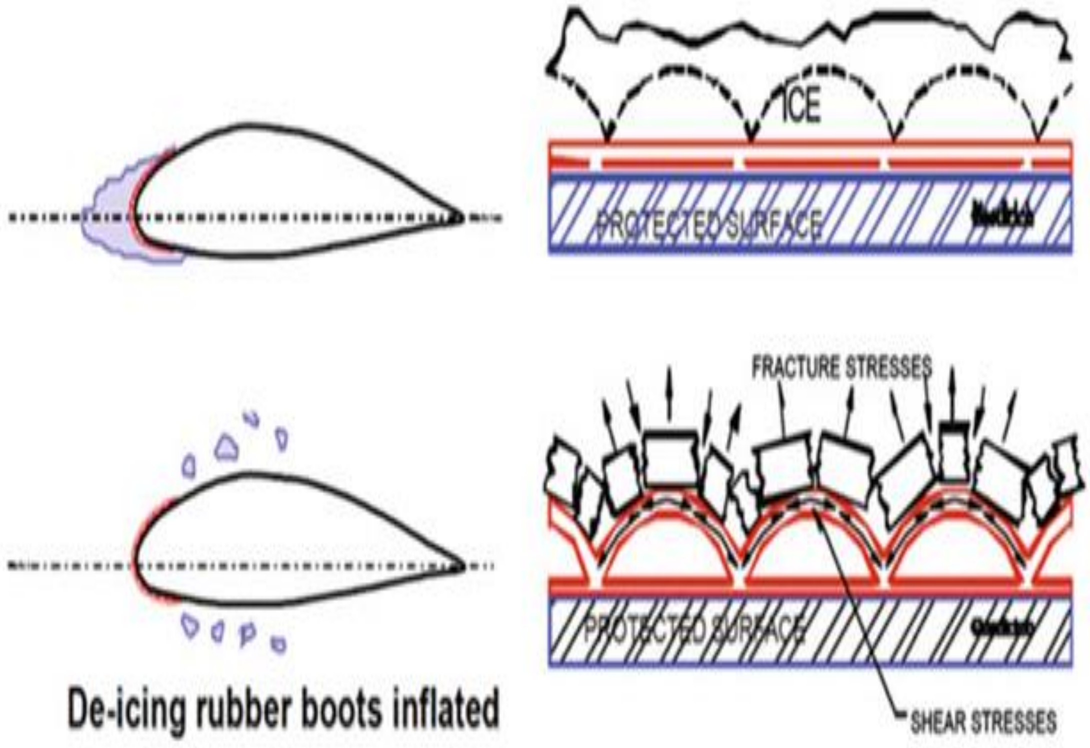

Figure 2.2: Working principle of Pneumatic Inflatable Boot (PIB). Source: Lorenzo Battisti (2015)

2.2.2 Anti-icing

Anti-icing systems that use hot bleed air, like Piccolo Tube Anti-Icing (PTAI), is very common. It has high efficient in anti-icing solution, and is therefore widely used in the nacelle lip skin and aircraft's wings. Hot air mass flow rate, distance from the holes to the surface, impingement angle and jet spacing are several parameters that affects PTAI's thermal performance (Raghunathan *et al*., 2006). The inner surface of the wing can be heated to a high velocity by hot air blasted from the engine compressor through staggered holes in the Piccolo tube. A piccolo tube that runs the length of the aircraft's slat in the D chamber is used to distribute the hot air. Conduction is used to move heat from the interior to the exterior surface in order to prevent ice. The waste air is subsequently expelled from the slats' aft bay using vents (Labuhn & Logeais, 2012).

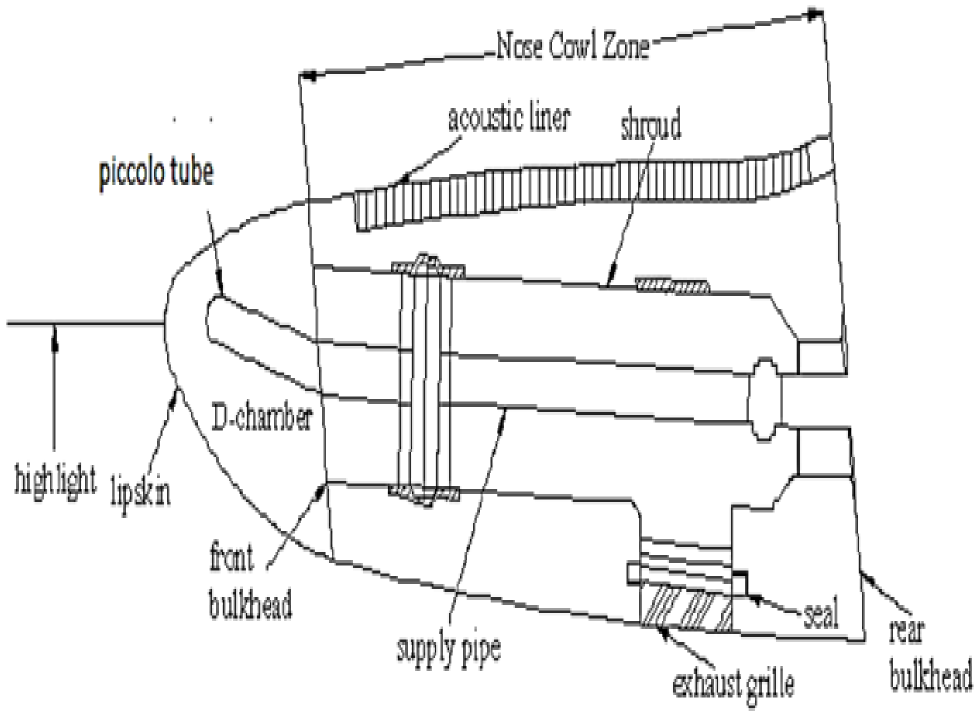

Figure 2.3: Part of nacelle intake . Source (Khai *et al*., 2020)

Electro-thermal ice protection systems can also be used in anti-icing mode, which allows them to be installed in crucial areas such as nacelle lips and windshields. Anti-icing mode reduces the amount of ice that accumulates on surfaces and activates partition strips in sequential order in order to save power consumption. Electro-thermal anti-icing requires an excessive amount of energy, which necessitates the usage of electricity. As a result, de-icing operations on larger surfaces are more feasible (Ma, 2010).

The FPD (Freezing Point Depressant) for grooved panels that are put in the front portions of the airframe serves as the basis for the TKS (Tecalemit-Killfrost Sheepbridge Stokes) installation's operating concept. To avoid ice formation, a mixture of water and the agent of choice, glycol, is mixed together. Water and glycol have different freezing points. Combining these two ingredients yields a freezing solution at -51^{0}C. When the two components are combined, they significantly lower the freezing point and under icing conditions, an aircraft outfitted with such a device will be ice-free (Gliwa *et al*., 2018).

2.3 Acoustic Liner

Modern acoustic liners (AL) often use a honeycomb structure sandwiched with a perforated face sheet and solid back-face between two plates, one of which is porous and the other is nonporous (Ives *et al*., 2011). There are two main sources of aircraft noise which are the engines and the airframe. The jet and fan noises are the key contributors to the overall engine noise. As a result of improvements made to turbo fan engines that have high bypass ratios, the noise produced by the fan now accounts for a greater proportion of the total noise produced by turbofan engines. Installing acoustic liners in the interior of the nacelle is a conventional method for lowering the amount of noise produced by the engine (Ma *et al*., 2020).

The perforated face plate not only improves the acoustic liner's ability to absorb sound, but it also ensures that the flow of aerodynamic forces against the internal wall of the nacelle is kept as smooth as possible. The term "single degree of freedom" refers to this acoustic liner, which consists of a perforated plate over a honeycomb backing (SDOF). The conventional SDOF liner produces an extremely narrow absorption spectrum. Resonant frequency corresponds to the point of maximum absorption that is determined by the thickness of the honeycomb (Ma *et al*., 2020).

Thanapal (2019) had investigated the influence of perforated liner porosity during grazing. According to the results obtained, at very low porosity, the perforated liner amplifies sound rather than dampening it. Perforated liners' acoustic dampening capacity increases with increasing porosity up to the point when optimal porosity is obtained. Liners' effectiveness will degrade if their porosity is allowed to increase any further.

A better efficiency of heat transfer between the surface and the fluid flow by convection occurs when the number of perforations in the fins is increased, as this result in higher temperatures at the fins' base and tip. Perforation creates higher turbulence intensity at the perforation area causes heat dissipated more rapidly (Shaeri *et al*., 2009).

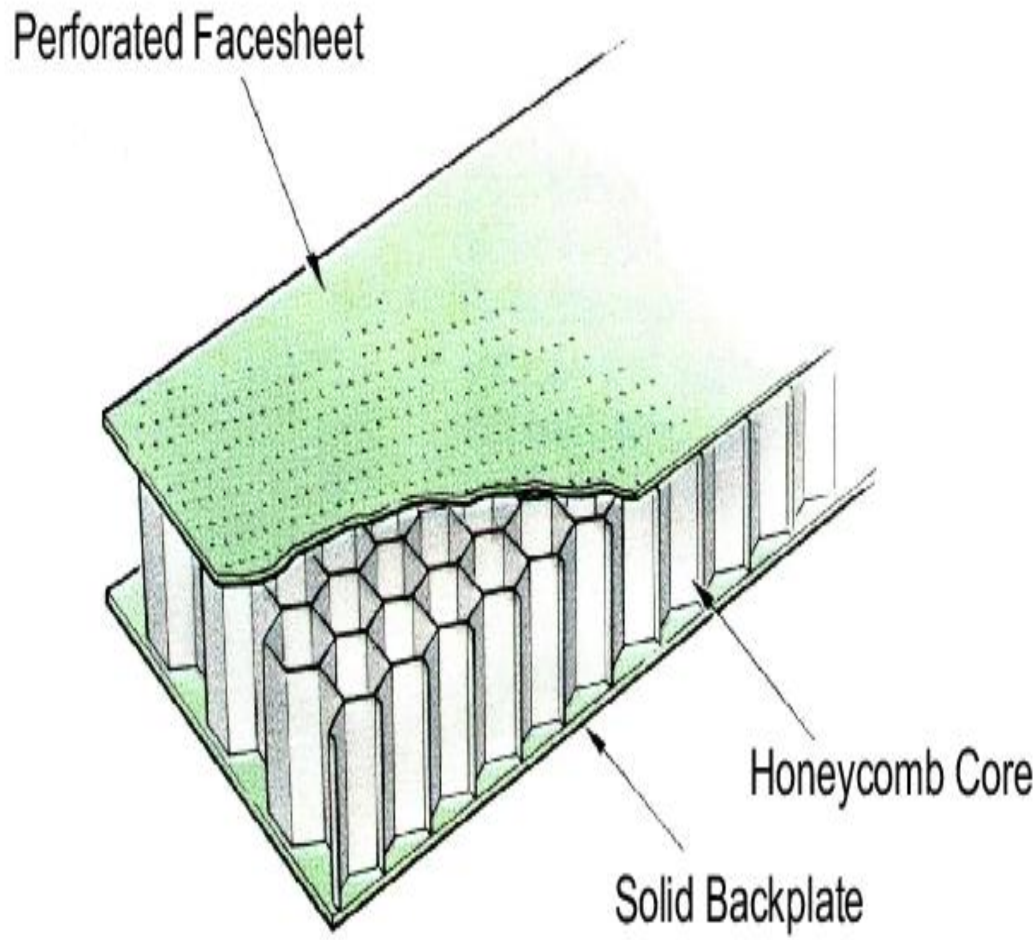

Figure 2.4: Conventional Acoustic Liner (AL). Source (Primus *et al*, 2013).

2.4 Heat conduction (Heat transfer for plate condition)

In a detailed analysis of Fourier's law of heat conduction, Mohd Azmi (2014) concluded that for a given value of air thermal conductivity, the rate at which heat is transferred from the surface to the fluid in the boundary layer is highly sensitive to the magnitude of those temperature gradients. Increased surface heat flux is a result of the larger temperature gradient created by the thinner boundary layer of impingement. Increasing the speed of the external flow increases the temperature gradient and causes a thinner boundary layer. Therefore, the heat transfer coefficient rises.

$$q = -k\Delta T \qquad 2.1$$

Where, q = heat flux

k = thermal conductivity

$\Delta T = T_{hotairavg} - T_{surfaceavg}$

Area, temperature difference, and thermal conductivity all increase proportionally with increasing heat transfer convection, as predicted by Newell Thomas (2003) through the analysis of heat flux. Alternatively, heat transfer by convection decreases with increasing thickness.

$$Q = -\frac{Ak}{t}\Delta T \qquad 2.2$$

Where, Q = Heat transfer conduction

A = area

t = thickness

T_{sur} = Surface temperature

T_{amb} = Ambient temperature

2.5 Reynolds Numbers

The Reynolds number (Re) is an arbitrary, dimensionless quantity used in fluid mechanics to describe the ratio of inertial to viscous forces. Originally, Reynolds was the one to differentiate between laminar and turbulent flows. A completely turbulent flow was assumed to be the standard for the flow through a circular nozzle. On the other hand, when (r/D)>10, the turbulent flow from a rounded converging nozzle should be fully developed. Heat transfer was investigated by Limaye, who explored flat-plate impingement jets at a various Mach and Reynolds numbers. Researchers found that at all radial distances from the stagnation point and the heat transfer rate increased with increasing Reynolds number (Salcedo *et al*., 2018)

2.6 Relationship between Reynolds Number and Nusselt Number

Nusselt and local numbers were larger when a single free liquid jet was utilized to analyze heat transfer than in the streaming flow zone, according to numerical and experimental results. This is due to a significantly thinner fluid film in the affected area than in the surrounding area. Fluid velocity in this area is expected to be at a higher average rate. For solo jets, there is a high degree of agreement between computational and experimental data. Increasing Reynolds numbers benefit both the local and Nusselt populations, which both increases (Molanan& Banooni., 2013).

Several aspects affecting the efficiency of convection heat transfer in an impinging jet array are studied by Ligrani (2016). The Reynolds number, jet-to-target distance, hole spacing and hole inclination are all examples of such variables. According to the findings, researchers found that the average Nusselt number increases linearly with Reynolds number. As the impingement distance propagated larger, the Nusselt number also increases up until a maximum was reached. The heat transfer rate decreased as the distance between each hole increases, demonstrating a negative correlation between the effect of hole design and the impingement geometrical configuration.

CHAPTER 3

METHODOLOGY

3.1 Overview

An experimental measurement of heat transfer rate with different velocities was conducted in this research to observe the behaviour of heat transfer rate on the acoustic liner. The goals of this research are to develop an experimental setup to determine the heat transfer rate on acoustic liner and to study the thermal distributions on the acoustic liner. A sample of a simplified acoustic liner was prepared with one hole on top and bottom plates in the center of the honeycomb cell. The sample was then tested, and measurements of temperature versus velocities were taken in order to calculate heat transfer coefficients of the acoustic liner.

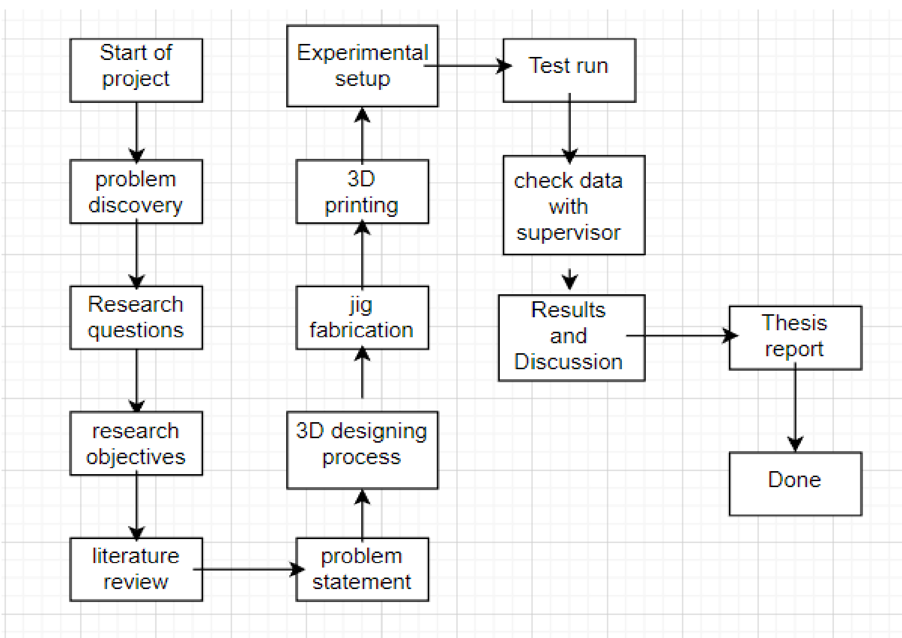

Figure 3.1: Flow chart of overall work

3.2 Experimental Setup

The experimental setup consists of multiple apparatuses such as the 3d printed acoustic liner, 12v DC fan, heater pad, a custom made jig, a custom made chamber, two 30v 12a DC power supply, a data logger and thermocouples. The acoustic liner is custom made by 3d printing according the given specifications which is 50mm long, 50mm wide and 24mm high including two 1mm thick backsheets on both ends and with the top end perforated. The material of the acoustic liner was closely chosen to as similar as possible with the material at the nacelle lip region of an aircraft. The heating pad recreates the function of the anti icing system which main purpose is to releasae heat to reduce the ice formation. The 12v DC fan is used as the impignment jet in this experiment with the chamber making sure that no other external air disturbs the air flow as we want to create a positive air flow. The custom made jig was made out of wood to act as an insulated holder of the heater pad and acoustic liner. The thermocouples and data logger was used to record the temperature difference in various spots on the acoustic liner. Both the power supplies are used to control the fan and heater pad which are the two variables was manipulated to see the heat transfer rate of the acoustic liner in various setups.

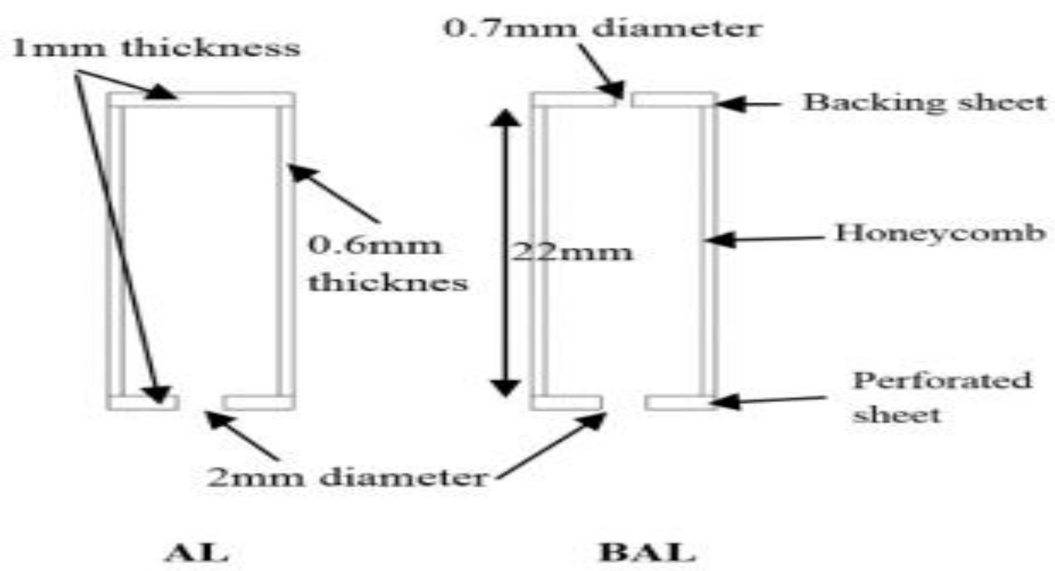

Figure 3.2: Dimension of acoustic liner

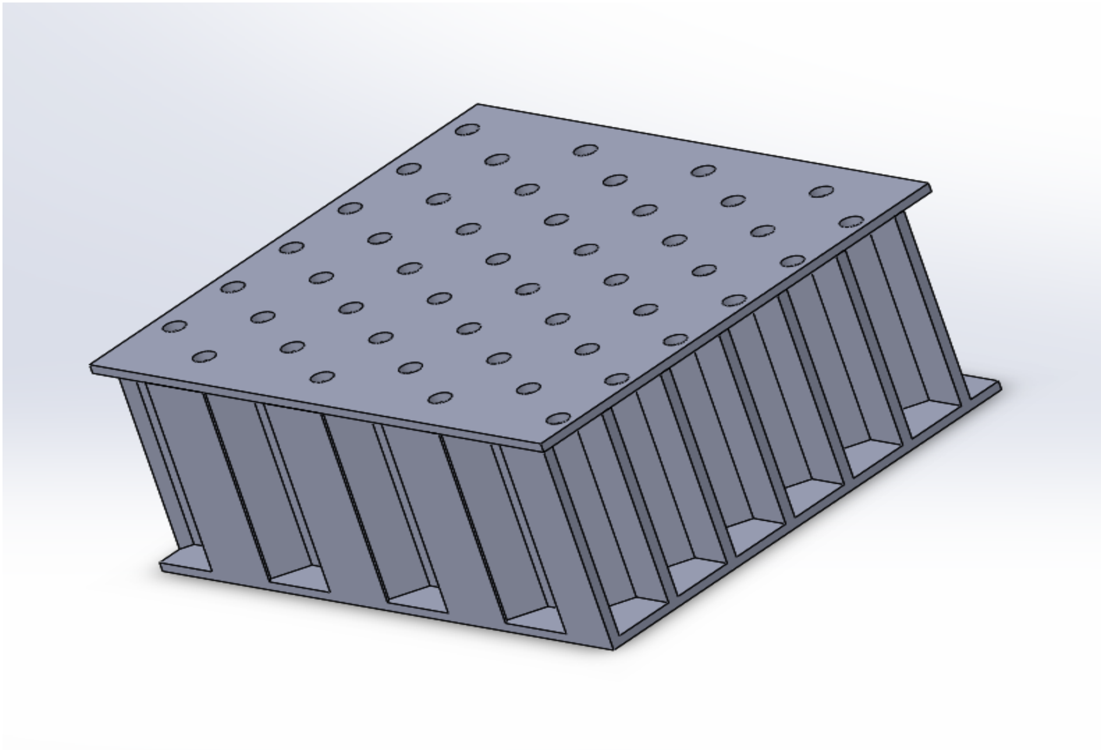

Figure 3.3: Acoustic liner 3d drawing

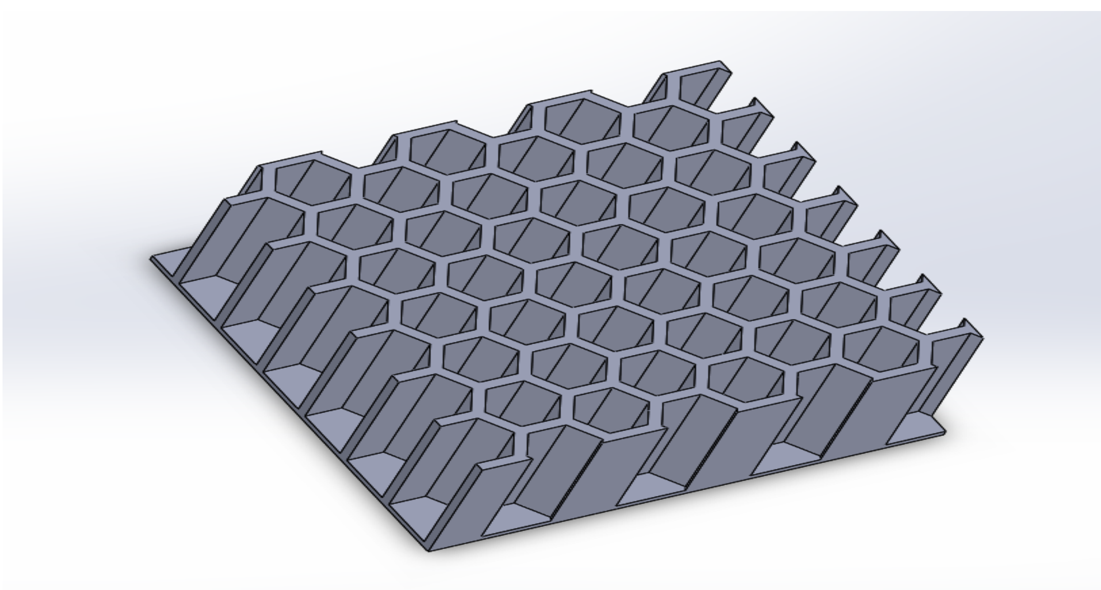

Figure 3.4: Acoustic liner honeycomb design

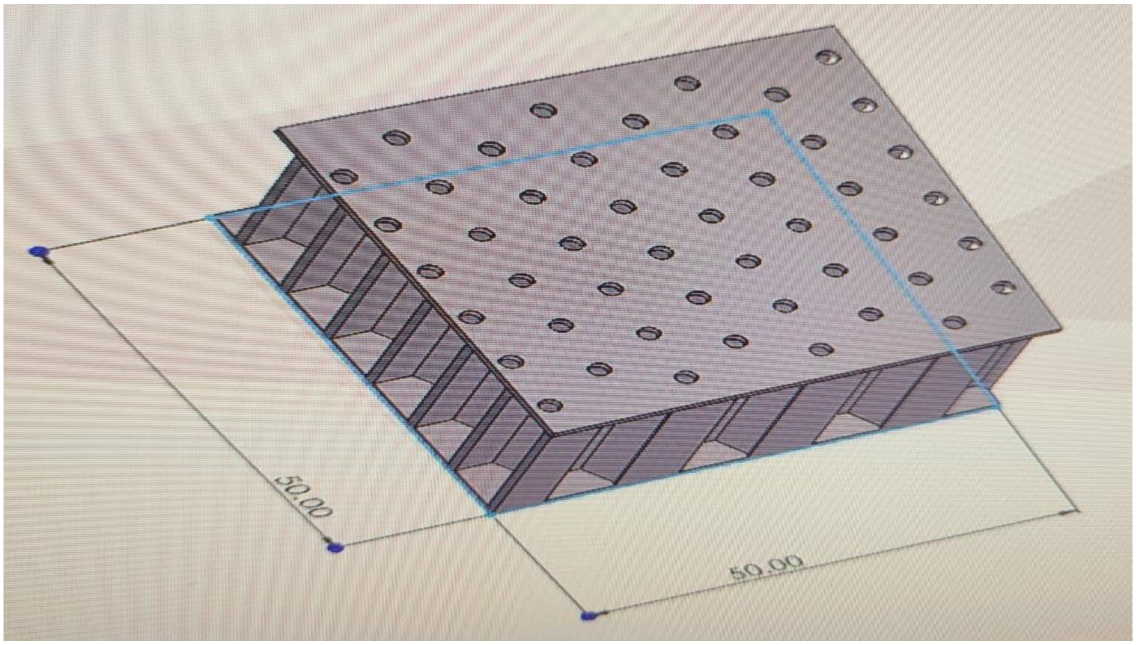

Figure 3.5: Acoustic liner measurement

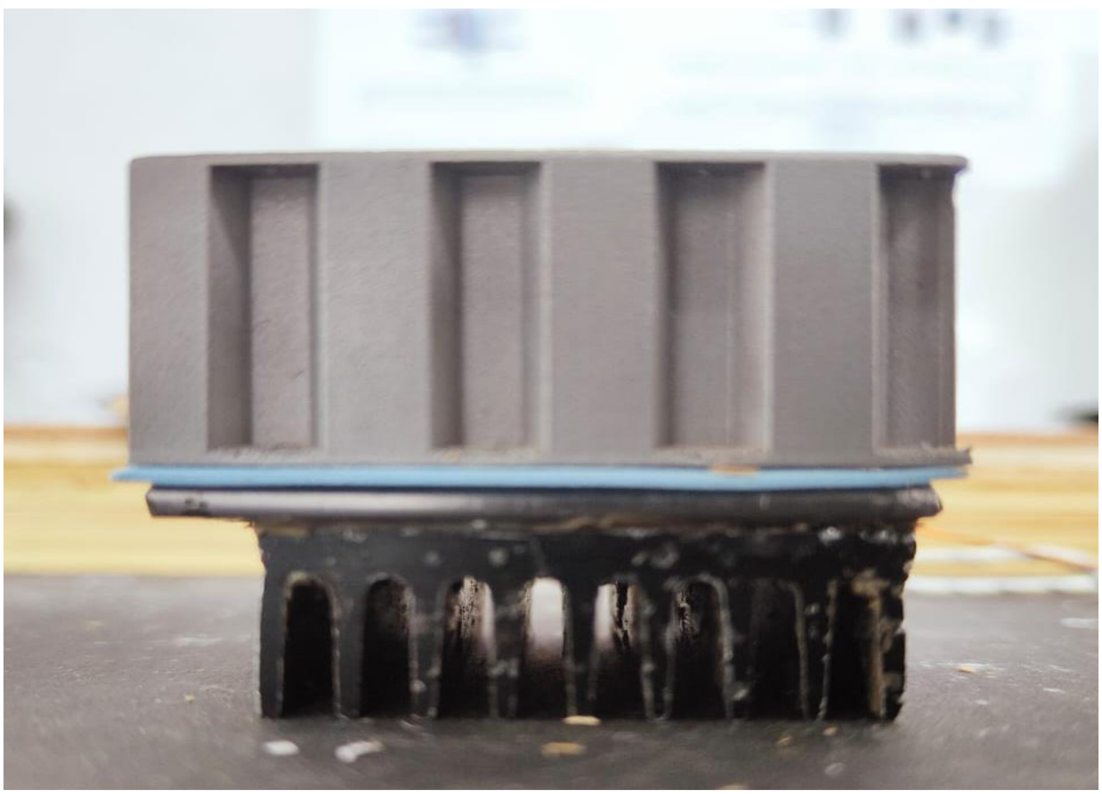

Figure 3.6: Acoustic liner on heater pad

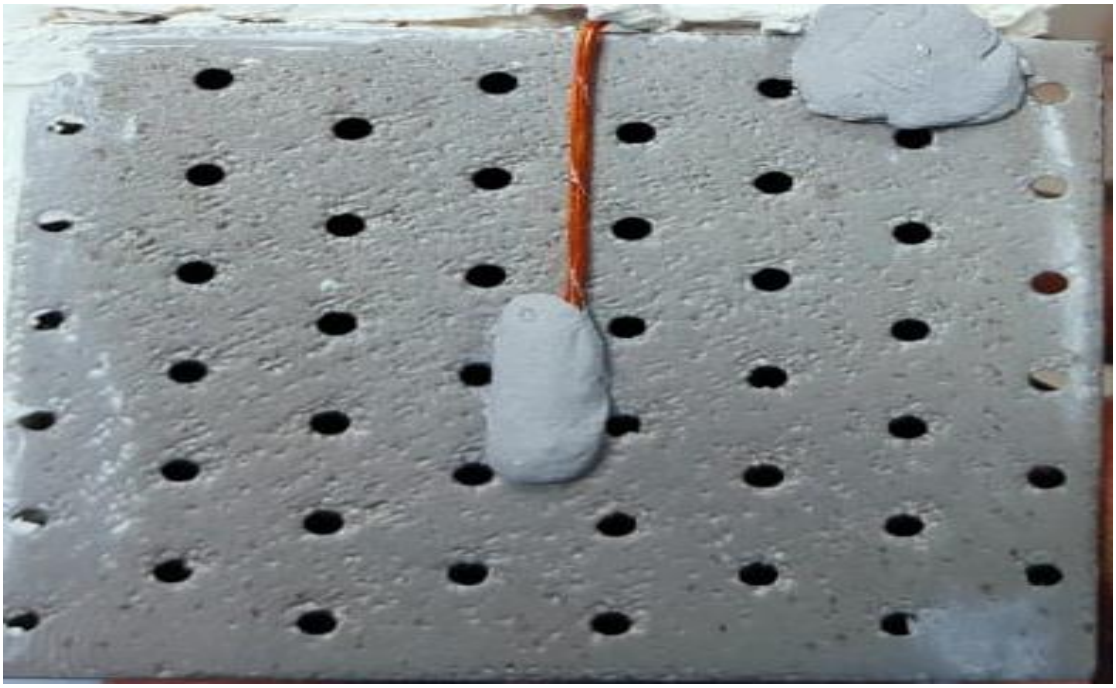

Figure 3.7: Thermocouple placement on Acosutic liner

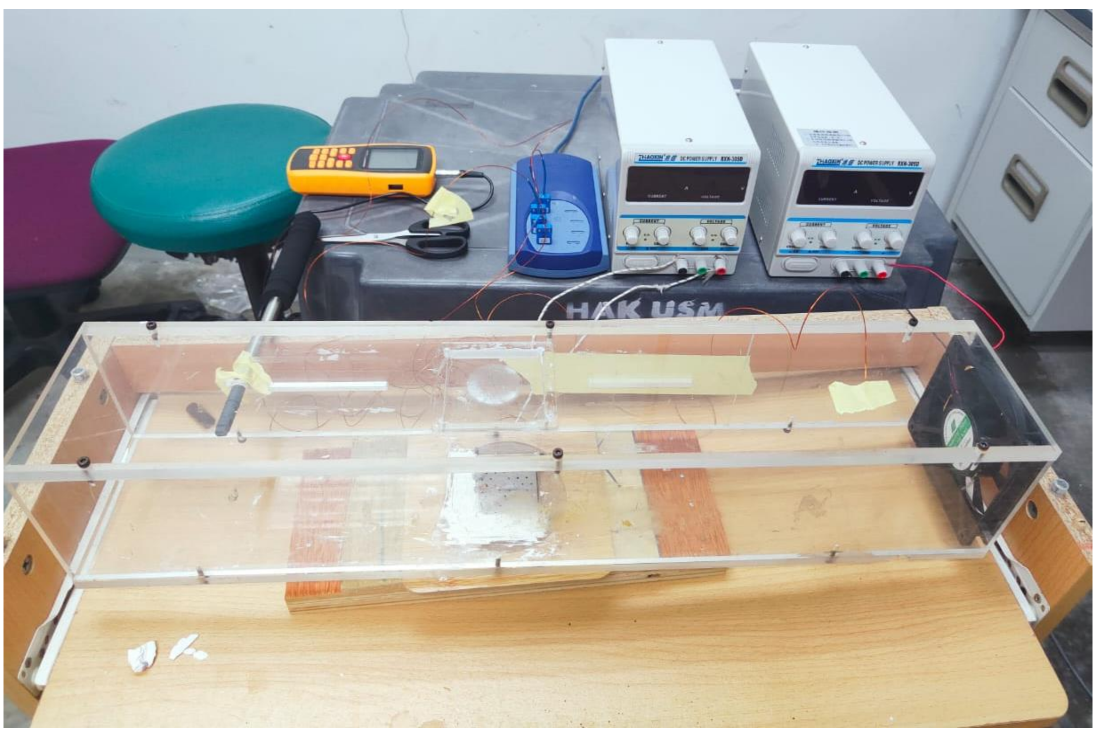

Figure 3.8: Experimental setup

3.3 Experimental Testing

After setting up experiment as the arrangement above, the initial reading of the heater pad temperature was recorded on two differents spots which are on the acoustic liner and the ambient temperature respectively. Next, the heater pad which is control by one of the DC power supply was turned on and setted at 0.5amp current supply for the first set of data. After the heater pad was turned on, it was left to reach it's peak temperature for approximately 45minutes. When the 45 minute mark was reached, all the respective temperature readings were recorded. Then, fan was switched on and the voltage supplied to the fan was setted at 5v for the next 30minutes. The maximum and minimum reading of the velocity inside the chamber were recorded after switching on the fan using an anemometer. After the 30 minutes mark, the all the respective temperatures were recorded. The process of changing the voltage supplied to the fan after 30 minutes, recording the maximum and minimum velocity reading and recording the respective temperature reading was repeated for a supplied voltage of 6v,7v,8v,9v,10v and 11v. A total of 7 different voltage supply to the fan was recorded. Before moving to the next set of data, the heater pad needs to be cooled down to the ambient temperature so that it can be ready for the next set of data recording, where the current supplied to the heater pad is manipulated to 0.75amp,1.0amp,1.25amp and 1.5amp. All the procedures mentioned above was repeated and recorded. This gives a total of 35 test runs to complete this experiment.

3.4 Data Reduction

Reynolds Number

Reynolds number (Re) is an important parameter as it can be used to differentiate layers in flowing fluid between laminar and turbulent flow Guo & Ghalambor (2014). The following equation was used to calculate the Reynolds number:

$$Re = \frac{VL}{V} \qquad 3.1$$

where: V = velocity

L = length

V = kinematic viscosity

Nusselt number

The Nusselt number on the impingement surface is calculated to investigate the influence of impingement ranges on the Reynolds number. The Nusselt number must be determined because it was directly proportional to the Reynolds number as a function of the hydraulic diameter parameters. The equation for the Nusselt number is as follows:

$$Nu = \frac{\bar{h}l}{k} \qquad 3.2$$

where $\bar{h}$ = convection of heat transfer coefficient over entire area

l = length of hydraulic diameter of D-chamber (nozzle diameter)

k = air thermal conductivity

The convection heat transfer coefficient over the entire area, $\bar{h}$ can be obtained from an equation of heat convection (Mohd Ami, 2013).

$$Q_{convection} = \bar{h}A(T_w - T_\infty) \quad 3.3$$

where $\bar{h}$ = convection heat transfer coefficient over the entire area, W/m^2K

A = heat transfer area, m^2

T_w = temperature of wall

T_∞ =ambient temperature