University of Derby

School of Computing & Mathematics

A project competed as part of the requirements for the BSc (Hons) Computer Games Programming

Entitled:

How the Specific Heat Capacity of a Material Affects Temperature when Interacting with the Atmosphere

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Abstract

This dissertation will summarize a rational and provide the aims and objective which are covered in a literature review. The review will cover my main research and the mathematical equations which will be employed along with some examples of other similar applications.
A methodology will discuss the methods used to obtain results from this project which will be analysed and given an opinion on based on the current hypothesis. Finally the project will conclude and reflect on the decision making and choices.

Acknowledgements

Thanks to Minsi Chen – Supervisor.

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1. Introduction

1.1. Project Rationale

The project will focus on the area of fluid dynamics however this is a large area of study, for this reason the project will be focused on aerodynamics, a subarea of fluid dynamics. This project is a design project, an application of an aerodynamic simulation will be created. This simulation will primarily be focused on calculating the ‘Specific Heat’ of different materials as they travel through the air. The project will collect data concerning the temperature of the materials under different circumstances including the velocity and altitude. The hypothesis for the project is feasible and realistic to achieve and will provide interesting data.

Hypothesis: **A materials specific heat capacity will determine the temperature of the material during flight, the temperature should be affected by varying altitudes and velocities.**

This will create a good project in which a model can be created to prove or disprove the hypothesis. The flight model will use lift, drag, weight and thrust to create the base conditions for flight. It shall use this conditions to manipulate the aircraft in an earth like atmosphere. The atmosphere will consist of the density, pressure, temperature and viscosity at varying altitudes from 0 Kilometres to 80 kilometres. The thrust of the aircraft will provide the velocity changes, with these variables it will be possible to calculate the average temperature of the aircraft given an altitude and velocity.
The project will examine this temperature and the effect it has on different materials. These materials will provide different ‘Specific Heat Capacities’, this will change affect the temperature has on the material, whether it increases the temperature passed melting point or decreases the temperature.

The project will examine other simulations that use fluid dynamic equations which achieve a similar goal, these include Flight Gear which is an open source project and X-Plane which is a commercial product. Both of these are flight simulators which claim to have a realistic simulation.

The project will also examine a game which has adopted a physics-based flight simulation similar to the specifications of this project but that wouldn't be considered as accurate as Flight Gear or X-Plane. This game is called '*Kerbal Space Program*'. This is less of a simulation and more of a sandbox but it still has characteristics that will be examined. These include the temperature build up as a craft is accelerated through the air and the inevitable affect this has if the temperature reaches critical levels. Unlike Kerbal Space Program, Flight Gear and X-Plane is not concerned by heat build-up during supersonic flight nor the affect this temperature would have on the aircraft however these simulation provide very accurate representations of flight.

Kerbal Space Program is the reason this project has been created. This game serves as a simple yet effective means of understanding the basic principles of aerodynamics however it is a simple representation that may or may not be accurate. This project will determine if the overheating mechanic in Kerbal Space Program would occur a real life situation and therefore could be included into a flight simulation like 'Flight-Gear' or 'X-Plane'.

1.2. Project Aim and Objectives

1.2.1. Aims

The First aim is to conduct extensive research into fluid dynamics to develop a better understanding of aerodynamics.
The Second aim is to gather the equations required to calculate the specific heat and its effect of the temperature.
The Third aim is to choose a suitable application to create the flight model, this needs to be able to handle all of the specifications required.
The Fourth aim is to design the flight model to the specifications required to prove or disprove the hypothesis.
The Fifth aim is to collect and analyse these results, giving a clear answer to the hypothesis.
The Final aim will be to discuss these results and what the outcome of the project.

1.2.2. Objectives

The First objective is to conduct research by examining existing works and documentation which will provide understanding on the subject matter. These include papers written about aerodynamics and the effects it has on aircraft.

The Second objective is to understand the equations behind aerodynamics, how these effect one and other and how these can use these to create a flight model. Various websites and documentation will be used to obtain these equations.

The Third objective is to find an application to construct the model, the software used will be a game engine either Unity or Unreal Engine. The project will use this to create the flight model. The project will most likely use Unreal Engine due to personal experience.

The Fourth objective is using the chosen application to create the flight model, this must include at a minimum, a method to calculate a materials temperature based on its specific heat capacity.

The Fifth objective is the collection and analysis of this data, the data will be recorded in a table which will allow the creation of graphs comparing the temperatures, velocities, altitudes and materials used. The data will be processed to give other results such as averages and means should it be necessary.

The Final objective is to discuss these results and there meaning, examining what the results mean for the hypothesis, if the project has completed what it has set out to accomplish or if during the project unknown variables had changed the outcome.

2. Literature Review

2.1. Introduction

During the Literature review many sources were searched which relate to this project. The main search terms used include; Fluid Dynamics, Fluid Mechanics, Aerodynamics and Specific Heat Capacity. Most of these are from the Internet however some have been searched for in other literature like library books which have given details on Fluid and Aerodynamics. The main source for this project is NASAs website '*(NASA, Guided Tours of the BGA, 2014)'*. This website hold the majority of the equations used. Other sources include documentation on Fluid Mechanics and Aerodynamics*'(Professor Paulo Lozano, Fluid Mechanics and Aerodynamics, 2008)'.*

This will cover the literature reviewed for the project giving the detailed accounts of work which is similar to this project. The mathematics which have been researched and implemented will be discussed.

This will cover the details about how the flight model uses atmospheric interaction, the process of an object interacting with the surrounding air, it will describe how material properties have been used to determine the specific heat, melting points and how this will affect the results. The equations will also be discussed in more detail giving an in-depth look into the flight model for this project.

Two flight simulators will be discussed which use a flight model to simulate flight, the first is called Flight-Gear and the second is called X-Plane. These two will provide a general understanding of what a flight simulation is and will give a nice example of other flight models used in modern simulators. Kerbal Space Program (KSP), a physics-based flight simulation will be discussed in more detail as this is the game which inspired this project.

2.2. Flight Model Components

2.2.1. Atmospheric Model

The project focuses on the interaction between the atmosphere and the object in question like an aircraft. This has been a challenging part of the project but using the website 'Beginner's Guide to Aeronautics' *(NASA Air Properties Definitions, 2014)* and by examining the source code of Flight Gear the project has been able to progress. The project has used these sources to add to the flight model and create a better understanding of how to go about this. The project will be created in Unreal and will call for creative thinking to implement the equations in its blueprint system.

The atmosphere is made up of many different properties which need to be taken into account. The properties included are as follows, these are all in SI units;

- Altitude. ([KM] Kilometres)
- Relative Density at Sea Level. ([kg/cu.m] Kilogram per Cubic Metre)
- Relative Pressure at Sea Level. ([N/sq.m] Newton per Square Metre)
- Relative Temperature at Sea Level. ([K] Kelvin)
- Temperature. ([K] Kelvin)
- Pressure. ([N/sq.m] Newton per Square Metre)
- Density. . ([kg/cu.m] Kilogram per Cubic Metre)
- Speed of Sound. ([m/s] Metres per Second)
- Viscosity. ([kg/m-s] Kilogram per Metre-Second)
- Kinematic Viscosity. ([sq.m/s] Square Metres per Second)
- Air Specific Heat Capacity. ([kJ/kg K] Kilojoule per Kilogram per Kilo)
- Gravitational Acceleration. ([m/s2] Metres per Second Squared)

These are the locations at which I am obtaining these values;

(PDAS, A Sample Atmosphere Table (SI Units), 2013)
(The Engineering ToolBox, U.S Standard Atmosphere, Unknown Year)
(The Engineering ToolBox, Air Properties, Unknown Year)

The flight model will use these properties to create different conditions at different altitudes, there will be a set altitude (0, 10, 20…) and at each set altitude these atmospheric properties will be set according to data gathered from the sources mentioned above. All of properties are dependent on the altitude, a different altitude will greatly alter the results obtained from the simulation.

These properties will also be used in other areas of the flight model to calculate Weight, Thrust, Lift and Drag which will be explained in the 'Flight Model' section below.
The Weight and Thrust equations of the object will take the Gravitational Acceleration into account, this will determine the mass of the object and the specific thrust of the engine.
The Density will be taken into account when calculating the Lift and Drag which partially controls the rise and fall of the aircraft, the Thrust equations will also use this when calculating the mass flow rate of the engine.

(Fig 1 & 2, Altitude and Atmospheric properties)

2.2.2. Material Model

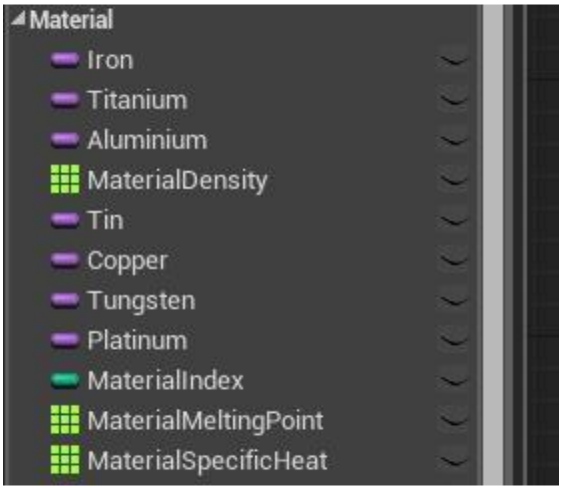
My project will take into account the type of material used as the object. To prove or disprove the hypothesis the project will include the appropriate properties of each material. The project will primarily use metal materials which have different specific heat capacities allowing for different rates of atmospheric heating. Each material will also contain a melting point at which point the material would be rendered useless or destroyed. The properties of the materials which I am interested in are and are all in SI units;

- Density. ([kg/cu.m] Kilograms per Cubic Metre)
- Specific Heat Capacity. ([kJ/kg K] Kilojoule per Kilogram per Kilo)
- Melting Point. ([K] Kelvin)

These are the location in which I obtained these values;

(The Engineering ToolBox, Metals - Specific Heats, Unknown Year)

(Periodic Table, Basic Info, 2015)



(Fig 3 & 4, Material Properties and Material Types)

The flight model will use these properties to create three different materials, the materials chosen will have variables which cover the scope of the values, one material will have a low Specific Heat Capacity, the second shall have a medium capacity and the last will have a high capacity. This will give a broad set of results for testing.

These properties will also be used in other areas of the flight model, The Weight will be calculated by taking the Density of the material to determine the Mass of the aircraft. The greater the density the greater the objects mass. The Density and Specific Heat Capacity is also used in the Temperature equation to find the temperature of the material given an altitude and velocity, this is the most important equation of the flight model as it is this which will give the results needed for analysis.

2.3. Flight Model

This section will give details on the flight model used in this project. This starts with The Beginner's Guide to Aeronautics *(NASA, Guided Tours of the BGA, 2014) which* is a website setup by NASA to teach the basics of Aerodynamics. The project uses this website to find, experiment and use the equations it contains to develop the flight model. The model uses Weight, Thrust, Lift and Drag and temperature equations to create data that can be used as the results.

2.3.1. Weight Equation

The weight equation governs how heavy an object is, in flight this force must be less than the lift force to achieve lift else the aircraft will lose altitude. The equation is split into multiple parts to find the overall weight of the object. The flight model uses these equations to calculate the overall Weight of the aircraft and the Centre of Gravity however due to the use of different materials in the flight model the Mass of the aircraft will be affected.

The Mass (m) of the object (i) is equal to the Density (d) of the material multiplied by the Volume (v) of the object.

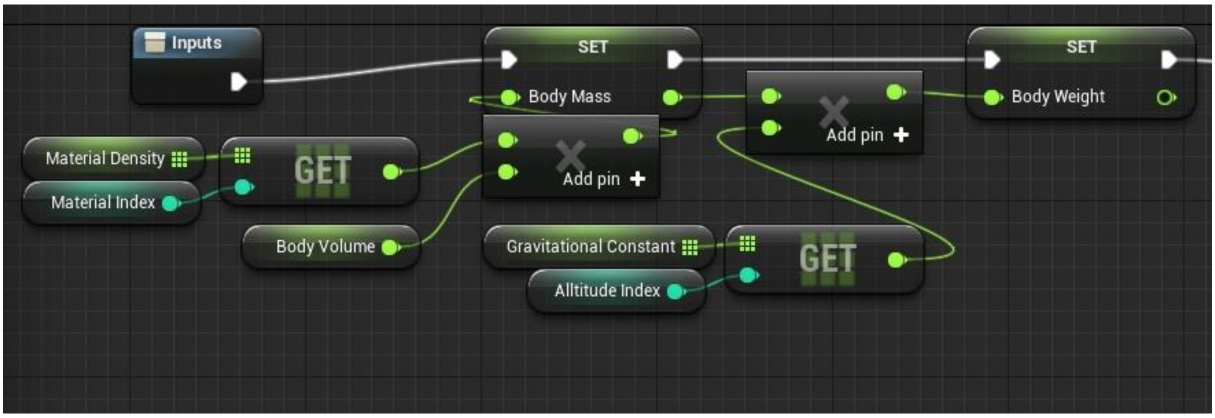
$$Mass_{ObjectOne} = Density * Volume$$
$$m_i = d * v$$

This equation calculates the Mass of the object which will be used to find the Weight of the object.

The Weight (w) of an Object (i) is equal to the Mass (m) of that Object (i) multiplied by the Gravitational Acceleration (g). The Weight Equation is as follows;

$$Weight_{ObjectOne} = \ Mass_{ObjectOne} * Gravitational\ Acceleration$$
$$w_i = \ m_i * g$$

This equation calculates the weight of one object. An Aircraft is usually made up of many of these objects, to calculate the Total Weight another equation must be used.



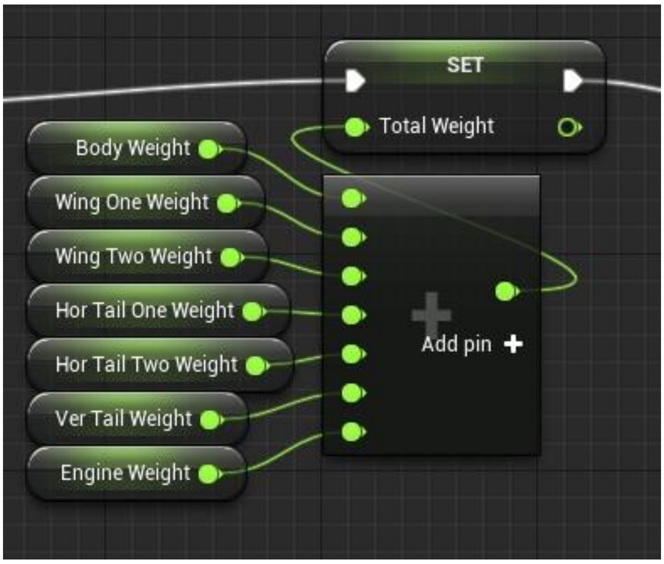
(Fig 5, Mass and Weight Equation)

The Total Weight (W) is equal to the Weight (w) of Object One (i) plus the Weight (w) of Object Two (j) plus the Weight (w) of Object Three (k). The Total Weight Equation is as follows;

$$TotalWeight = Weight_{ObjectOne} + Weight_{ObjectTwo} + Weight_{ObjectThree} + \cdots$$
$$W = w_i + w_j + w_k + \cdots$$
$$W = \int w(x)dx$$

(NASA, Determining Aircraft Weight, 2014)

This equation calculates the Total Weight of the aircraft, after calculating each component weight these weight are added together to create the Total Weight, this is used in the flight model as the Weight component.



(Fig 6, Unreal Total Weight Equation)

To calculate the Centre of Gravity the model uses another equation. It uses the weight of each object and a distance from that object to a reference point. The Centre of Gravity equation is as follows;

The Centre of Gravity (*cg*) Multiplied by the Total Weight (*W*) is equal to the distance (*d*) of the Object One (*i*) multiplied by the weight (*w*) of Object One (*i*) plus the distance (*d*) of the Object Two (*j*) multiplied by the weight (*w*) of Object Two (*j*).

$$CentreOfGravity * TotalWeight = Distance_{ObjectOne} * Weight_{ObjectOne} + \cdots$$

$$cg\ W = d_i w_i + d_j w_j + \ \dots$$

$$cg\ W = \sum_{i}^{n} (wd)_i$$

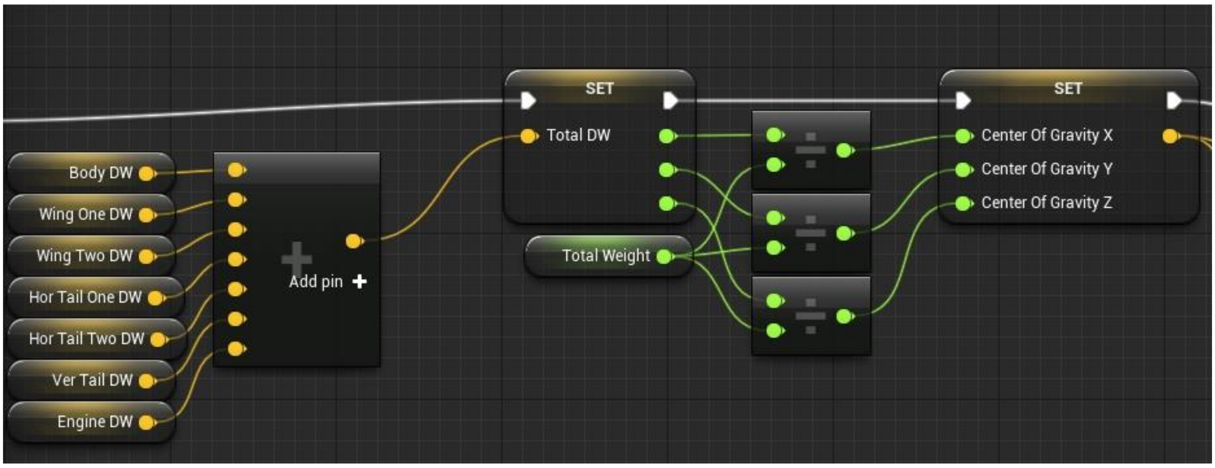
(NASA, Centre of Gravity – cg, 2014)

This equation will find the Centre of Gravity multiplied by the Total weight. Since we already have the Total Weight calculated we can change the equation to find just the Centre of Gravity.

$$CentreOfGravity = CentreOfGravity * TotalWeight \ / \ TotalWeight$$

$$cg = cg * W/W$$

These two equations must be calculated from X, Y and Z coordinates to obtain the position of the Centre of Gravity.



(Fig 7. Centre of Gravity Equation)

2.3.2. Thrust Equation

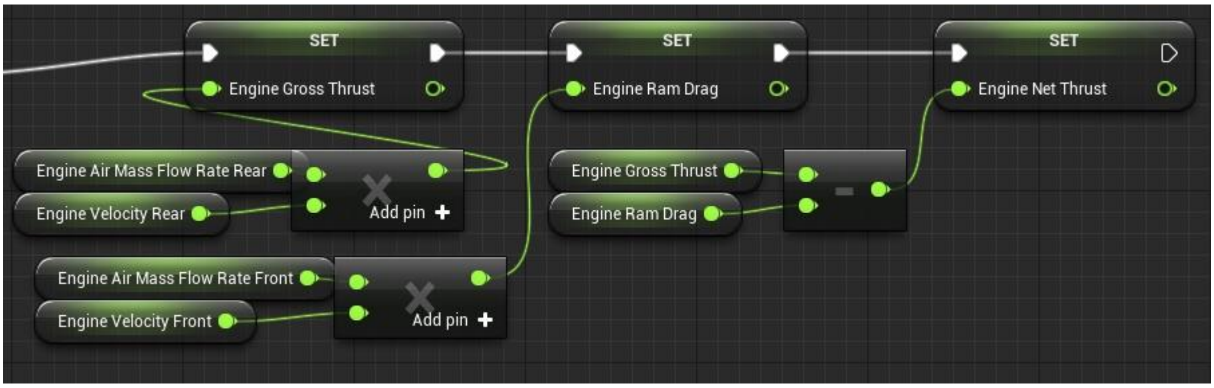
The flight model is using the General Thrust Equation to calculate the thrust of an engine for the aircraft. This component will provide the velocity used at varying levels during testing. The Force (*F*) is equal to the Mass Flow Rate ($\dot{m}$) at the engines rear or Exit (*e*) multiplied by the Velocity (*v*) at the Exit (*e*) minus the Mass Flow Rate ($\dot{m}$) at the engines Entrance (*0*) multiplied by the Velocity (*v*) at the Entrance (*0*) The General Thrust Equation is as follows;

$$Force = MassFl\dot{o}wRate_{Exit} * Velocity_{Exit} - MassFl\dot{o}wRate_{Entrance} * Velocity_{Entrance}$$

$$F = \dot{m}_e v_e - \dot{m}_0 v_0$$

(NASA, General Thrust Equation, 2014)

By using this equation the flight model will control the force or velocity of the aircraft to enable different levels of thrust at varying altitudes. This will affect the Temperature of the material by increasing the velocity which is a component of the Temperature Equation.



(Fig 8, Thrust Equation)

2.3.3. Lift Equation

The flight model uses the lift equation to provide lift to the aircraft dependent on the lift coefficient and other atmospheric properties. The Lift coefficient is a complex variable which is usually calculated experimentally, these include shape, inclination and flow conditions related to lift.

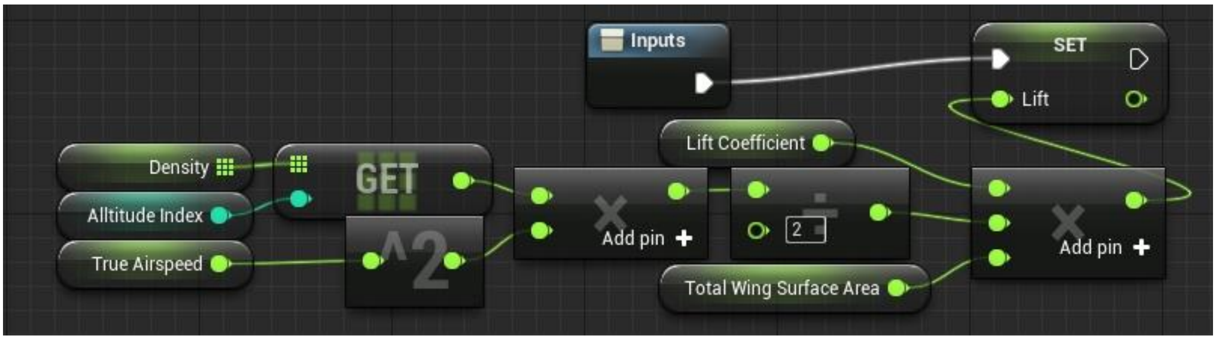
The Lift (L) is equal to the Lift Coefficient (Cl) multiplied by the Density (p) multiplied by the Velocity squared (v^2) divided by Two and multiplied by the Area of the Wing (A).

$$Lift = LiftCoefficient * (Density * Velocity^2 / 2) * WingArea$$

$$L = Cl * (p * v^2 / 2) * A$$

(NASA, The Lift Equation, 2014)

The flight model uses the Density of the air at the given altitude and the Velocity of the aircraft to calculate the Lift on the Wings, this will affect the temperature by changing the altitude of the aircraft which will change the ambient temperature which is used in the Temperature Equation.



(Fig 9, Lift Equation)

2.3.4. Drag Equation

The flight model uses the drag equation to calculate the drag of the aircraft. This equation is similar to the lift equation however its drag coefficient is a complex variable which is usually calculated experimentally. This contains the shape, inclination and flow conditions related to drag.

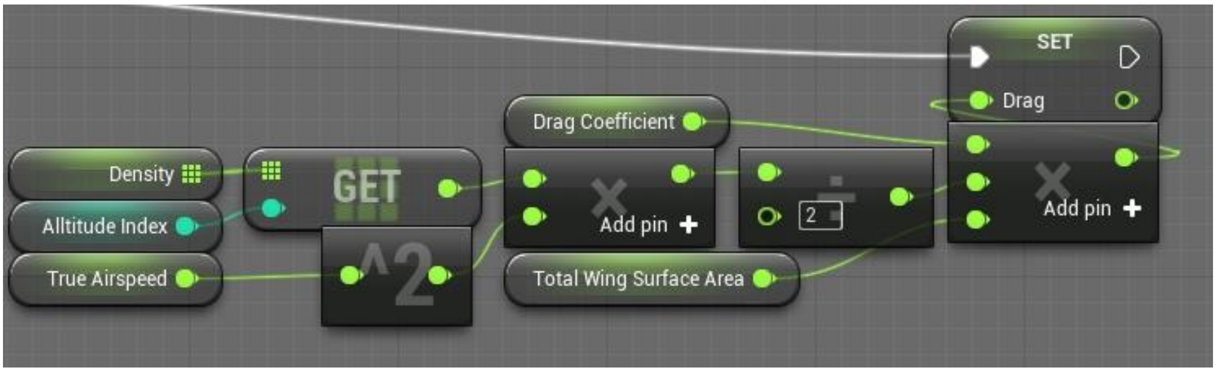
The Drag (*D*) is equal to the Drag Coefficient (*Cd*) multiplied by the Density (*p*) multiplied by the Velocity squared (v^2) divided by Two and multiplied by the Area of the Wing (*A*).

$$Drag = DragCoefficient * (Density * Velocity^2 / 2) * WingArea$$

$$D = Cd * (p * v^2 / 2) * A$$

(NASA, The Drag Equation, 2014)

The flight model uses the Density of the air and the Velocity of the aircraft like the Lift Equation, This will affect the temperature by slowing the velocity and reducing the temperature however in theory the drag will add to the temperature generation but I have not added this equation to the flight model.



(Fig 10, Drag Equation)

2.3.5. Temperature Equation

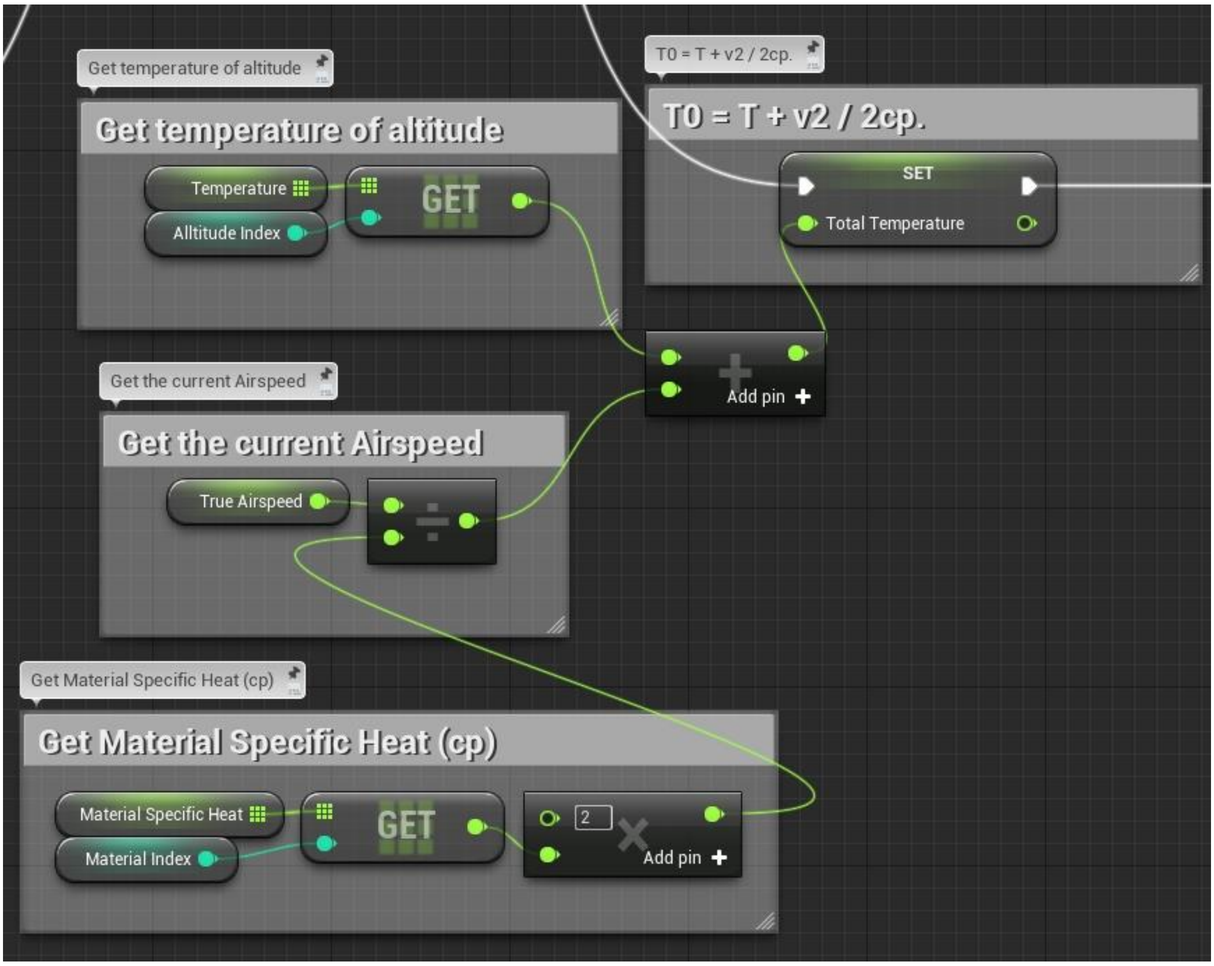
The flight model uses this equation to calculate the temperature of the aircraft dependent on the material which is being used. The Total Temperature (T_0) is equal to the Ambient Temperature (T) plus the Velocity of the aircraft squared (v^2) divided by 2 multiplied by the Specific Heat Capacity of the material. ($2c_p$).

$$TotalTemperature = AmbientTemperature + \frac{Velocity^2}{2 * Specific\ Heat\ Capacity}$$

$$T_0 = T + \frac{v^2}{2c_p}$$

(McGraw-Hill, Compressible flow, 2008)

This is the calculation used to find the temperature, this gives a basic formula to calculate the temperature of a material given a specific heat capacity, a temperature and velocity.



(Fig 11, Temperature Equation)

2.4. Simulators

2.4.1. Flight-Gear

This final section will discuss the flight simulators and their flight model. Flight-Gear is a flight simulator which is free and open-source. This program has been studied to determine how it was using the atmosphere to interact with aerodynamic objects. Flight-Gear uses a pre-built table of atmospheric properties to calculate the aircrafts interaction given there altitude.

Flight-Gear has several different flight models to choose from. First is 'JSBSim', this is a generic flight model which requires a list of details to be filled in, in order for the aircraft to be affected by the flight model. This is one of the simpler methods available in Flight-Gear. *(Flight-Gear, Features, 2015)*

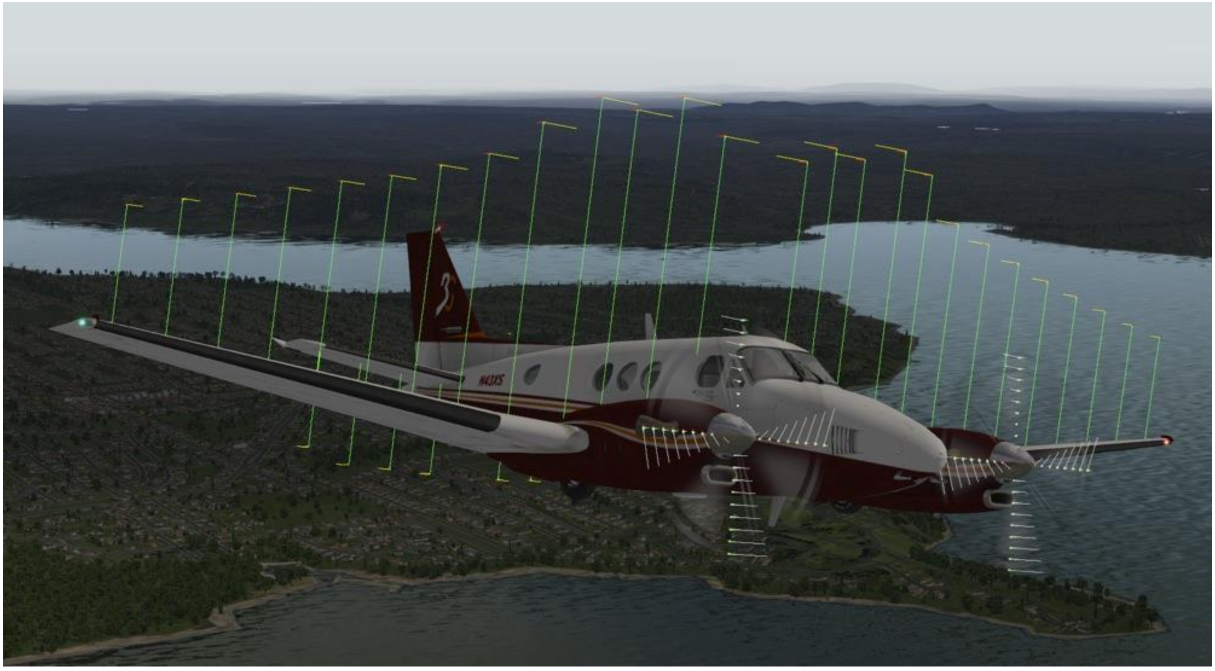
The Second option for a flight model is 'YASim', instead of a list of details this flight model using the meshes to determine how the flight model interacts with the aircraft. This is a much more accurate method but it is also a more complex to calculate. *(Flight-Gear, Features, 2015)*

(Fig 12, Flight-Gear) (Flight-Gear, Introduction, 2015)

2.4.2. X-Plane

X-Plane is another flight simulation, it is a commercial product which employs a different flight model to calculate aerodynamics. X-Plane uses ‘Blade Element Theory’ for its flight model.

According to X-Place, ***“This method of computing the forces on the airplane is much more detailed, flexible, and advanced than the flight model that is used by most other flight simulators.”*** *(X-Plane, How X-Plane Works, Unknown Year)*



(Fig. 13, X-Planes Blade Element Simulation) *(X-Plane, How X-Plane Works, Unknown Year)*

The flight model ‘Blade Element Theory’ is fairly simple method of predicting the performance of a propeller however X-Plane also applies this to wings. The wings, propellers, horizontal stabilizers and vertical stabilizers are broken down into multiple sections with ten being the maximum amount allowed. The aerodynamics calculations are 2-D and can be calculated separately for each section that exists, the more sections on a wing the more accurate the results.

2.4.3. Kerbal Space Program

The inspiration for this project is Kerbal Space Program (KSP). KSP is a physics-based simulation, it contains aircraft which are made from many different parts and you can create your own aircraft and test them. This flight model has been created for novices who can enjoy destroying the aircraft they create should they not function as expected.

Similar to the flight model of this project, KSP applies a mechanic in which the aircraft will overheat should your craft exceed a safe velocity within the atmosphere. Each aircraft component have a max temperature tolerance. If this tolerance is exceeded then the component will explode. They also have this calculation for other parts like engines, should you accelerate too fast then these components like the engine will over heat.

2.5. Conclusions

2.5.1. Key Issues

In Terms of simulations this project has unique characteristics, it has been difficult finding specific literature covering this projects aims. Even the simulators this project has reviewed do not share much with the project but the do provide a good understanding of flight models. These other simulations may use temperature in their calculations however no proof has been found during research that they calculate a temperature for a material and calculate the breaking point (melting point) of the material. The only simulation mentioned with this type of data seems to be Kerbal Space Program.

A realistic simulation doesn't seem to worry about temperature to the extent attempted in this project, in a simulator like Flight-Gear or X-Plane you are flying in a realistic situation. In these situations it is unlikely that you will ever be moving fast enough to cause a serious change in temperature that could cause a component to fail.
One the other hand this type of data is very useful to engineers who are developing these materials to use in modern aircraft. Or to those who are creating fun sandbox like games who wish to add these mechanics as gameplay elements.

3. Research Methodology

3.1. Introduction

In this section the best methods for the project to use will be explained. They will give a brief summary of the research strategy, how this will generate the data using these methods and how it will be analysed.

A description of the data sample types and sizes, the ethics involved in the project and the limitations that may occur. A conclusion of these aspects of the project will finish this section.

3.2. Research Strategy

There are multiple strategies that can be used for this project which will result in different types of data. The strategies employed will result in either Correlational data, quantitative data, experimental data or a combination of these. The project will be best suited to quantitative data however it will also contain experimental data as the results can be manipulated by the different variables.

3.2.1. Correlational Data

Correlational Data can be collected from the data gathered. Collocational Data is data which consists of a relationship between two sets of data. In this case the correlation is between the Specific Heat Capacity and the Temperature which is generated at a given altitude and velocity.

This can go one step further by creating more than one set of data then creating a correlation between the different materials used. A correlation can be set up between the Specific Heat Capacity of each material and what affect it has had on the temperature of each individual material.

3.2.2. Quantitative Data

Quantitative Data can be collected from the data gathered. Quantitative Data is data which can be measured. In this case the quantitative data is the temperature results obtained from the data. There will be a large amount of temperature data in correlation to the velocity and altitude. This can be compared and measured against the data gathered in the same set of data and other sets of data which are created.

3.2.3. Experimental Data

The project is also capable of producing Experimental Data. Experimental Data is data that can be produced with experimental design. The project and the data it generates can be manipulated by changing the variables involved. For instance I can change the velocity of the aircraft or I can change the altitude which in turn affects the atmospheric model the project uses to gather data.

The project will focus on using these methods to analyse the data to make sense of the results. The project will research different academic documentation, other works competed by students and researching the mathematics behind the fluid dynamic equations implemented in the project, this will provide the means to generate the data.

3.3. Data Generation Methods

To generate the data the project will creating an object (plane) made of a material which will interact which the atmospheric model and it's components to create an aerodynamic simulation which will calculate the temperature generated by the material due to its Specific Heat Capacity via different Velocities and Altitudes. The project shall analyse and implement equations which will help generate the data required. The data which is required is the *Altitude*, *Velocity* and the *Temperature*.

These are the numerical methods used which are mentioned in ‘Flight Model’, these include;

1. Lift Equation - Generates the Lift which will affect the *Altitude*.
   (NASA, The Lift Equation, 2014).
2. Drag Equation - Generates the Drag which will affect the *Altitude* and the *Velocity*.
   (NASA, The Drag Equation, 2014).
3. Weight Equation - Defines the weight of the aircraft which affects the *Velocity* and the *Velocity* of the assent and descent.
   (NASA, Determining Aircraft Weight, 2014), (NASA, Centre of Gravity – cg, 2014)
4. Thrust Equation - Generates the thrust which provides the *Velocity*.
   (NASA, General Thrust Equation, 2014)
5. Temperature Equation – Generates the *Temperature* data depending on the Altitude and Velocity.
   (McGraw-Hill, Compressible flow, 2008).

To interact with the object and create accurate data the project will implement an atmospheric model which will contain the properties which are used in the equations. The project will cover three types of materials with their properties previously mentioned in ‘Material Model’ defined for use in the temperature equation. The atmospheric properties ***(See Appendix A and B)*** and material properties ***(See Appendix C and D)*** will be in SI units which I have obtained from reputable websites.

3.4. Data Analysis

When analysing the data received, tables will be created which will hold the relevant data, graphs will be created from these tables which will compare the results.
The tables will hold data on the temperature of a material at three different altitudes with a given velocity, this will be done for each material then a graph will display these materials and compare the altitude and the temperature of the materials at a specific velocity. A comparison will be made for the variables of the results to provide three different graphs providing useful data which can be examined and analysed with the methods mentioned previously.

This will give me a better understanding of the results however it will be difficult to attain if they are valid without a method to check the data and its viability, to determine this online facilities like calculators can be used or comparing the results with other similar results to find a rough estimate as to how accurate and valid the results are.

3.5. Sampling

My project will create a large sample of results for me to study and analyse. My results should consist of 3 sets of experimental data which can be modified to generate different results. This includes a velocity to determine the speed at which a material is traveling, different materials which will determine the generation of heat energy (temperature) and an altitude which will increase or decrease the affect. The data will modify the experimental data which will result in a large amount of quantitative data which can be processed. This data should provide a large sample size for testing.
A large range of velocities will be chosen shall choose when experimenting, from 10 Metres per Second to 2000 Metres per Second. (10, 100, 500, 1000, 1500 and 2000) These high speeds should provide high temperatures which may exceed the materials melting point but provide a clear decent range of data. Three different altitudes will be chosen from 0 – 80 Kilometres (0, 40, 80). The project will consist of three materials, these materials will have different Specific Heat Capacities and Melting Points which will be included in the results.

My Flight Model is capable of producing many more results in a much wider range however it is best to provide a decent amount of data which can be processed effectively. The data provided will be cover a wide spectrum of this capable production so no two data sets are alike. This will keep the results to a manageable size.

3.6. Ethics

This project considers the ethical constrains like; Consent, Withdrawal, Confidentiality, Data Protection, Debriefing.

This project does not have to involve participants however the option is open, should this occur then the ethics must be present. The ethics to consider are as follows;

1. The participant must consent to helping with the project.
2. They must be able to withdraw from the project whenever they like.
3. Confidentiality will be available to them.
4. Any participant will have data protection, any information taken will be protected and destroyed on project completion.
5. Participants may need to be debriefed on the basics of the project before they consent to participate.

These are all of the ethics which will be considered. The project will not include any ethics which will not affect the project or participants.

3.7. Limitations

The project may be limited in research and design time available. The project may not be as complete or as detailed as it could be due to any time limitations however the project will need to be completed to a level in which it can receive useful data. For this reason concentration will be focused on the main aspects of the project, creating an application which will be able to use the atmospheric model to control temperature, a velocity and material model to generate reasonable data.

Knowledge of fluid dynamics may also be a limiting factor, research into the subject area (Aerodynamics) will be in as much detail as possible however it may end up using some equation incorrectly.

From the recent research on the project, some aspects of aerodynamic flight cannot be calculated analytically. The Lift and Drag coefficient is usually calculated experimentally with the use of a wind tunnel even though this project does not have access to one of these, there are methods of calculating lift with pre-calculated coefficients.

Researching into the unreal engine has revealed that the blueprints system does not use the variable type of ‘Double’ the highest precision usable in blueprints is a ‘Float’. This will impact the accuracy of the calculations but not by a great deal unless the project calls for a very accurate decimal number. If the project needs to be more accurate, then the use of C++ will give me access to the ‘Double type, however this will take more time which is already limited. Using the blueprint system will be faster and of sufficient accuracy.

3.8. Conclusions

With this methodology the project can progress with a good understanding of what needs to be research and how this will occur. The strategy provides a clear understanding of the different methods at the disposal of the project. The analysis will need to be in-depth and the sample size will need to be sufficient to collect a decent amount of valid results. The ethics may affect the project if it needs others to test the flight model but they have been sufficiently thought out and with the project in its current state it should overcome the limitations discovered.

4. Findings and Analysis

4.1. Introduction

The flight model has been finished and has gathered a medium size data sample. Three materials have had their temperature calculated at six different velocities. The materials chosen are Tin, Aluminium and Tungsten. These material have varying densities, melting points and more importantly specific heat capacity.

Nine tables of raw data have been created, 3 for each material (Tin, Aluminium and Tungsten) and each one is at a different altitude (0 Km, 40 Km and 80 Km). ***(See Appendix E, F and G)***.

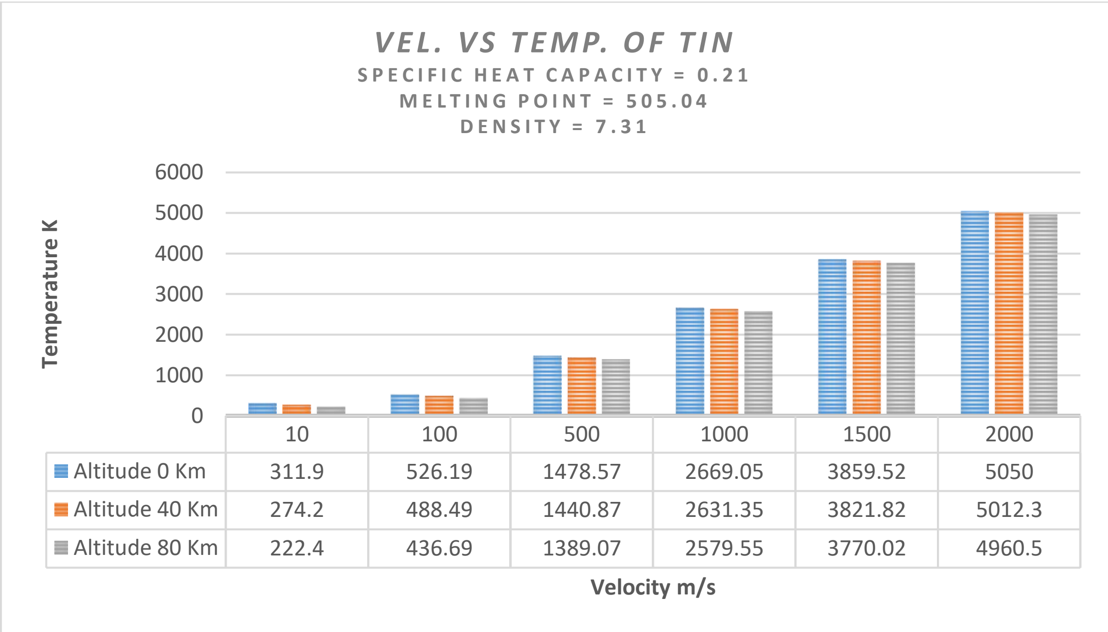
Appendix E, F and G are the raw results obtained from the flight model before they have been processed, these have been included to give an example of all of the data collected and the data being used to create the tables of results.

These raw results have been taken and the useful data has been added to 3 bar charts which depict the velocity vs the Temperature of the three materials in all 3 altitudes. This data will be analysed in relation to the methods mentioned in the methodology. The data will be analysed for Correlational Data, Quantitative Data and Experimental Data.

4.2. Analysis

These graphs when analysed should give a reasonable amount of Correlational and Quantitative data. The next three sections will contain the results from the flight model tests, all of the tests are of the velocity verses the temperature of the material chosen.

4.2.1. Table of Data – Tin



	10	100	500	1000	1500	2000
Altitude 0 Km	311.9	526.19	1478.57	2669.05	3859.52	5050
Altitude 40 Km	274.2	488.49	1440.87	2631.35	3821.82	5012.3
Altitude 80 Km	222.4	436.69	1389.07	2579.55	3770.02	4960.5

This graph shows the results of the velocity vs the temperature at three different altitudes for Tin. Tin has a medium heat capacity, the lowest melting point and a lowest density compared to the other materials.

Observing this graph has resulted in different sets of correlating data.

Concentrating on the first column of results, at 10 Metres per Second, the temperatures at lower altitudes are greater than the temperature at a higher altitudes.

Looking at all of the columns, the overall temperature increases as the velocity increases.

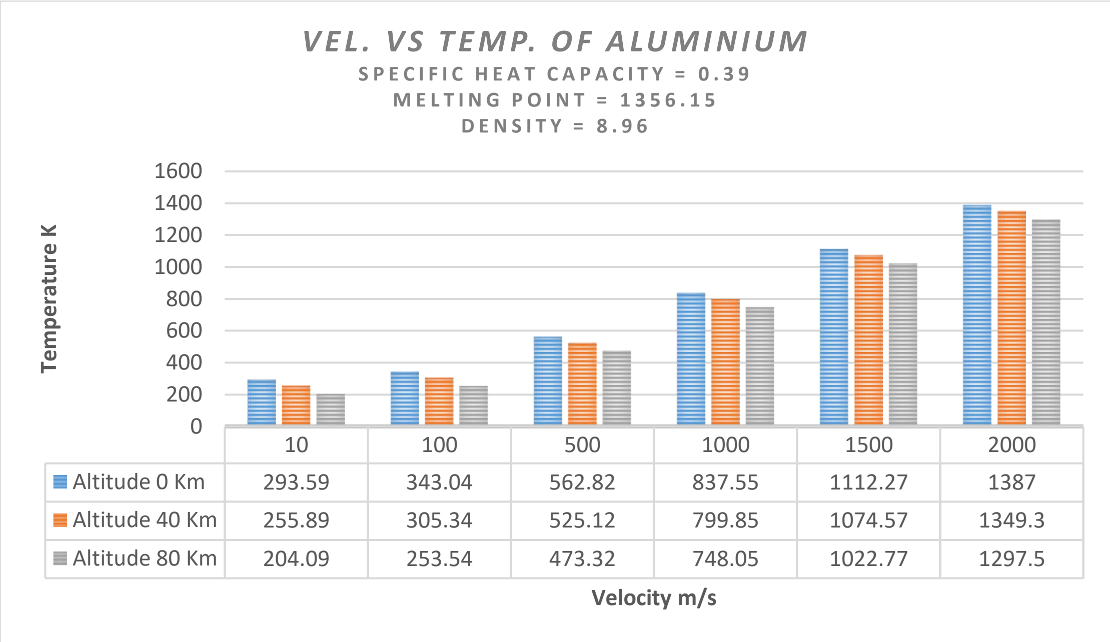
The Third column has a velocity of 500 and the Forth column has double that speed however this does not double the temperature which is generated.

In terms of Quantitative Data the second column contains a value which is greater than the melting point of the material. At 0 kilometres the material would be destroyed however at 40 or 80 kilometres the material would be below the melting point.

Every column after the second would melt the material as the temperatures generated at that velocity and altitude would be too great.

The density of this material would make it a good material to use for flight as it has a light mass however with the low melting point the material would not hold together at medium speeds.

4.2.2. Table of Data – Aluminium



	10	100	500	1000	1500	2000
Altitude 0 Km	293.59	343.04	562.82	837.55	1112.27	1387
Altitude 40 Km	255.89	305.34	525.12	799.85	1074.57	1349.3
Altitude 80 Km	204.09	253.54	473.32	748.05	1022.77	1297.5

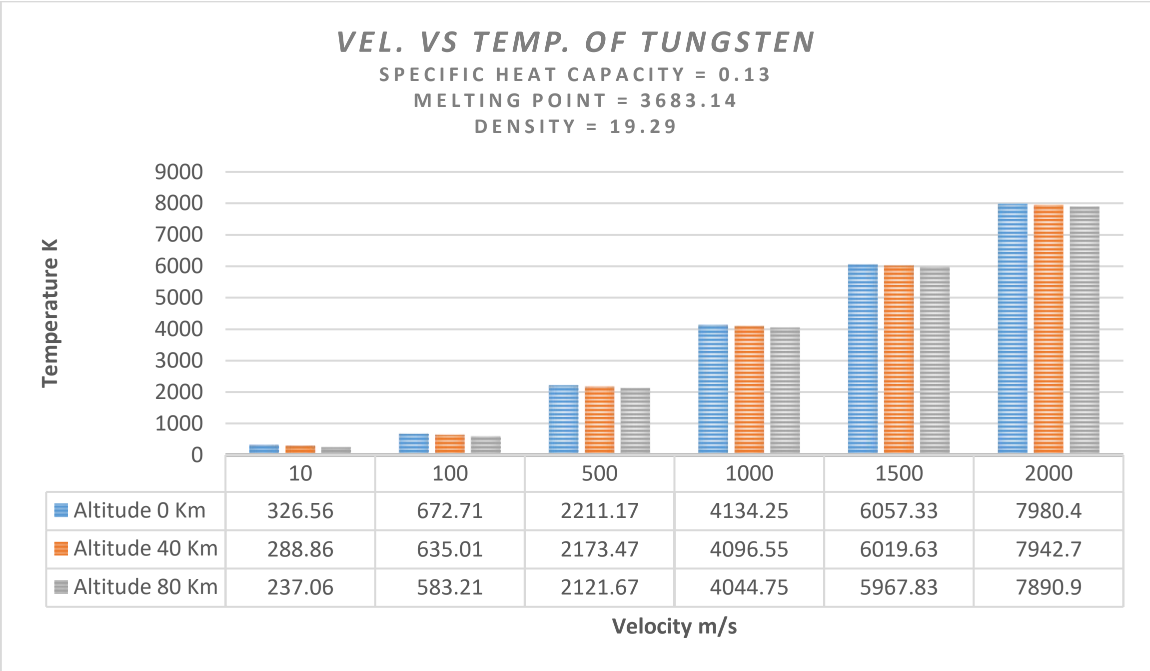
Like the last graph, this shows the results of the velocity vs the temperature at three different altitudes for Aluminium. Aluminium has the highest specific heat capacity, a medium melting point and a medium density compared to the other materials.

Again a correlation in the first column can be seen, the temperature drop as the altitude increases. Also as with the first graph a correlation can be seen in all columns between the velocity and the temperature, as the velocity increases so does the temperature.

The main difference in this graph seems to be the qualitative data. This time the melting point is at the far end of the velocities, in the last column at 2000 metres per second the material would melt only if it was at an altitude of 0 kilometres. The rest of the graph suggests that the material will remain intact.

This material is usually used in the aerospace industry as well as other greater alloys and these results can confirm the material is useful at keeping cool at high velocities. Aluminium has a greater density the tin however this should only serve to strengthen the material as it is still a light weight material. Its high melting point will also be a great benefit for high speed aircraft.

4.2.3. Table of Data – Tungsten



This final graph shows the results of the velocity vs the temperature at three different altitudes for Tungsten. Tungsten has the lowest heat capacity, the highest melting point and the highest density.

From examine all these three graphs a new piece of correlation becomes present. As the Specific Heat Capacity of a material decreases so does its tolerance to temperature.
Aluminium has the highest Specific Heat Capacity (0.39) and has a low maximum temperature in the last column of the graph at around 1387 Kelvin at the highest.
Tin has a lower Specific Heat Capacity (0.21) and sees a higher max temperature in the last column up to 5050 Kelvin.
Now Tungsten has the lowest Specific Heat Capacity at (0.13) and has the highest max temperature in its last column at 7980 Kelvin.

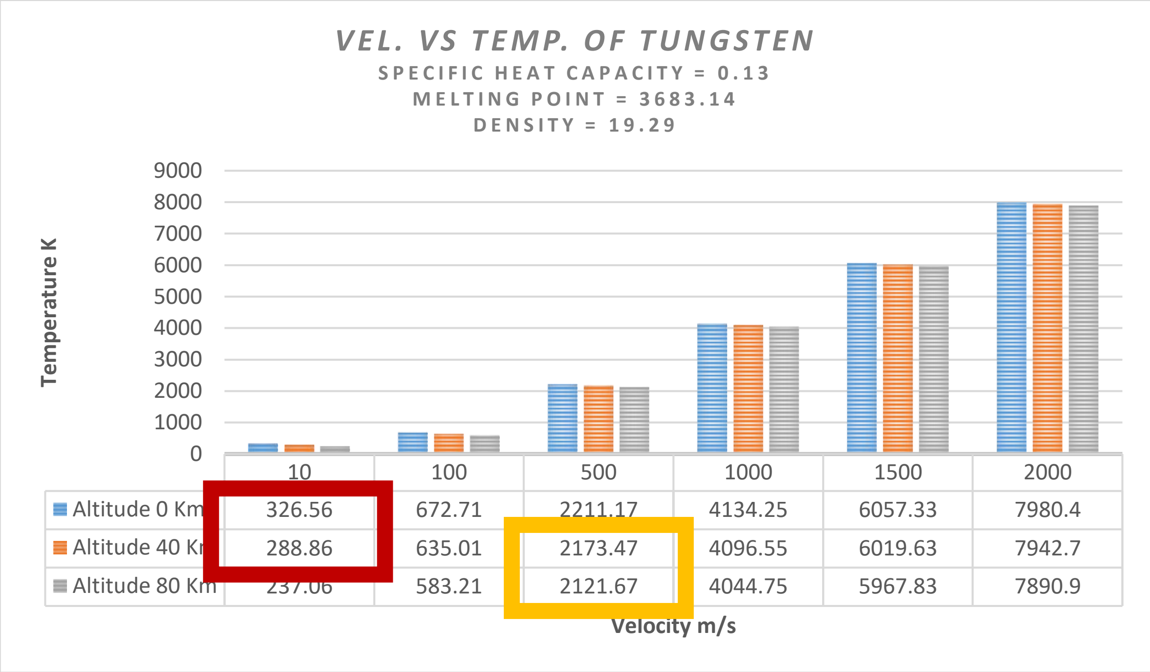
From this it is safe to say a material with a Higher Specific Heat Capacity can achieve much lower temperatures than that of a lower Specific Heat Capacity.
In the case of quantitative data, the melting point of the material begins at the forth column at 1000 metres per second. At this point the temperature generated has already surpassed the melting point no matter which altitude is examined.

When considering if this material could be used for aircraft at first it may seem tempting as tungsten has a very high melting point however from the results gathered it also has a very low Specific Heat Capacity which will multiply any heat generated and pass its melting point at supersonic speeds. It also has one of the highest densities of all of the materials which would be it very heavy, unsuitable for aircraft.

4.3. Conclusions

These results provide good evidence to support the hypothesis, all the materials examined have different specific heats and the temperatures will change when the velocity or altitude is changed. What was unknown was how the Specific Heat Capacity would affect the materials.

Aluminium has a high Specific Heat Capacity which contributes to the resistance of temperature change. When increasing the velocity the temperature will noticeably rise but far less than a material with a lower Specific Heat Capacity



No matter what Specific Heat Capacity is used for the material, the temperature generated seems to share similar patterns. Each temperature at a constant velocity will change by the same value between altitudes. Take this graph as the example, The 'Red Box' highlights Altitudes 0 and 40 with a Velocity of 10. The value 326.56 (Altitude 0) minus 288.86 (Altitude 40) is equal to 37.7. This is the same for all temperatures in each graph. If you negate Altitude 0 by Altitude 40 you will always obtain 37.7 as the result.
The same can be said for the 'Orange Box', negate any Altitude 40 with any Altitude 80 and you shall get 51.8 as the answer.
This strange condition may prove that the calculation I have used to find the temperature are flawed however it could also be by design, that cannot be said for sure unless further testing is carried out.

Another conclusion to take away is these test results are unrealistic when compared to any other flight model when dealing with Velocity and Altitude. It is very unlikely that an aircraft would be able to achieve 2000 metres per second at sea-level. The flight model is not meant to be realistic but has been developed to test the extremes however it is fair to say that to get any more accurate data the flight model will need to include many more variables which affect aero dynamics and temperatures generated by aircraft.

5. Conclusions and Recommendations

5.1. Conclusions

5.1.1. Hypothesis Conclusion

The project has come to an end and in conclusion my findings supports my hypothesis. The Specific Heat Capacity of a material determines the impact the temperature generation will have on that material. Changing variables like Velocity and Altitude will also have an impact on the temperature, the Velocity has a much greater influence on temperature than Altitude. This project has been an interesting one to see through to the end, it has been difficult to research this let alone create a small flight model to prove the hypothesis.

5.1.2. Flight Model Conclusion

The plan with the project was to create a flight simulation which would have the working of a simple flight model, including the temperature readings. In the end the project wasn't as completed as it could have been but it was sufficient to provide the data needed for the hypothesis to prove or disprove it. A better and more in-depth plan will be needed in the future to avoid losing out to time constraints.

5.1.3. Overall Conclusion

Overall the project has been a success, the literature reviewed has pushed this project forwards. Without the research into the equations which have enabled the development of the flight model, the project would not have been able to provide a reasonable conclusion. The project has completed all of the objective by meeting the aims set out in the beginning of the project. The methodology answered the questions of what methods would be used to analyse the results and provide evidence that the hypothesis is proven correct however it has also provided other information which may indicate that some mistakes may have been made.

5.2. Recommendations

5.2.1. Bigger Project

In the future the project must be bigger, it should extend on what I have already achieved however it may not be within the same area of study, branching from this can only improve the experience. An application will need to be developed to gain more useful data, creating the application whether a flight model or something completely different. This type of project would also best serve as fun physics game like Kerbal Space Program rather than a realistic and accurate flight simulation. The bigger project must involve controlling your temperature yet attempting to move as fast as possible through an environment.

5.2.2. Data Accuracy

The data produced by this project should be valid however more research into whether my equations and the results received are valid and accurate will not hurt. Cross referencing the results with similar results created by a valid piece of software will determine if my equations are at all accurate. After this project, deeper research into this area is needed until an understanding of what could have gone right, wrong and what could have gone better will deepen the experience.

6. Personal Reflection

Once I had begun the dissertation I was confused as to what area of fluid dynamics I was covering and how I would implement this into the project. After researching many water based fluid dynamic equations I sorted the project out and continued to research the area of aerodynamics.

I could have done much better with this project, I have only gotten what I would consider as just over half of the design project completed but the project was far enough along that it didn’t take too much time to create the necessary equations and implement them to gather all of the data that I needed.

I think my results were accurate in terms of the equation which I put in place however I’m no expert on this subject and may have incorrectly used the equation which would invalidate the results. The only way to test for this would be to find someone else’s data which is verified or a calculator for the specific equation. I spent too much time on another project which caused this one to lack behind.

Before the referral I wanted extra time to make the dissertation acceptable but the damage had already been done. Fortunately with the referral I can spend more time on the project perfecting areas and obtaining the thoughts of the markers which will only help me to further increase the quality of the dissertation however because I cannot receive the normal grading due to the referral, but it will allow me to feel satisfied that the project has been completed to a level which I am happy with.

I have enjoyed working on this project, more so if this was the only project I was working on but time management is a very important aspect of this line of education and work, something I still need work getting right.

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8. Appendices

8.1. Appendix A

In this table

alt is altitude in kilometers.
sigma is density divided by sea-level density.
delta is pressure divided by sea-level pressure.
theta is temperature divided by sea-level temperature.
temp is temperature in kelvins.
press is pressure in newtons per square meter.
dens is density in kilograms per cubic meter.
a is the speed of sound in meters per second.
visc is viscosity in 10**(-6) kilograms per meter-second.
k.visc is kinematic viscosity in square meters per second.

alt km	sigma	delta	theta	temp K	press N/sq.m	dens kg/cu.m	a m/s	visc kg/m-s	k.visc sq.m/s
-2	1.2067E+0	1.2611E+0	1.0451	301.2	1.278E+5	1.478E+0	347.9	18.51	1.25E-5
0	1.0000E+0	1.0000E+0	1.0000	288.1	1.013E+5	1.225E+0	340.3	17.89	1.46E-5
2	8.2168E-1	7.8462E-1	0.9549	275.2	7.950E+4	1.007E+0	332.5	17.26	1.71E-5
4	6.6885E-1	6.0854E-1	0.9098	262.2	6.166E+4	8.193E-1	324.6	16.61	2.03E-5
6	5.3887E-1	4.6600E-1	0.8648	249.2	4.722E+4	6.601E-1	316.5	15.95	2.42E-5
8	4.2921E-1	3.5185E-1	0.8198	236.2	3.565E+4	5.258E-1	308.1	15.27	2.90E-5
10	3.3756E-1	2.6153E-1	0.7748	223.3	2.650E+4	4.135E-1	299.5	14.58	3.53E-5
12	2.5464E-1	1.9146E-1	0.7519	216.6	1.940E+4	3.119E-1	295.1	14.22	4.56E-5
14	1.8600E-1	1.3985E-1	0.7519	216.6	1.417E+4	2.279E-1	295.1	14.22	6.24E-5
16	1.3589E-1	1.0217E-1	0.7519	216.6	1.035E+4	1.665E-1	295.1	14.22	8.54E-5
18	9.9302E-2	7.4662E-2	0.7519	216.6	7.565E+3	1.216E-1	295.1	14.22	1.17E-4
20	7.2578E-2	5.4569E-2	0.7519	216.6	5.529E+3	8.891E-2	295.1	14.22	1.60E-4
22	5.2660E-2	3.9945E-2	0.7585	218.6	4.047E+3	6.451E-2	296.4	14.32	2.22E-4
24	3.8316E-2	2.9328E-2	0.7654	220.6	2.972E+3	4.694E-2	297.7	14.43	3.07E-4
26	2.7964E-2	2.1597E-2	0.7723	222.5	2.188E+3	3.426E-2	299.1	14.54	4.24E-4
28	2.0470E-2	1.5950E-2	0.7792	224.5	1.616E+3	2.508E-2	300.4	14.65	5.84E-4
30	1.5028E-2	1.1813E-2	0.7861	226.5	1.197E+3	1.841E-2	301.7	14.75	8.01E-4
32	1.1065E-2	8.7740E-3	0.7930	228.5	8.890E+2	1.355E-2	303.0	14.86	1.10E-3
34	8.0709E-3	6.5470E-3	0.8112	233.7	6.634E+2	9.887E-3	306.5	15.14	1.53E-3
36	5.9245E-3	4.9198E-3	0.8304	239.3	4.985E+2	7.257E-3	310.1	15.43	2.13E-3
38	4.3806E-3	3.7218E-3	0.8496	244.8	3.771E+2	5.366E-3	313.7	15.72	2.93E-3
40	3.2615E-3	2.8337E-3	0.8688	250.4	2.871E+2	3.995E-3	317.2	16.01	4.01E-3
42	2.4445E-3	2.1708E-3	0.8880	255.9	2.200E+2	2.995E-3	320.7	16.29	5.44E-3
44	1.8438E-3	1.6727E-3	0.9072	261.4	1.695E+2	2.259E-3	324.1	16.57	7.34E-3
46	1.3992E-3	1.2961E-3	0.9263	266.9	1.313E+2	1.714E-3	327.5	16.85	9.83E-3
48	1.0748E-3	1.0095E-3	0.9393	270.6	1.023E+2	1.317E-3	329.8	17.04	1.29E-2
50	8.3819E-4	7.8728E-4	0.9393	270.6	7.977E+1	1.027E-3	329.8	17.04	1.66E-2
52	6.5759E-4	6.1395E-4	0.9336	269.0	6.221E+1	8.055E-4	328.8	16.96	2.10E-2
54	5.2158E-4	4.7700E-4	0.9145	263.5	4.833E+1	6.389E-4	325.4	16.68	2.61E-2
56	4.1175E-4	3.6869E-4	0.8954	258.0	3.736E+1	5.044E-4	322.0	16.40	3.25E-2
58	3.2344E-4	2.8344E-4	0.8763	252.5	2.872E+1	3.962E-4	318.6	16.12	4.07E-2
60	2.5276E-4	2.1668E-4	0.8573	247.0	2.196E+1	3.096E-4	315.1	15.84	5.11E-2
62	1.9647E-4	1.6468E-4	0.8382	241.5	1.669E+1	2.407E-4	311.5	15.55	6.46E-2
64	1.5185E-4	1.2439E-4	0.8191	236.0	1.260E+1	1.860E-4	308.0	15.26	8.20E-2
66	1.1668E-4	9.3354E-5	0.8001	230.5	9.459E+0	1.429E-4	304.4	14.97	1.05E-1
68	8.9101E-5	6.9593E-5	0.7811	225.1	7.051E+0	1.091E-4	300.7	14.67	1.34E-1
70	6.7601E-5	5.1515E-5	0.7620	219.6	5.220E+0	8.281E-5	297.1	14.38	1.74E-1
72	5.0905E-5	3.7852E-5	0.7436	214.3	3.835E+0	6.236E-5	293.4	14.08	2.26E-1
74	3.7856E-5	2.7635E-5	0.7300	210.3	2.800E+0	4.637E-5	290.7	13.87	2.99E-1
76	2.8001E-5	2.0061E-5	0.7164	206.4	2.033E+0	3.430E-5	288.0	13.65	3.98E-1
78	2.0597E-5	1.4477E-5	0.7029	202.5	1.467E+0	2.523E-5	285.3	13.43	5.32E-1
80	1.5063E-5	1.0384E-5	0.6893	198.6	1.052E+0	1.845E-5	282.5	13.21	7.16E-1
82	1.0950E-5	7.4002E-6	0.6758	194.7	7.498E-1	1.341E-5	279.7	12.98	9.68E-1
84	7.9106E-6	5.2391E-6	0.6623	190.8	5.308E-1	9.690E-6	276.9	12.76	1.32E+0
86	5.6777E-6	3.6835E-6	0.6488	186.9	3.732E-1	6.955E-6	274.1	12.53	1.80E+0

This table displays atmospheric information in scientific notation which after I converted was used in my project. *(PDAS, A Sample Atmosphere Table (SI Units), 2013)*

8.2. Appendix B

U.S Standard Atmosphere Air Properties in SI Units

Geo potential Altitude above Sea Level - *h* - (*m*)	Temperature - *t* - (^oC)	Acceleration of Gravity - *g* - (m/s^2)	Absolute Pressure - *p* - (10^4 N/m^2)	Density - *ρ* - (10^{-1} kg/m^3)	Dynamic Viscosity - *μ* - (10^{-5} $N.s/m^2$)
-1000	21.50	9.810	11.39	13.47	1.821
0	15.00	9.807	10.13	12.25	1.789
1000	8.50	9.804	8.988	11.12	1.758
2000	2.00	9.801	7.950	10.07	1.726
3000	-4.49	9.797	7.012	9.093	1.694
4000	-10.98	9.794	6.166	8.194	1.661
5000	-17.47	9.791	5.405	7.364	1.628
6000	-23.96	9.788	4.722	6.601	1.595
7000	-30.45	9.785	4.111	5.900	1.561
8000	-36.94	9.782	3.565	5.258	1.527
9000	-43.42	9.779	3.080	4.671	1.493
10000	-49.90	9.776	2.650	4.135	1.458
15000	-56.50	9.761	1.211	1.948	1.422
20000	-56.50	9.745	0.5529	0.8891	1.422
25000	-51.60	9.730	0.2549	0.4008	1.448
30000	-46.64	9.715	0.1197	0.1841	1.475
40000	-22.80	9.684	0.0287	0.03996	1.601
50000	-25	9.654	0.007978	0.01027	1.704
60000	-26.13	9.624	0.002196	0.003097	1.584
70000	-53.57	9.594	0.00052	0.0008283	1.438
80000	-74.51	9.564	0.00011	0.0001846	1.321

I used the acceleration of gravity from this table in my project to simulate gravity at different altitudes. *(The Engineering ToolBox, U.S Standard Atmosphere, Unknown Year)*

8.3. Appendix C

Basic Information

Name: Aluminum
Symbol: Al
Atomic Number: 13
Atomic Mass: 26.981539 amu
Melting Point: 660.37 °C (933.52 K, 1220.666 °F)
Boiling Point: 2467.0 °C (2740.15 K, 4472.6 °F)
Number of Protons/Electrons: 13
Number of Neutrons: 14
Classification: Other Metals
Crystal Structure: Cubic
Density @ 293 K: 2.702 g/cm^3
Color: Silver
British Spelling: Aluminium
IUPAC Spelling: Aluminium

I used the melting point from this site to gather data on the different materials I am using. *(Periodic Table, Basic Info, 2015)*

8.4. Appendix D

The specific heat of common metals are indicated in the table below:

Metal	Specific Heat - c_p		
	(kJ/kg K)	(kcal/kg^{o}C)	(Btu/lb$_m$^{o}F)
Aluminum	0.91	0.22	0.22
Antimony	0.21	0.05	0.05
Barium	0.20	0.048	0.048
Beryllium	1.83	0.436	0.436
Bismuth	0.13	0.03	0.03
Cadmium	0.23	0.055	0.055
Calsium	0.63	0.15	0.15
Carbon Steel	0.49	0.12	0.12
Cast Iron	0.46	0.11	0.11
Cesium	0.24	0.057	0.057
Chromium	0.46	0.11	0.11
Cobalt	0.42	0.1	0.1
Copper	0.39	0.092	0.09
Gallium	0.37	0.088	0.088
Germanium	0.32	0.076	0.076
Gold	0.13	0.031	0.03
Hafnium	0.14	0.033	0.033
Indium	0.24	0.057	0.057
Iridium	0.13	0.031	0.31
Iron	0.45	0.108	0.11
Lanthanum	0.195	0.047	0.047
Lead	0.13	0.031	0.03
Lithium	3.57	0.85	0.85
Lutetium	0.15	0.036	0.036
Magnesium	1.05	0.243	0.25
Manganese	0.48	0.114	0.114
Mercury	0.14	0.033	0.03
Molybdenum	0.25	0.06	0.06
Nickel	0.44	0.104	0.10
Niobium (Columbium)	0.27	0.064	0.064
Osmium	0.13	0.031	0.031
Palladium	0.24	0.057	0.057
Platinum	0.13	0.032	0.03
Plutonium	0.13	0.032	0.032
Potassium	0.75	0.180	0.180
Rhenium	0.14	0.033	0.033
Rhodium	0.24	0.058	0.058
Rubidium	0.36	0.086	0.086
Ruthenium	0.24	0.057	0.057
Scandium	0.57	0.14	0.14
Selenium	0.32	0.077	0.077
Silicon	0.71	0.17	0.17
Silver	0.23	0.057	0.057
Sodium	1.21	0.29	0.29
Strontium	0.30	0.072	0.072
Tantalum	0.14	0.034	0.034
Thallium	0.13	0.03	0.03
Thorium	0.13	0.03	0.03
Tin	0.21	0.054	0.05
Titanium	0.54	0.125	0.13
Tungsten	0.13	0.032	0.032
Uranium	0.12	0.028	0.028
Vanadium	0.39	0.116	0.116
Yttrium	0.30	0.072	0.072
Zinc	0.39	0.093	0.09
Zirconium	0.27	0.06	0.06
Wrought Iron	0.50	0.12	0.12

I used this table to find all of the metals I am using and their specific heat capacities.

(The Engineering ToolBox, Metals - Specific Heats, Unknown Year)

8.5. Appendix E

AltitudeSpeedMaterialTemp.txt

```
Material:                Tin
MaterialSpecificHeat:    0.21
MaterialMeltingTemp:     505.04

Altitude:                0
Density:                 1.225
AirTemp:                 288.1
SpeedOfSound:            340.29

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.02         311.90       No
100              0.29         526.19       Yes
500              1.46         1478.57      Yes
1000             2.93         2669.05      Yes
1500             4.40         3859.52      Yes
2000             5.87         5050         Yes
----------------------------------------------------------------------
Material:                Tin
MaterialSpecificHeat:    0.21
MaterialMeltingTemp:     505.04

Altitude:                40
Density:                 0.003995
AirTemp:                 250.39
SpeedOfSound:            317.20

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.03         274.20       No
100              0.31         488.49       No
500              1.57         1440.87      Yes
1000             3.15         2631.35      Yes
1500             4.72         3821.82      Yes
2000             6.30         5012.30      Yes
----------------------------------------------------------------------
Material:                Tin
MaterialSpecificHeat:    0.21
MaterialMeltingTemp:     505.04

Altitude:                80
Density:                 0.000018
AirTemp:                 198.60
SpeedOfSound:            282.5

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.03         222.40       No
100              0.35         436.69       No
500              1.76         1389.07      Yes
1000             3.53         2579.55      Yes
1500             5.30         3770.02      Yes
2000             7.07         4960.50      Yes
----------------------------------------------------------------------
```

These are my raw results I obtained from my project, these are for Tin.

8.6. Appendix F

AlltitudeSpeedMaterialTemp.txt

```
Material:               Aluminium
MaterialSpecificHeat:   0.39
MaterialMeltingTemp:    1356.15

Altitude:               0
Density:                1.225
AirTemp:                288.1
SpeedOfSound:           340.29

TrueAirSpeed    MachNumber  PlaneTemp   ExceededMeltingPoint
10              0.02        293.59      No
100             0.29        343.04      No
500             1.46        562.82      No
1000            2.93        837.55      No
1500            4.40        1112.27     No
2000            5.87        1387        Yes
----------------------------------------------------------------------
Material:               Aluminium
MaterialSpecificHeat:   0.39
MaterialMeltingTemp:    1356.15

Altitude:               40
Density:                0.003995
AirTemp:                250.39
SpeedOfSound:           317.20

TrueAirSpeed    MachNumber  PlaneTemp   ExceededMeltingPoint
10              0.03        255.89      No
100             0.31        305.34      No
500             1.57        525.12      No
1000            3.15        799.85      No
1500            4.72        1074.57     No
2000            6.30        1349.30     No
----------------------------------------------------------------------
Material:               Aluminium
MaterialSpecificHeat:   0.39
MaterialMeltingTemp:    1356.15

Altitude:               80
Density:                0.000018
AirTemp:                198.60
SpeedOfSound:           282.5

TrueAirSpeed    MachNumber  PlaneTemp   ExceededMeltingPoint
10              0.03        204.09      No
100             0.35        253.54      No
500             1.76        473.32      No
1000            3.53        748.05      No
1500            5.30        1022.77     No
2000            7.07        1297.50     No
----------------------------------------------------------------------
```

Normal text file

These are my raw results I obtained from my project, these are for Aluminium.

8.7. *Appendix G*

AltitudeSpeedMaterialTemp.txt

```
------------------------------------------------------------------------
Material:                Tungsten
MaterialSpecificHeat:    0.13
MaterialMeltingTemp:     3683.14

Altitude:                0
Density:                 1.225
AirTemp:                 288.1
SpeedOfSound:            340.29

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.02         326.56       No
100              0.29         672.71       No
500              1.46         2211.17      No
1000             2.93         4134.25      Yes
1500             4.40         6057.33      Yes
2000             5.87         7980.40      Yes
------------------------------------------------------------------------
Material:                Tungsten
MaterialSpecificHeat:    0.13
MaterialMeltingTemp:     3683.14

Altitude:                40
Density:                 0.003995
AirTemp:                 250.39
SpeedOfSound:            317.20

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.03         288.86       No
100              0.31         635.01       No
500              1.57         2173.47      No
1000             3.15         4096.55      No
1500             4.72         6019.63      No
2000             6.30         7942.70      No
------------------------------------------------------------------------
Material:                Tungsten
MaterialSpecificHeat:    0.13
MaterialMeltingTemp:     3683.14

Altitude:                80
Density:                 0.000018
AirTemp:                 198.60
SpeedOfSound:            282.5

TrueAirSpeed     MachNumber   PlaneTemp    ExceededMeltingPoint
10               0.03         237.06       No
100              0.35         583.21       No
500              1.76         2121.67      No
1000             3.53         4044.75      Yes
1500             5.30         5967.83      Yes
2000             7.07         7890.90      Yes
```

Normal text file

These are my raw results I obtained from my project, these are for Tungsten.