CHAPTER 1

INTRODUCTION

1.1 Background of Study

Boomerang is synonym to Australia as it is geographically invented in that country. Boomerang is well known for its behaviour that aloft or sustain in air and somehow if thrown correctly can return to its origin. A boomerang is a curved piece of wood used as a weapon and for sport. Boomerangs come in many shapes and sizes depending on their geographic or tribal origins and intended function. Historical evidence also points to the use of boomerang for killing animals. Boomerangs have been used primarily for leisure or recreation. Modern returning boomerangs can be almost any size or shape and are made from a variety of materials [5].

The origin of the boomerang is uncertain. The oldest Australian Aboriginal boomerangs are ten thousand years old, but older hunting sticks have been discovered in Europe. The standard patent of boomerang is almost hard to find because boomerang is generally hand-made by aborigines. Presently, there are only a few numbers of product or toy which refers to boomerang that has optimum performance. Ancient boomerang is lack in design and the material chosen for fabricating it is not properly selected has result in poor performance. Boomerang may be hard to make it return back to its origin after thrown and can harm the user while bring danger to surrounding [5].

Aboriginal boomerang is actually hard to return to its origin when thrown. Therefore, this research is embarked to enhance the performance of Australian aboriginal boomerang. This research is particularly focusing on to develop a boomerang model that compatible for high sport performance. The target is to produce a boomerang with high lift force so it can stay on air for long time. This includes designing of the boomerang where the shape of the overall boomerang and the profile of the wing are properly examined [5].

This is to ensure that the aerodynamic of the boomerang can make sure the sustainability of the boomerang on air is maximized while the shape and angle of attack will clearly affecting the return-ability of the boomerang [5].

1.2 Problem Statement

As mentioned earlier, there are a few problems with the design of the Australian aboriginal boomerang. It is said that the boomerang is able to return to its origin but only in certain circumstances; such as throwing technique and presence of wind; otherwise it is very hard to have it return to its origin. The profile of the wing is the most crucial part and need to be improved by designing a profile that will give a good aerodynamic to the system. The angle of attack for leading edge of boomerang's wing must also be considered. These two parameters (aerodynamic and angle of attack) is the key to determine the lift force of the boomerang, thus determining the air-time if this boomerang. However, for this research, the focus will be narrowed down to choose an optimum area that can give highest lift force. This is because area plays crucial impact towards the lift force of the boomerang.

It is a necessity to consider the overall shape of the boomerang which includes the number of wings which is blades and arm, the shape of the tips and also the length of the boomerang. These parameters will affect the rotational speed, the momentum, and also the inertia of the boomerang. The area wing geometry has a large effect on the amount of lift generated. The airfoil shape and wing size will both affect the amount of lift. This research will try to do a comparison between small sized and bigger sized area of boomerang wing. Last but not least, the angle between blades somehow will affect the flight of the boomerang. This study will try to find the optimum angle between blades that for the boomerang to have a good flight. Angle between boomerang blades can be referred from Figure 1.1.

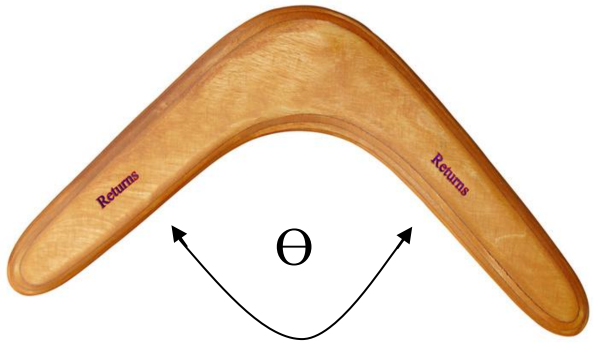

Figure 1.1: Angle between boomerang's blades [14].

1.2.1 Problem Identification

Australian aboriginal boomerang is mostly hand-made by aborigines so the design is not studied properly. It has many disadvantages regarding to its design. This project is mainly aim to study and observe how actually variation in, area of the boomerang and angle of blades will affect the flight of the boomerang.

1.2.2 Significance of Project

The significance of this project is that in the future it could help in designing the correct and better boomerang for sport usage. The mechanism of boomerang itself is very complicated as it is a rotating and transitioning object so this research could help to get better understanding on the mechanism of boomerang. The improved design can be further brought to sports tournament.

1.3 Objective of Study

The objective of this research is to "Redesign the Australian aboriginal boomerang". A basis model boomerang that is alike Australian aboriginal boomerang will be chosen as conventional design and will be compared to a redesign one. The main goal is to produce a boomerang that can high lift force so it can stay on air longer and also safe for user. Below are the specific parameters that are going to be studied throughout this project:-

- Effect of wing area towards lift force.
- Effect of angle between blades towards lift force.

1.4 Scope of Study

The scope of the study will focus on the design which dominantly affects the performance of the boomerang. The shape and the area of the boomerang will be carefully studied. The study will focus on to see the effect of wing area towards the lift force which comparison will be done between designs and to find the effective angle between blades of the boomerang. Study will involve the analysis of the result produces by computational method through GAMBIT and FLUENT to see whether there is a relationship between the parameters stated above.

1.5 Relevancy of Project

This project is relevant in the present engineering world as the trend of boomerang tournament is increasing. Country like Australia, United States and Germany is currently organizing annual boomerang competition. Boomerang design is getting improved time by time. So it is essential for us to embark a research for this topic for us to have our own design that is ready for sport performance.

1.6 Feasibility of Project Within

The project is feasible as it utilizes engineering programs called AutoCAD, FLUENT and GAMBIT to analyze the model and study the effect of stated parameters to the velocity profile and flow rate. This project is low in cost as it uses simulation and analysis. The time given for the project to be done is approximately two semesters of studies. The project certainly will consume a lot of time for all the researches, the experiments which should take a while and as the period of the FYP is sufficient to make the project a success.

CHAPTER 2
LITERATURE REVIEW/THEORY

2.1 Lift Force

A fluid flowing past the surface of a body exerts a force on it. Lift is defined to be the component of this force that is perpendicular to the oncoming flow direction. It contrasts with the drag force, which is defined to be the component of the fluid-dynamic force parallel to the flow direction. If the fluid is air, the force is called an aerodynamic force. An airfoil is a streamlined shape that is capable of generating significantly more lift than drag [11].

Aerodynamic lift is commonly associated with the wing of a fixed-wing aircraft, although lift is also generated by propellers; helicopter rotors; rudders, sails and keels on sailboats; hydrofoils; wings on auto racing cars; wind turbines and other streamlined objects. While common meanings of the word "lift" suggest that lift opposes gravity, lift can be in any direction. When an aircraft is flying straight and level (cruise) most of the lift opposes gravity. However, when an aircraft is climbing, descending, or banking in a turn, for example, the lift is tilted with respect to the vertical. Lift may also be entirely downwards in some aerobatic manoeuvres, or on the wing on a racing car. In this last case, the term down force is often used. Lift may also be horizontal, for instance on a sail on a sailboat [11].

Non-streamlined objects such as bluff bodies and plates (not parallel to the flow) may also generate lift when moving relative to the fluid. This lift may be steady, or it may oscillate due to vortex shedding. Interaction of the object's flexibility with the vortex shedding may enhance the effects of fluctuating lift and cause vortex-induced vibrations [11].

Lift is generated in accordance with the fundamental principles of physics. The most relevant physics reduce to three principles. First is Newton's law of motion, especially Newton's second law which relates the net force on an element of air to its rate of momentum change. Second is conservation of mass, including the common assumption that the airfoil's surface is impermeable for the air flowing around, and the third one is an expression relating the fluid stresses (consisting of pressure and shear stress components) to the properties of the flow [11].

When a fluid flows relative to a solid body, the body obstructs the flow, causing some of the fluid to change its speed and direction in order to flow around the body. The obstructive nature of the solid body causes the streamlines to move closer together in some places, and further apart in others. When fluid flows past a 2-D cambered airfoil at zero angle of attack, the upper surface has a greater area (that is, the interior area of the airfoil above the chord line) than the lower surface and hence presents a greater obstruction to the fluid than the lower surface. This asymmetry causes the streamlines in the fluid flowing over the upper surface to move closer together than the streamlines over the lower surface. As a consequence of mass conservation, the reduced area between the streamlines over the upper surface results in a higher velocity than that over the lower surface. The upper stream tube is squashed the most in the nose region ahead of the maximum thickness of the airfoil, causing the maximum velocity to occur ahead of the maximum thickness [11].

In accordance with Bernoulli's principle, where the fluid is moving faster the pressure is lower, and where the fluid is moving slower the pressure is greater. The fluid is moving faster over the upper surface, particularly near the leading edge, than over the lower surface so the pressure on the upper surface is lower than the pressure on the lower surface. The difference in pressure between the upper and lower surfaces results in lift. If the lift coefficient for a wing at a specified angle of attack is known (or estimated using a method such as thin-airfoil theory), then the lift produced for specific flow conditions can be determined using the following equation [11]:-

$$L = \frac{1}{2}\rho v^2 A C_L \quad (2.1)$$

Where:

- L is lift force,
- ρ is air density
- v is true airspeed,
- A is planform area, and
- C_L is the lift coefficient at the desired angle of attack, Mach number, and Reynolds number

The lift coefficient (C_L or C_Z) is a dimensionless coefficient that relates the lift generated by an airfoil, the dynamic pressure of the fluid flow around the airfoil, and the planform area of the airfoil. It may also be described as the ratio of lift pressure to dynamic pressure. Lift coefficient may be used to relate the total lift generated by the total area of the wing of. In this application it is called the aircraft lift coefficient C_L [11].

The lift coefficient C_L is equal to:

$$C_L = \frac{L}{\frac{1}{2}\rho v^2 A} = \frac{L}{qA} \quad (2.2)$$

Where:

- L is the lift force,
- ρ is fluid density,
- v is true airspeed,
- q is dynamic pressure, and
- A is planform area.

Lift coefficient may also be used as a characteristic of a particular shape (or cross-section) of an airfoil. In this application it is called the section lift coefficient c_l. It is common to show, for a particular airfoil section, the relationship between section lift coefficient and angle of attack. It is also useful to show the relationship between section lift coefficients and drag coefficient [11].

The section lift coefficient is based on the concept of an infinite wing of non-varying cross-section. It is not practical to define the section lift coefficient in terms of total lift and total area because they are infinitely large. Rather, the lift is defined per unit span of the wing (*L'*). In such a situation, the above formula becomes [11]:

$$Cl = \frac{L'}{\frac{1}{2}\rho v^2 c} \tag{2.3}$$

Where:

- c is the chord length

2.2 Dynamic Pressure

In incompressible fluid dynamics dynamic pressure (indicated with *q*, or *Q*, and sometimes called *velocity pressure* or impact pressure) is the quantity defined by:

$$q = \frac{1}{2}\rho v^2 \tag{2.4}$$

Where (using SI units):

- q = dynamic pressure in pascals,
- ρ = fluid density in kg/m3 (e.g. density of air),
- v = fluid velocity in m/s.

Dynamic pressure is closely related to the kinetic energy of a fluid particle, since both quantities are proportional to the particle's mass (through the density, in the case of dynamic pressure) and square of the velocity. Dynamic pressure is in fact one of the terms of Bernoulli's equation, which is essentially an equation of energy conservation for a fluid in motion. The dynamic pressure is equal to the difference between the stagnation pressure and the static pressure [13].

Another important aspect of dynamic pressure is that, as dimensional analysis shows, the aerodynamic stress (i.e. stress within a structure subject to aerodynamic forces) experienced by an aircraft traveling at speed v is proportional to the air density and square of v, i.e. proportional to q. Therefore, by looking at the variation of q during flight, it is possible to determine how the stress will vary and in particular when it will reach its maximum value. The point of maximum aerodynamic load is often referred to as max Q and it is a critical parameter, for example, for spacecraft during launch [13].

The dynamic pressure, along with the static pressure and the pressure due to elevation, is used in Bernoulli's principle as an energy balance on a closed system. The three terms are used to define the state of a closed system of an incompressible, constant-density fluid [13].

2.3 Bernoulli Equation

In describing the concept of lift that is produced by wing, it is physically correct that both Bernoulli equation and Newton's Third law applicable. The Bernoulli equation is simply a statement of the principle of conservation of energy in fluids. Conservation of momentum and Newton's 3rd law are equally valid as foundation principles of nature [8].

Bernoulli's equation relates the pressure, elevation, and speed of an incompressible fluid in steady flow. It follows from Newton's laws and is most easily derived by applying the work-energy theorem to a segment of the fluid [3]. The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids [8].

The qualitative behaviour that is usually labelled with the term "Bernoulli effect" is the lowering of fluid pressure in regions where the flow velocity is increased. This lowering of pressure in a constriction of a flow path may seem counterintuitive, but seems less so when you consider pressure to be energy density. In the high velocity flow through the constriction, kinetic energy must increase at the expense of pressure energy [3].

Bernoulli equation is denoted by:-

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (2.5)$$

From this equation we can see Bernoulli equation relates pressure energy, kinetic energy, and potential energy.

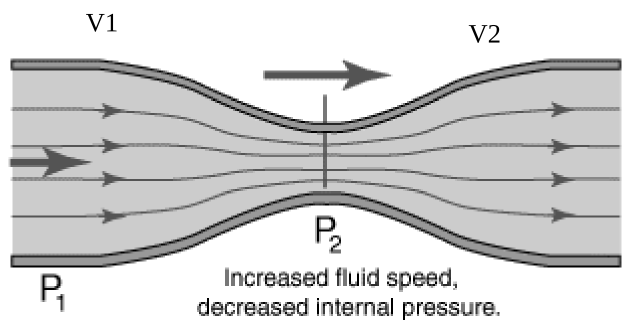

Figure 2.1: Bernoulli theory along pipeline [4].

Bernoulli equation can be applied to airfoil wing of boomerang. The air across the top of a conventional airfoil experiences constricted flow lines and increased air speed relative to the wing. This causes a decrease in pressure on the top according to the Bernoulli equation and provides a lift force. Thus, an increase in one form of pressure must result in a decrease in the other [4].

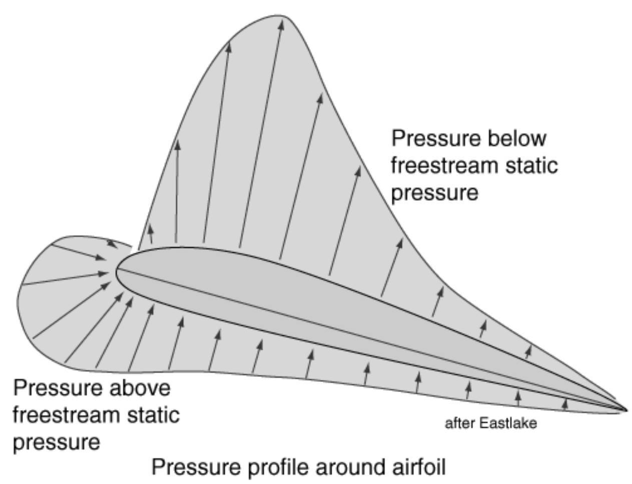

Figure 2.2: Bernoulli theorem on wing [4].

2.4 Newton’s Third Law

Force is described as the interaction between two objects. When two objects interact, they exert forces on each other. Newton’s third law states that these forces are equal in magnitude and opposite in direction. Thus, forces always occur in pairs[1]. Newton's third law state that: All forces in the universe occur in equal but oppositely directed pairs. There are no isolated forces; for every external force that acts on an object there is a force of equal magnitude but opposite direction which acts back on the object which exerted that external force [8].

Newton's laws appeal to the clear existence of a strong downwash behind the wing of wing. The fact that the air is forced downward clearly implies that there will be an upward force on the airfoil as a Newton's 3rd law reaction force. From the conservation of momentum viewpoint, the air is given a downward component of momentum behind the airfoil, and to conserve momentum, something must be given an equal upward momentum [8].

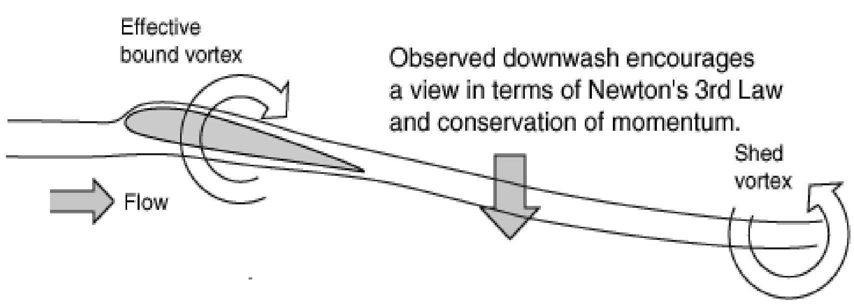

Figure 2.3: Newton’s Third Law theory [8].

2.5 Area effect on lift.

The amount of lift generated by an object depends on the size of the object. Lift is an aerodynamic force and therefore depends on the pressure variation of the air around the body as it moves through the air. The total aerodynamic force is equal to the pressure times the surface area around the body. Lift is the component of this force perpendicular to the flight direction. Like the other aerodynamic force, drag, the lift is directly proportional to the area of the object. Doubling the area doubles the lift [8].

There are several different areas from which to choose when developing the reference area used in the lift equation. Since most of the lift is generated by the wings, and lift is the force perpendicular to the flight direction, the logical choice is the wing planform area. The planform area is the area of the wing as viewed from above the wing, looking along the "lift" direction. It is a flat plane, and is NOT the total surface area (top and bottom) of the entire wing, although it is almost half that number for most wings. We could, in theory, use the total surface area as the reference area. The total surface area is proportional to the wing planform area. Since the lift coefficient is determined experimentally, by measuring the lift and measuring the area and performing the necessary math to produce the coefficient, we are free to use any area which can be easily measured. If we choose the total surface area, the computed coefficient has a different value than if we choose the wing planform area, but the lift is the same, and the coefficients are related by the ratio of the areas [8].

2.6 Lift and Drag Curve

Lift and drag curve obtained in wind tunnel testing as shown below. The curve represents an aerofoil with a positive camber so some lift is produced at zero angle of attack. With increased angle of attack, lift increases in a roughly linear relation, called the slope of the lift curve. At about eighteen degrees this aerofoil stalls and lift falls off quickly beyond that. Drag is least at a slight negative angle for this particular aerofoil, and increases rapidly with higher angles. Aerofoil design is a major facet of aerodynamics [9].

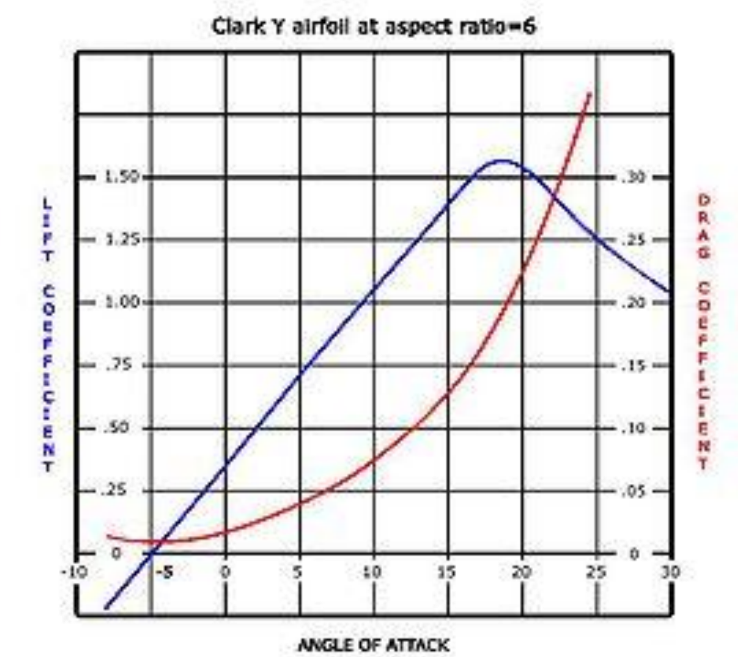

Figure 2.4: Lift and drag curve [9].

2.7 Gyroscopic Precession

A boomerang is an example of gyroscopic precession. A gyroscope is a common example of motion in which the axis of rotation changes direction[1]. One typical type of gyroscope is made by suspending a relatively massive rotor inside three rings called gimbals. Mounting each of these rotors on high quality bearing surfaces insures that very little torque can be exerted on the inside rotor [10].

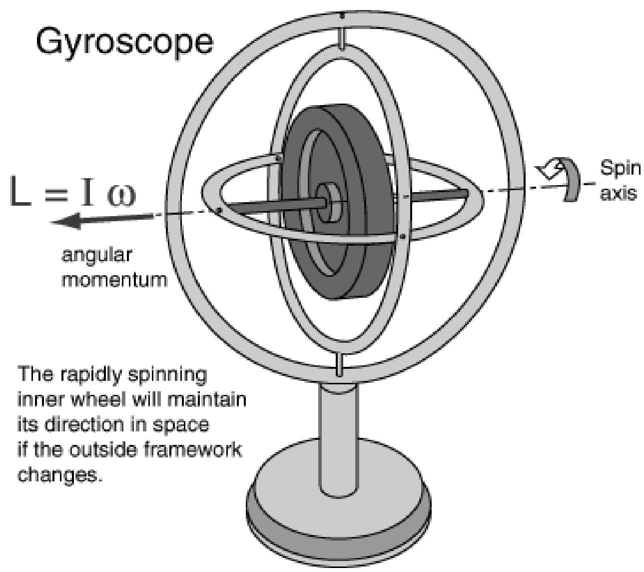

Figure 2.5: Gyroscope Precession [10]

The throw of the boomerang gives it an angular velocity perpendicular to its path as shown. The cross-section of the boomerang is an airfoil which gives it more lift on the top, leading edge than on the bottom. This gives it a torque in the sense shown, which always acts to the boomerang counter clockwise as seen from above. Since it will tend to "fly" in the direction of the airfoil, the precession causes it to fly in a curved path, circling back toward the thrower [10].

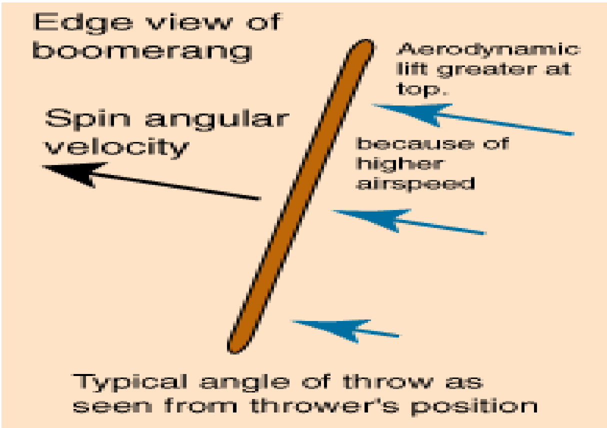

Figure 2.6: Angle from right hand thrower [10]

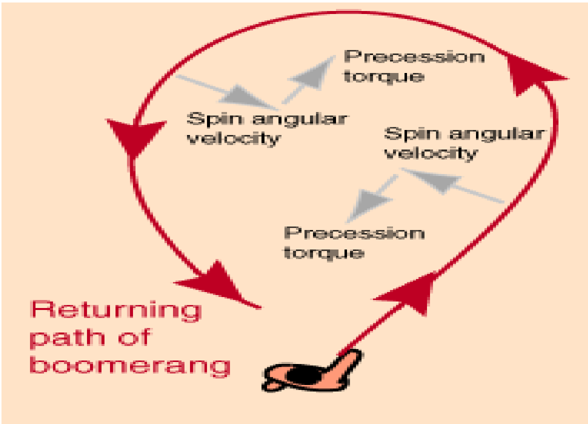

Figure 2.7: Hovering path of a boomerang [10]

2.8 Angular momentum, angular velocity and moment of inertia

The angular momentum of a rigid object is defined as the product of the moment of inertia and the angular velocity. It is analogous to linear momentum and is subject to the fundamental constraints of the conservation of angular momentum principle if there is no external torque on the object. Angular momentum is a vector quantity. It is derivable from the expression for the angular momentum of a particle. Angular momentum is denoted by [10]:-

$$L = I \times \omega \qquad (2.5)$$

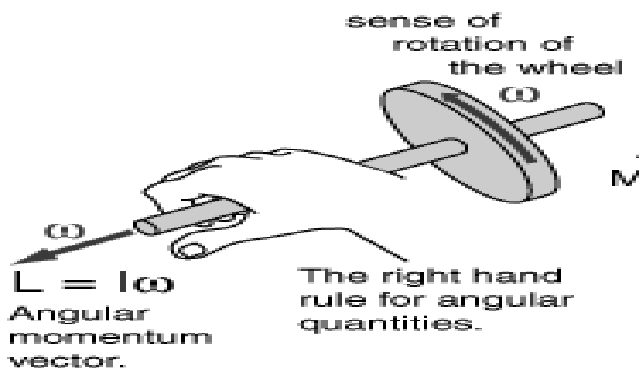

Figure 2.8: Angular momentum [8].

For an object rotating about an axis, every point on the object has the same angular velocity. The tangential velocity of any point is proportional to its distance from the axis of rotation. Angular velocity has the unit's rad/s.

Angular velocity is denoted by:-

$$\omega = v/r \quad (2.6)$$

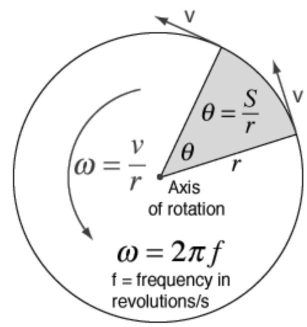

Figure 2.9: Angular Velocity [8]

Since the moment of inertia of an ordinary object involves a continuous distribution of mass at a continually varying distance from any rotation axis, the calculation of moments of inertia generally involves calculus, the discipline of mathematics which can handle such continuous variables. Since the moment of inertia of a point mass is defined by [8]:-

$I = mr^2$ (2.7)

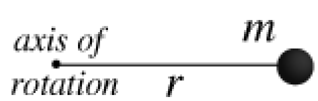

Figure 2.10: Moment of Inertia [8].

The moment of inertia contribution by an infinite small mass element dm has the same form [10].

CHAPTER 3

METHODOLOGY

3.1 Research Methodology Background

This project is divided into two parts which are:-

1. Research, analyzing, calculation and designing the boomerang and drawing using AutoCAD.

2. Simulation using GAMBIT and FLUENT software, and then analyze the result.

For the first part which is FYP 1, the study will emphasize on the research and data gathering on the boomerang. Firstly, one design will be chosen as conventional design .The Australian aboriginal boomerang will be analyzed inside out to determine its disadvantages. Then the research will proceed to find improvement for the Australian aboriginal boomerang. The study will try to focus on the shape of the overall boomerang which is the area and angle between blades of the boomerang. It is hoped by the end of the first half, the conceptual design for the boomerang is completed.

On the second part which is FYP 2, after the design and drawing are ready, the next step will be simulating the boomerang using GAMBIT and Fluent software. AutoCAD drawing will be imported to GAMBIT for meshing. The meshing is then exported to FLUENT for further analysis. From here we can obtain result. Comparison will be made between boomerang designs. The optimum design will be chosen based on the result of the simulation. Last but not least, the material used for the boomerang will be recommended after the calculation has been made.

3.2 Project Activities

Below is the flow chart representing the flow process of the research.

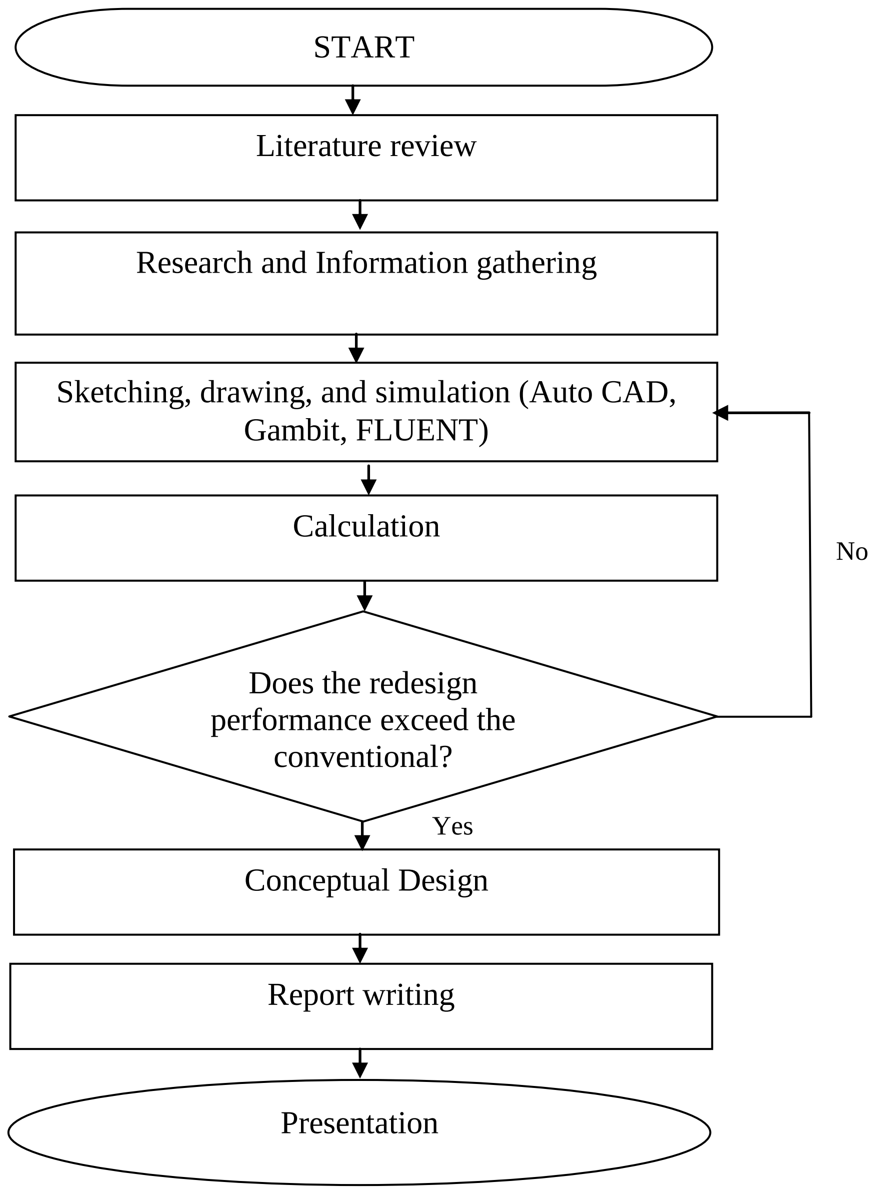

Figure 3.1: Project flow chart

3.3 Research Process

3.3.1 Gathering Data

Find the basis shape of Australian Aboriginal boomerang to be analyzed. The boomerang itself will be analyzed to see it disadvantages and what have cause it. The shape of the boomerang will be improved. For this research, the focus will be on the area and angle between blades of the boomerang. This parameter will be varied to see how it reacts towards the lift force.

3.3.2 Drawing using AutoCAD

All the drawing will be done using AutoCAD. The first test will be on the effect of varying area of the boomerang. There will be 6 designs of different area to be analyzed. Next, after the optimum area is chosen, another 5 design with different angle between blades will be drawn using AutoCAD.

3.3.3 Modelling Using Gambit

All the drawings are modelled in 2-D using GAMBIT. Then the file is exported to FLUENT.

3.3.4 Specifying the problem and run the model using FLUENT

After the model has been generated, boundary condition, medium used is specified so that the simulation could be initiated. Assumption used for FYP I are:

- Fluid is assumed to be incompressible, isothermal, homogeneous and Newtonian.
- All the boomerang is rotating at 5 rad/s.
- All the boomerangs travel at tangential velocity of 15 m/s^2 and transitional velocity of 20 m/s^2.

3.3.5 Construct the graph of relationship between parameters

After the simulation is done, some pattern of relationship between the parameters study is plot into graph so that the relationship between them is clear.

3.3.6 Discussion

The result is then discussed. The right explanation is required to justify the result.

3.4 Gantt Chart

Refer to APPENDIX A and APPENDIX B

3.5 Tools and Equipment Needed

The tools and equipment which are required in this Final Year Project are a Windows based PC together with the programs such as Microsoft Office, AutoCAD, FLUENT and GAMBIT which is used to analyse the parameters and produce the related graph, 2-D or 3-D model.

CHAPTER 4
RESULT AND DISCUSSION

One conventional Australian Aboriginal Boomerang is chosen. Refer to Figure 4.1. it is chosen because of certain properties that is fit the properties of Australian Aboriginal boomerang. The properties are angle between blades is 110^0, V-shaped, flat plate wing profile, and wing span is 0.31m. From field test that have been done, it is found that the boomerang is very hard to aloft in air. [13]

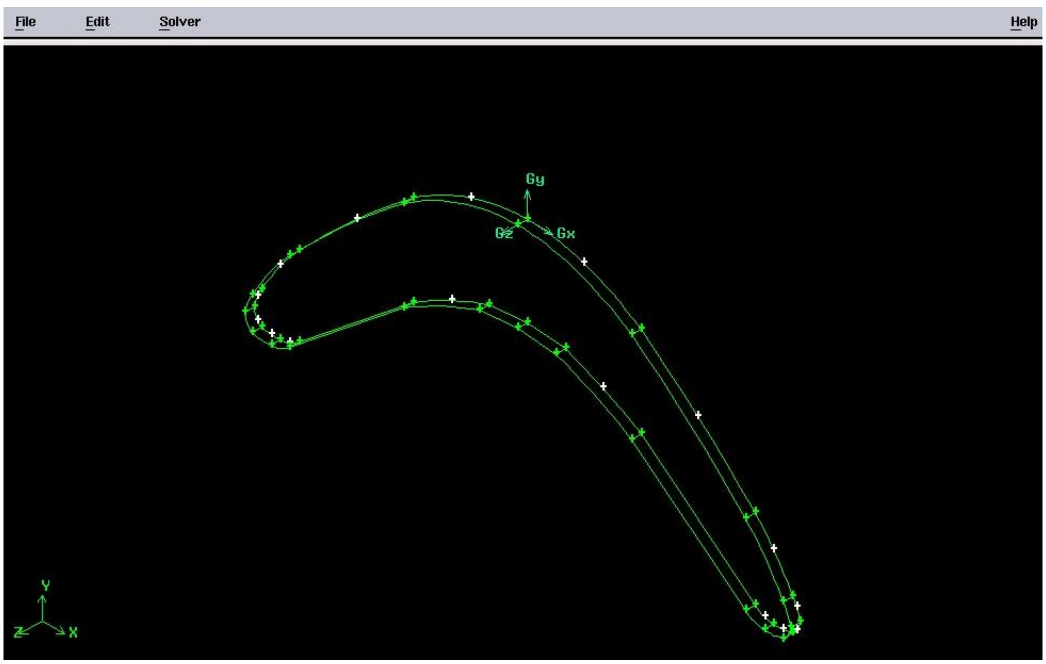

Figure 4.1: Conventional boomerang.

Due to this, a new design is drawn. Referring to Figure 4.2, we can see that an improvement has been made at the tip of the blades. The area of the tips of the blades is increased because that area plays major role in lifting the boomerang.

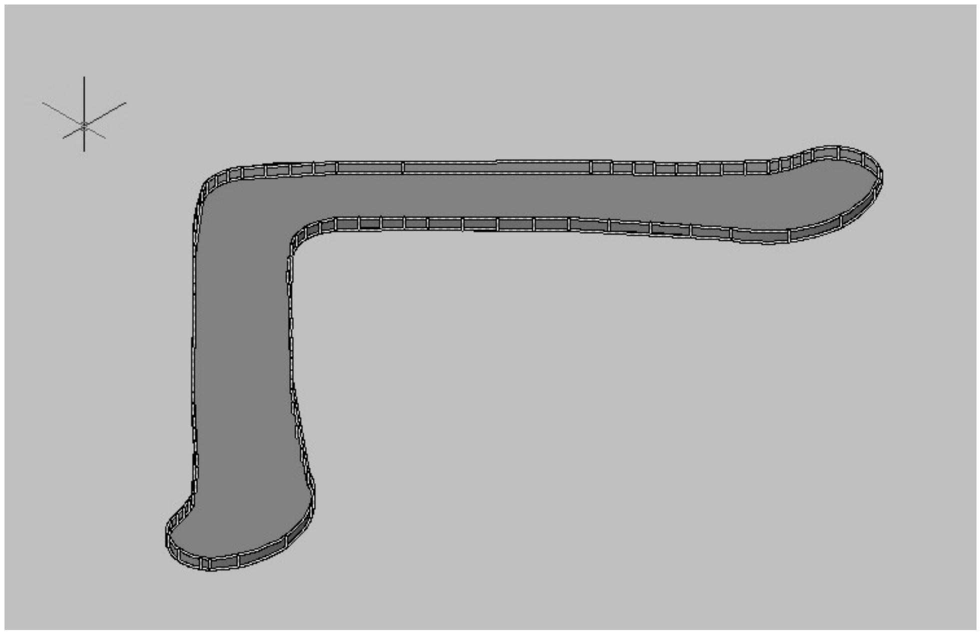

Figure 4.2: Isometric view of redesign boomerang

Next, this design will be meshed using GAMBIT and exported to FLUENT for further analysis. The area of this design will be varied to find the variation on lift force.

Each of the boomerangs is drawn using AutoCAD. It is then saved and exported to gambit for further meshing. In Gambit, the face of the boomerang will be set into Face 1, Face 2, and Face 3 which is shown below. It is then mesh using interval count 100. Then, the drawing will be exported to Fluent for further analysis. In Fluent, the condition is then been set and the reading it taken from 150 iteration. The result is then gathered for further analysis.

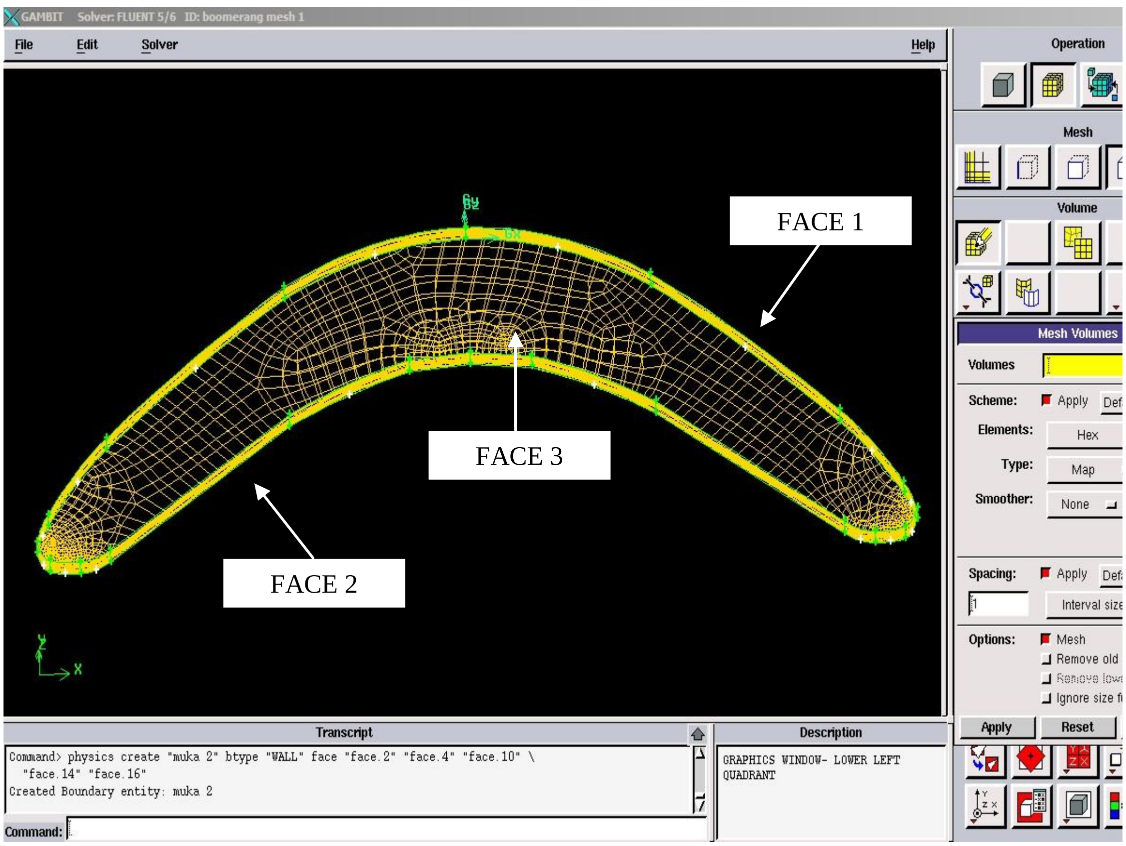

Figure 4.3: Drawing of boomerang in GAMBIT

4.1 (Test 1) Effect of area towards Lift Force

4.1.1 Boomerang 1.

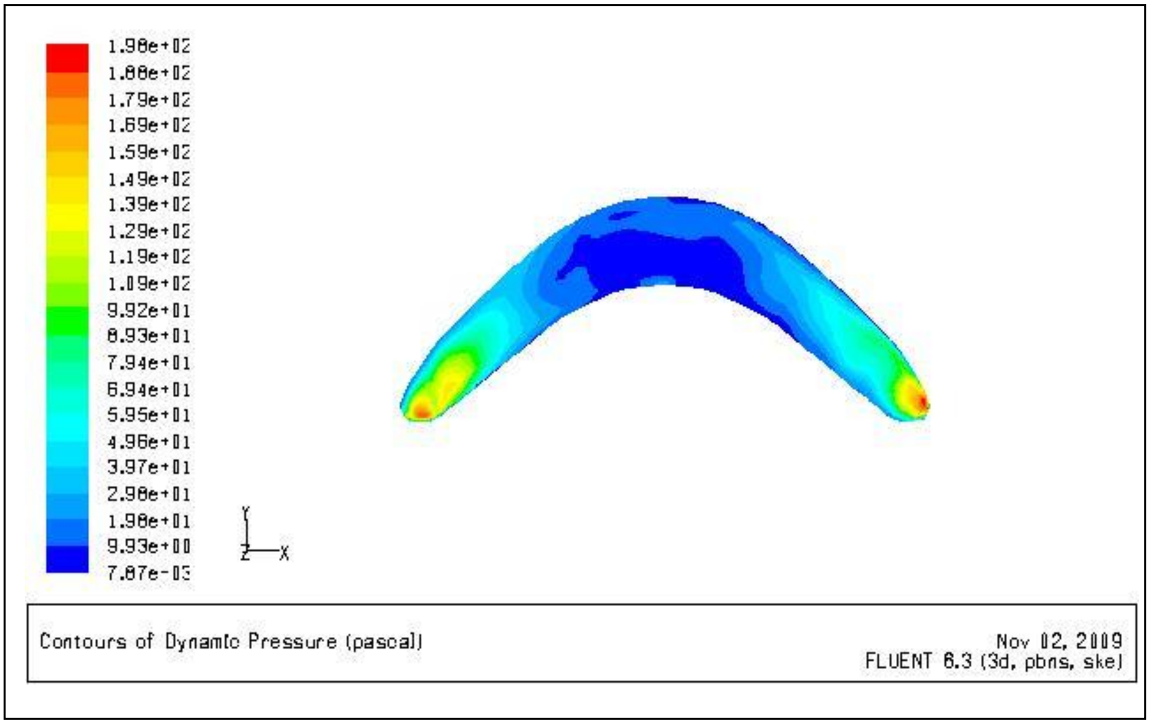

Figure4.4: Contours of Dynamic Pressure for Boomerang 1.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.31m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.04m)}$$

= 0.0316

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 198.36 Pa.

4.1.2 Boomerang 2.

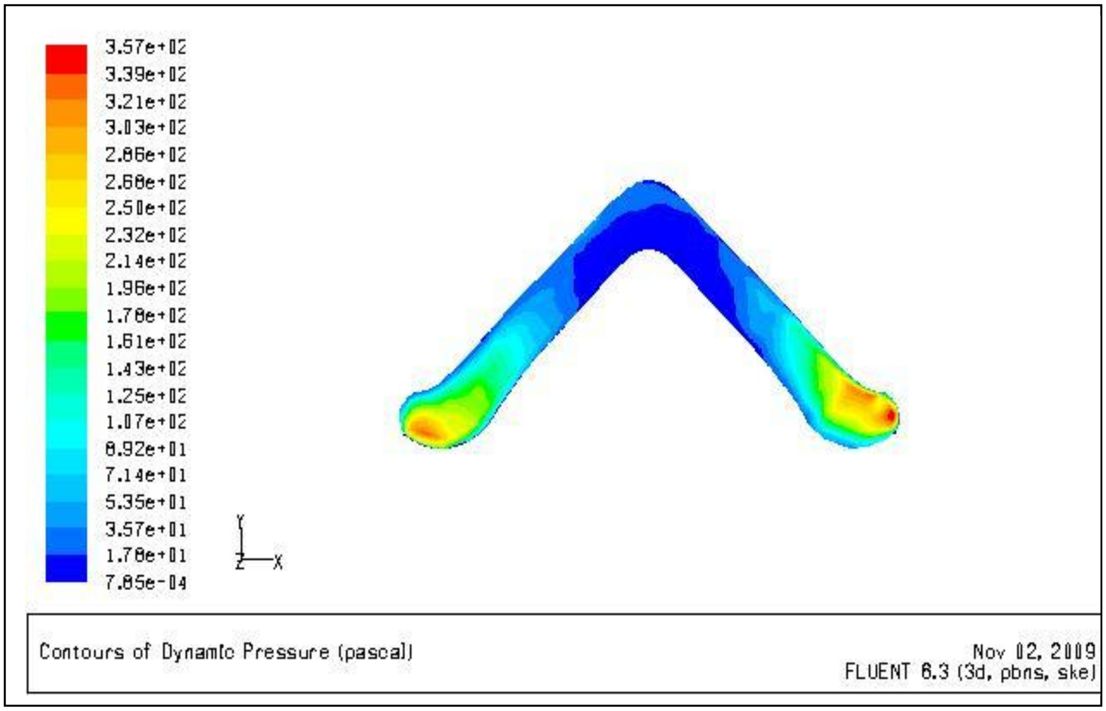

Figure 4.5: Contours of Dynamic Pressure for Boomerang 2.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.37m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.043m)}$$

= 0.035

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 356.97 Pa.

4.1.3 Boomerang 3.

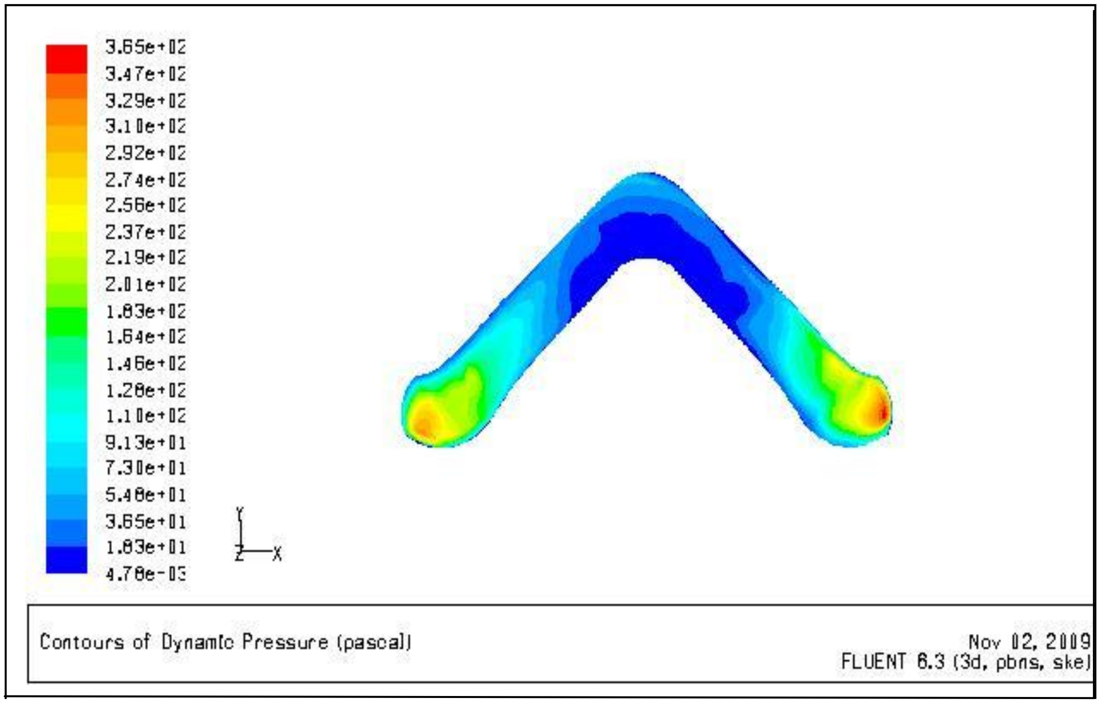

Figure 4.6: Contours of Dynamic Pressure for Boomerang 3.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.37m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.0485m)}$$

= 0.0311

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 365.21 Pa.

4.1.4 Boomerang 4.

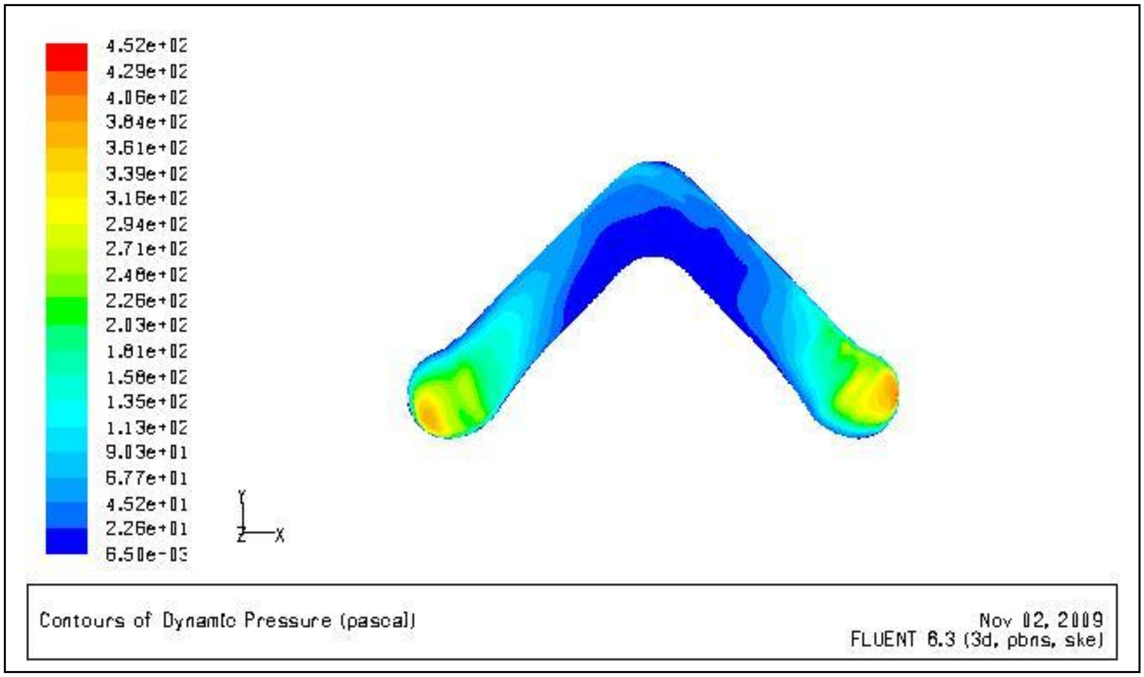

Figure 4.7: Contours of Dynamic Pressure for Boomerang 4.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.37m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.025

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 451.60 Pa.

4.1.5 Boomerang 5.

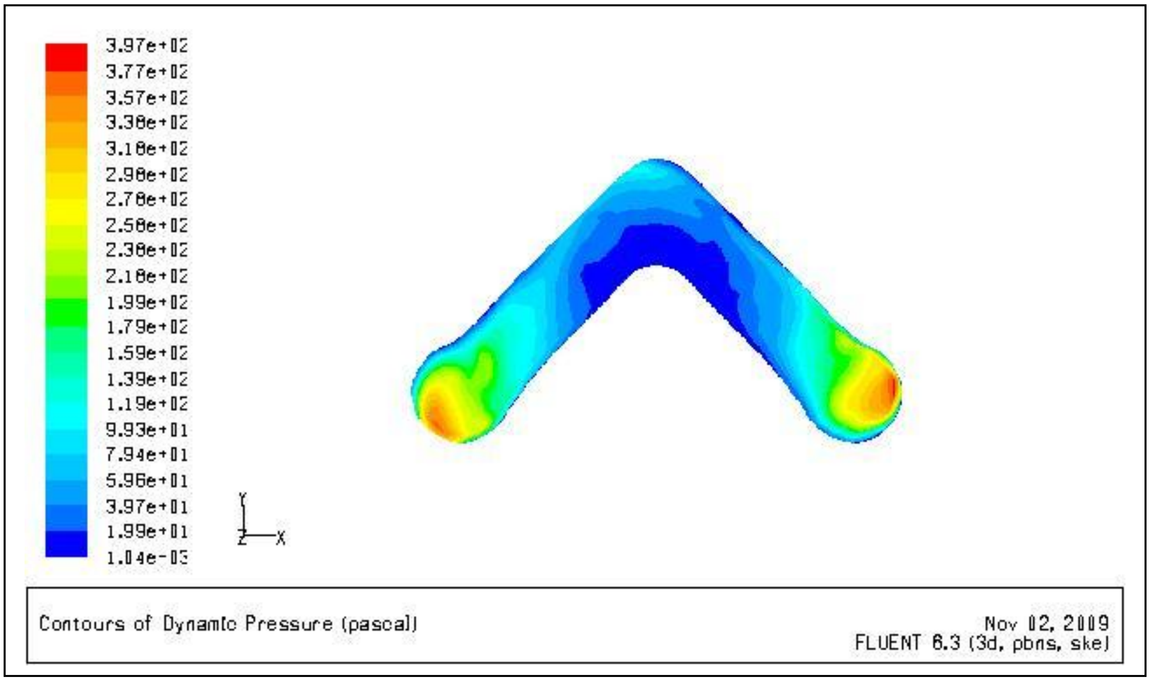

Figure 4.8: Contours of Dynamic Pressure for Boomerang 5.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.37m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.064m)}$$

= 0.0235

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 397.14 Pa.

4.1.6 Boomerang 6.

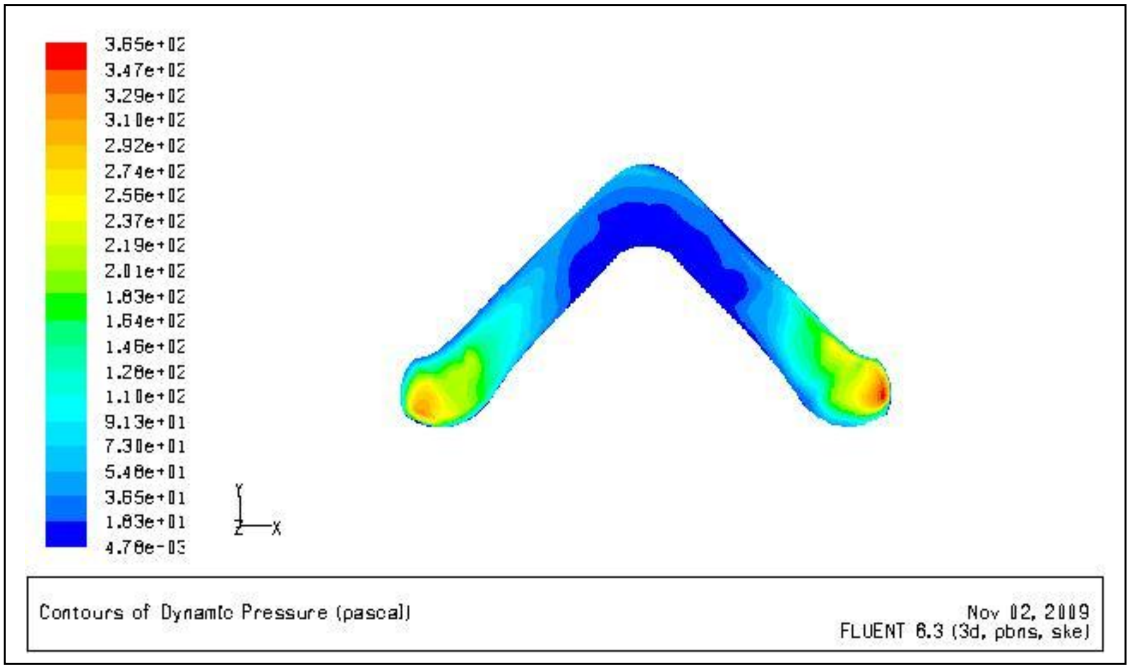

Figure 4.9: Contours of Dynamic Pressure for Boomerang 6.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.40m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.082m)}$$

= 0.0199

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 368.41 Pa.

The data is then being gathered in table as shown below. Lift force is computed using equation (2.1.2).

Table 4.1: List of Boomerang (different area) with Lift Force.

Boomerang No.	**Area (m^2)**	**Cl (Lift Coefficient)**	**Dynamic Pressure (Max) (Pa)**	**Lift Force**
1	1.27E-02	0.0316	198.36	7.94E-02
2	1.86E-02	0.0351	356.97	2.33E-01
3	2.31E-02	0.0311	365.21	2.62E-01
4	2.65E-02	0.0252	451.60	3.01E-01
5	3.03E-02	0.0235	397.14	2.83E-01
6	3.98E-02	0.0199	368.41	2.92E-01

Graph is then plotted to see the trend of varying area toward lift force.

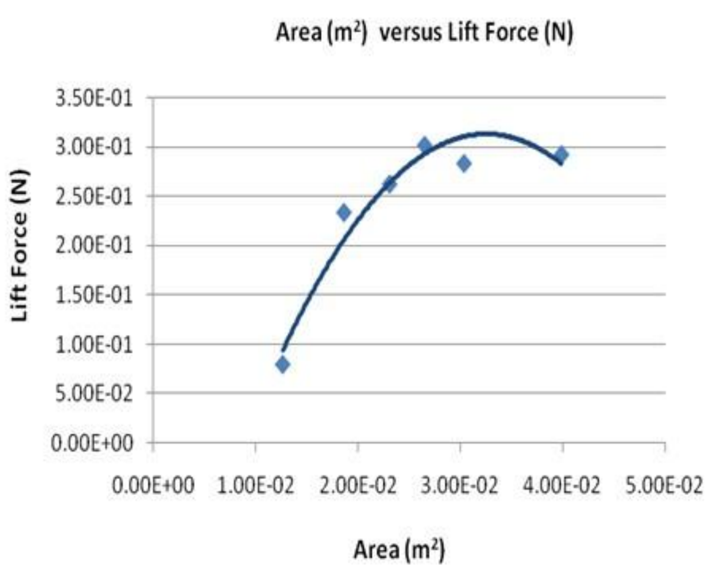

Figure 4.10: Graph of Area (m^2) versus Lift Force (N)

Figure for dynamic pressure of the boomerang can be found at APENDIX C. From graph above, we can see that lift force is increasing by increasing of area. But at one point, it is then decreasing gradually. So from this analysis, I recommend to choose Boomerang 4 as it gives the highest lift force apart from other. For further analysis, the angle of blades for boomerang 4 will be varied and analyzed using FLUENT.

4.2 (Test 2) Effect of angle towards Lift Force

4.2.1 Angle 30^0.

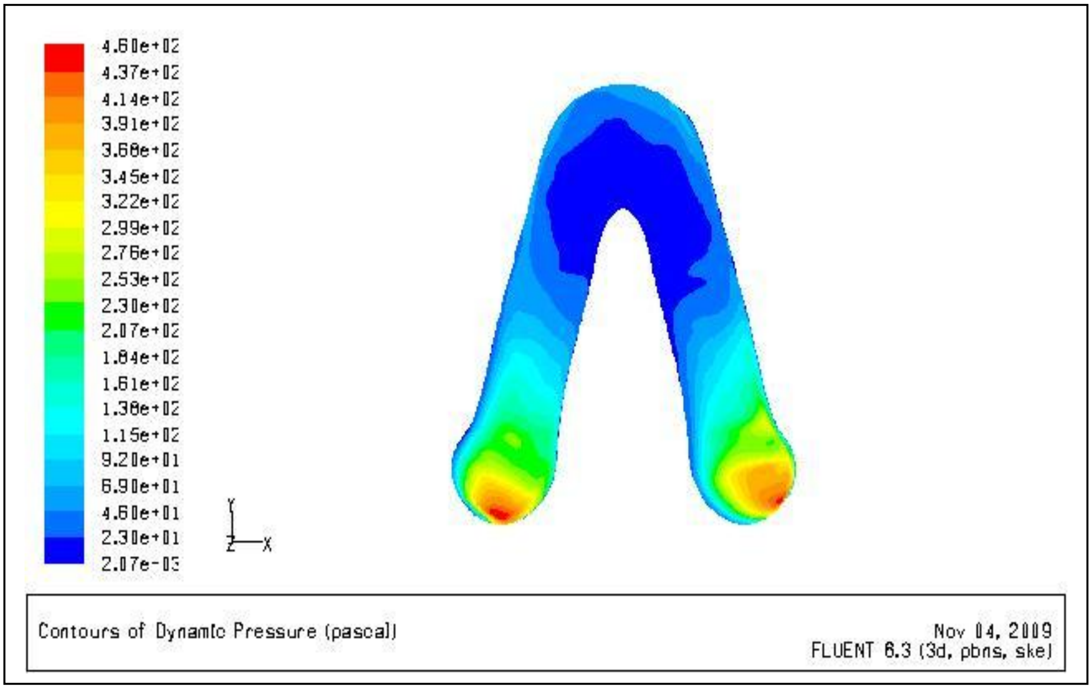

Figure 4.11: Contours of Dynamic Pressure for Boomerang 4 with angle between blades is 30^0.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.2274m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.0155

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 460.13 Pa.

4.2.2 Angle 60^0.

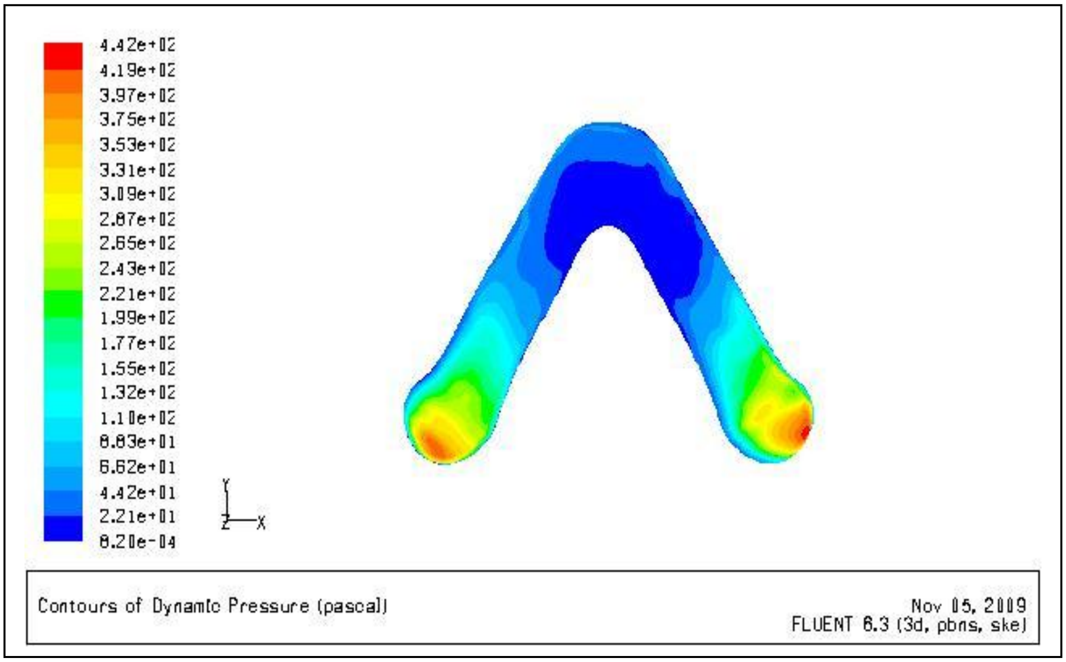

Figure 4.12: Contours of Dynamic Pressure for Boomerang 4 with angle between blades is 60^0.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.3054m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.02077

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 441.51 Pa.

4.2.3 Angle 90^0.

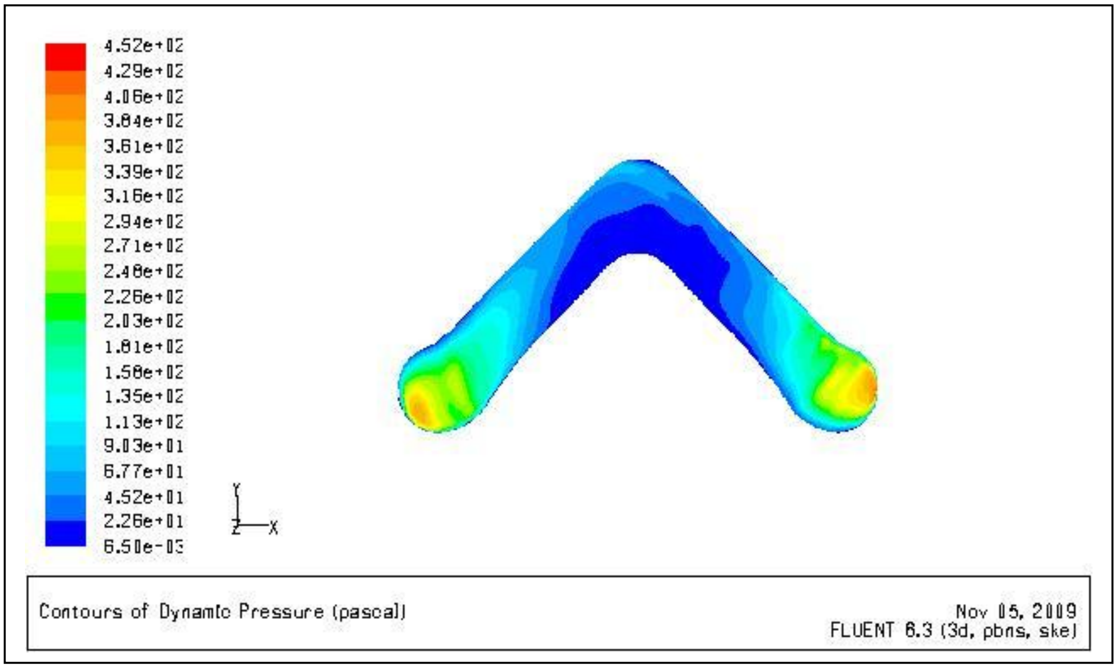

Figure 4.13: Contours of Dynamic Pressure for Boomerang 4 with angle between blades is 90^0.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.37m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.025

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 451.60 Pa.

4.2.4 Angle 120^0.

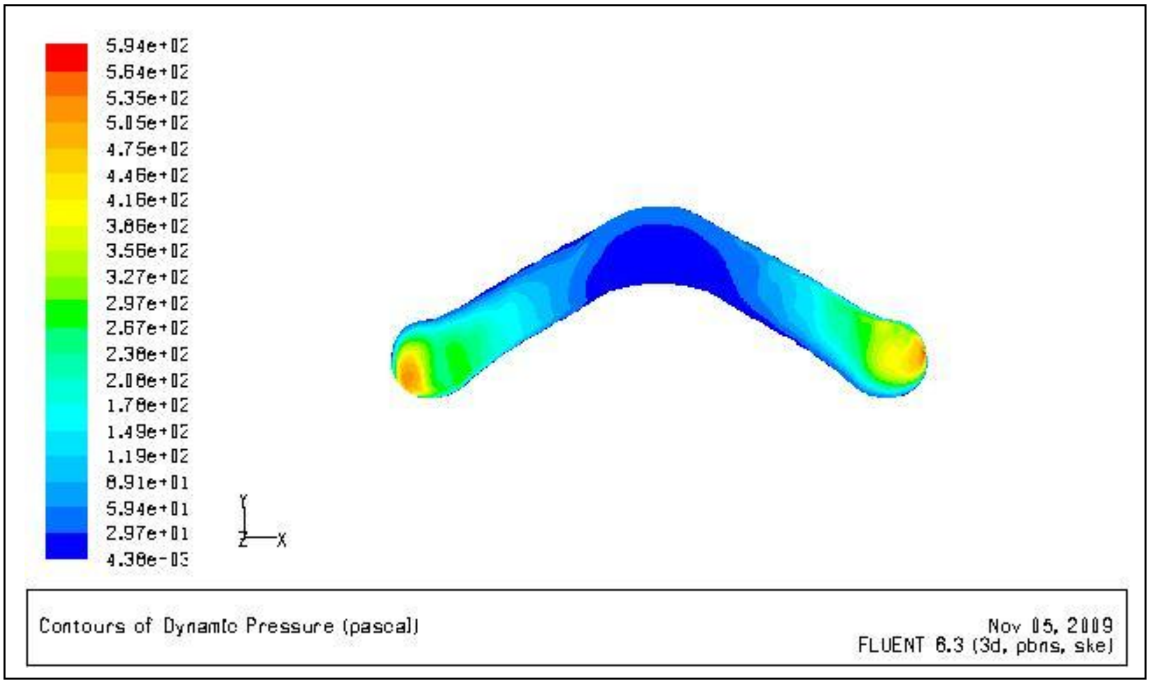

Figure 4.14: Contours of Dynamic Pressure for Boomerang 4 with angle between blades is 120^0.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.447m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.0317

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 594.16 Pa.

4.2.4 Angle 150^0.

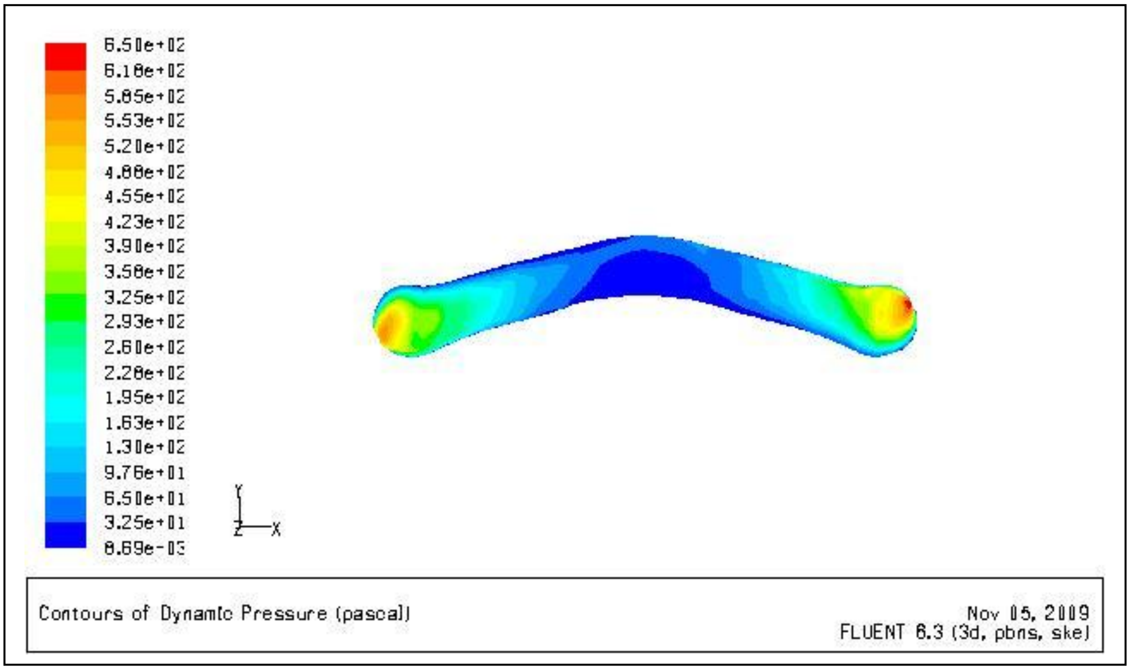

Figure 4.15: Contours of Dynamic Pressure for Boomerang 4 with angle between blades is 150^0.

By using equation (2.3) we can find the lift coefficient. Chord length is assumed to be taken as the average chord length of the overall boomerang.

$$Cl = \frac{0.5013m}{\frac{1}{2}(1.225kg/m^3)(20m/s^2)(0.06m)}$$

= 0.0356

From Fluent, the dynamic pressure (assume maximum as the dynamic pressure) of the boomerang is (from figure above) = 650.31 Pa.

The data is then being gathered in table as shown below. Lift force is computed using equation (2.1.2).

Table 4.2: List of Boomerang (different angle) with Lift Force.

Boomerang No	**Angle (^{0})**	**Area**	**Cl**	**Dynamic Pressure (Max) (Pa)**	**Lift Force (N)**
1	30	2.94E-02	0.0155	460.14	2.09E-01
2	60	2.78E-02	0.0207	441.51	2.54E-01
3	90	2.65E-02	0.0252	451.6	3.01E-01
4	120	2.76E-02	0.0317	594.16	5.20E-01
5	150	2.79E-02	0.0356	650.31	6.46E-01

Graph is then plotted to see the trend of varying angle toward lift force.

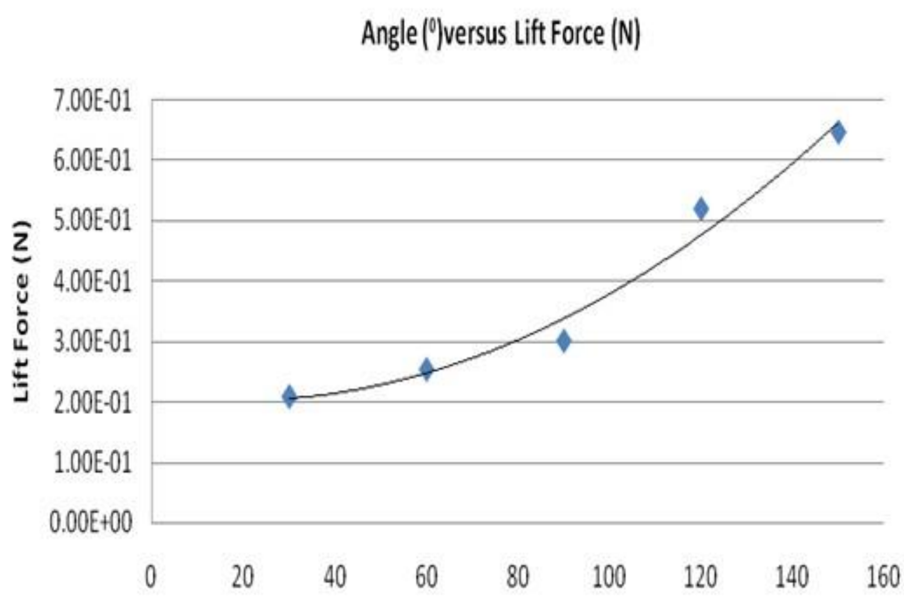

Figure 4.16: Graph of Angle (^{0}) versus Lift Force (N)

Table 4.3: Density, volume, mass and weight of different type of wood

Type of Wood	Density (kg/m^3)	Volume	Mass	W=mg
Balsa	170	1.3957E-04	2.3727E-02	2.3276E-01
Bamboo	300	1.3957E-04	4.1871E-02	4.1075E-01
Pine (Red)	370	1.3957E-04	5.1641E-02	5.0660E-01
Aspen	420	1.3957E-04	5.8619E-02	5.7506E-01
Ash, black	540	1.3957E-04	7.5368E-02	7.3936E-01
Mahogany	545	1.3957E-04	7.6066E-02	7.4620E-01
Hardwood Core Plywood	580	1.3957E-04	8.0951E-02	7.9413E-01
Oak	590	1.3957E-04	8.2346E-02	8.0782E-01
Apple	660	1.3957E-04	9.2116E-02	9.0366E-01
Ash, white	670	1.3957E-04	9.3512E-02	9.1735E-01
Birch (British)	670	1.3957E-04	9.3512E-02	9.1735E-01

Red indicates the Weight is exceeding the lift force that is taken from Boomerang with angle of 150^0. (6.4624E-01 N).

Table of wood and its density can be referred in APPENDIX C

4.3 Discussion

From Test 1 which is varying the area to see the effect toward lift force, by referring to the graph, there is a trend for area versus lift force. Lift force increase gradually as the area is increased until it has reach one point where the lift force is decreasing. From the graph, it is noted that the Lift Force start to decreasing somewhere when the area is $0.03m^2$. This may happen due to the area of the boomerang is increasing without changing significantly the wing span of the boomerang thus will affect the lift force. From the result, Boomerang 4 has the higher lift force so it will now used for Test 2 which will varying the angle between blades of the boomerang.

From Test 2 which is varying the angle of the boomerang's blades to see the effect toward lift force, there is a clear trend for angle versus lift force. Lift force increase gradually as the angle of the blades is increased. From the graph, it can be seen that boomerang with angle between blades of 150^0 has the higher lift force compare to all. So the recommended angle for high lift force is 150^0.

Table 4 is constructed to find the best material for the boomerang. The density of some possible material for boomerang is identified. By knowing the volume of the selected boomerang, the mass of the boomerang with respective material can be calculated. From that we can calculated weight, W which is equal to mass times gravity.

From that, we can compare the down force towards the lift force. The red labelled material is the group that has exceed the lift force of the boomerang. The black labelled is in the zone of selection. So from the table, it is calculated that Balsa will give the lowest down force thus will give more lift force. This will help the boomerang to increase the flight time of the boomerang.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings, several conclusions can be made:

Conventional boomerang that has smaller area 1.27E-02 m^2 has lower lift force compared to redesign boomerang which has larger area 2.65E-02 m^2 and larger lift force. This reflects that increasing the area will increase the lift force but until at certain point where the lift force will then decrease. So from the result, I recommend Boomerang 4.

From Test 2, by varying the boomerang's angle between blades (from 30^0 to 150^0), the lift force is increasing. This reflects that increasing the angle of the boomerang will increase the boomerang lift force.

Material for the boomerang has to be chosen carefully in order to maximize the lift force. Material will affect the weight of the boomerang thus will also affect the down force. The down force of the boomerang should not exceed the lift force for the boomerang to aloft. The chosen material is Balsa.

In addition, recommended further developments on this project are:

1. To study the effect of plated wing profile compared to aerofoil wing profile.
2. To include gyroscopic theory in order to see the return-ability of the boomerang.

5.2 Recommendation

From the result, it is proved that the new design boomerang give better lift force compared to conventional boomerang. The changes made at the tip of the blades surely affect the performance of the boomerang. From Test 1 and Test 2, it is recommend that for boomerang to have high lift force so that it can aloft longer is Boomerang 4 with area of 264.85×10^{-4} m^2 with angle between blades is 150^0. The lift force generated by this design will be $6.46E^{-01}$ N. The material for the boomerang will best be Balsa which will only give weight force of $2.3276E^{-01}$ that is not exceeding the lift force.

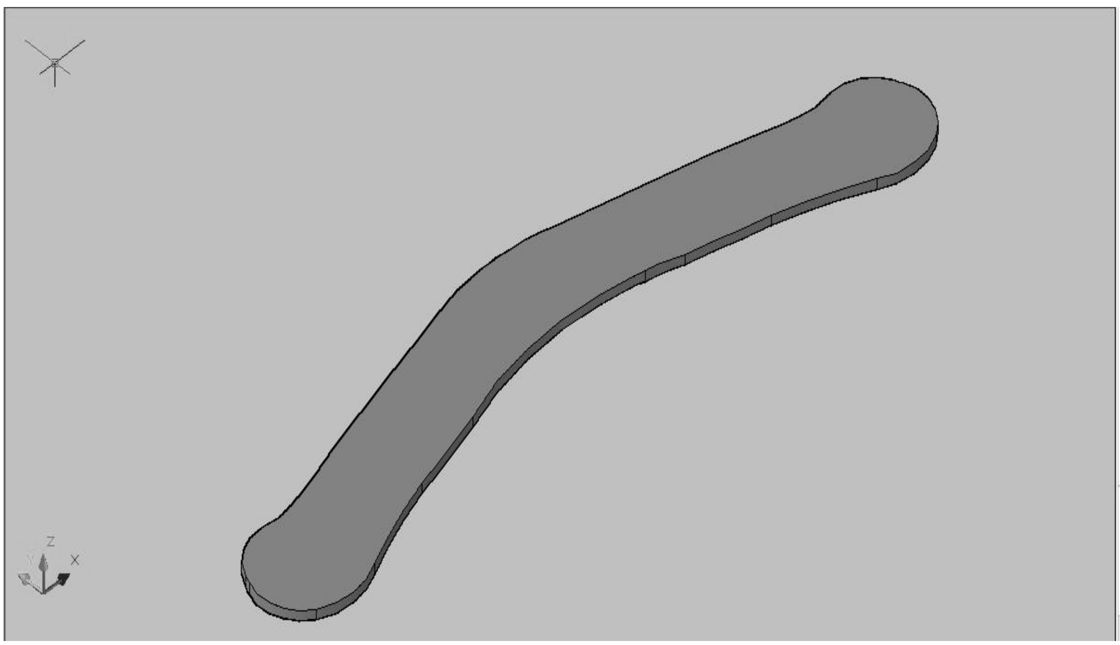

Figure 5.1: Isometric view of recommended design boomerang.

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APPENDICES

APPENDIX A

GANTT CHART
Time line for Final Year Project I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	**Selection of Project Topic**	■	■								Mid-semester break& Error Planning Margin					
2	**Preliminary Research Work**		■	■												
	- Preliminary report preparation				■											
3	**Submission of Preliminary Report**				●											
4	**Project Work**															
	- Conceptual study					■	■	■								
	- Collection of Data						■	■								
	- Progress report preparation								■							
5	**Submission of Progress Report**								●							
6	**Seminar (compulsory)**								●							
7	**Project work continues**															
	- Sketching and brainstorming									■		■				
	- Drawing using AutoCAD												■	■		
8	**Submission of Interim Report Final Draft**														●	
	- Presentation preparation															■
9	**Oral Presentation**															●
Final Semester Break & Error Planning Margin																

● Suggested timeline
■ Process

APPENDIX B

Time line for Final Year Project II

No.	Detail/ Week	1	2	3	4	5	6	7	8	9		10	11	12	13	14
1	Project work continues – Modelling Boomerang	■	■	■												
2	Submission of Progress Report 1					■●										
3	Project work continues – Meshing Using Gambit				■	■	■	■	■	■						
	- Analyze using FLUENT						■	■	■	■						
4	Submission of Progress Report 2									■●						
5	Seminar (compulsory) – Present on the result											■●				
5	Project work continues – Complete on the final report											■	■	■		
6	Poster Exhibition													■	■	
7	Submission of Dissertation (soft bound)													■●		
8	Oral Presentation													■	■●	
9	Submission of Project Dissertation (hard bound)											7 days after oral presentation				

● Suggested milestone

■ Process

APPENDIX C

Wood - seasoned & dry	kg/cu.m
Afromosia	705
Apple	660 - 830
Ash, black	540
Ash, white	670
Aspen	420
Balsa	170
Bamboo	300 - 400
Birch (British)	670
Cedar, red	380
Cypress	510
Douglas Fir	530
Ebony	960 - 1120
Elm (English)	600
Elm (Wych)	690
Elm (Rock)	815
Iroko	655
Larch	590
Lignum Vitae	1280 - 1370
Mahogany (Honduras)	545
Mahogany (African)	495 - 850
Maple	755
Oak	590 - 930
Pine (Oregon)	530
Pine (Parana)	560
Pine (Canadian)	350 - 560
Pine (Red)	370 - 660
Redwood (American)	450
Redwood (European)	510
Spruce (Canadian)	450
Spruce (Sitka)	450
Sycamore	590
Teak	630 - 720
Willow	420