A Conceptual Design and Analysis of two Seat General Aviation Aircraft

Karnail Singh Saini, Ankitkumar Patel

Abstract: *Aviation covers a huge range of activities, both commercial and non-commercial, including private, flight training, police aircraft, air-ambulance, air charter and etc. General aviation aircrafts generally use piston propeller engine especially single piston propeller engine. This more traditional class of aircrafts includes nearly all aircraft from Wright Brothers up through World War II. Today, piston engines are used almost exclusively on light, general aviation aircraft. In this project conceptual design of a two seat, piston propeller general aviation aircraft will be performed. It is expected that aircraft will fly around 130 knots at 8000ft and to a range of 500 nautical miles. Design study will be performed both by taking design account in and comparing to competitor data, and with considering historical values. Design method is mainly based on textbook on Raymer [1].*

Index Terms: Wing Geometry, Tail Geometry, Tail Airfoil, ANSYS CFD, Fuel Tanks, Fuselage and Interior Design, Propulsion, Shock Absorber.

I. INTRODUCTION

Single piston propeller nose mounted aircrafts are more traditional which are generally preferred for general aviation or training. These types of aircrafts configuration are important because they are cheap and have lower fuel consumption according to turboprop for the same hp. For many years, peoples have flied with general aviation aircrafts, so there are many different choices for this type if someone wants to buy. By considering this situation, it is important to design aircraft which has lower cost, lower fuel consumption and better performance. Thus, it can be found a place in the market.

II. FIRST GUESS SIZING.

First guess sizing is an important stage to create an aircraft. In this chapter, the aim is doing an introduction to the design process. That is to say, this study offers quick method of estimating takeoff weight, empty weight and fuel weight from a conceptual sketch. In this direction; first, a conceptual sketch is constituted. Then, with the design requirements which are given below, it is started to make calculations to estimate takeoff weight.

DESIGN REQUIREMENTS & MISSION PROFILE

For a two seat, training aircraft with following objectives

are given below: Range : 500 nm = 3040000ft

Vcruise: 130 knots = 219.44 ft/s hcruise : 2440m = 8000ft
Wcrew : 100kg = 220.26lb
Wpayload : 100kg = 220.26lb
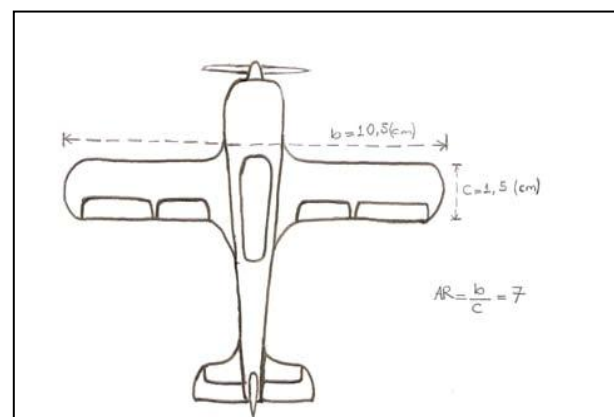
CONCEPTUAL SKETCHING & INITIAL SIZING

Figure 1. Conceptual Sketching & Initial Sizing

III. AIRFOIL AND GEOMETRY SELECTION

I. WING AIRFOIL SELECTION

Airfoil selection is the most important part of the aircraft design process because the Airfoil has a major effect on aerodynamic efficiency during all phases of flight. For example, cruise speed, takeoff and landing distances and stall speed are affected by the airfoil. Therefore, an airfoil with suitable flight characteristics must be chosen out of hundreds of available sections when designing a plane.

The purpose in the airfoil selection is to obtain the lowest drag at low angles of attack while obtaining a high CLmax. According to this, airfoil varies as to lots of characteristics such as Reynolds number, design Mach number, design lift coefficient, stall characteristics, thickness ratio etc. Most important data are Reynolds number and design Mach number. Each airfoil is designed for a certain Reynolds number. Before deciding to an airfoil, it is calculated the Reynolds number according to the given cruise conditions.

Revised Manuscript Received on March 20, 2019.

Karnail Singh Saini, Department of Aeronautical, SVIT, Vasad, Vadodara (Gujarat), India.

Anitkumar Patel, Department of Mechanical and Aeronautical Engineering, SVIT, Vasad, Vadodara (Gujarat), India.

A Conceptual Design and Analysis of two Seat General Aviation Aircraft.

II. SELECTION OF TAIL AIRFOIL

FOR MOST AIRCRAFT DESIGNS, THE CONVENTIONAL TAIL WILL USUALLY PROVIDE ADEQUATE STABILITY AND CONTROL AT THE LIGHTEST WEIGHT and also 70% or more of the aircraft in service use conventional type. Although T-tail is effective because of not being in the wake of wing, it is heavier than the conventional type. Therefore, conventional tail is selected for tail arrangement from Figure 4.30 Aft Tail Variations table [1].

First mission of the tails is not provides to lift. Most of lift is generated by wings. It can be said that tails are little wings. Tails' priority function is provides for trim, stability and control. Therefore, it is important to become the stall speed of tail later than the wing but it isn't the most crucial parameter for design because tail doesn't produce more lift, it is only a fraction of its lift potential. Thus, it is considered another specification of tails. These are pitch moment and wing incidence. To provide balance of the moment, horizontal tail has negatively incidence angle of about 2-3 degree and thus, the balance the wing pitching moment is stabilized by negative incidence of horizontal tail. According to it, wing incidence angle of tail is chosen as - 2 degree.

To select the tail airfoil, it is needed some specifications. For instance, the thickness ratio of tails is usually similar to the wing thickness ratio, according to the historical data. Therefore, it is selected in this study both of horizontal and vertical tail thickness ratio is the same of the wing thickness ratio as 15 %.

Vertical and horizontal tail airfoils are not the same. It is selected in this design that vertical and horizontal tail airfoils are different. To prevent unbalanced yawing moment, most aircraft use symmetric airfoil for vertical airfoil because any lift obtaining from vertical tail is not needed. In this case, it isn't required any camber of tails airfoil. For four digit and five digit NACA airfoils, it couldn't any necessary information about same thickness ratio. Although 6-digit airfoils are laminar, it can be selected a six digit airfoil NACA 652015. This airfoil is selected because it is symmetric and its drag coefficient is lower than other NACA

symmetric airfoils. Takeoff is the phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air. A number of different values are referred to as "takeoff distance". The most noticeable definition of takeoff distance or "balance field length (BFL)", is the distance that pilot can stop the aircraft safely if a problem occurs at one of the engines or to continue takeoff on the remaining engines at decision speed. Balance field length is sometimes called the "FAR 23 takeoff field length". However, Far 23 doesn't require meeting balance field length. Landing distances consist basically of two segments: the air run from a height of 50ft to the surface accompanied by a slight deceleration and flare which is defined as "FAR 23 landing field length", and the ground deceleration from the touchdown speed to a stop as shown in the figure below. Landing distance is largely determined by wing loading. Wing loading affects the approach speed, which must be certain multiple of stall speed. This is 1,15*Vstall for the general aviation aircraft.

1. RUBBER-ENGINE SIZING

Rubber sizing formula is given below:-

$$W_o = \frac{W_{crew} + W_{payload}}{1 - \left(\frac{W_s}{W_o}\right) - \left(\frac{W_f}{W_o}\right)}$$

2. CONFIGURATION LAYOUT AND INTERIOR DESIGN

The configuration layout and interior design is very important part of the design. In this part includes all drawings of the aircraft such as wing, tail, control surfaces and whole aircraft. Drawing means of the product of the aircraft. All of the calculations or analytical tasks are very important, too. Drawing comes after these calculations of the aircraft. While the analytical tasks are vitally important, the designer must remember that these tasks serve only to influence the drawing, for it is the drawing alone that ultimately will be used to fabricate the aircraft.

The purpose of this study is to make necessary calculations for determining the aircraft configuration layout and draw the external geometry and interior design includes cockpit of the aircraft.
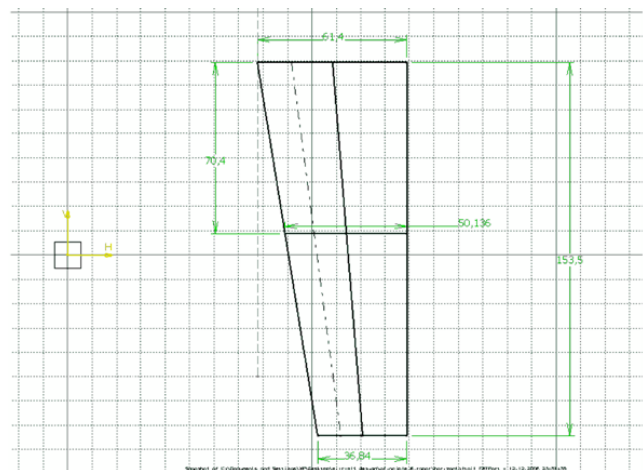

FIGURE 2. TOP VIEW OF THE HORIZONTAL TAIL

When the wing is designed, it is considered that the length of the entering part to fuselage as nearly 0, 30m. This part exists at the location of the maximum fuselage diameter. However, the aileron and flap lengths sums are approximately 3, 4m. After flap, there is 0, 42m to the fuselage. In order to not close the flap to fuselage, it is selected the distance between the flap and fuselage on wing is 0, 30m. Flaps, ailerons, elevator and rudder dimensions are determined in previous study "Initial Sizing".

Flaps: Flaps are placed on the wing which is 40% of the span and 24% of the chord. cf / cw = 0.24; bf / bw = 0.40
cw = 1.246m and cf = 0 24 ×1.246 = 0.299m
bw = 8.217m and bf = 0.40× 8.217 = 3.2868m (For each wing = 1.6434m)

Ailerons: Ailerons are placed on the wing which is 45% of the span and 20% of the chord. ca / cw = 0.25; ba / bw = 0.45
cw = 1.246m and ca = 0.20 ×1.246 = 0.2492m
bw = 8.217m and ba = 0.45 × 8.217 = 3.697m (For each wing = 1.84 m)

Elevator: Elevators are placed on the horizontal tail which is 100% of the span and 40% of the chord.

ce / cw = 0.40; be / bw = 1

ce = 0.40 × 0.614 = 0, 2456m

be = 0.100 ×3.07 = 3.07m (For each horizontal tail = 1.535m)Rudder: Rudder is placed on the vertical tail which is 90% of the span and 35% of the chord. cr/cVT=0.35; br / bw = 0.90

cr = 0.40 × 0.688 = 0.2752   br = 0.90× 1.032= 0.9288m

3. Cockpit Design

For cockpit design there are four important points to be considered:

➢ The pilots and other crew members can reach all the controls comfortably.

➢ The pilots and other crew members must be able to see all flight essential instruments without undue effort.

➢ Communication by voice and by touch must be possible without undue effort.

➢ Visibility from cockpit must adhere to certain minimum requirements.

Cockpit will be designed for two crew members, pilot and co-pilot. For two crew member including configurations, 100inch (2.54m) cockpit length can be considered. [1] Pilots arelocated by observing requirements for pilot visibility and for pilot ability to reach important control and instruments. It is also considered a smooth exterior, 20º unobstructed vision angle above the horizontal axis considering the pilot's eye and 15º vision over the nose from the front windshield. Besides, Lc (length between the pilot's eye and the windshield) value is generally between the 0, 5 and 0, 6m. According to this interval, Lc is considered about 0.5m. Cockpit width is considered as 1.08m.

4. PROPULSION AND FUEL SYSTEM INTEGRATION

There are many options for aircraft propulsion. These propulsion system options [1]. According to this figure, the most suitable one should be selected for desired aircraft at given conditions. All aircraft engines operate by compressing outside air, mixing it with fuel, burning the mixture, and extracting energy from the resulting high- pressure hot gases. However, the engine types have some advantages and disadvantages with respect to each other and their specific properties determine the application areas of each engine. Therefore, here, it is discussed which engine is selected and why selected because the propulsion system selection is important for the aircraft. Firstly, when it is considered the [1], it can be seen easily that aircraft design Mach number determines the engine type. For lowest Mach number (for the project, M is found nearly 0, 2), the best engines are both piston-prop and turboprop. The engine choice is reduced from ten to two. It is preferred the piston-propeller engine instead of turboprop. Piston-props generally are cheaper than the turboprops. Also, piston-props use lowest fuel consumption. However, turboprops use more fuel for the same horsepower. Although producing a lot of noise and vibration, it is selected the piston-prop engine for the design project because still the piston-props are the best choice for the lighter aircrafts.

5. Propeller Location

For example, the propeller can be settled on the fuselage, wing, tail or front, behind, top etc. For this project, it is decided the tractor location. Tractor engine location offers a fuselage mounted engine configuration. Tractor location is the standard for most of the history of aviation. The heavy engine is in the front for the tractor location. This causes the shorter fore body, and allowing smaller tail area and improved stability. Also, whether water or air cooled, front placement offers the most efficient position for cooling for tractor location. Because of these causes, for this generalaviation aircraft, the conventional tractor engine location is selected.

6. 3-D MODELLING AN AIRCRAFT USING A CAD MODEL

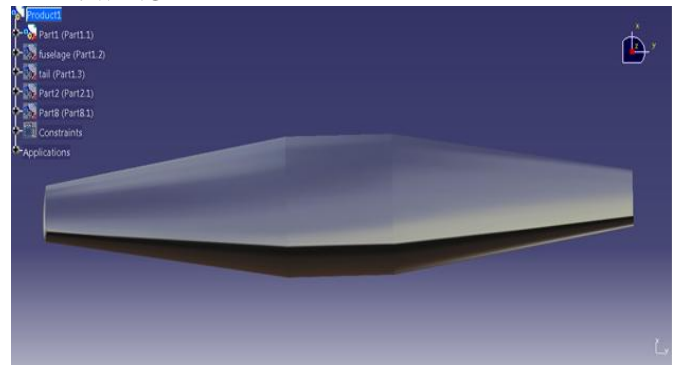#### A. WING

Figure 3. 3D Model of Wing
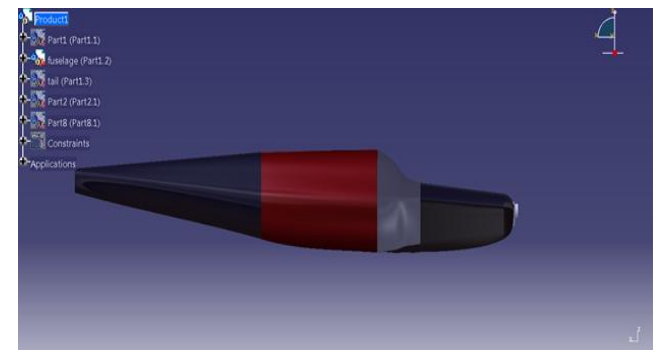
B. FUSELAGE OF AN AIRCRAFT

Figure 4. 3D Model of Fuselsage an aircraft
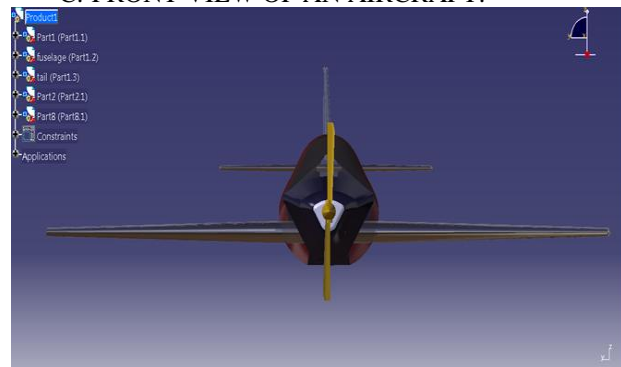
C. FRONT VIEW OF AN AIRCRAFT.

Figure 5. 3D Model of Front View of an Airecraft

A Conceptual Design and Analysis of two Seat General Aviation Aircraft.

FINITE ELEMENT IMPLEMENTATION

In order to analyze the designed wing and study its reliability, the commercial finite element software ANSYS is used in order to implement and model the wing under the calculated aerodynamic loads. The geometry of the wing is constructed using the CAD software Pro-E or Catia and imported into ANSYS . The aerodynamic loads are defined and the whole model is meshed using free tetrahedral elements with a total of 11000 elements. The finite element mesh is shown in Figure 9. In order to verify that the proposed design is safe and reliable, elastic failure theories such as the Max Stress Theory is applied in order to check that the stress in the span wise direction does not exceed the yield strength of the material used in the wing structure which is aluminum for the spar-webs, wing skin and ribs while steel is used for the flanges. To simplify the model, the FE model for the wing is constructed of two steel spars with rectangular cross sections and three aluminum ribs including the skin as shown in figure 6 to 9 . After applying the load it was found that the maximum span-wise stress $\sigma z = 318$ MPa. By comparing it to the yield strength of annealed steel 4140 (361 MPa) we can conclude that the designed wing can sustain the loads according to the elastic failure theories.

ANALYSIS OF AN AIRCRAFT COMPONENTS USING ANSYS

Here the aircraft's parts wing, horizontal stabilizer, and vertical stabilizer are kept in a square domain so that the flow and pressure analysis can be done
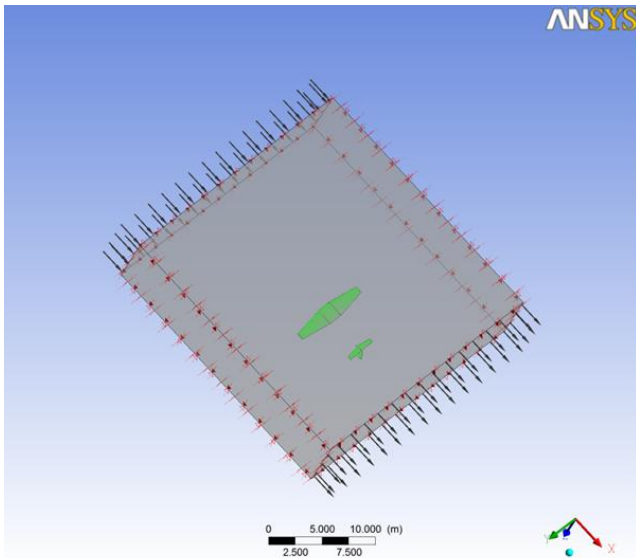Hear the boundary condition for the parts are given below.

Figure 6. ANALYSIS OF AN AIRCRAFT COMPONENTS USING ANSYS

Now for two conditions at different Mach number the variations in pressure distribution and velocity distribution is given below

1. At Mach number 0.242
2. At Mach number 0.7
First condition

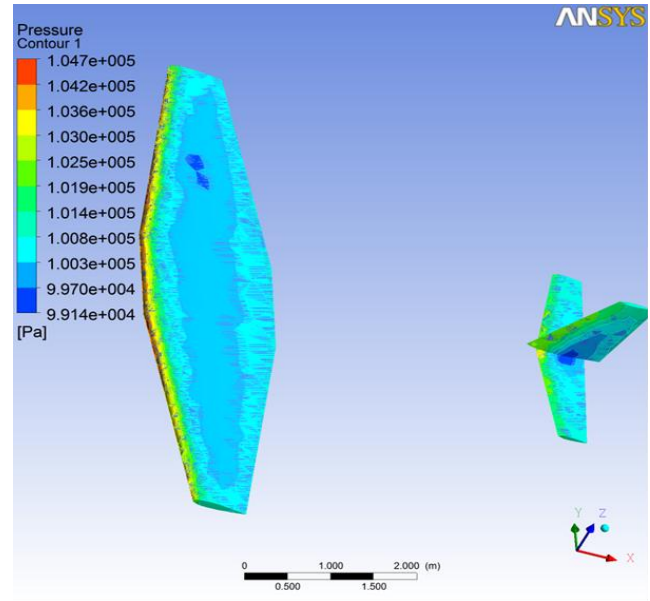(1) At mach no 0.242 (as calculated)
The pressure distribution

Figure 7. Analysis of Wings at first mach condition at 0.242
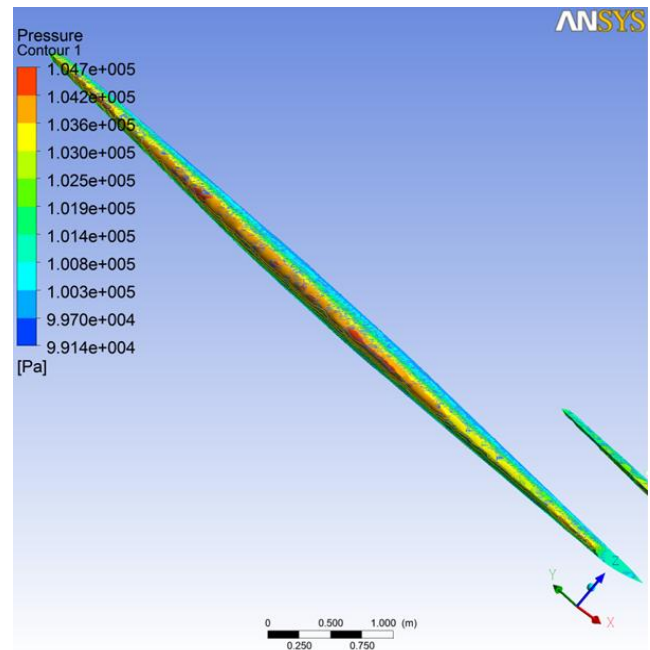

Figure 8 . Analysis of Wings at first mach condition at 0.242

Velocity stream lines over on wing, horizontal stabilizer and vertical stabilizer
The aerodynamic loads that mainly affect aircraft wings are the lift and drag forces. The lifting line theory is applied in this study to achieve the span wise loading on the wing; it assumes that the presence of a vortex generating a circulation causes the load, it also assumes that the wing is segmented into several span wise locations were a two-dimensional flow exists.

After calculating the loads at the span wise locations separately, they are brought together in order to form the span wise load distribution. For this preliminary design phase
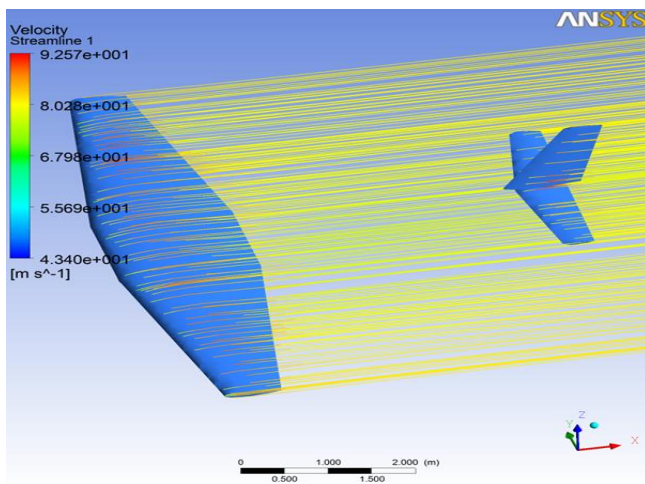

Figure 9. Analysis of Wings at velocity distribution on wings

Here from the figure it is seen that the flow over wing, horizontal stabilizer, and vertical stabilizer are shown in figure and how the velocity affects that is seen from the figure
The velocity is in mitre per second(m/s)
Second condition
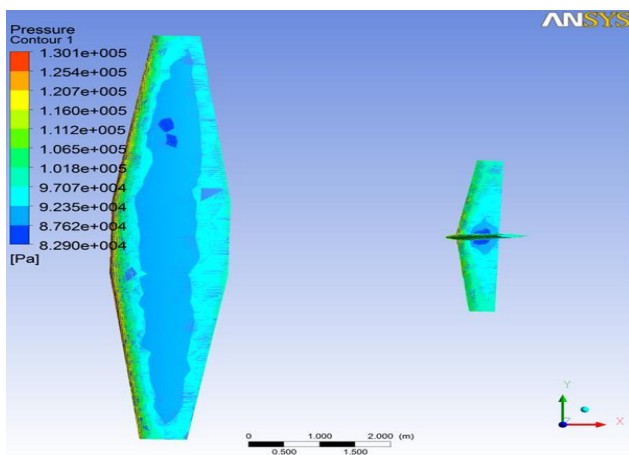(2) At mach no 0.7 (as calculated)
The pressure distribution

Figure 10 . Analysis of Wings at second mach condition at 0.7

Wing stress analysis Two of the Idealized booms are placed at the quarter of the cord each having an area of A, and another two at three quarters of the cord . The reason for a higher area at the quarter cord is due to the fact that the aerodynamic center is at that location requiring a larger area at that position. The following analysis calculates the area of these booms based on the bending stress and finds the thickness of the skin according to the shear flow in it
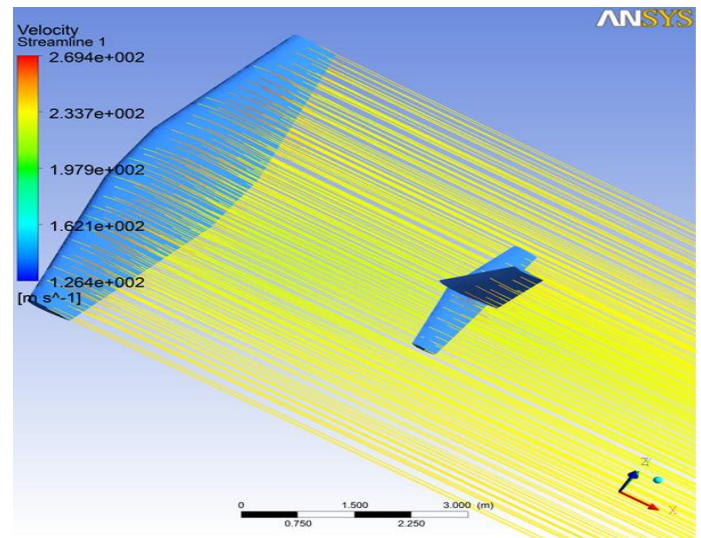Velocity stream lines over on wing, horizontal stabilizer and vertical stabilizer

Figure 11 . Analysis of Wings at velocity distribution in horizontal and vertical stabilizer.

IV. CONCLUSION

Conceptual design of the two seat general aviation aircraft provided insight four us between final layout of the aircraft and mission requirements. Aircraft was designed to meet mission requirements, and it is seen that after final layout it satisfies almost all of them.. This result is not very important because the difference is not very high, and aircraft can meet the design requirement.

The visual appearance of the aircraft is similar to this type aircraft, but most of the lighter aircrafts have low or high wing. In this project, mid-wing design was selected for desired aircraft because it was wanted to design an aerobatic aircraft by considering the cost. Also, the landing gear arrangement is not oleo, although oleo is common type today. It was decided to use solid spring landing gear arrangement. This type is both simple and economic. Except wing location and landing gear arrangement, this new design is similar to its competitors with the general appearance. The project gives sufficient and reasonable results that can be proceed by a preliminary design based on this study.
About the course, it can be said that this project and lecture gave us skills and chance to use and gain knowledge on engineering and real problems one can face during design.
The main objective of the conceptual design is to provide a drawing of the airplanes smooth, producible and aerodynamically accepted external features. The process of lofting is one that defines the external geometry of an airplane. Conic lofting is a lofting technique which incorporates a family of second degree curves such as a circle, ellipse, parabola and hyperbola. In this study, the conic lofting technique is used to generate a drawing of the designed airplane using the CAD software.

REFERENCES

1. Raymer D. P., "Aircraft Design: A Conceptual Approach", AIAA Education Series, 1992
2. NACA Report 824
3. Riegels F. W., "Airfoil Sections", 1961
4. Acar H., Flight Mechanics Lecture Notes
5. www.lycomig.com
6. en.wikipedia.org/wiki/Lycoming_O-320
7. Jane's all of the World's Aircraft
8. Grove Aircraft Landing System Inc, Part Catalog 110http://www.halcyon.com/pub /journals/21ps03-vidmar

AUTHORS PROFILE

Karnail Singh Saini
Qualification: BE Aeronautical from SVIT Vasad 2012 pass out.
Having more than 5 years of teaching experience in Diploma Mechanical and Aeronautical engineering. More than 15 gtu diploma question papers set for external exams. Member of GTU Curriculum Development. Design the syllabus of various subject of Diploma aeronautical such as Mechanism for Machines and Aircraft, Fundamentals of Engineering Thermodynamics, Airplane performance and Stability, Fundamentals of fluid mechanics.

Anitkumar Patel
Qualification:- B.E. Aeronautical from SVIT Vasad
Having more than 5 years of teaching experience in Diploma Mechanical and Aeronautical engineering. Design the syllabus of various subject of Diploma aeronautical such as Mechanism for Machines and Aircraft, Fundamentals of Engineering Thermodynamics, Airplane performance and Stability, Fundamentals of fluid mechanics.