IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. IV (May- Jun. 2016), PP 78-87
www.iosrjournals.org

Conceptual design, Structural and Flow analysis of an UAV wing

Abdus Samad Shohan [1], G.M. Asif Ahmed [2], Fahad Alam Moon[3],
Wing Commander S A Savanur[4]
1, 2, 3(Department of Aeronautical Engineering, Military Institute of Science & Technology, Dhaka-1216, Bangladesh
4(Associate Professor, Department of Aeronautical Engineering, Military Institute of Science & Technology, Dhaka-1216, Bangladesh

Abstract: *Unmanned Aerial Vehicles (UAVs) are considered as the largest integration of modern technology which have enormous potential for both military special operations & civil applications. UAVs are often preferred for missions that are too "dull, dirty, and dangerous". Its efficiency & success depends on factors such as performance, maintenance costs, design etc. This Paper aims to optimize the design of the wing of a medium size surveillance type UAV, by carrying out both analytical and computational analysis of aerodynamic and structural loads & also to study various materials and techniques for the fabrication of the designed wing. During the study, an attempt was made to familiarize with the theoretical aerodynamics, aircraft structural design methodologies and historical trends in wing design. The preliminary design dimensions as well as relevant loads of the wing structure were calculated based on the design lift and loading requirement for the UAV. The wing design was further analyzed by creating a software model of the UAV wing and simulating the flow and the structural loads using Solid Works and Design Foil software packages. The study attempts to record the steps followed, the calculations done, the theories applied and the references used during the project in a gradual progression to aid any future developmental work or study on wing design. The simplified analytical development of the conceptual design of a UAV wing can be used as a design reference for other types of aircrafts in some generic point of view.*
Keywords: *Solidworks, simulation, airfoil, design, wing, control surface etc*.

I. Introduction

An UAV is defined as a "powered, aerial vehicle which does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems, or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload [1]. Its aircrew is removed and replaced by a computer system and a radio link. In contrast to general aviation, UAVs have taken the pivotal point in certain autonomous operations including: military task execution, aerial renaissance, aerial survey and rescue, crop management and numerous remotely piloted operations.UAV has been in the zone of curiosity of aeronautics for last several decades. However, contrary to the manned aircraft, empirical sources of data for UAVs are not well enriched. This report focuses on building up a topological base for the conceptualize design of the wing of a “Medium Size Surveillance” type UAV and supporting this base with linear static and computational fluid dynamics analysis. This report proposes selection of suitable wing construction material, latter on the report. Conceptual design of the wing deals with wing shape and relevant characteristics. The objective of this report is to provide perspicacity on wing parameters, layout, construction, aerodynamic characteristics, responses to load, behavior of the fluid flow around it and simplified idea of construction. This report focuses on converging to a suitable design for the given mission requirement. To optimize the solution two different design perspectives are going to be approached; wing with tubular spar and wing with I-beam spar. Methodical procedures are followed to obtain various wing parameters. Static structural analysis using Solidworks provides optimum selection of ribs and flow simulation on over the wing is discussed later on the study.

1.1 Design Requirements and parameters

These parameters are taken comparing with global specifications to conceptualize the wing design[1].

Parameters	Units
Empty weight	78.622 lbs.
Payload	5 lbs.
Fuel weight	16.377 lbs.
Overall weight	100 lbs.
Range	4.5 km
Endurance	2.5 hrs.
Altitude	8000 ft.

Table 1-list of physical parameters

1.2 Methodology

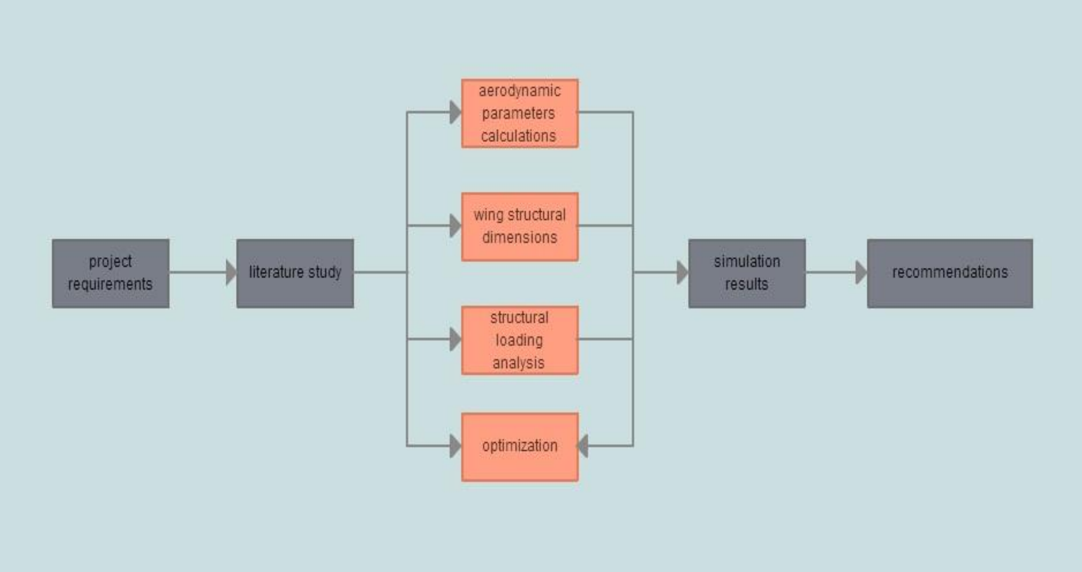


Fig 1: Methodology flow chart

II. Aerodynamic Analysis

2.1Wing Configuration: Despite some advantages of taper or elliptical wing planform this option is not chosen for avoiding complexities involved in its manufacture. Hence rectangular wing is chosen as the UAV of this project is a low speed low altitude aircraft and rectangular wing is suitable for it.

For this UAV wing design, high wing position is selected considering its suitability and ease of assembly with the fuselage compared to the mid wing position where it would require the wing to go through the fuselage and complexities of mounting it would be more in mid position. Low wing is generally not the trend for UAVs as no additional advantage is gain from low wing design.[3]

2.2 Design Parameters:

This section deals with the design parameters (wing span, aspect ratio, taper ratio etc.) focusing on which the wing has to be designed. The calculated values are-

Parameters	**Calculated Values**
Wing span, b	4.5m=14.8ft=15ft (approx)[10]
aspect ratio (length of wings / their width), AR	7 (historical trend)[11]
Thickness Ratio, t/c	0.155 or 15% [12]
Wing area, S	$3\ m^2$ [4]
Coefficient of lift, C_L	0.32
Taper Ratio, (C_t /C_r), λ	1 (most efficient for rectangular wing)
Root chord, C_r	2.16 ft
Tip Chord, C_t	2.16 ft
Mean Aerodynamic Chord (MAC), $\bar{c}$	2.16 ft [4]
Aerodynamic center, AC	0.54 ft (typical value for subsonic)
Leading edge Taper angle, $\Lambda_{L.E}$	0^0 [14]
Wing Tip	Simple cut-off
Dihedral/Anhedral	No dihedral or anhedral was chosen.[3]

2.3 Aero foil Selection

Calculated Reynolds number = 58574.45 [12]

Previously from the design parameter section it is obtained that the thickness ratio approximately 15% is desired as per the historical trend and NACA2415 has the same thickness ratio and the aero foil properties are also obtained for from the respective Reynolds number of the expected operating condition.[17]

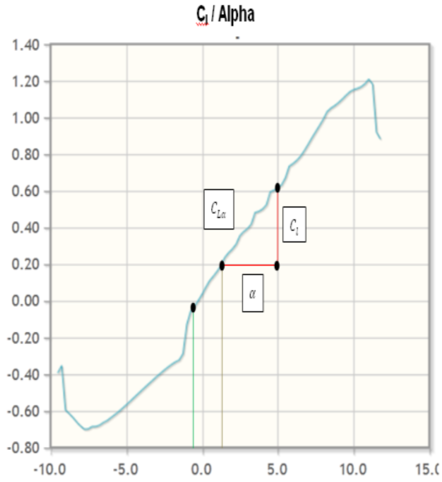


Fig 2: C_l Vs AOA Graph [9]

AOA	C_L (3D)
0	0.0698
1	0.157
2	0.244
Cruise 3	0.3317
4	0.4190
5	0.5063
6	0.5936
7	0.681
8	0.768
9	0.8556
10	0.943
Stall 11	1.03

Table 2- 3D C_L at various AOA

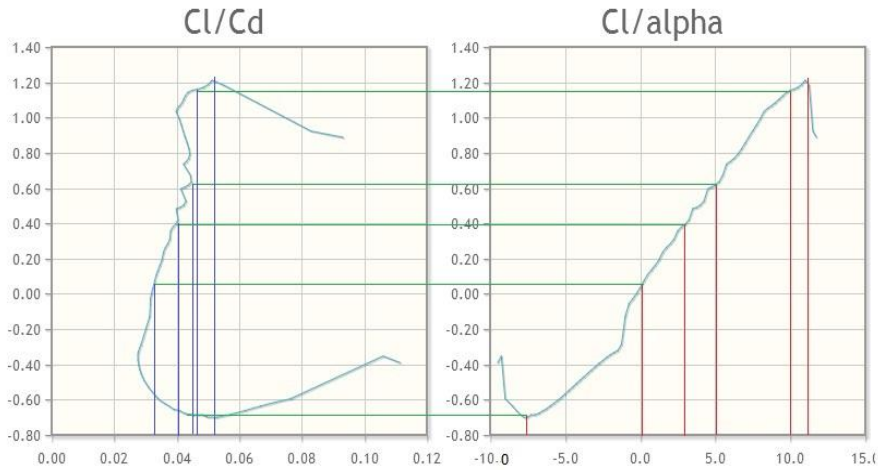


Fig 3: Co-efficient of drag [18]

AOA		C_D (3D)
0		0.0322
3	Cruise 3	0.045
5		0.0569
10		0.0843
11	Stall 11	0.1

Table 3- C_D at different AOA [18]

2.4 Performance parameter

At cruise condition the required coefficient of lift, C_L=0.32 (calculated). Therefore, from the selected aero foil, this required coefficient of lift can be produced at 3^0 angle of attack. Therefore, from the selected aero foil, this required coefficient of lift can be produced at 3^0 angle of attack. From calculation, Ground distance travelled during gliding, R_{max}= 83083.18 ft.[3]

2.5 Control Surfaces and High Lift Devices Geometry

High lift devices are the aircraft components that are designed to increase lift. The devices may be a fixed component or a movable mechanism which are deployed when required. Some common high lift devices are flaps and slats.Aileron and flaps are conjoined with main wing. Ailerons and flaps geometry calculated values are- [19]

Parameter	Aileron	Flap
Chord (considering C_a/C_w=0.2 , as the typical value) [11]	0.5 ft	0.2 ft [11]
Total Span	7.5 ft	6.75 ft
Length of each	3.75 ft	3ft
Area	1.62 ft^2	0.6 ft^2
Taper Ratio	1	1

III. Structural Analysis

Structural analysis is performed to evaluate whether a specific structural design will be able to withstand external and internal forces and stresses.

3.1 Load Distribution on Wing

The net wing beam load distribution along the span is given by, q(y) = L (y) − N gm(y) [12]
By calculation, Net beam loading=23.87 lb/ft.

3.2 Structural Analysis on Tubular Spar

Analysis is done mainly two different design consideration. One is tubular spar with strut and another is tubular spar without strut.

3.2.1 Tubular Spar without Strut

It is assumed the load is evenly distributed according to the wing chord. This is not quite true as the lift falls off towards the wing tip and the lift loads are transferred to the main spar by the ribs, also the wing has weight which will reduce the bending load.

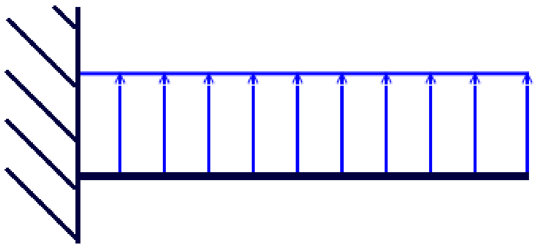


Fig 4: Free Body Diagram (FBD) of Load distribution on wing[7]

Bending moment on wing spar=18127.08 lb-in.

3.2.2 Tubular Spar with Strut: The load is divided up into three sections, inner load, middle load and outer load. The outer load includes the outer cantilevered section. The total calculation is shown for both tapered and straight wing below. [7]

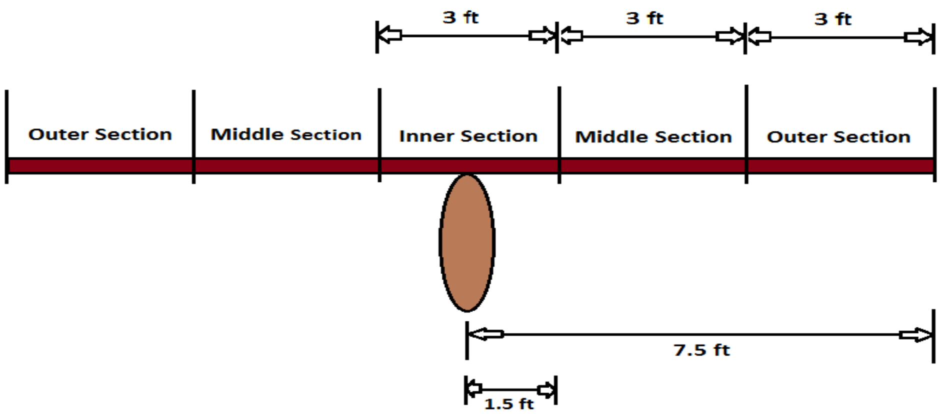


Fig 5: Tubular Spar with strut.

Parameters	**For Tapered wing (λ=0.4)**	**For straight wing (λ=1)**
Average wing loading	214.67 lb-ft	214.67 lb-ft
Root loading	178.9 lb-ft	143.11 lb-ft
Tip loading	71.6 lb-ft	143.11 lb-ft

Difference loading	107.3 lb-ft	0 [25]
Total Inner load	203.97 lb	214.665 lb
Total middle load	708.48 lb	644 lb
Outer load	901.52 lb	966 lb
Tensile load	901.52 lb	966 lb
Bending Moment	2364.72 lb-in	4722.6 lb-in
Max. Stress in spar	36471.1516 psi	72830 psi [20]

Comparison: So the maximum bending stress is higher for taper ratio 1 than the taper ratio 0.4.Though in case of straight wing (λ=1) stress is higher but sometimes if the straight wing is enable to fulfill the design requirement, then it is used instead of taper wing to avoid complexity.

3.2.3 Deflection in tubular spar

The net load produces shear and bending moment in the structure. The formulas of determining deflection angle and deflection[23] are:

$$d\theta = \frac{M}{EI}\, dy$$

$$dw = \theta\, dy$$

parameters	For without strut	For with strut
Deflection angle	4.8 rad	1.25 rad
Deflection	432 in	112.5 in

Comparison: So it is seen that the deflection is much higher in tubular spar without strut (432 in) than the tubular spar with strut (112.5 in). But in this case deflection with strut of tubular spar is also very much high. But this can be reduced by changing or increasing the size of the tubular spar. But this will also add load which is indeed a weight penalty for this design. That's why for I beam the load, stress, displacement, torsion again calculated and compared with tubular spar.

3.3 Structural Analysis on I - Beam

Structural analysis on spar consisting of I – Beam structure gives more strength then using a single circular tube spar.

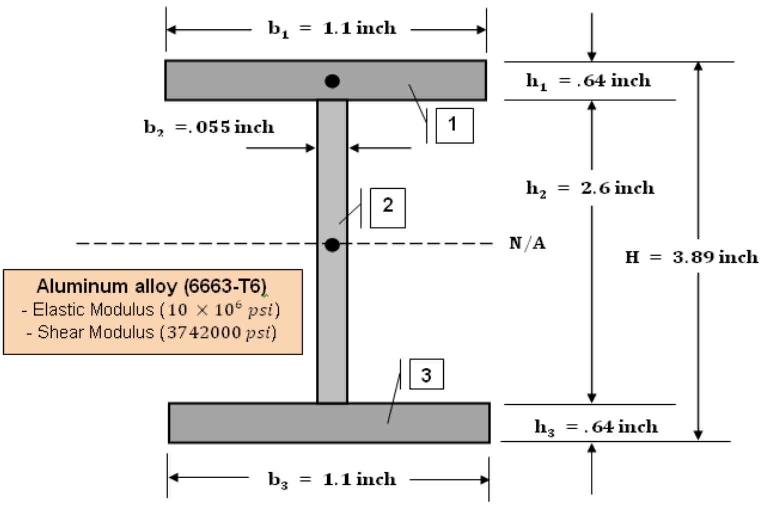


Fig 6: I- Beam

Two types of analysis is done for I - beam Aluminum alloy (6663-T6).

1) Without landing gear on wing
2) Landing gear on wing.

the calculated values for location of centroid, C_1=1.94 in.

Moment of Inertia, I_{xx}=3.824 in^4 & I_{yy}=0.142 in^4.From calculation,

Parameters	Without Landing gear on wing	Landing gear on wing
Maximum shear force	179.03 lb	1490.7 lb
moment	8056.32 lb-in	40243.65 lb-in
Max Bending stress	4087 psi	20416.4961 psi
Max shear stress	1010.368 psi	8412.901 psi
Non uniform Torsion	2232.14 lb-in	11150.18841 lb-in
Angle of twist	0.24 rad	1.18 rad
Displacement, u	0.5 in	2.3 in

Comparison: After calculating all the loading parameters for both tubular and I beam spar, I beam spar design is chosen for this UAV as it is more sustainable than tubular spar in case of strength and displacement. Again as I beam with landing gear add more complexity to the calculation, it is chosen the wing structure without landing gear for this UAV this design report is concerned about.

IV. Software Modelling and Analysis

SolidWorks is an excellent tool for cad modelling, linear static analysis and CFD simulation.For the CAD modelling, SolidWorks 2013 and DesignFoil are used. Airfoil's curved entity first generated on DesignFoil and then it sent to the SolidWorks for the further completion of the Rib modelling. Entire Cad modelling of the spar and overall assembly are accomplished in SolidWorks.

4.1Solid Works Models

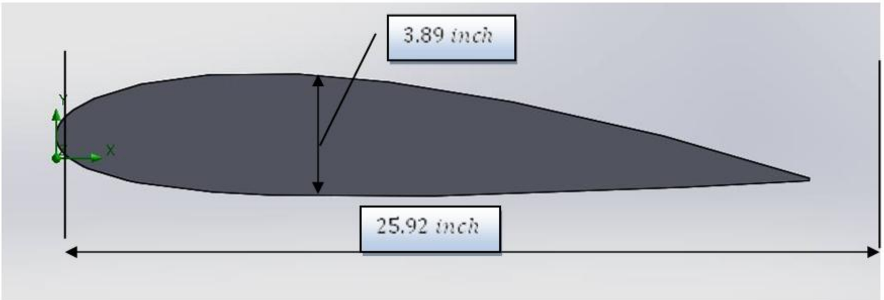


Fig 7: Solid works model of NACA 2415

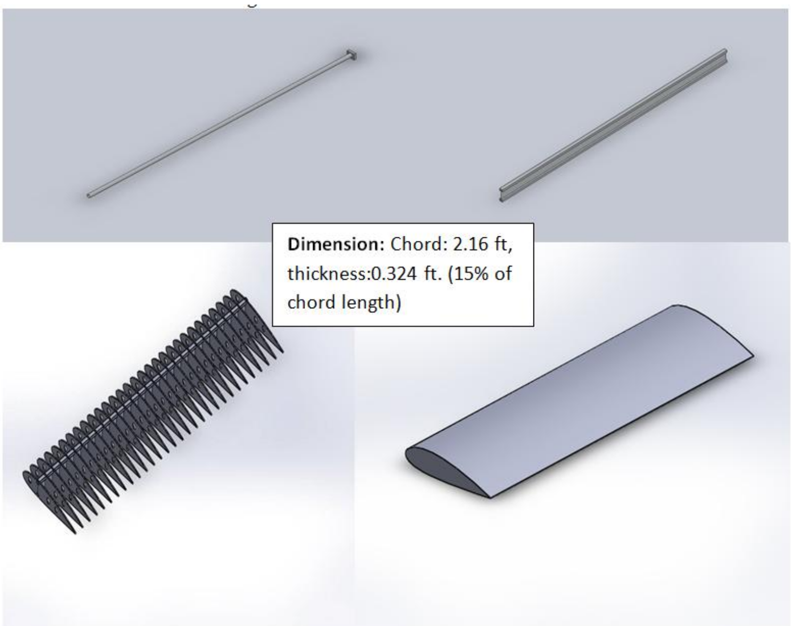


Fig 8: Solidworks models of Tubular & I-beam spar,Spar ribs assembly and entire wing model.

4.2 Simulation Results of Flow Analysis over Wing

SolidWorks Flow Simulation is used to investigate the characteristics of of flow around the wing.The behavior of the flow around the wing at different angle of attack i.e. O°, 3° and 10° is given here.

4.2.1 Velocity Distribution

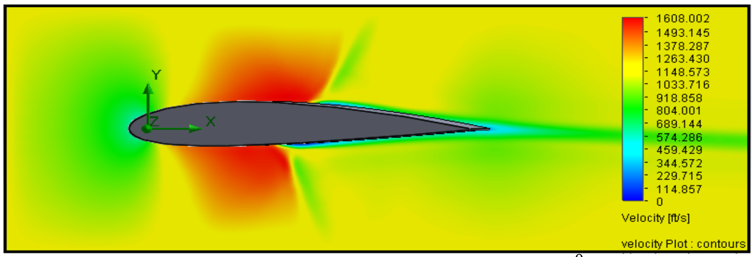


Figure 9-1 Velocity distribution for 0^0

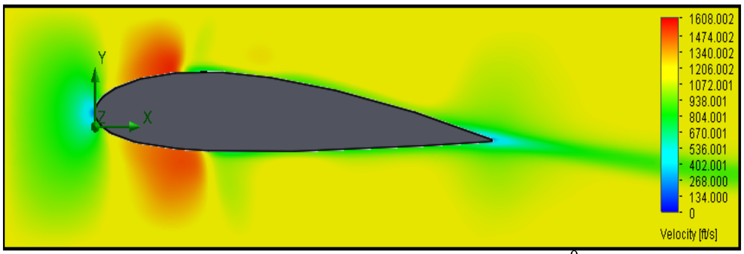


Figure 9-2 Velocity distribution for 3^0

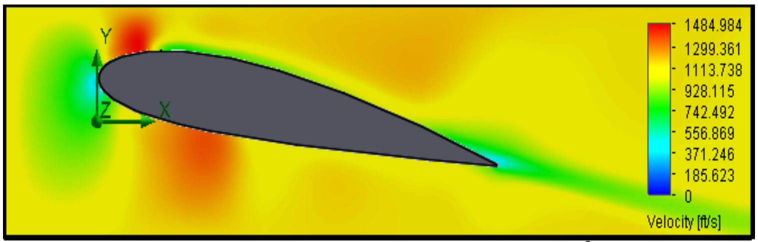


Figure 9-3 Velocity distribution for 10^0

From the observation of flow characteristics for three different angles of attack we've seen that velocity flow field diverges as the angle of attack increases.

4.2.2 Pressure Distribution: From the observation of the flow characteristics for three different angles of attack we've observed that pressure distribution over the entire wing converges as the AOA increases.

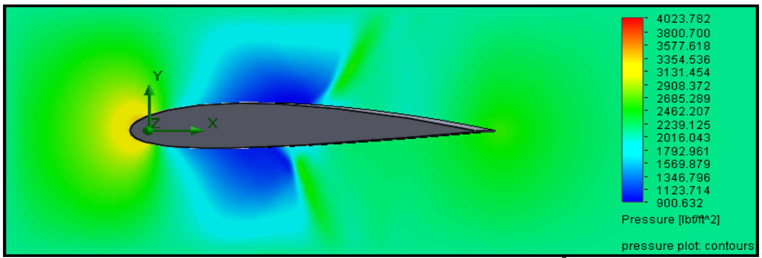


Fig 10-1 Pressure distribution at 0^0

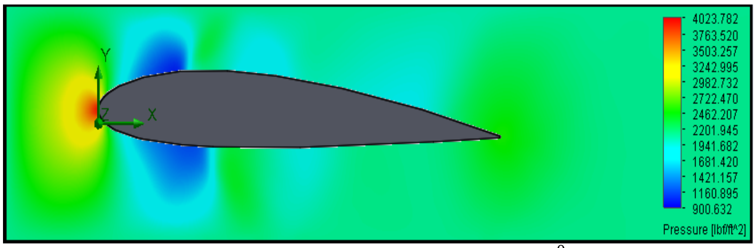


Fig 10-2 Pressure distribution at 3^0

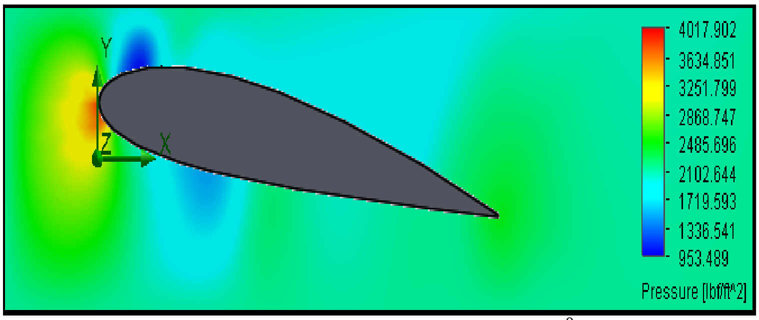


Fig 10-3 Pressure distribution at 10^0

4.2.3 Temperature Distribution

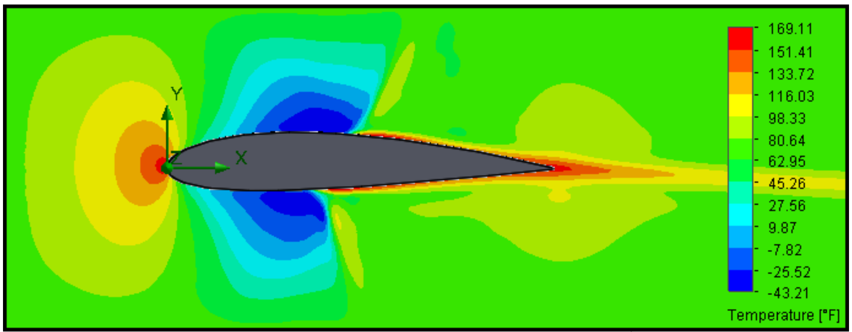


Fig 11-1 Temperature distribution at 0^0

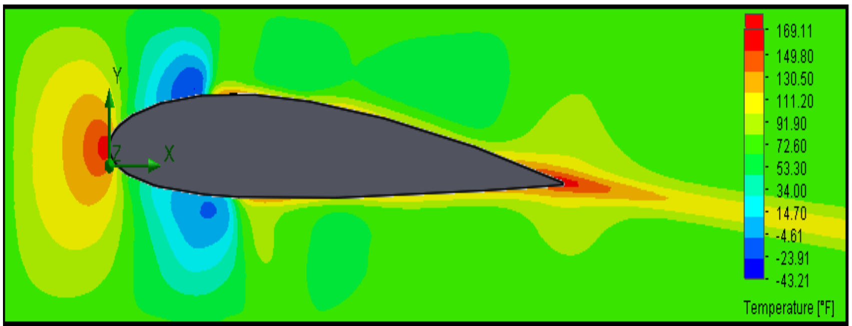


Fig 11-2 Temperature distribution at 3^0

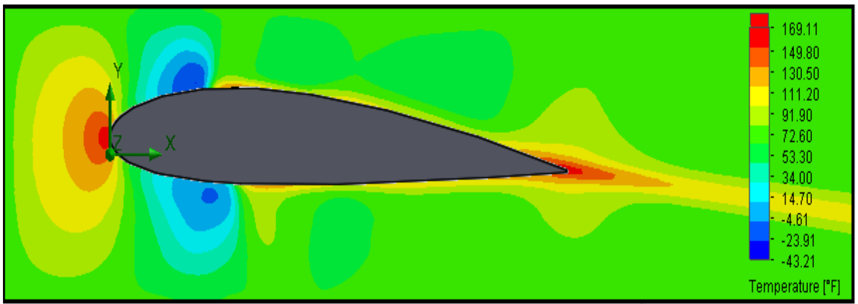


Fig 11-3 Temperature distribution at 10^0

From the observation of the flow characteristics for three different angles of attack, we've observed that the stagnation temperature region diverges as the angle of attack increases.

4.2.4 Vorticity Distribution: From the observation of flow characteristics for three different angles of attack we've seen the strength of vortices increases as the angle of attack increases. However, increases in vortex lift correspondingly increases high drag.

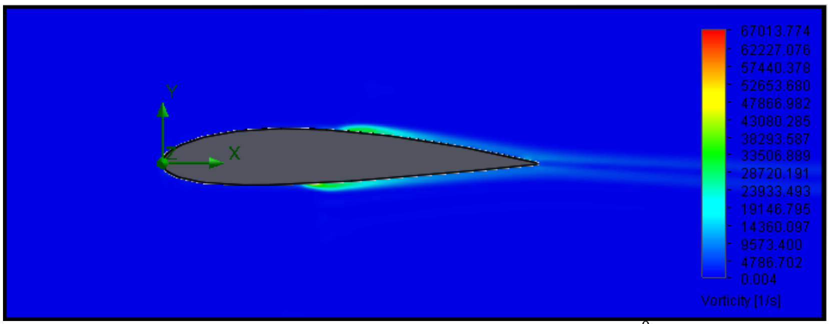


Fig12-1 Vorticity distribution at 0^0

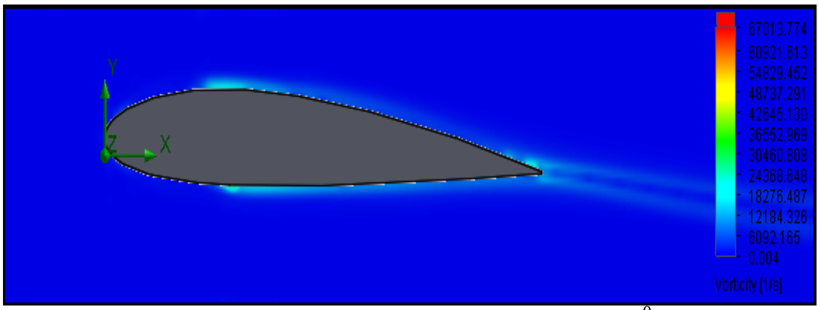


Fig 12-2 Vorticity distribution at 3^0

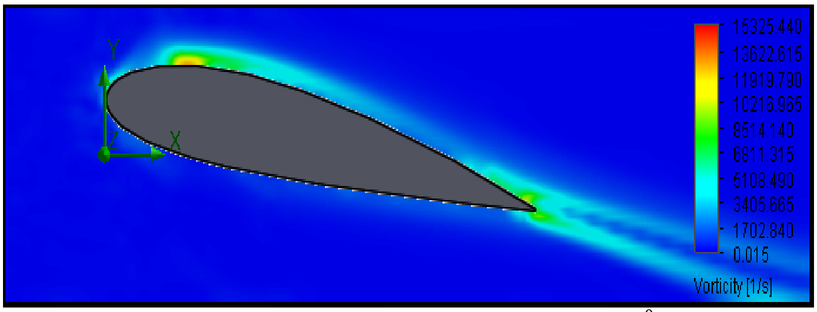
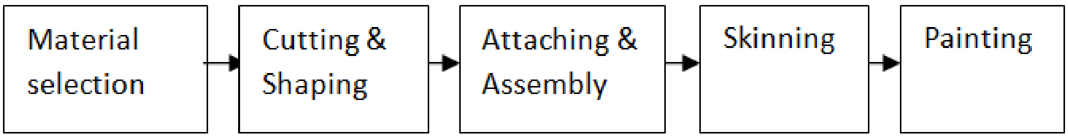


Fig 12-3 Vorticity distribution at 10^0

V. Wing Construction

The flow chart for manufacturing the can be as following-



VI. Recommendations

The design of any kind of aircraft including UAV is mostly dependent on its purpose for which it is going to be used or operated. All the performance parameters must be fulfilled for any design to be a successful one. The following recommendations are put forward for the further advancement:

a) The present study on UAV wing has been worked on a simple surveillance type UAV, capable of carrying moderate payloads for functional operation. That's why the design point evaluations were commenced to meet the overall maximum weight of the aircraft which needs to be lifted up to the maximum altitude and the lift force that must be produced by the wing. The design focus could also have been upon various other pivotal operating optimization criteria such as velocity, altitude, range, endurance, propulsive power etc.

b) The aerodynamics is solved for finding the design parameters and performance analysis based on the traditional aerodynamic theories and historical trends. As the concepts and design ideas are being developed day by day, more efficient design can be achieved by applying new innovative design and experimentation. Some more features can be added to the wing structure like solar panels, blended wing body configuration but these types of design require very advanced level of expertise.

c) For selecting the spar material, the calculations of structural analysis are done for only aluminum alloy and the recommendation is done from this example considered. Some other materials also could have been considered such as titanium alloy or some high strength light weight composites. In case of using composites, better performance could be achieved though the cost will be very high.

d) Upon construction of a scaled wing structure, the static load testing could have been done by applying weights and compared with the analytical and simulation results.

e) In this wing design process, the scaled models of the wing structure and structural components are modeled using solid works software and static loadings and flow characteristics are analyzed through various simulations presented in this report. The simulation results obtained have varied from analytical and expected results in many cases shown here but the intention is to examine the design from both analytical and simulation works. The simulation results have helped a lot for better understanding the design outcomes and comparing the calculated and simulated findings. The deviations in the software simulations from the analytical results might have occurred because of lack in expertise and accuracy in software modeling and simulation works or some errors in defining ambient initial conditions. Computer configuration was also a challenge to meet because it requires very high configuration computing devices to perform these simulations more efficiently which is not affordable at this time.

VII. Conclusion

This project report represents a conceptual design approach of a medium weight surveillance type UAV wing in a chronological order including the structural linear static analysis to defy the undecidability of the CAD model of the proposed UAV wing. Software aided flow analysis is also implemented to understand the behavior of the flow over the wing surface including velocity distribution, temperature distribution, pressure distribution, vorticity distribution etc. Substantial steps of construction are also proposed in this report. Through this report, an attempt has been made to understand an idea about the design approach of an aircraft wing through the study on an UAV wing. The standout point of this paper is that it attempts to conduct a dedicated study on overall aspect and illustrates details about the concepts of the UAV wing.

References

[1]. Reg austin, UAVS Design, Development and Deployment, P-34, , Introduction to UAS
[2]. Daniel P. Raymer , "Aircraft design: A conceptual approach", Thickness Ratio historical trend , Fig 4.14, Fourth Edition, Pg 51, 2006
[3]. John D. Anderson Jr, "Aircraft Performance and Design", Tata McGraw-Hill Edition 2010.
[4]. Mohammad Sadrey, "Chapter 5 Wing Design", July 27, 2013
[5]. Ajoy Kumar Kundu, "Aircraft design", 2010
[6]. Ajoy Kumar Kundu, "Aircraft design", Wing design, fig. 5.1, Pg 169, 2010
[7]. Available at http://www.propdesigner.co.uk/html/load_on_wing.html
[8]. Wing Bending Calculations, MIT open course, Lab 10 Lecture Notes
[9]. www.nptel.ac.in/courses/Webcourse-contents/IIT-
[10]. Barnard Microsystems website, UAV design guidelines.
[11]. Ajoy Kumar Kundu, "Aircraft design" , Aerodynamic Considerations, Table 3.1, Pg 86, 2010
[12]. John D. Anderson Jr, "Aircraft Performance and Design", Tata McGraw-Hill Edition 2010.
[13]. Google image
[14]. Daniel P. Raymer,Aircraft design: A conceptual Approach,Wing sweep historical trend, fig. 4.20, Pg 57, 2010
[15]. Daniel P. Raymer , "Aircraft design: A conceptual approach", Wing tips, Fig. 4.29, Fourth Edition, Pg 70, 2006
[16]. Mohammad Sadrey, "Chapter 5 Wing Design", Airfoil geometric parameters, Fig. 5.5, Pg 180, July 27, 2013
[17]. www.airfoildb.com
[18]. Available at http://airfoiltools.com/airfoil/details?airfoil=n2415-il
[19]. Daniel P.Raymer, "Aircraft design: A conceptual approach", Aileron guideline, fig. 6.3, Fourth Edition, Pg 124, 2006
[20]. www.engineeringtoolbox.com/young-modulus-d_417.html, "Aluminum Alloys"
[21]. www.sketchup.engineeringtoolbox.com/aluminum-seamless-extruded-pipes-tubes
[22]. http://en.wikipedia.org/wiki/Buckling
[23]. Institute for steel development & growth,teaching materials – contents, no 17, beams subjected to torsion and bending
[24]. http://en.wikipedia.org/wiki/Load_factor
[25]. Daniel P. Raymer, "Aircraft design: A conceptual approach", Chapter 4, Fourth Edition, 2006