Real time Characteristics of Tandem Wing UAV

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Abstract

The paper deals with the study of aerodynamics of small Unmanned Aerial Vehicle for the purpose of reconnaissance which usually carries payloads like Camera. The two wing setup is termed as Tandem Aircraft. Researchers authenticated that tandem wing setup provides better aerodynamic efficiencies at low Reynolds Number compared to conventional. The airfoil used in experimental study is NACA 651-212. The scaled model was tested in the wind tunnel to study the flight behavior and the results have been compared with the value obtained from the computational analysis using Ansys fluent. The prototype interior structure was fabricated with light weight and higher strength glass fiber and multigrain wood. The skin was made of polyester fabric. Field test with various conditions were done. The results were efficient enough that the study further investigated to use of light energy as a power source of the aircraft, which in turn can provide increased mission hours.

Index terms— reynolds number, solar power, glass fiber, wind tunnel test, computational analysis.

1 Introduction

nmanned Aerial Vehicle has become an active research area due to the vehicles drastically making a difference in versatile field, such as remote sensing, reconnaissance, surveillance, disaster relief, mineral exploration, military forces, search and rescue. The advent of small UAVs (MAV) has made the task much simpler than large UAVs. Moreover the small UAVs are portable in a bag pack i.e., they follow the break apart system which is useful in the time of emergency situations. The early biplane configuration is well known, which has a pair of wings one over the other making low aspect ratio high agility aircrafts possible but had a drawback of interference effect, to be specific. By replenishing and modifying this order version for better aerodynamic performance, a tandem wing arrangement is adopted in which the wings are placed one behind the other. This arrangement is chosen because of its increased number of lifting surfaces.

Along with the developments of smaller UAVs, termed mini UAVs, has come issues involving the endurance of the aircraft. Endurance in mini UAVs is An airplane in motion through the atmosphere is responding to the "four forces of flight" –lift, drag, thrust and weight. Just how it responds to these four forces, determines how fast it flies, how high it can go, how far it can fly, and so forth. These are some of the elements of the study of airplane performance by [3] "John Anderson" on his 7 th Edition of Introduction to flight book. He further said that, an aircraft should be stable in order to come back to its equilibrium position after when it is deviated from its flight path. Highly stable aircraft requires powerful control to take the aircraft from one equilibrium to other. This paper will focus on quantifying the energy available from ambient sunlight and the UAVs performance and stability study. On considering problematic because of the limited size of the fuel systems that can be incorporated into the aircraft. Energy harvesting is an attractive technology for mini UAVs because it offers the potential to increase their endurance without adding significant mass or the need to increase the size of the fuel system. This paper will focus on the aerodynamic analysis and construction of sUAV using ambient sunlight. The concept of analyzing two wing configurations termed as Tandem Aircraft will provide better aerodynamic characteristics at low Reynolds Number than conventional aircraft. The merits of such arrangements are payload can be increased because of two low aspect ratio wings, lift produced is more than the conventional aircraft, and cruising velocity is high. The maximum flight duration of unmanned aerial vehicles varies widely. ”In 2007, Scientists André Noth, Roland Siegwart, and Walter Engel” [1] proposed from their research that solar electric UAVs hold the potential for unlimited flight. Further, they expiated on how these Solar Powered Micro Vehicle uses the energy obtained from the sun through the solar cells installed on the surface areas of the aircraft model that is going to be designed. Solar Powered MAV is an emerging field of flight research aimed towards attaining limitless endurance to explore vast areas in a single flight whereas solar powered flights will develop from MAV's into huge stable flights travelling in the future and helps make flight travelling ecofriendly and economical which is an innovative initiative said by ”C.K.Patel, H.Arya and K.Sudhakar” [2] on the International Seminar and Annual General Meeting of the Aeronautical Society of India presentation where they presented their work on design, build and fly a Solar Powered Aircraft held at 2002. the above said merits, the project takes the path towards the design and analysis of tandem wing configuration sUAV.

2 II. Preliminary Design

From the Literature survey, it is identified that the small unmanned aerial vehicle used for the purpose of surveillance is mostly reliable and simple. Initially, the dimensions and parameters of sUAV were identified for the design. The wing span is around 2m which is the special feature of sUAV for the tandem wing arrangement and moreover the length of the sUAV is about 1.8 m. The tandem wings are also suggested to be placed at a distance where the interaction is to be low. Therefore different horizontal arm distances are considered viz., 3 times the chord (3c), 5 times the chord (5c). Similarly the width of the fuselage is calculated to be around 0.15m, based on accommodating the components like electric motor, GPS, etc. By taking this into account, the vertical arm distances are categorized into 0c, 0.5c, 1c. Among these distances, one of the combinations is chosen using analysis. The wing loading for this tandem arrangement is calculated by doing simple weight estimation and the resultant value comes out to be 4.55kg/m 2 . The aspect ratio is considered to be in the range of 4 to 6 for a small aerial vehicle and hence AR is assumed to be 4. From the AR, the chord of the airfoil is determined to be 250 mm. Now the dimensions are found accordingly and the 2D design is triggered with brief estimation from [4] ”Daniel P. Raymer” book on Aircraft Design: A Conceptual Approach shown in Fig1.

3 a) Wing Planform Analysis

The aerofoil selected for the wing is the low drag laminar series NACA 65 1 212 with reference from the NASA Contractor Report 165803 by [5] ”Carmichael, B. H” on Low Reynolds number airfoil survey on November 1981. This series is chosen due to the following reasons: 1. High maximum lift coefficient 2. Very low drag over a range of operating conditions 3. Increased laminar zone for the flight Reynolds number.

The significance of having two main wings is to be deeply studied for its aerodynamic efficiency because of its difference from the pure aerodynamic design. To start with, the airfoil sketch is made for the analysis work exclusively designed at the aerodynamic efficiency results. Several combinations are chosen for the design such as 3c-0c, 3c-0.5c, 3c-1c, 5c-0c, 5c-0.5c, 5c-1c, where c represents the chord of the airfoil as mentioned in Fig2. From the analytical results, the tandem wings are decided to be located at 5c-0c & 0.5c distance.

This project deals with the tandem configuration of a fixed wing aircraft where there are two wings. One is placed at lower, front side and the other is placed at higher, rear side. The Wing structure consists of front and rear spars of dimension 10 x 8 mm and 11 ribs which are placed at equal spacing between each other. The front spar is placed at 15% of the chord distance and the rear spar is placed at 65% of the chord distance. The spars and ribs are then covered with a fabric cloth which then doped with nitro cellulose solution to increase the stiffness of the screen as indicated in Fig3.

4 b) Fuselage Analysis

The fuselage design is initially considered to have different shapes but the finalized design is one having a simple shape with low drag making it easy for fabrication for further wind tunnel testing. Therefore the fuselage design starts with a simple square shape with a nose ensuring the streamlined flow over the entire body. This can even be suitable for the motor fixation. The dimensions of the fuselage are set according to the Year 2017

5 c) Wing-Fuselage Attachment Design

The major challenge is to attach the wing model to the above mentioned fuselage design. The attachment should be made such that wing and fuselage should hold together firmly and should not vibrate or deviate from its position while acting upon the loads and stresses. Hence while designing the wing, about 5 cm clearance has been given to both the front and rear spars which will be used as a portion to attach the entire wing into the fuselage. The spar box designed where wing's spars will be directly inserted into the hole and then joined with special adhesives such that spar box and spar should not rotate or move independently. The integrating part of the wing and fuselage was shown in Fig5.

6 d) Weight Estimation

A sUAV can be sized using some existing motor, battery and solar panel and other electronics. The existing motor, battery and solar panel are fixed in size and thrust. They can be scaled to any thrust so the thrust-to-weight ratio can be held to some desired value even as the SUAV weight is varied. This approach allows the designer to size the SUAV to meet both performance and range goals, by solving for takeoff gross weight while holding the thrust-to-weight ratio required meeting the performance objectives. In the weight estimation, the different components like solar panel, avionics, batteries, servos are considered in terms of surface area of the wing after performing comprehensive studies and estimations from 85 th volume of [6] The total weight of the aircraft is found to be 4.55 kg including the structural and solar panel weight of 2.55 kg. While calculating, the wing loading is assumed to be 4.55kg/m 2 , since it ranges from 4 to 6 kg/m 2 for slow fliers. From the known values, the wing area, wing span and aircraft length are estimated as 1m 2 , 2m and 1.8m. Choosing the thrust to weight ratio as 0.3 and considering the cruising altitude as 1.3km which is limited with the avionics, the required thrust is calculated to be 1.365 kg and the cruising thrust to be 1.1675 kg. The thrust required is estimated using the propulsion thrust bed test. The thrust bed is designed in order to have an experimental study over the thrust produced, using plywood board and rail movement mechanism as indicated in Fig6.

7 e) Airfield Requirements

If the required runway length is too short, the aircraft cannot take-off with full fuel or full payload and the aircraft economics are compromised. The landing velocity depends upon the deceleration and landing distance. Landing distance has been estimated as per CAR regulations and chosen as 360 meter runway. The deceleration is usually taken as 0.18g and 0.2g if reverse thrust is applied. Then, the landing velocity and the stall velocity are estimated as 37.5851m/s and 32.6827m/s respectively.

8 f) Aircraft Performance

Aircraft performance includes many aspects of the airplane operation. Here we deal with a few of the most important performance measures including airfield performance, climb and cruise.

The ability of the aircraft to fly up and over obstacles depends critically on its climbing characteristics are compared and plotted various altitude as shown in Fig7.

Time required reaching the cruising altitude by the airplane is determined by using the 1/(R/C) max vs Altitude plot. The Area under this plot gives the time to climb to cruising altitude as mentioned in Fig8. These

9 g) Endurance

Endurance (E) is the time duration for which the Airplane can fly with maximum fuel and with maximum payload. Range (R) is the maximum Horizontal Distance Covered by an Airplane. Once endurance is known, Range (R) can be estimated by multiplying it with cruising velocity. Without the solar panel, the endurance is estimated to be 17 min. From the above values it's evident that the obtained value is higher than the assumed value. In order to increase the endurance, the solar panel is mounted on the surface of the wing with the reference to the [8] "Solar powered High Efficient Dual Buck Converter for Battery Charging" journal by EstherGlory.S, Dhivya.P.S, Sivaprakasam.T.

10 III.

11 Discussion of Test Results

The aerodynamic and performance characteristics of sUAV had done by two analyses: CFD analysis and Wind Tunnel analysis with scaled model.

12 a) CFD Analysis

Computational fluid dynamics (CFD) is a tool that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The geometry of the airfoil is initially sketched in CATIA V5R20 by importing the NACA 65 1 212 airfoil coordinates and suitable size of rectangular domain is drawn. The domain with the airfoil is then meshed with a fine dimensional grid. The meshed airfoil is read in ANSYS FLUENT and the grids were checked. The main scope of the analysis is to find the airfoil combination having: 1. Greater Aerodynamic efficiency 2. Less interaction 3. Acceptable aerodynamic center shift Using Ansys Fluent, the above different combinations are analyzed for aerodynamically efficiency combinations. The algorithm and theoretical study for the research were carefully studied from research journal named [9] "An introduction to theoretical and computational aerodynamics" by Moran Jack and Dover. P. The domain is drawn accordingly by giving opening boundary condition. The velocity is calculated to be 12m/s. For different angles of attack the domain is kept constant and the direction of the flow is changed with respect to the chord line. From the analyses, the forces and moments over each airfoil are calculated. The contours and the flow patterns across each airfoil are depicted below for all the combinations. Initially the 6 combinations of airfoil locations are considered and the analysis is made determining the total lift and drag. From this substantial analysis, the combination was confined which is having good aerodynamic efficiency, smaller shifts in aerodynamic center and further taken to the design for 3D layout as shown in Fig9.

13 b) Aerodynamic Efficiency

The lift and drag values across the front airfoil (A1) and the aft airfoil (A2) are tabulated along with the total lift and drag using wind tunnel balance. For different angles of attack the forces are resolved to get Year 2017 The determination of aerodynamic centre plays a key factor in the stability of the aircraft. Thus before taking the maximum C L and minimum C D values into account for design from the previous analysis, it is important to carry out the analysis for minimum shift in aerodynamic centre. By choosing the configuration with minimum shift in aerodynamic centre, CG is fixed and the design process is then carried out. The mesh files used for analysis of different wing arrangements is again used for the determination of aerodynamic centre. The graphs are plotted between the pitching moment coefficients and the distance at which they are calculated from the leading edge as shown in Fig13.

From the graphs, the shift in aerodynamic centre is calculated from which the one with least is chosen.

The shift in moment is less for the 3c combination but comparing this with the interaction analysis using the velocity and streamline patterns, 3c combination has more interactions while comparing with 5c. Therefore, the 5c-0.5c combination is selected because of its acceptable shift in ac and less interactions depicted by the following contours at different angles of attack as shown in Fig14.

14 d) Structural Stability Analysis of the Wing Members

The structural stability analysis of the wing have been tested with computerized software such as Static structural analysis on ANSYS , Harmonic analysis on Nx -Nastran and also experimental load test on the wing structure. The wing analysis was carried out with the study of T.H.G Megson [11] The comparison between the spars have been made based on many factors such as cost effectiveness, market availability and required deflection and concluded that spar with dimension 10 x 8 x 1000 mm have been finalized.

15 e) Wind Tunnel Testing

The lift and drag values have been obtained using 5c-0.5c scaled model which is fabricated in the material of wood. This model was tested by using the balance setup with the help of wind tunnel, the values were obtained by the software termed as SCAD 508 and the device named as PYRODYNAMICS where the values displayed in the monitor connected to the device as shown in Fig15.

The angle of attack of the model was changed by using pitch-yaw controller setup which is available in our laboratory. The values taken for the following angle of attack: 0 0 , 5 0 , 10 0 and 15 0 . The values were tabulated and the graphs were plotted and compared with 2D analysis results as mentioned in Fig16.

16 f) Models Testing

After the scrupulous testing and estimations with reference to [12] "Estimating R/C Model Aerodynamics and Performance" by Nicolai, Leland M, A remote controlled hobbyist aircraft was chosen as the test bed for this study because the aircraft is inexpensive and easy to assemble, spare parts are readily available, and the aircraft is on the same length and weight scale as some existing military UAVs. The test bed has been divided into two categories. First the test fly was made possible using the chloroplast sheet of 5mm thickness. The aircraft is constructed with an electric propulsion system composed of an electric motor and an 11. Finally, the prototype was made using glass fiber for wings and plywood for fuselage. Several modifications were performed on the original aircraft in order to include the photovoltaic energy device for generating alternative energy source as shown in Fig19.

IV.

17 Conclusion

An experimental study has been carried out to analysis the aerodynamic and performance characteristics of small unmanned aerial vehicle. The thrust required and available are determined by analyzing the characteristics of the given motor and also the power required has been determined for the unmanned aerial vehicle. The endurance of the aircraft is determined and increased by placing alternative solar energy power source. The structure of the aircraft was designed and analyzed through the software and compared with the results obtained from the wind tunnel. Based on the flight tests that have been performed, it can be concluded that the sUAV is effective in aerodynamic design and the solar energy device has the capability of charging energy storage devices with high endurance meticulously studied from, [1] [2] [3] 1 

Figure 1: DFig. 1 :

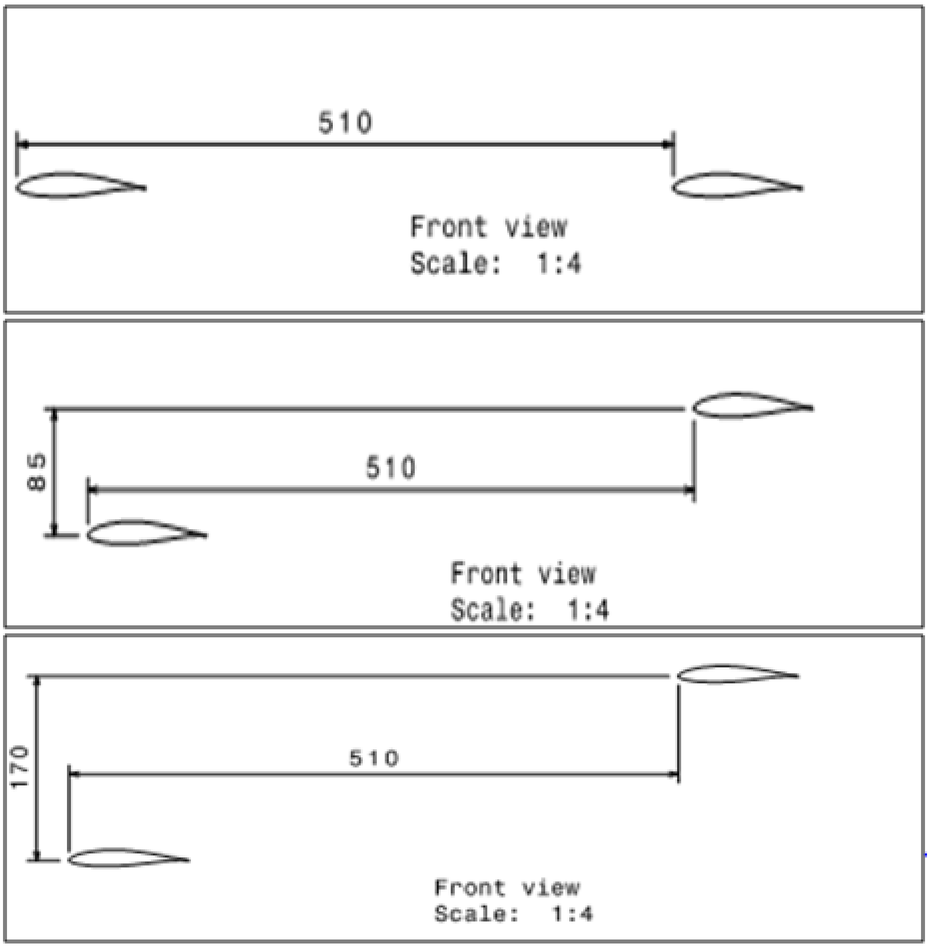
2 

Figure 2: Fig. 2 :

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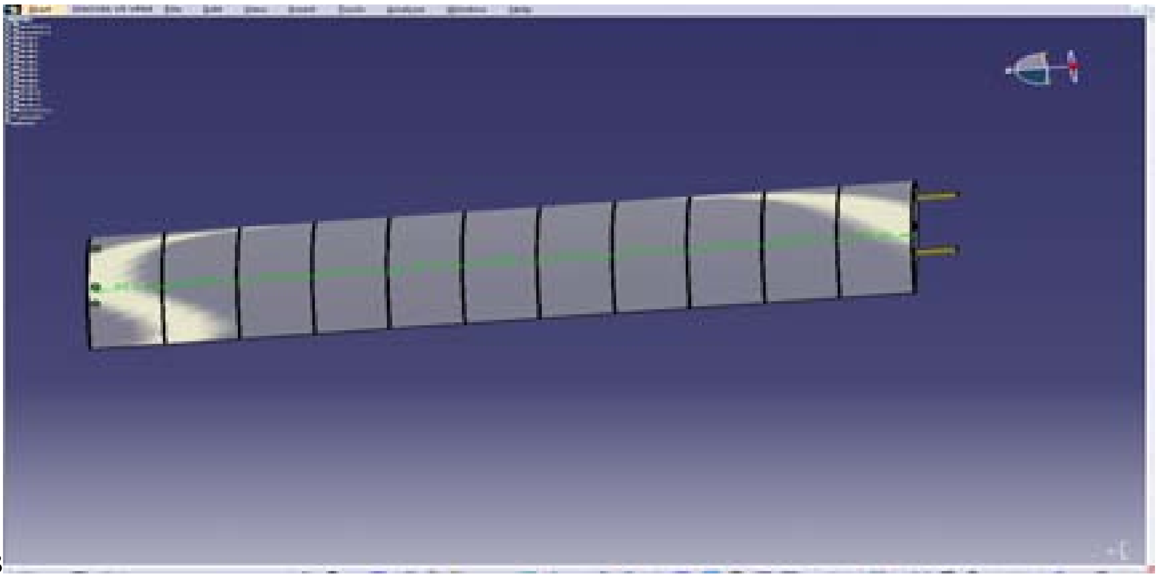

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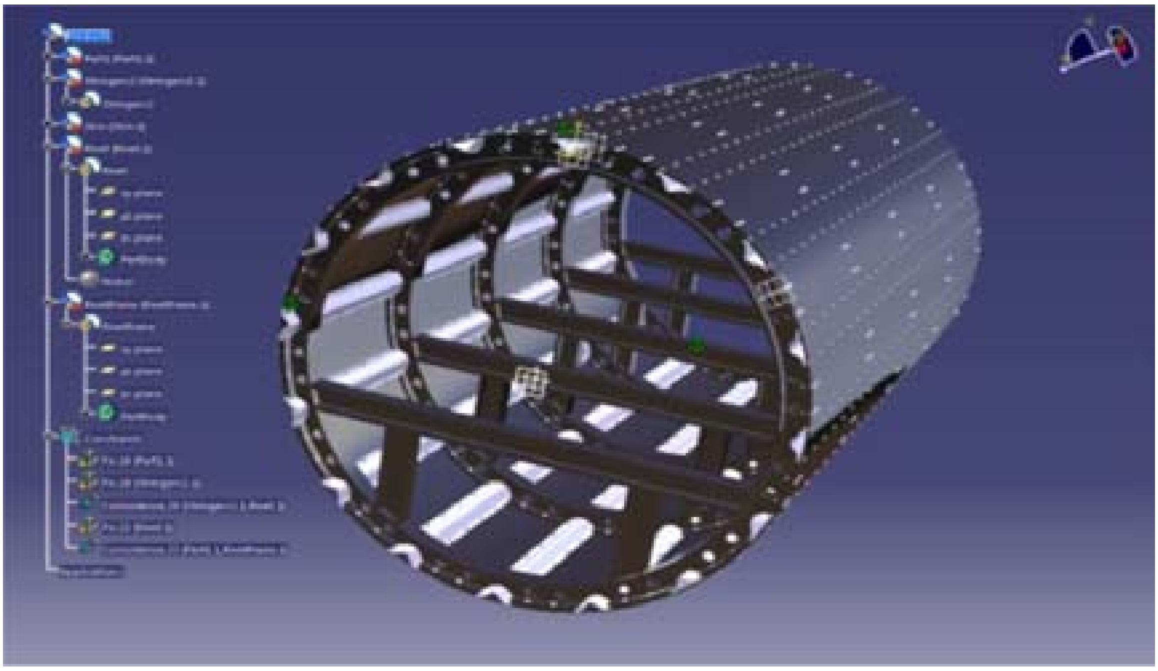

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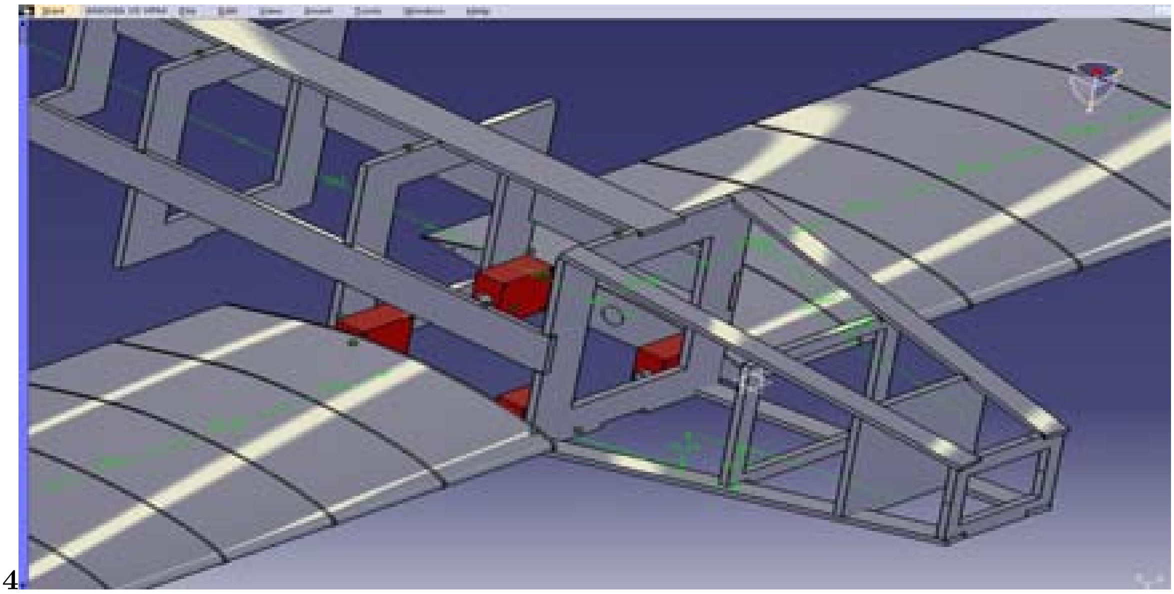

Figure 5: Fig. 4 :

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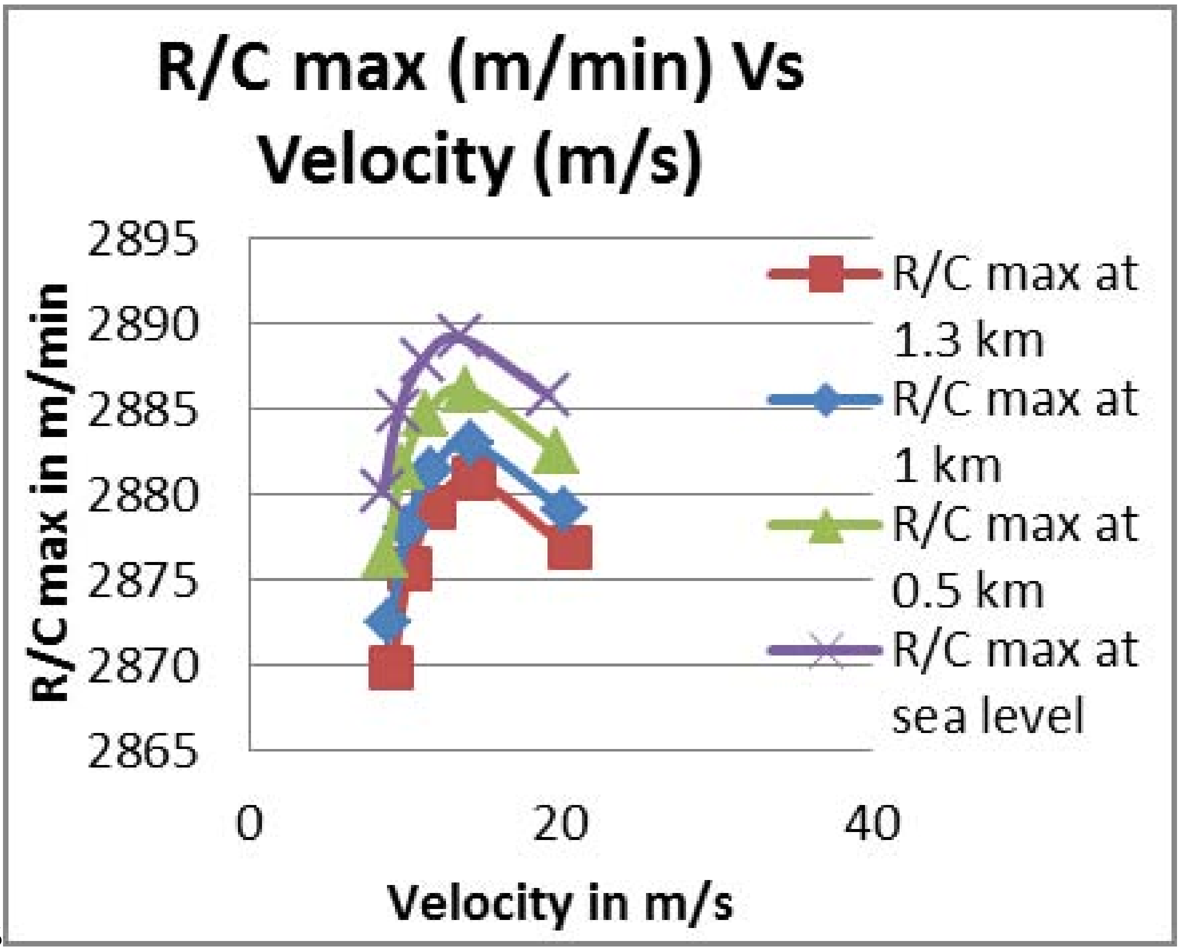

Figure 6: Fig. 5 :

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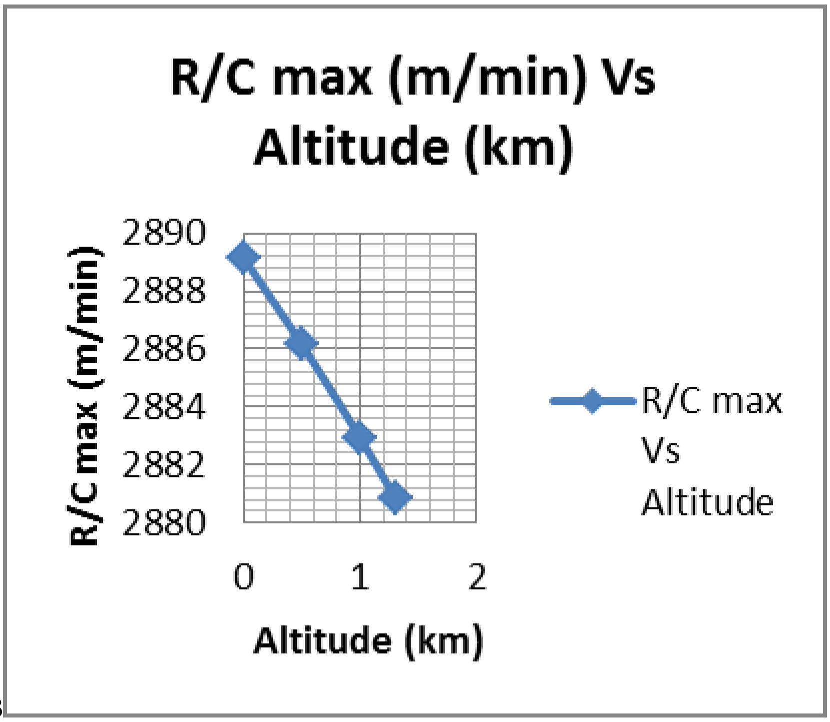

Figure 7: DFig. 7 :Fig. 8 :

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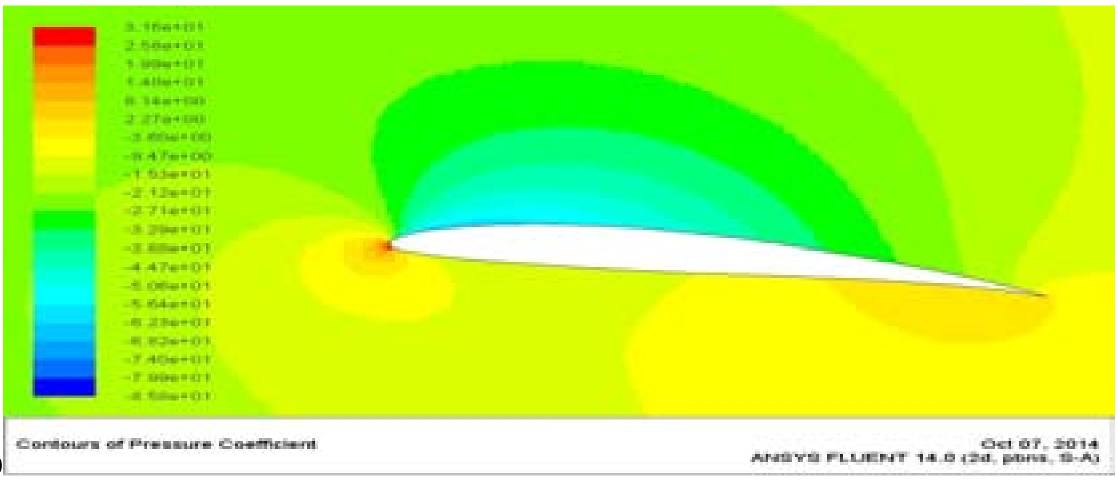


Figure 8: Fig. 9 :

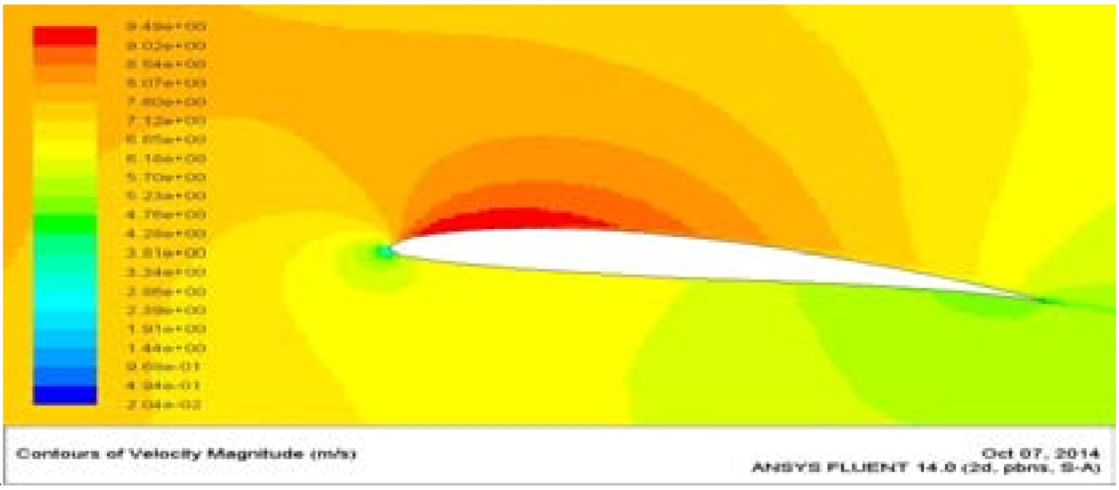
11 

Figure 9: Fig. 11 :

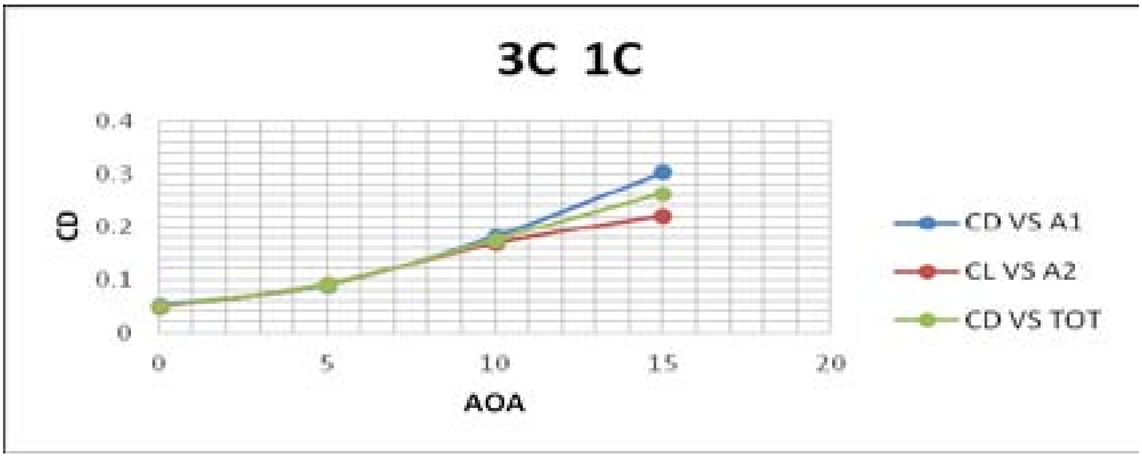


Figure 10:

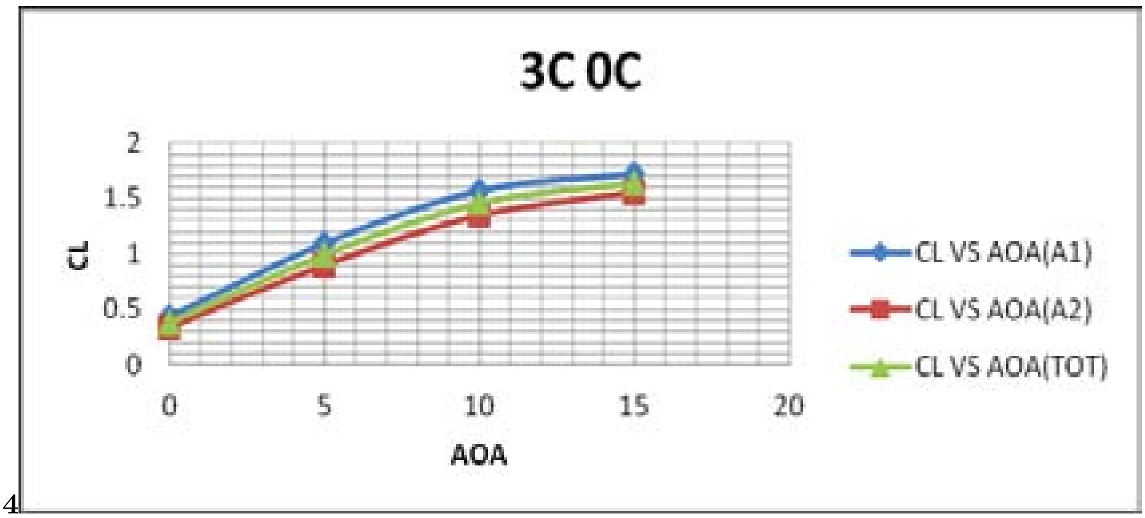
14 

Figure 11: Fig. 14 :

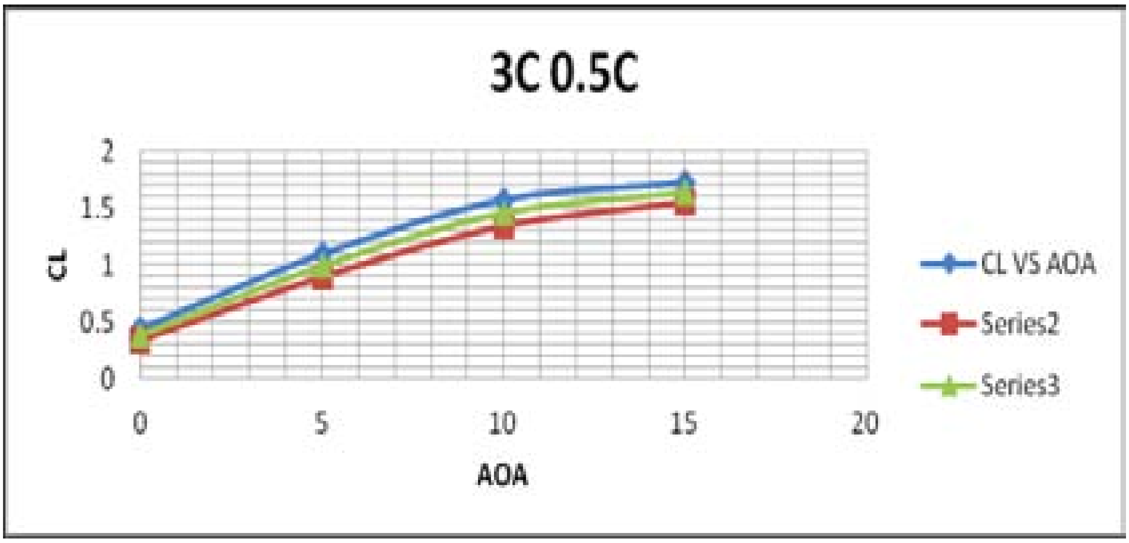


Figure 12:

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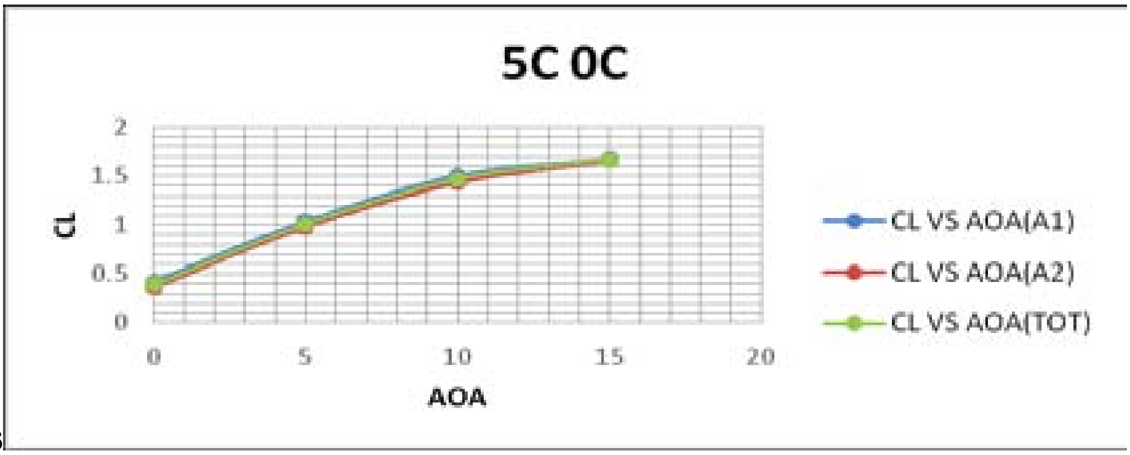

Figure 13: Fig. 16 :

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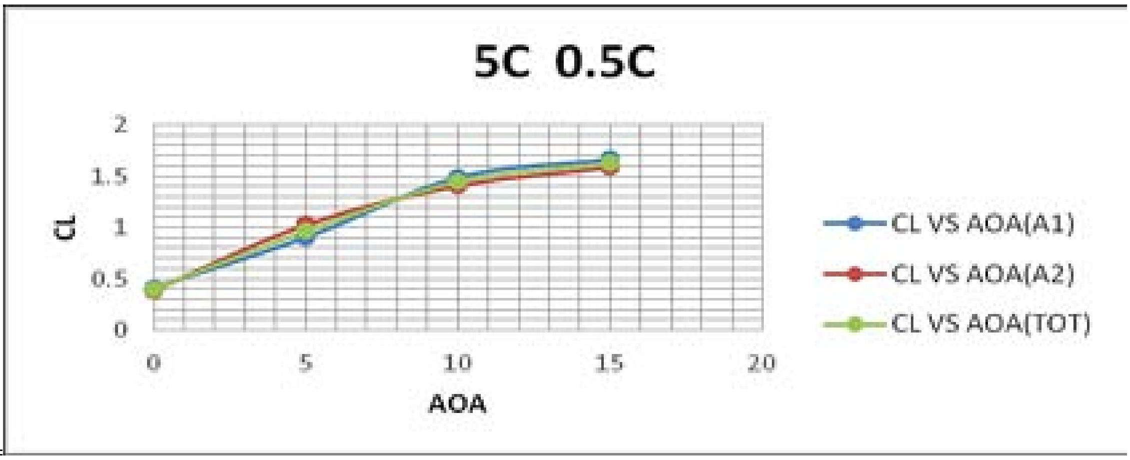

Figure 14: [14]

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.2 Appendix

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