International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.1, Jan-Feb. 2013 pp-58-64 ISSN: 2249-6645

An Approach for the Verification of Aerodynamic Analysis for Selection of Airfoil in Electric Powered Racing Airplane both Analytically and By FEM

Sneha Tahilyani[1], Kushal Singh[2], Mudra Gondane[3]
[1, 2](Aeronautical Department, Priyadarshini College of Engineer, Nagpur, India)
[3](Mechanical Department, Priyadarshini College of Engineer, Nagpur, India)

ABSTRACT: *Aircraft racing is fast becoming an exciting and popular sport event in the world. To meet the needs of racing airplanes, improved designs and new concepts are necessary. This project aims to design an electric powered racing aircraft. The design process started with detailed study of various existing electric powered racing aircraft models. The Rutan VariEze is one of the pioneers in this field. The VariEze is notable for popularizing the canard configuration and composite construction for homebuilt aircraft. Rutan's stated goals for the design included reduced susceptibility to departure/spin and efficient long range cruise. Keeping in mind these designing features, calculations for the mission specifications were made. Modeling is done in CATIA followed by analysis in ANSYS. The modelling work is substantiated with the help of graphs as a part of this research. The calculations thus made were helpful in the designing of the aircraft. For any aircraft it is imperative for the theoretical calculations to coincide with the software based analysis hence efforts were mostly concentrated in this direction for the designing of the Electric Powered Racing Aircraft.*

Keywords: *Racing aircraft, Electric powered, mission specifications, design feature, canard configuration.*

I. INTRODUCTION

Sport aviation has traditionally been a suitable way of developing such technologies into commercial opportunities. Air racing is currently reported to be the fastest growing motor sport in the USA. Commercial sponsorship and television sports coverage of weekend race meetings have generated renewed interest in the sport. This environment offers the means by which we could gain flying experience with a new propulsion system in a highly controlled environment.

As we will be designing a new racing aircraft, it is important to investigate the current air-racing scene. At present, there are several classes of air racing. The two most closely controlled pylon-racing organisations are Formula 1 and Formula V (vee). The main difference between these lies in the specification of the engine type. Formula 1 relates to the 200 cu. in. Continental (0–200) engine and for Formula V to a converted Volkswagen engine (hence the significance of the vee).

Using this pattern, we should project a new Formula (E) to relate to the electric propulsion. An electric powered aircraft is the aircraft that run on electric motors rather than internal combustion engine with electricity coming from the fuel cells, solar cells, ultra capacitors and batteries.

Configuration analysis

In reviewing all the different types of aircraft that are similar to our expected design, it is clear that the main configuration decision to be made rests between the choices of tractor or pusher propeller position. Both have advantages and disadvantages associated with airflow conditions over the aircraft profile. As neither configuration has emerged in the preferred layout for modern racing aircraft, there seems to be no over-riding technical (racing efficiency) reason for the choice.

From the review, the conventional tractor layout is seen to have less variation in the overall aircraft layout. The traditional two-surface layout prevails with the main plane ahead of the control surfaces. On the other hand, the pusher layout offers several options. These include either tail or canard control surfaces. If the tail arrangement is selected, this presents difficulties at the rear fuselage. Using a twin boom layout avoids the tail surfaces/propeller interference but complicates the wing and fuselage structure. Lifting the propeller line above the fuselage may cause trim changes with power and also complicates the rear fuselage profile. The choice of landing gear geometry lies between the nose (tricycle) and the tail (tail dragger) arrangements. The tail wheel layout is lighter but introduces the possibility of ground looping.

Current formula rules prohibit retraction of the wheels but our proposed Formula E rules will allow the auxiliary wheel to be retracted as this does not seem to overcomplicate the design yet improves aerodynamic efficiency. In selecting the aircraft configuration, the most significant criterion is the requirement for high aerodynamic efficiency (i.e. low drag).

This implies: smooth profiling of the external shape of the aircraft, avoidance of the canopy/windscreen discontinuity, fairing of the landing gear and other structural details, reduction of airflow interference areas (e.g. mid-mounting of the wing to fuselage), avoidance of engine/propulsion system cooling drag. Many of the low drag features would be considered during the manufacturing (surface smoothness and preparation) and operational (gap taping and surface cleaning) phases. For this project, the most significant difference in configuration compared with conventional designs is the location of the various components of the propulsion system. Whereas conventional designs have the propeller and engine closely positioned, in an electric system only the electric motor is linked to the propeller. This motor is much smaller than a conventional internal combustion engine and can therefore be streamlined into the fuselage profile. All other components in the electrical system can be located in convenient positions in the aircraft. These options will create an installation that has potentially less drag and higher propeller efficiency. It is also envisaged that the electrical system will require less cooling than the equivalent internal combustion engine. This will also reduce aircraft drag.

Name	Length	Span	Area	AR	Empty Weight	Take-off Weight	W/S	T/W
Nemesis	6.71	6.41	6.22	6.6	236	340	536	0.16
AR-5	4.42	6.4	5.12	8.0	165	290	556	-
Monnett Sonerai	5.08	5.08	6.97	3.7	199	340	479	0.15
Perigree	4.78	8.53	7.57	9.6	172	326	422	0.13
FFT Speed Canard	7.79	7.79	7.88	7.7	440	715	890	0.17
Cassult Special	4.88	4.57	6.27	3.3	227	363	568	0.17
Pottier P70s	5.15	5.85	7.21	4.7	215	325	442	0.2
Monnett Money	4.67	5.08	4.27	6.0	191	295	678	0.19
Aerocar Micro Pup	4.57	8.23	7.49	9.0	118	238	312	0.15

Electric propulsion system

A fuel cell is a chemical and mechanical device to convert chemical energy stored in a source fuel into electrical energy without the need to burn the fuel. The fundamental operation of a fuel cell matches that of a traditional battery. Electrons are freed from one element in order to create an electrical potential. The essential difference between a battery and a fuel cell lies in the ability of the fuel cell to perform the process of dissociation of the chemical components continuously, providing fuel is supplied to the cell. The fuel cell is fed with hydrogen. After the electrons have been removed, the spent hydrogen protons pass through an electrolyte to combine with oxygen to form pure water, an environmentally acceptable emission. Several types of electrolyte could be suitable for our application.

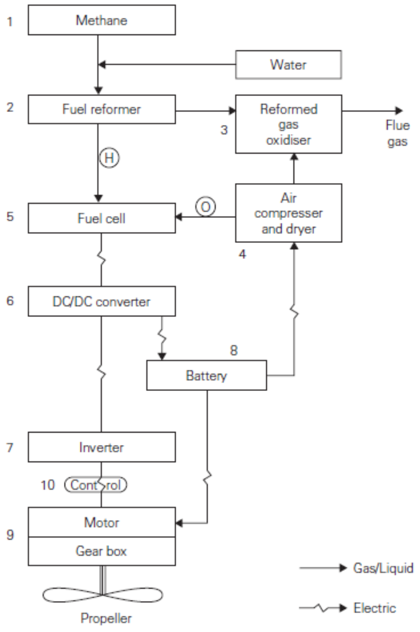

Fig. 1 Flowchart of Electric Propulsion System

To provide higher power, for example on take-off and climb or some emergency condition, it would be necessary to supplement the fuel cell energy with a battery. The battery could be recharged by the fuel cell during low-energy flight periods. This feature may be less appropriate for a racing aircraft that continually uses full power. Several components are required for a fuel cell system. These are shown diagrammatically in Figure 1.

Specifications

The following parameters are taken into consideration for fabrication of the canard airplane. For this Gross weight, geometrical and aerodynamic parameters of the aircraft is to be calculated analytically and then its validity is to be analysed using ANSYS.

Parameter	**Value**
Wing Span	6.77 m
Wing Area	4.98 m^2
Length	4.32 m
Height	1.50 m
Range	1368 km
Empty Weight	263 kg
Maximum Velocity	87.22 m/s
Cruise Velocity	73.88 m/s
Stalling Velocity	30.48 m/s

II. ANALYTICAL CALCULATIONS

Mission Specification Diagram and Weight Estimation

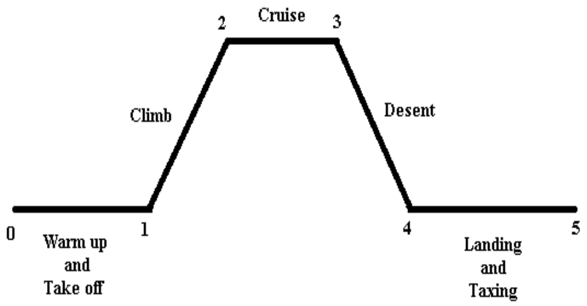

Fig 2: Mission Specification Diagram

Standard values of weight fraction are given as in the below table:

PHASE	**W_i/W_{i-1}**
Warm up and take off	0.97
Climb	0.985
Landing	0.995

Weight Fraction for mission Segments:

1.Warm up and take off:

$$\frac{W_1}{W_0} = 0.97$$

2. Climb:

$$\frac{W_1}{W_0} = 0.985$$

3.Cruise: Following are the available values

$$\frac{W_3}{W_2} = \exp\left\{\frac{-R \times C}{V_c \times (L/D)_c}\right\} = \exp\left\{\frac{-1368 \times 10^3 \times 1.389 \times 10^{-4}}{73.88 \times 16.454}\right\} = 0.8759$$

PARAMETER	**VALUE**
Range, R	1368 km
Specific Fuel Consumption, C	$1.389*10^{-4}$ /s
Cruise Velocity, V_{cruise}	73.88 m/s
$(L/D)_{max}$	19
$(L/D)_{cruise}$	19*.866= 16.454

4.Descend
Fuel Fraction for Cruise back to starting station is:

$$\frac{W_4}{W3} = 0.8520$$

5.Landing:

$$\frac{W_5}{W_4} = 0.9950 \quad \frac{W_5}{W_0} = \frac{W_5}{W_4} \times \frac{W_4}{W_3} \times \frac{W_3}{W_2} \times \frac{\cancel{W_2}}{W_1} \times \frac{W_1}{W_0} = 0.995 \times 0.8520 \times 0.8759 \times 0.985 \times 0.97$$

$$= 0.7095$$

1. Gross Weight Calculations

The Gross weight of an aircraft is denoted by W_0

Type of airplane	A $W_{O \text{ in (kgf)}}$	C
Sailplane-Unpowered	0.8312	-0.05
Sailplane-Powered	0.8805	-0.05
Homebuilt-metal/wood	0.9342	-0.09
Homebuilt-composite	0.8879	-0.09
Twin Turboprop	0.9249	-0.05

$$A = 0.8879$$

$$C = -0.09$$

$$\frac{W_E}{W_0} = AW_o^c \quad ; \frac{263}{W_0} = 0.8879 \times W_0^{-0.09}; \; W_0 = 520kg$$

1. Geometric And Aerodynamic Calculations

1. Aspect ratio

$$AR = \frac{b^2}{s} = \frac{(6.77)^2}{4.98}; \; AR = 9.203$$

2. Chord length

$$c = \frac{s}{b} = \frac{4.98}{6.77}; \; c = 0.7356$$

3. We know that,

$$\mu = 1.79 * 10^{-5} \, Pa.s$$

Therefore, Reynolds's number can be calculated by using the formula,

$$\mathrm{Re} = \frac{\rho \times V_c \times C}{\mu} = \frac{1.225 \times 73.88 \times 0.7356}{1.79 \times 10^{-5}} = 3.7193 \times 10^6$$

4. Maximum Coefficient of lift ,

$$C_{l\max} = \frac{2 \times W_0}{\rho \times V_s^2 \times S} = \frac{2 \times 520 \times 9.81}{1.225 \times 30.48^2 \times 4.98} = 1.8001$$

5. Coefficient of lift for aerofoil,

$$C_{l,aerofoil} = \frac{C_{l\max}}{0.95} = \frac{1.8001}{0.95} = 1.8948$$

III. SOFTWARE MODELING AND ANALYSIS

Modelling using CATIA

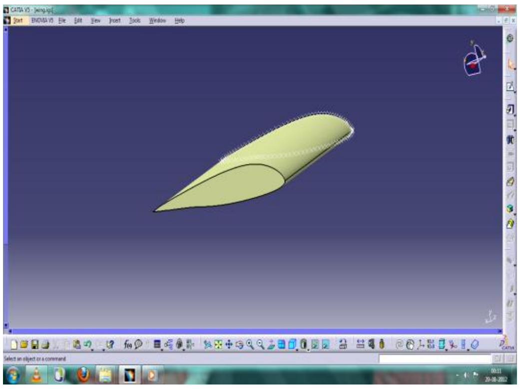

Fig3: CATIA model of Wing Section

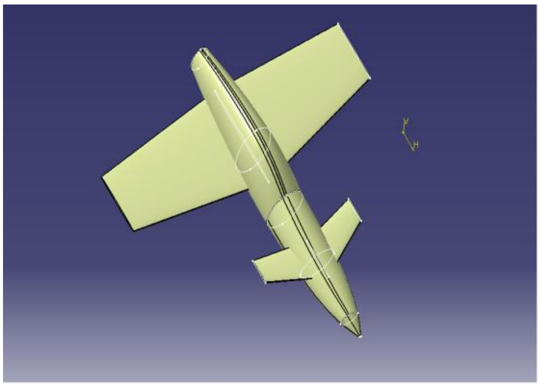

Fig4: CATIA model of the entire aircraft

Analysis using ANSYS

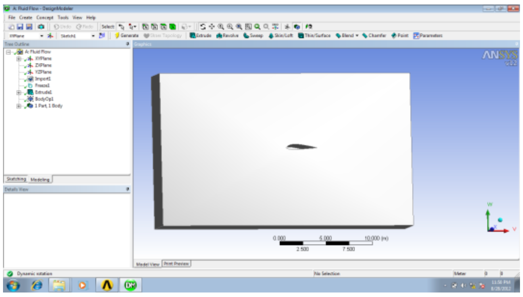

Fig5 .Geometry of the airfoil

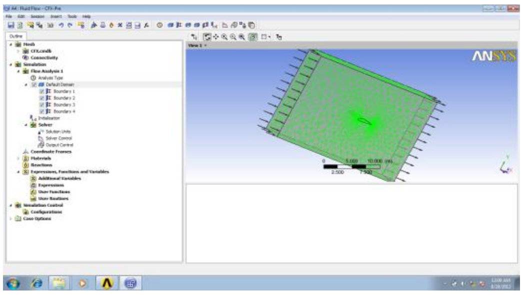

Fig6: Setup for calculations

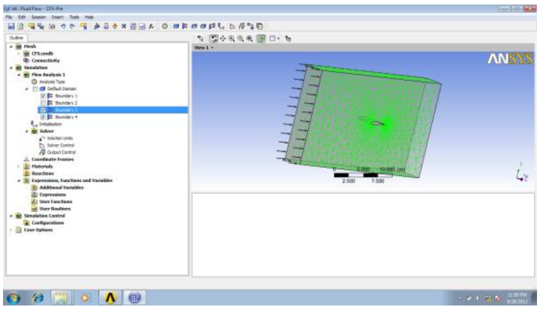

Fig7: Inlet

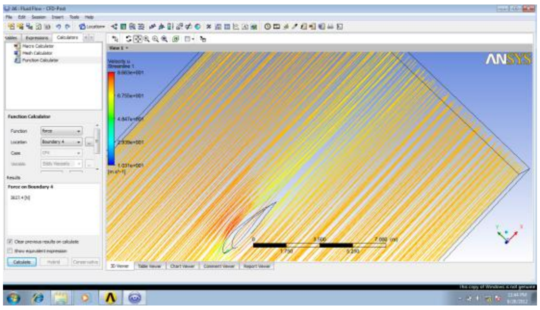

Fig8: Lift generated on the airfoil

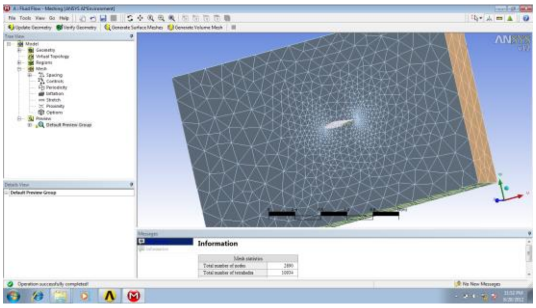

Fig 9: Meshing

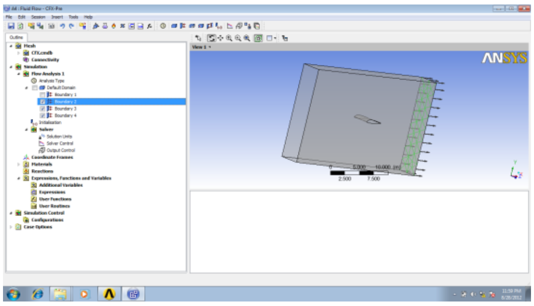

Fig10: Outlet

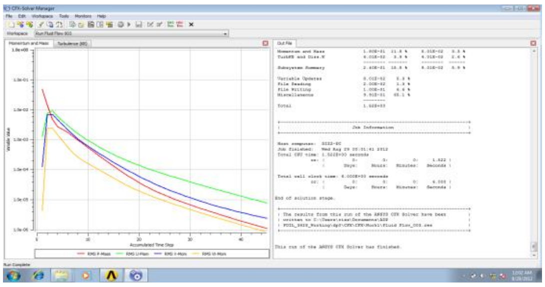

Fig 11: Solver

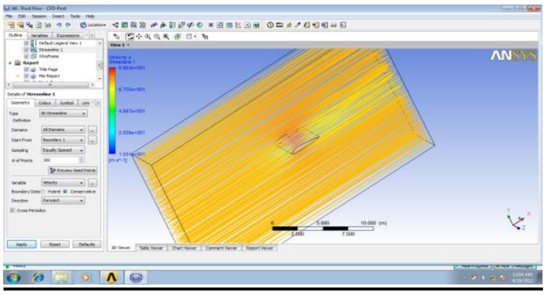

Fig12: Result

GRAPHS

With the help of data generated by ANSYS,Airfoil-Epplor 1230 is selected and graphs for various parameters are plotted.

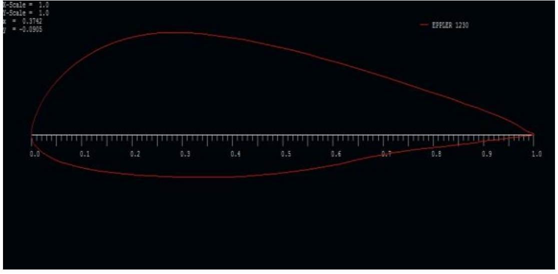

Fig13: Airfoil-Epplor 1230

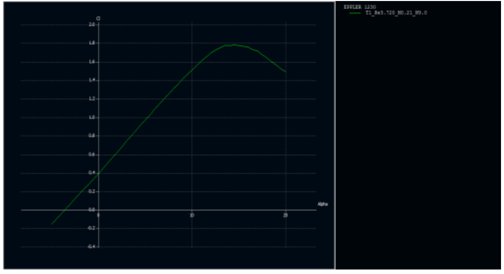

Fig14: Coefficient of lift v/s angle of attack

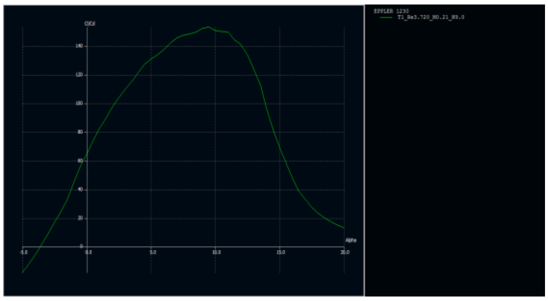

Fig15: Coefficient of lift v/s length of the chord

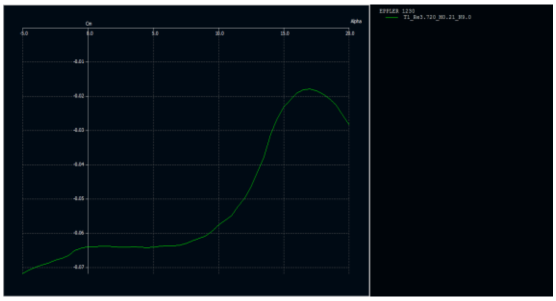

Fig16: Coeficient of moment v/s angle of attack

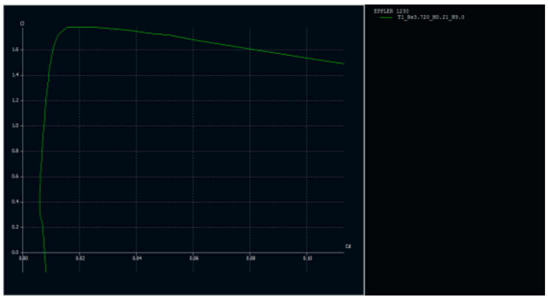

Fig17: Coefficient of Lift v/s Coefficient of Drag

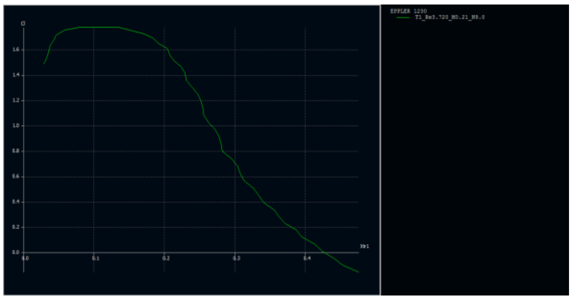

Fig18: Glide Ratio v/s angle of attack

COMPARING SIMILAR AIRFOILS

The airfoil used in Rutan VariEze is “EPPLER 1230”. There are other similar airfoils which fall under this series. These include:EPPLER 1211,EPPLER 1213,EPPLER 1214,EPPLER 1233.

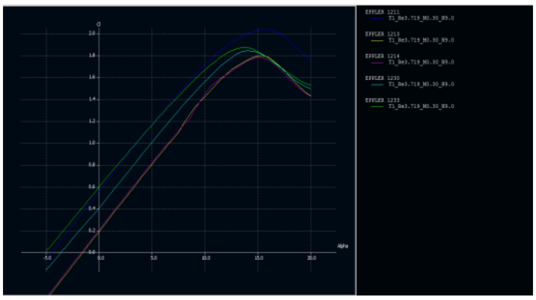

Fig23: Coefficient of lift v/s angle of attack

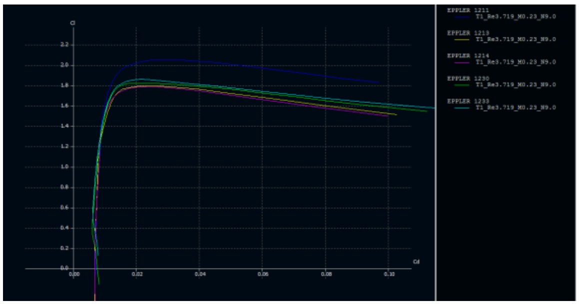

Fig24: Coefficient of Lift v/s Coefficient of Drag

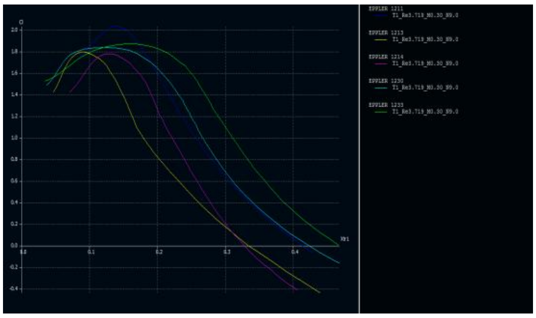

Fig25: Coefficient of lift v/s length of the chord

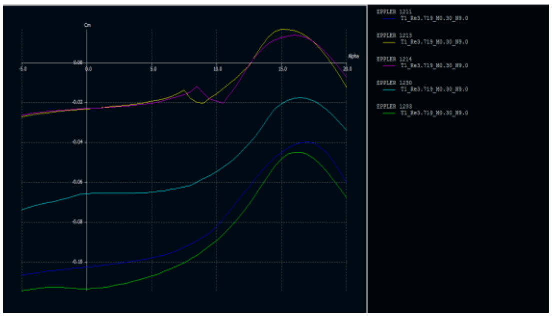

Fig26: Coeficient of moment v/s angle of attack

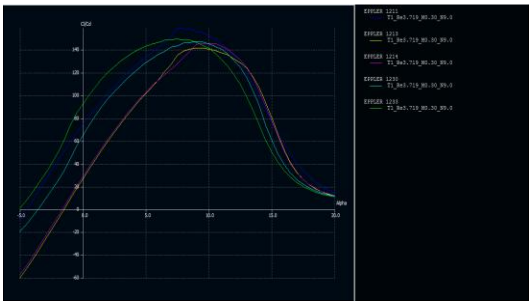

Fig27: Glide Ratio v/s angle of attack

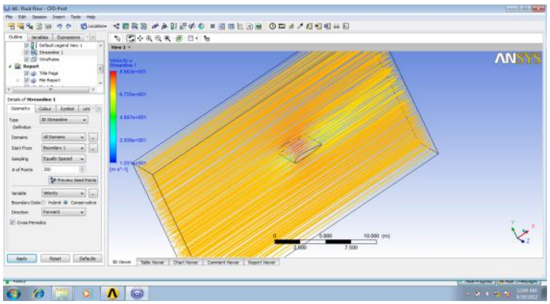

Fig27: Flow Analysis

Above graphs deduce the following facts:

The maximum lift is obtained by the airfoil EPPLER 1211. On the other hand a sufficient amount of lift is generated by the airfoil EPPLER 1230 and the maximum lift is found out to be 1.84 which is very close to the calculated value 1.8001.The C_L by C_D graph shows that the maximum value is obtained by the airfoil EPPLER 1211 which enhances the chance of this airfoil being chosen for fabrication. However, the airfoil EPPLER 1230 along with the other airfoils gives us the desired and required amount of this value.A gradual increase in the lift and a smooth decrease in the lift is noted by the airfoil EPPLER 1230 along the length of the chord. This gives us a very smooth and well maintained pressure distribution over the airfoil thereby producing the desired amount of lift with minimal drag.The coefficient of moment increases gradually for the change in angle between 0 to 5 degree for the airfoils EPPLER 1211 and EPPLER 1233.

However, this value should remain a constant for this range and if it does not then it may create instability. The coefficient of moment remains constant for the propeller EPPLER 1230 and thus the stabilty of the system is maintained.The Best Glide ratio is obtained by the EPPLER 1230 and thus the consumption of fuel used by the aircraft with the above mentioned propeller will be less.

Considering all the above points we see that the airfoil best suited for the airplane “Rutan VariEze” is EPPLER 1230 and thus we have disregarded the other airfoils similar to this airfoil.

IV. CONCLUSION

The analytical calculations yield certain important parameters like Gross weight, Coefficient of Lift for Aerofoil and of entire airplane. These were estimated to be:

PARAMETER	VALUE
Gross Weight	520kg
Coefficient of lift of airfoil	1.8948
Coefficient of lift of wing	1.8001
Reynolds Number	$3.7193*10^6$

Calculations of coefficient of lift and Reynolds number were done with help of ANSYS and results were found to coincide. The maximum lift coefficient was found to be 1.8001 analytically and by inputting the value in ANSYS, this value turns out to be 1.84 at an angle of attack of 14˚ which is fairly close to the analytical value.

Thus an approach for the Verification of Aerodynamic Analysis for selection of Airfoil in Electric Powered Racing Airplane both analytically and by FEM is done successfully and the results were found to be satisfactory.

Future work of this project will be for the verification of performance analysis of the same airfoil as velocities at different performance parameters plays an important role for a racing aircraft.

REFERENCES

Journal Papers:

[1] R. J. Boucher, History of Solar Flight, AIAA Paper 84-1429, June 1984

[2] Douglas P. Wells, NASA Green Flight Challenge: Conceptual Design Approaches and Technologies to Enable 200 Passenger Miles per Gallon.

Books:

[3] Raymer, D., Aircraft Design – A Conceptual Approach, AIAA Education Series, ISBN 1-56347-281-0, third edn, 1999.

[4] Brant, S. A. et al., Introduction to Aeronautics: A Design Perspective, AIAA Education Series, 1997, ISBN 1-56347-250-3.

[5] Tully, C., ‘Aircraft conceptual design workbooks’, Final-year project study, Loughborough. University, May 2001.

[6] Howe, D., Aircraft Conceptual Design Synthesis, Professional Engineering Pub. Ltd, UK, October 2000, ISBN 1 86058 301 6

[7] Stinton, D., the Design of the Aeroplane, Blackwell Science Ltd, 1983, ISBN 0-632-01877-1

[8] D. Stinton, The Design of the Aeroplane, Second edition, Blackwell Science, Oxford, UK, 2001.

Thesis:

[9] Michael DeRosa, Optimizing Airfoil Sections for Remote Controlled Pylon Racing, ME Thesis, April 2012.