10th International Research Conference of KDU

KF IMPLEMENTED FLYING WING

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Abstract— *In modern aviation the main emphasis is pointed towards the direction of improving the efficiency of operation. The design of the aircraft is solely concerned on providing the most effective operating conditions. Designing and developing a new aircraft design needs to be encompassed with the best corporation of forces acting upon to bring out the most efficient flight. In any aircraft design the major apprehensions are on the basic coefficients such as lift and drag. Respectively with the combination of forces acting upon will bring out the collective operating perspectives of the aircraft. With the aid of a 3D designing software and with the assistance of manual designing the aircraft is modelled. The comprehensive use of K – epsilon model in a 3D domain with second order upwind discretization have promptly provided the results as satisfying. The working conditions are to be complied with the general operating conditions of a major airliner used aircraft. The conventional designs are optimized up to a crucial level that have reached the peak with the rising edge of technology. The computational fluid dynamic methods need to be carried out in the rudimentary operating conditions in order to ascertain the condition of the design in the natural constraints. The analytical data have taken a path toward a considerably profound aspect ratio, though the basic design is optimal in operational conditions. Apart from the upper and lower boundaries of operation envelop, the calculations need to be conducted from an inferior level that can bring out its primary stages of operation and build up towards all the conditions with future simulations. Which can be subjected with further computational power towards more effective simulation data finding.*

Keywords: Flying wing, Kline Fogelman airfoil, Computational Fluid Dynamic

I. INTRODUCTION

The concept of flying wing had been in play even before the First World War. William Dunne's flying wing design was given to the world before the world war but was still in the research stage. After 1915 Hugo Junkers' firm was able to build up a better design for the flying wing. The designs made for world war one was able to give a stable and greater leap in flying wing concept.

After the world war the flying wing concept was taken for consideration to be built for commercial airliners. With lest drag this concept was an ideal design to carry passengers in a larger number. With time the flying wing concept was kept aside in only for military purposes.

The flying wing concept is kept under research in the modern world such that there are new power sources to increase the efficiency of the concept. The latest accomplished design in flying wing Northrop Grumman Switchblade (2008) as a UAV project done in United States.

The KF airfoil is the least sophisticated design that can be manufactured with less effort but after manufacturing can gain greater efficiency in use. As the material usage is less the manufacturing cost is reduced to a minimum. The KF airfoil is designed over a 50 year ago but still is in a developing stage. There are 10 KF designs but only 6 of them have been analyzed and 4 are still under development. As the KF airfoils have the least possibility of stalling as it has the ability to achieve higher angle of attack even greater than 60degrees.

The KF airfoil shapes have the capability of successfully achieve higher or lower speeds in a wide range. These wings have the ability to gain more lift with a heavier pay load and can gain faster speeds with less pay load.

As drag is a crucial factor with the KF design the drag acting on an airfoil is being able to be reduced to a minimum. As most of the shape of the airfoil is maintained by circulation of air the friction also have reduced to a minimum thus giving a greater advantage in acquiring greater speeds with less power.

The design issues that have risen from the flying wing concept have withdrawn more designers from developing the concept far more. The inability of smooth manoeuvring has become a major scale disadvantage in this concept as this is a tailless aircraft. Also, problems occurred when fitting in the pilot cockpit, engines, flight equipment etc.

With the abilities of KF airfoils the path for easier control and building up space for all the essential components without decreasing the efficiency of the aircraft are looked forward in achieving.

II. LITERATURE REVIEW

The literature review under the topic of KF implemented flying wing designs as such. Within this research, a new design in flying wing concept is to be proposed in implementing with greater capacities in all aspects. In this literature review it is based on the details which were comprehensively surveyed by other researchers. This review will be done sequentially with literature regarding Kline Fogelman air foils, Flying wing designs and implementation of flying wing concept.

The facts will be taken into consideration in designing the new flying wing design and the proven drawbacks will be considered in mitigating in the new design as well as the advantages to be improved.

In accordance with the reviewed research papers, the analytical facts were given as follows.

A. Kline–Fogleman (KF) Airfoils

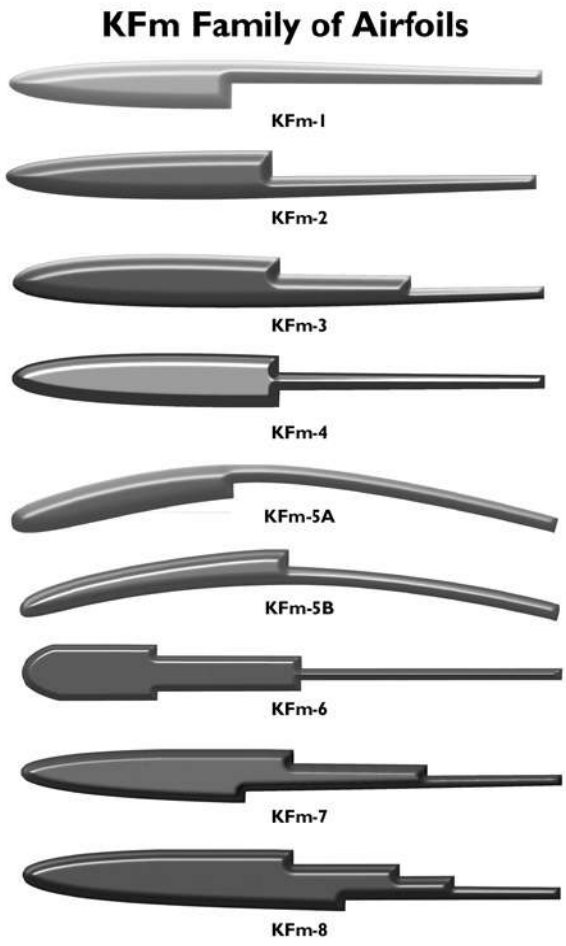

Figure1. KF Airfoil family

According to Kline (2009) there are several advantages of using a KF airfoil over a conventional airfoil. As the prime condition that any aircraft design is looked forward in achieving is the reduction of weight and increment of strength and efficiency the KF airfoil have the ability to achieve those conditions in an effective and economical manner. As mentioned by Kline the reduction of drag had been a major outburst in KF airfoils. As the air passes over the airfoil part of the air itself acting as the surface of the foil had given the largest perk in using KF airfoils over conventional airfoil. According to the study the number of advantages given by the KF airfoil have increased with the change of shape. As the KF airfoils have the ability of deviating its centre of gravity it the payloads that being carried can be increased accordingly. The stability of this airfoil shape has increased in a higher range compared to the conventional airfoil. The most essential fact of the KF airfoil according to this study was the elimination of the stabilizers and the rudder as the shape having its own ability of keeping the stability, thus it has created a design with less drag. Having the ability of smooth flying over higher speeds of air flow have given an added advantage for this foil. As the fuel efficiency of the foil have got increased due to reduction of friction have given an economical leap to this design. As the final implementation is about to go on UAVs as per the study indicates the financial expenditure have reduced to a minimum due to the less use of material to accomplish the design of the KF airfoil.

With respect to the literature it has been proven that KF airfoils have the least drawbacks with respect to conventional airfoils. As there were several areas which an airfoil should increase its ability KF airfoil had the ability of keeping all those aspects in a stable range.

Powers (2009) have brought out the study in analysing the KF airfoil in practical conditions. The study had given the CFD analysis of one of the KF airfoil shapes from the KF family designs. With this analysis, the prototype has given the necessary details in order to understand the design philosophies of KF airfoils.

B. Flying Wing Concept

As the study of Mialon (2002) emphasises the use of flying wing concept was mainly generated due to the need of increment in passanger capacity. Thus to create the working design it had to overcome the efficiency and environemntal constraints.

As per the findings of Patil (2006) the design of flexible flying wing was carried out with a model made as a beam and was taken into consideration with respect to the conventional airfoil shape. The research was carried out through an analytical method with an aero elastic system. The design was given 3 propulsive points such that it will keep up the stability as well as the thrust. With the minimum components, it gave the leap of increasing the payload which was an added advantage. With the concentrated payload pods it was focused on keeping the mass distribution even after the mass differ with the payload on. The study was given the design concept on acquiring a better efficiency in use of power.

Fleming (1940) designed a model of flying wing aircraft with greater stability in take-off and landing. Also, this was focused on increasing the load capacity of the aircraft design. In this design, it was based on conventional airfoil design and was faced along high speeds with minimum resistance. The design was kept with minimum internal components.

The design given by Grow (1986) was more concerned in keeping the stability and increasing the angle of attack variations. This was achieved by trimming the trailing edge of the design. In order to gain the stability an upper and also a lower control component was added. Though the components were kept conventional the design aspects were moderated to keep the original objectives to be met.

With another leap of moderated aircraft actions Chen (2005) had given the design the ability of vertical and/or short take-off and landing with a fan propulsion system. The main propulsions used in this design used the vertical thrust generation and the forward thrust generation in cruise.

Due to the limitations with the tube and wing aircrafts being fenced with size factor as the Antonov 225 being the largest and skipping the edge of size was proven to be harder. Such that with this research it promoted a flying wing method in order to overcome the weight factor.

Figure2. Northrop YB-49 flying wing

With the above literature, it had become open for research, a more efficient method of overcoming the errors of flying wing concept is in need. Also with these references it had been proven that though the conventional airfoil was suitable for the flying wing concept it was practically proven to be ineffective in some conditions and with that the conventional design have become not the ideal airfoil shape in designing the flying wing concept. Alterations needed to be done in order to overcome all the errors and issues which raised with the above literature. And in order to go past these modern concepts should be taken into consideration and should be put into analysis parallel with conventional design philosophy issues.

In this design, the above data referred from the literature will be critically analysed and will be presented with the use of a design carrying modern concepts which have the ability to overcome those issues mentioned in the literature and will be given systematic solutions for each issue delivered.

II. METHODOLOGY

0An improved model of the flying wing concept will be designed with all the key aspects which are required in developing a proper airworthy aircraft.

The concept of flying wing will be considered due to its unique properties and characteristics. This design will be propagated such that it exercises the basic aspects at the same time avoiding the conventional issues.

The family of KF airfoils will be taken into account as per giving a base for the design to be developed. The specific characteristics which are only provided by KF type airfoils are a major advantage in designing with the least drawbacks.

The design will be made whilst interpreting solutions for the prevailing issues in the flying wing design concepts. There will be proposed modifications for the design to improve the available advantages.

III. FACTORS TO CONSIDER IN FLYING WING CONCEPT

In developing a design that can overcome all constraints there are several factors to consider in basic design aspects. The basic factors are,

A. *Weight and Balance*

- CofG
- Design symmetry
- Longitudinal Stability (zero static margin)

B. *Aerodynamic profile*

- Airfoil shape
- Aerodynamic forces
- Air flow profile
- Naturally Trimmed aircraft (Without tail)
- Maximum thickness of airfoil
- Increase maximum L/D ratio

C. *Environment and Operation conditions*

- Operating Speed
- Operating altitudes
- Environmental factors

The developed design will be able to exercise the above factors with maximum caution and specific characteristics.

IV. BUILDING DESIGN

The design which developed is with the aid of the Northrop YB-49 flying wing as well as the Northrop Grumman B2 Bomber. These two aircrafts being the only flying wing designs that are used in NON-CAT operation the design which will be developed need to be operational in any condition. This need to comply with any commercial situation.

As the design is considered to be operated in high safety concerned conditions the parameters need to be taken from an aircraft which is already working under the perfect airworthy conditions.

With the aid of the prevailing blended wing designs the primary flying wing will be designed and put into simulation to present the forces and coefficients acted upon contained with the flow patterns.

The combination of flying wing concept and the KF airfoil design build the theoretical assumption of better lift to drag ratio. With this design it is looked forward in developing the design to have the optimal L/D ratio that is achievable.

IV. PROPOSED DESIGN

Given below is the developed design in the concept of flying wing with combination of Kline Fogleman airfoil concept. This design is provoked with only the basic design put towards identifying the aerodynamic parameters by simulations.

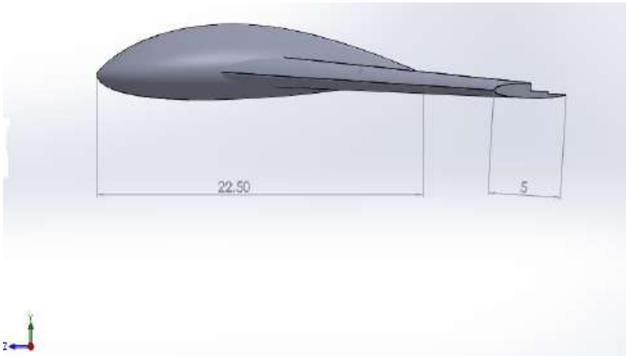

Figure3. End elevation

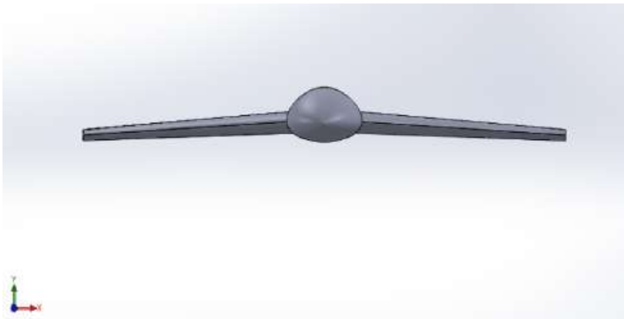

Figure4. Front elevation

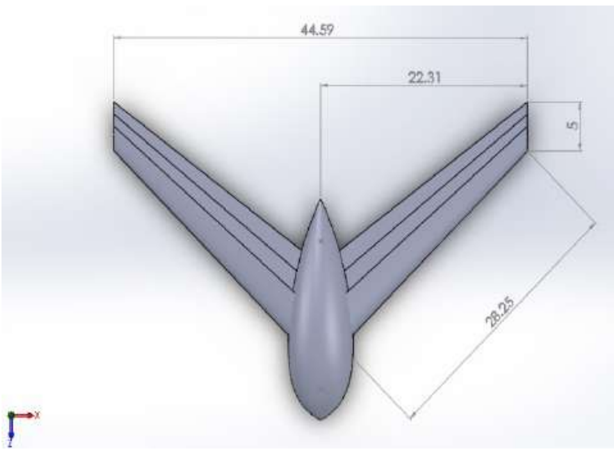

Figure5. Plan

(All dimensions are in meters)

The AoA is kept at 3^0 provided that it can improve the coefficients. Above provided design is the basic design keeping all key factors in developing the flow simulations in order to achieve a model with optimum aerodynamic capabilities and beyond.

A. Aerodynamic Profile

1) Airfoil Shape:

As it's mentioned above the airfoil shape used in this design is extraordinary than the conventional airfoil shapes. There are several reasons in using this airfoil shape.

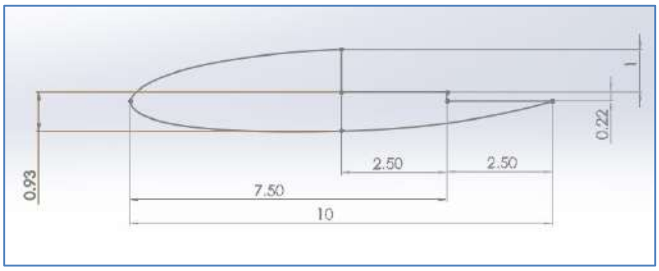

Figure6. Airfoil Shape

This airfoil shape is inspired by the KF3 generation airfoils. As mentioned previously the steps are propagated from the coordinates of 50% and 75% of the Chord length.

The main reason being the reduction of weight and drag. With this concept as the design is hollower less material weight is involved. As for the drag reduction, the vortex cell generated near the steps will reduce the drag by theory. With this the stepped part will not directly produce friction because it is air against air.

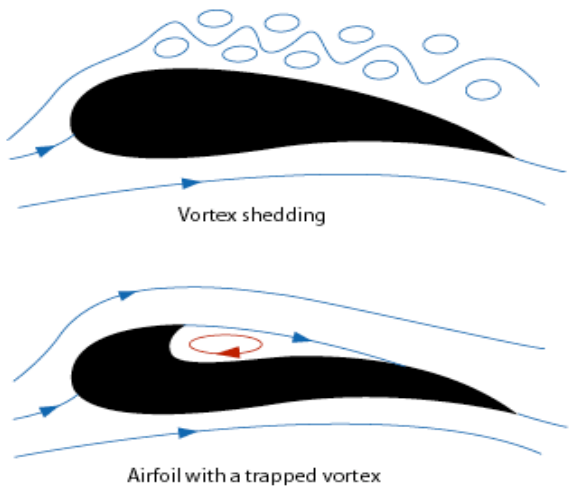

Figure7. Air vortex cell

2) Mean Aerodynamic Chord (MAC):
The mean aerodynamic chord of the designed aircraft is calculated with the geometrical design theory using Solidworks.

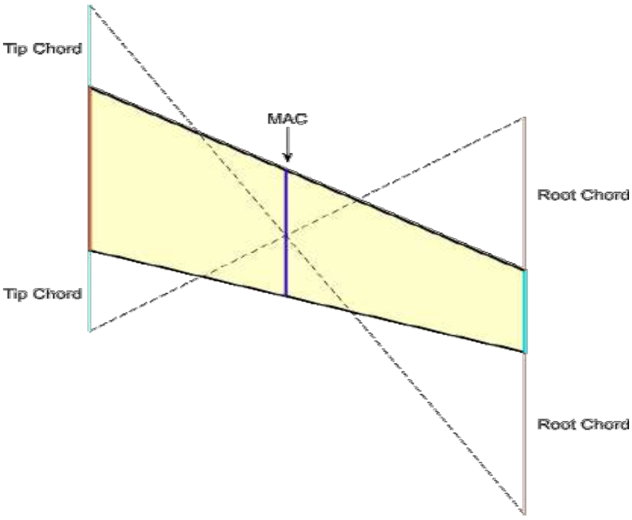

Figure8. Geometrical method

With the use of this method the design is modified in order to find the MAC.

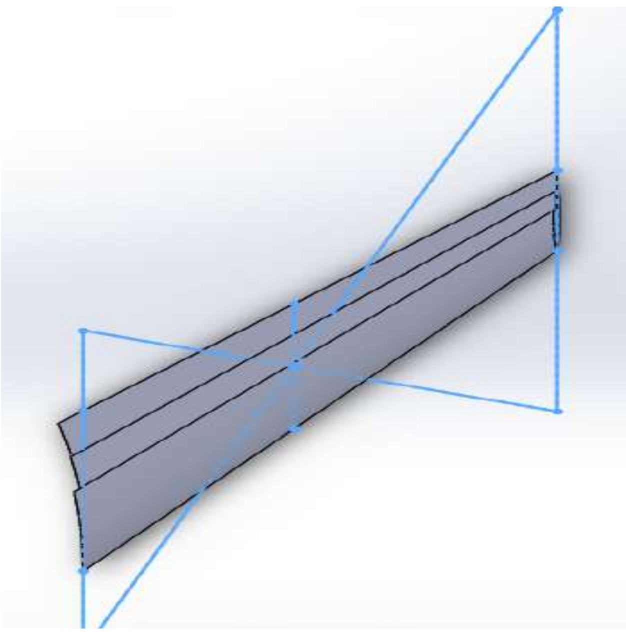

Figure9. Modified design

RC=Root Chord
t = Taper Ratio = (Tip Chord ÷ Root Chord)

$$MAC = RC \times 2/3 \times ((1 + t + t^2) \div (1 + t))$$

With this modification, the MAC is measured to be 7.777 m.

This value is used as the reference length in the simulations as well as the Chord length throughout the simulation process

B. Naturally Trimmed Aircraft (Without Tail)

Figure10. Flying wing Design

The design is built with the concept of tailless aircraft pre-known as the flying wing.

IV. FLOW SIMULATIONS OVER THE AIRCRAFT DESIGN

With the aid of the computational fluid dynamics (CFD) softwares ‘OpenFoam’ and ‘Ansys Fluent’ the simulations were used to identify the flow patterns of the basic design. In order to achieve these data several hypotheses were taken into consideration and standard operational conditions were given in accordance with general aircraft nature similarities.

A. Hypothesis and Operating conditions

In order to run the simulations through OpenFoam and Fluent the following hypothesis have been taken into account with the aid of operational conditions in general aircrafts.

- The flow considered to be Compressible.
- The flow considered to be Turbulent.
- The flow considered to be Newtonian.
- The gravitational effects are neglected.
- Sea level conditions are considered.
- Non-static components of aircraft are neglected (Propeller, Landing gear, etc.).

The above stated assumptions are made through all the simulations.
The operating conditions are decided with the aid of Airbus A320 flying conditions as it is the most commonly used aircraft in the aviation world. As per the A320 operation the cruising altitude stands at 39,000 ft. Thus, in this simulation the parameters selected to build the premise in both upper and lower limits.
The basic operating conditions and aerodynamic parameters that are considered in the simulations are,

Table 1. Operating Conditions

Altitude	Sea level	39,000 ft.
Temperature	300 K	216.65 K

Pressure	101325 Pa	19672.46 Pa
Density	1.225 kg/m^3	0.3175249 kg/m^3
Viscosity	1.7894e-05 kg/m-s	1.4220437e-05 kg/m-s
Specific Heat (Cp)	1006.43 j/kg-K	1003 j/kg-K

The operating speed is kept as at 240 m/s (Mach = 0.7059) as per the A320 operations.

B. Meshing and applying boundary conditions

The meshing is done with the aid of Ansys Workbench and provided with the optimal resolutions such that the smoothest output values can be calculated. The basic drawback in improving the mesh is the computational power of the processors are being limited to a certain level.

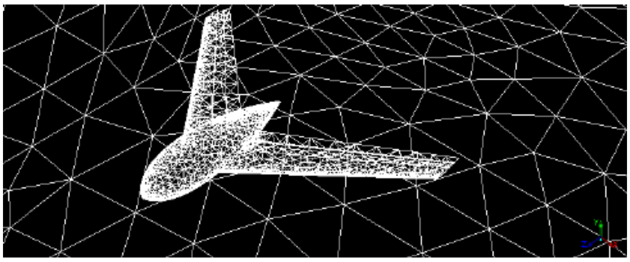

Figure11. Meshed aircraft

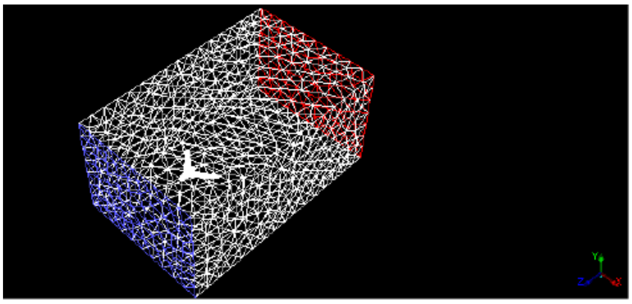

Figure12. Mesh with domain

C. *Fluent Simulation Background*

The mesh which is generated with the help of Ansys workbench is exported to fluent as a '.msh' file. The solver used is a pressure based solver with a velocity selected as a condition for numerical solution process in a 3-D domain. The K – epsilon model with realizable and with Non-Equilibrium Wall Functions. A coupled scheme was selected with second order upwind discretization method and courant number is kept at 50 with relaxation factor of 0.25 (Momentum and Pressure). As the prime objectives were to calculate the aerodynamic force coefficients monitors were activated for C_D and C_L with a hybrid initialization.

The K – epsilon model is a two equation model which is commonly used for mean flow characteristics for turbulent flow conditions.

V. RESULTS

A. CFD Simulation Data

The simulations are carried out with the above given conditions and results were collected accordingly. According to Table 2 the values which are calculated are accurate with respect to general aircrafts in use.

Table 2. Calculated Data from Simulations

	C_D	C_L
Sea Level	0.18722	0.45608
39,000 ft.	0.17399	0.41221

As the design being a newly modelled aircraft the theoretical calculations are harder to achieve with the lack of data regarding the required parameters, this includes critical components such as,

- Material density
- MTOW of Green Aircraft

After considering the above factors the theoretical data can be calculated as well. In the meantime, the process of wind tunnel testing with a scaled down model with exact design should be carried out to check the changing factors of some parameters such as,

- Turbulent Intensity
- Turbulent Length Scale
- Turbulent Viscosity

With the collected data, the basic design can be improved as well.

VI. DISCUSSION

The designing of the flying wing is carried out primarily with manual drawing of basic components and with the complete design of 3D modelling with the aid of Solidworks software.

As the non-static components are neglected the basic shape of the aircraft is provided for the simulations. As mentioned above the workbench is used for meshing. OpenFoam can be used as a meshing software as well in this scenario.

With the aid of the CFD software 'Fluent' the simulation process is carried out. At this stage, there were many drawbacks due to lack of computational power and processing speed of the available computers. As a requirement, this could have been compensated by a workstation with greater processing capacity. This will be recommended as future simulation work.

In fluent the convergence need to be selected and proven correct. In order to give the output with the minimum error percentage the number of iterations need to be increased to a considerable value. Accordingly, to achieve this the number of iterations were increased up to 10,000.

In any designed aircraft, the conditions need to be calculated in both sea level and in a range of operating altitudes. With the time limitations and resource limitations the operation conditions of sea level and 39,000 ft. cruising altitude was selected as the primary scope.

Due to computational incompetency, the stability analysis will require further secondary steps towards the future simulations.

The analytical areas of AoA with Drag and Lift domain variation will be able to be delivered with each computation, provided with further resources.

V. CONCLUSION

A. Comparison with A320

With the theoretical calculations for the airbus A320,

C_L=2mg / ρV2S

m=50000 kg g=9.81 m/s^2

V=240 m/s S=122.6 m^2

ρ=1.225 kg/m^3

With the theoretical calculation the lift coefficient value calculated to be C_L = 0.1134 thus with the simulation data the designed aircraft brings out better lift coefficient.

According to the findings and data collected from simulations the flying wing design proven to be an effective in both sea level and high altitude conditions. A considerably higher C_L value was presented and the C_D value being relatively low builds up the argument of the aircraft model being compiled with a greater Lift to Drag ratio.

With the data collected the design is proven to be aerodynamically stable and in steady condition to be an optimal design of its kind.

The concept of flying wing is considered to be having a greater range when compared with other conventional concept aircrafts. With the combination of KF airfoils the complexity of the design has been improved and the lift to drag ratio is improved as well.

The original objectives of the research have been met up to an exceptional level. With further simulations, the aircraft can be optimized to turn into a better design.

These coefficients are calculated for the whole aircraft.

VI. FUTURE WORK

- Follow through the 'Openfoam' simulations as well to improve the effectiveness of calculated data.
- Carryout further simulations for changing of AOA, altitude, gravitational effects, etc.
- Workout a wind tunnel practical with a scaled down model to provide more accurate values of force coefficients.
- Improve the design to build up the blended effect.
- Provide more stability to improve the tail down manoeuvring and carryout stability analysis.
- Design changes and simulations with non-static component involvement.
- Modify the smoothness of the aircraft controlling.

REFERENCES

Abeygoonawardene JI, Bandara RMPS, Rangajeeva SLMD, et al, 2015. Airplane Performance Modelling Through CFD Results; Assessment of Complete 3-D Wing-Body Combination. International Journal for Advance Research in Engineering and Technology, 3(X), pp. 25-29.

Abeygoonewardene JI, Bandara RMPS, Assessment of Aerodynamic Behaviour of the NACA 64A212 airfoil on the context of Computational Fluid Dynamics. s.l., s.n.

Armstrong MJ, J. C. N. P. e. a., 2016. Comparison of Candidate Architectures for Future Distributed Propulsion Aircraft. IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, 26(6).

Brown GV, F. J. K. H., 2011. Turboelectric Distributed Propulsion in a Hybrid Wing Body Aircraft, Cleveland, Ohio: NASA Glenn Research Centre.

Choi, B., 2014. Propulsion Powertrain Simulator. IEEE Electrification Magazine, pp. 23-34.

Hauser J, J. A., 2002. Control of a thrust-vectored flying wing: a receding horizon-LPV approach. INTERNATIONAL JOURNAL OF ROBUST AND NONLINEAR CONTROL, Issue 12, pp. 869-896.

ACKNOWLEDGMENT

Throughout this research, I received enormous help without any hesitation from several parties without whom this research wouldn't have been completed in an exceptional manner.

This research was highly supported by the Department of Aeronautical Engineering, General Sir John Kotelawala Defence University. Firstly, I would like to give my utmost gratitude to Mr. SLMD Rangajeeva of Department of Aeronautical and Mr. RMPS Bandara of Department of Mechanical Engineering for their highly appreciative guidance and supervision throughout this research and for the helping hand lent in all the times in need with their expertise in guidance and also for lending the knowledge of Computational Fluid Dynamics which gave me the added advantage of successfully completing this research.

I offer my sincere gratitude to Wg. Cdr. CJ Hettiarachchi of department of Aeronautical Engineering for directing me in every possible way to make this research a success and for his advice and assistance in reaching my final outcome.

Also, my greatly appreciated support of Ms. L. Willarachchi of Language department of General Sir John Kotelawala Defence University for her help in finalizing the paper.

Finally, this research became a success with the aid of encouragement given by parents in both financial and moral support for this study.