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Design and Computational Fluid Dynamic Analysis of a Medium Haul Commercial Aircraft Wing and Fuselage

Pratulya Rajan S.M., Vinusha D.G., Pushkala Gopikrishnan, Jensin Joshua

Abstract - Medium haul commercial aircrafts are used by airliners for medium range flights which includes domestic and international routes, below 4000 km but not less than 1500 km. These are widely used type of aircrafts for airliners. It is a very challenging process to design such an aircraft and there are a lot of processes and parameters which need to be assessed before finalizing a design. The aircraft is designed to seat a hundred passengers and one of the main requirements of such medium haul aircrafts is that they are designed to carry the heavy loads for longer durations and yet provide a smooth flying experience. The design aspects include the selection of airfoil and engines. The airfoil selected has high lift capabilities and has a gentle stall quality providing for a perfect fit for this category of aircraft and the fuselage has been analysed in order to withstand the various aerodynamic forces that the aircraft might endure during flight. The design of the Wing was performed on CATIA V5,the design of the fuselage was performed on SOLIDWORKS Inc. and the analysis of the wing and fuselage were performed on ANSYS R19.2(Student Version).The design is said to provide better lift capabilities with the help of the airfoil chosen which could provide for a better performance on modern day aircrafts.

Keywords: Medium haul, airfoil, airliners, analysis, aircrafts

I. INTRODUCTION

Modern aircraft are a complex combination of aerodynamic performance, lightweight durable structures and advanced systems engineering. Air passengers demand more comfort and more environmentally friendly aircraft. Hence many technical challenges need to be balanced for an aircraft to economically achieve its design specification. Aircraft design is a complex and laborious undertaking with a number of factors and details that are required to be checked to obtain optimum the final envisioned product. The design process begins from scratch and involves a number of calculations, logistic planning, design and real-world considerations, and a level head to meet any hurdle head on. Every airplane goes through many changes in design ink about four main areas of aeronautics: *Aerodynamics*, *Propulsion*, *Structures and Materials*, and *Stability and Control*.

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I. DESIGN PARAMETERS

The weight estimation depends upon the mission profile of the aircraft.

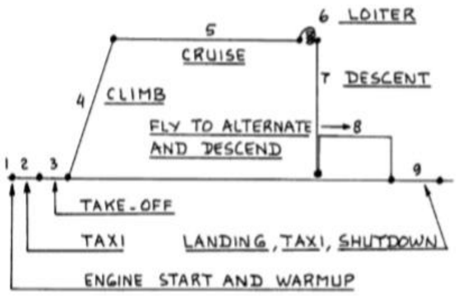

Fig. 1 Mission Profile for the aircraft

The mission profile depicts the different stages the aircraft will be flying in from the time the engine starts to the time the engine is shutdown in one cycle

Table 1. Mean Design Parameters for aircraft

PARAMETERS	VALUES
Aircraft Speed(Kmph)	871
Wing Loading(Kg/m^2)	542
Empty Weight(Kg)	17270
Thrust(KN)	93.61
Maximum Altitude(m)	11230
Thrust/Weight Ratio	0.35
Take Off Weight(Kg)	40000
Aspect Ratio	9.7
Wingspan(m)	31.37
Length(m)	34
Height(m)	11
Range(Km)	4800
Loaded Weight(Kg)	22370
Rate of Climb(feet/min)	2800
Wing Area(m^2)	101.5

A 3-view diagram of the aircraft was modelled using the BLENDER 2017 3D open creation software typically to showcase the design of the aircraft and specify it's dimensions pictorially. The front view, side view and top view all are in display respectively.

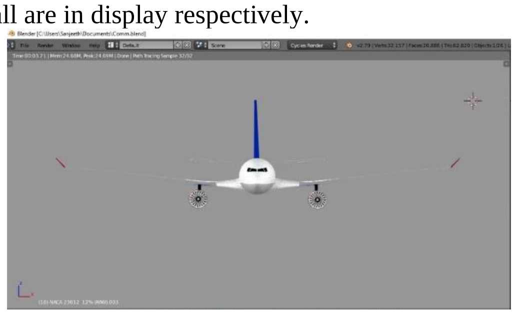

Fig.2 Front View of the Passenger Aircraft

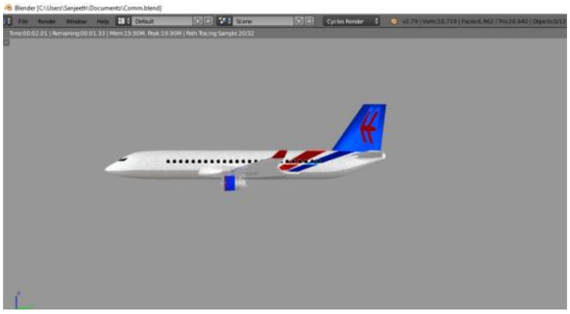

Fig. 3 Side View of the Passenger Aircraft

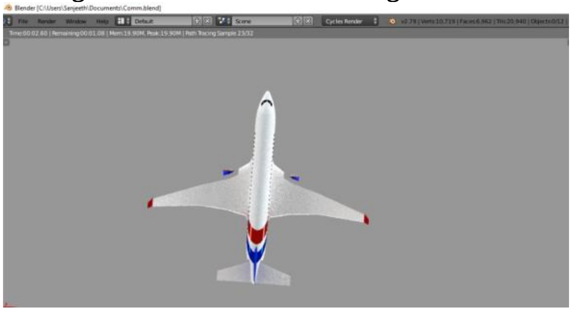

Fig. 4 Top View of the Passenger Aircraft

1) Weight :

The weight of the following parameters of an aircraft must be found:

- Take-off weight (WTO)
- Fuel Weight (Wf)
- Empty weight (WE)

The following are the data which are obtained from the case studies to proceed for the weight estimation.

- Cruise speed = 241.9m/s
- Gross weight = 88200 lbs
- Maximum altitude = 11230 m
- Range = 4800 km
- Payload = 21500 lbs

Phases involved in the Weight estimation will assist in the calculation of the final parameters that are required.

1 = Engine startup
2 = Taxing
3 = climb
4 = Cruise
5 = loiter
TO = Take-off
6 = Descent
7 = Taxing
8 = Landing and shutdown

- Take-off weight WTO = 40000 kg
- Fuel weight WF = 6069.71 kg
- Actual weight WE = 23431.45 kg

2) Wing type :

Tapered wing with monoplane configuration mounted as a low-wing.

3) Aero foil chosen :

The chosen aero foil is NACA 23012.

4) Fuselage type:

A semi-monocoque fuselage has been constructed.

5) Empennage type :

Conventional- tail configuration is mounted.

6) Engine type :

Wing mounted twin engine placed below the wing region.

7) Landing Gear :

Retractable Tri-Cycle landing gear is constructed.

8) Lift calculation:

Lift during takeoff: L_{TO} = 276934.99 N
Lift during cruise L_C = 392165.34 N
Lift during landing L_L = 1328.48 N

9) Drag calculation:

Drag during takeoff D_{TO} = 10742.08 N
Drag during cruise D_C = 18366.30 N
Drag during landing D_L = 632.81 N

II. DESIGN & ANALYSIS OF WING

Table 2. Wing Design Data

Wing Area	101.5 m^2
No. Of Wings	1 pair of wings
Position of	Wing Low wing
Aerofoil	NACA 23012
Aspect Ratio	9.7
Taper Ratio	0.319
Tip Chord	1.56m
Root Chord	4.9m
Span	31.37m

DESIGN:

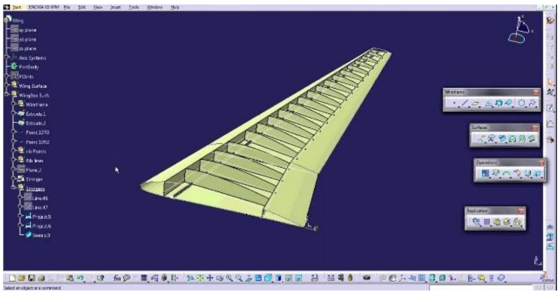

Fig. 5 Wing Design Internal Structure

The design of a tapered swept back wing of the aircraft is in focus. The design of the wing was carried on the Catia V5 designing software licensed by Dassault Systems Ltd as shown in Fig. 5

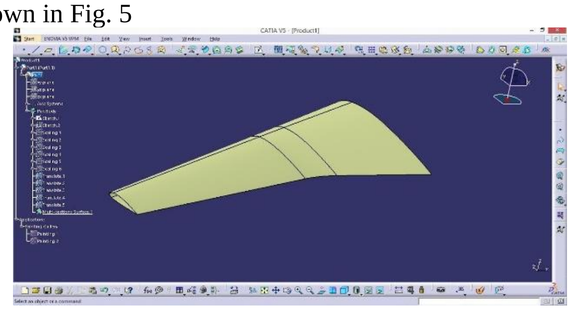

Fig. 6 **Wing Design Exterior**

The airfoil NACA23012 was chosen and imported into the software which formed the base of the design. 20 Airfoils were then placed along the axis with decreasing chord lengths to help make the tapered wing.

The Airfoils were each given a thickness of 10mm and supporting ribs were designed to move across the length of the wing.

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The wingspan in total is 320mm therefore one section of the wing across which the rib is placed is approximately 160mm. Champhering the edges and extruding the airfoil's gives the complete structure of the wing. The wireframe is made in 3D with the extra flap extensions starting at 100mm near the fuselage and reducing across it's length until its tip as shown in fig. 6.

ANALYSIS:

Analyzing the performance of a wing using a 2D mesh in the ANSYS Inc. fluid analysis software for students. The analysis has been carried out with the specifications of the aircraft which is focus and the results will be crucial in determining it's airworthiness.

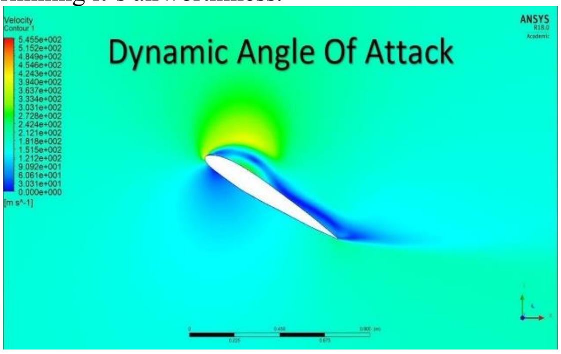

Fig.7 Dynamic Angle of attack

- The analysis of this wing is done by using a 2D model of the airfoil used .The analysis has been done on ANSYS Inc. Student Version R18.0 which limits the number of cells for a 3D analysis thereby restricting students to perform the analysis in 2D.
- The dynamic angle of attack is the angle of attack just before which stalling can occur. Therefore the lift generated over the airfoil will be minimum in this case which is depicted by the bluish stream of air as shown in fig. 7.

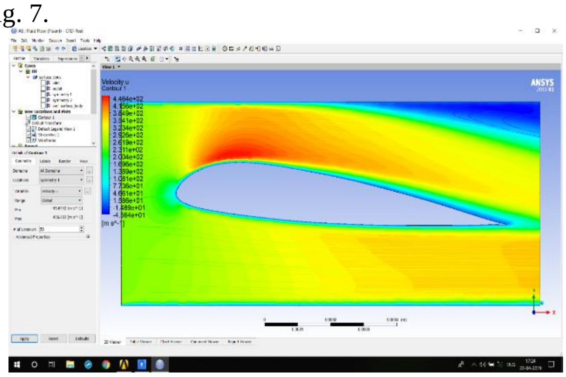

Fig. 8 Analysis at 5˚ Angle of Attack

- The analysis of this wing is done by using a 2D model of the airfoil used .The analysis has been done on ANSYS Inc. Student Version 2019R1 which limits the number of cells for a 3D analysis thereby restricting students to perform the analysis in 2D.
- At 5° angle of attack it can be observed that at the leading edge of the airfoil the velocity is low but as we move across the upper surface we can see that the maximum velocity is produced which is depicted by the red and yellow regions as shown in fig. 8.

III. DESIGN AND ANALYSIS OF FUSELAGE

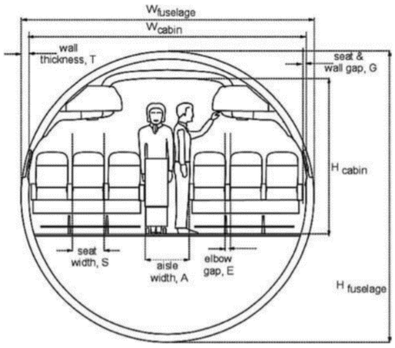

Fig. 9 Fuselage design Cross Section

[Courtesy: Book- Airplane Design by Jan Roskam]

The fuselage is desired to follow an airfoil shape to reduce drag. Which implies that the rear fuselage should be tapered to a zero diameter. Since the engine is not intended to be accommodated by the rear fuselage, the diameter of the fuselage must be reduced from the cabin diameter to almost zero.

DESIGN:

In conventional aircraft the fuselage serves to accommodate the payload. The wings are used to store fuel and are therefore not available to accommodate the payload. The payload of civil aircraft can consist of passengers, baggage and cargo. The cockpit and key aircraft systems are also located in the fuselage.

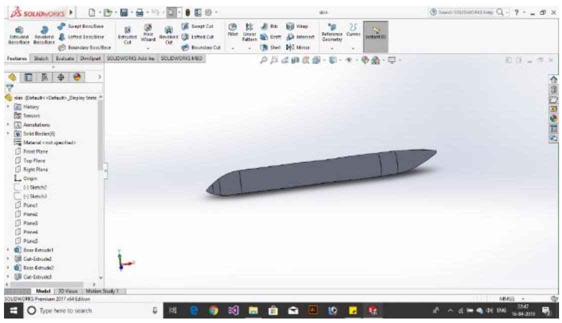

Fig. 10 Solid Fuselage Body

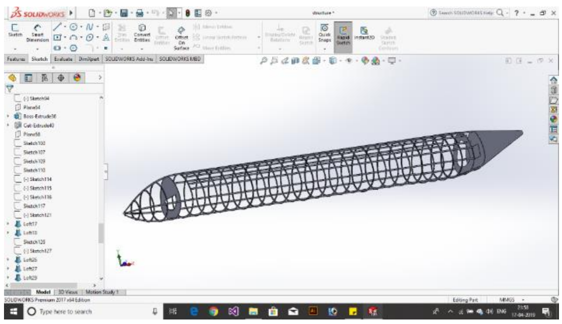

Fig. 11 Skeleton Fuselage Body

We concur that the design of a Semi-Monocoque fuselage is constructed primarily of Aluminium Alloy. The primary loads are taken by the Longerons, which usually extend across several points of support, holding the bulkheads, frames and formers.

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These are supplemented by Stringers. Stringers are more numerous and lighter in weight than Longerons. Stringers have some rigidity, but are chiefly used for giving shape and allow attachment of the skin. Stringers and Longerons prevent tension and compression stresses from bending the fuselage.

- Leaves a large proportion of the inside free to accommodate crew, passengers and cargo.
- Bulkhead, Frames, Stringers and Longerons aid in producing a streamlined fuselage and add to the strength and rigidity of the structure.

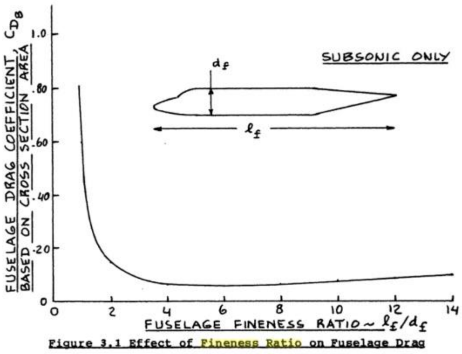

Fig. 12 Fuselage Finesse Ratio

[Courtesy: Airplane Design by Jan Roskam]

Two of the main fuselage design parameters are the fuselage length (Lf) and the maximum diameter (Df). The fuselage optimum length-to-diameter ratio (or slenderness ratio) may be determined based on a number of design requirements.

The design objectives may be to determine the fuselage length-to-diameter ratio such that it:

- Results in the lowest zero-lift drag;
- Creates the lowest wetted area;
- Delivers the lightest fuselage;
- Provides the maximum internal volume;
- Generates the lowest mass moment of inertia;
- Contributes the most to aircraft stability;
- Requires the lowest cost to fabricate.

ANALYSIS:

The analysis of the aircraft fuselage is done on a 2D mesh in the ANSYS Inc Student version software. The design was imported from SOLIDWORKS as an .iges file and the parameters were set across the reference frame. Around 500 iterations were carried out to achieve the calculated result from the software.

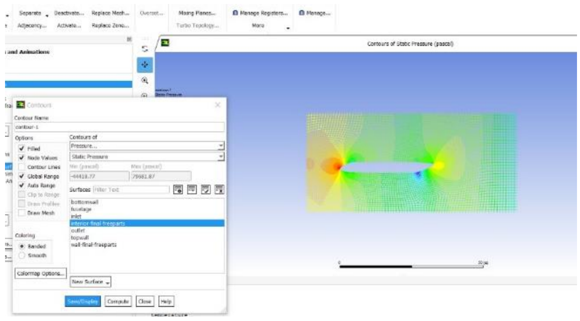

Fig. 13 Pressure Distribution Analysis

Pressure distribution analysis has been carried out on ANSYS Inc. 2019 R1 fluid simulation software.

- The region shaded in red denotes points of maximum pressure which is at the nose portion of the fuselage. Along the length of the fuselage the pressure is relieved and reduces drastically.
- The yellow region at the tip signifies the air that leaves from the tail of the aircraft fuselage where moderate pressure is acting
- The blue and green regions indicate points of minimum pressure which is basically along the top and bottom surfaces of the fuselage where the air flow is smooth and attached.

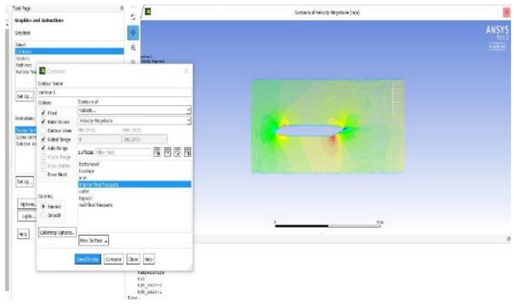

Fig. 14 Velocity Flow Analysis

- Velocity flow analysis has been carried out on ANSYS Inc. R19.2 fluid simulation software.
- The region in green represents the minimum velocity across the fuselage section which is at the front end where the flow is dispersed via the nose.
- Over the top and bottom surfaces of the fuselage we can see the yellow regions i.e., the regions of moderate to maximum velocity and the flow is attached and somewhat streamlined.
- The red region just below the fuselage is the point of maximum velocity where the fuselage section begins to curve. The Blue region at the end is the point of lowest velocity as there is no airflow at the tail region of the fuselage.

IV.CONCLUSION

The structural analysis and design of a medium haul commercial aircraft is done and the various design considerations and performance parameters required are calculated and found out. The obtained design values are not necessarily a define reflection of the airplane's true and conceptualized design, but the basic outlay development has been obtained.

The final design stays true to the desired considerations of the medium haul aircraft that can provide high performance and carry heavy payload. Also, it has a considerable value of TSFC as well. This is no ideal design and is highly subjected to improvisations and innovations to make the design as ideal as possible. During the onset of our work we faced various phases of the project that made us understand how challenging the process of designing is so as to make a perfect design. A lot of efforts have been put into this project and as much as we have learnt at the same time.

It can be safely said that a sincere effort in this subject is more than sufficient to understand the procedure involved in the actual design of an aircraft .

The challenges we faced at various phases of the of project made clear the fact that experience plays a vital role in successful design of any aircraft or aircraft component . With the design project as a base , our understanding of various concepts in the field of aerospace design has been fortified . We would like to express our heartfelt gratitude to all those who have been instrumental in the successful completion of our aircraft design project.

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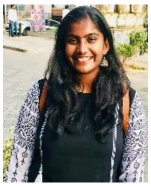
AUTHOR’S PROFILE

Pratulya Rajan. , currently pursuing my B.Tech in Aerospace Engineering at Hindustan Institute of Technology and Science in Chennai. I have had a vivid interest in space flight dynamics, orbital mechanics and Spacecraft Propulsion systems which is what led me to choose this course. My interest in Computational Fluid Dynamics helped me with this Journal paper and I hope that it reads out well to the scientific community. This is my first publication in college and I also have a patent that has been recognized. I further plan to complete my higher studies in the field of Astronautics or Astrodynamics in the US and hope to someday work fulltime in this particular field.



Vinusha D.G. , I am in my final year of college. I am currently studying Bachelors of Technology in Aerospace Engineering at Hindustan Institute of Technology and Science located in Chennai. I am interested in the field of Aerodynamics and Propulsion . My other interests include learning and working in design and analysis software . Learning computational analysis methods has helped me to understand , predict and simulate the behaviour of various objects in fluid flow . I would like to further continue my studies by specializing in hypersonic aerodynamics and computational fluid dynamics. I am hoping to establish a career in the aerospace industry.

Pushkala Gopikrishnan. , I am a student at Hindustan Institute of Technology and Science, Chennai studying B.Tech Aerospace Engineering and am currently in my final year. I am interested in the field of designing and aerodynamics. Other than practical research I am more into mathematics, derivations and theorizing the quantities. I look forward to research in the field of aerodynamics and want to pursue my higher studies in the field of Aerospace specializing in aerodynamics.

John J. Joshua. , I am a teaching professional currently at Hindustan Institute of Technology and Science located in Chennai and have an experience of four years in the teaching field. It is my pleasure to guide the students in their research work and allow them to express their interests in various fields. I have gained knowledge in the field of Fluid Mechanics and Aerodynamics and specialize in the study of Unmanned Aerial Vehicles. These interests are what interested me to take up the aircraft design project. I continue to help my students and publish more papers in this field of study.