Design and Optimization of a Transonic Truss Braced Winged Aircraft

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Abstract
This paper confers the conceptual design, performance analysis and configurational optimization of a transonic airliner structured with Truss Braced Wings in a bid to achieve sustainable aviation globally. The burning of fossil fuels has always been among the primary source for the carbon emissions and one of its chief origins being Transportation other than industry power production. It is known that Aviation caps the second highest carbon emissions (approx. 15-20%) among the modes of transportation. In the view to these growing concerns, several steps are being implemented to attain environmental sustainability to aviation such development of Sustainable Aviation Fuels (SAF), Hybrid Electric Aircraft (HEV) and various initiatives by engine manufacturers to produce much more fuel efficient and less carbon emitting engines such as the General Electric GE9X deployed on Boeing 787 and Rolls Royce Trent XWB deployed on Airbus A350. Parallel to these methods several companies such as Boeing, Airbus and other leading aerospace companies have suggested various conceptual designs aiming towards achieving sustainable aircraft design. In a similar fashion this paper proposes an aircraft design and computational performance analysis that can assist in achieving sustainable aviation. The aircraft is primarily designed to be a long-range airliner capable of commuting in transonic flight and seat up to 150 passengers (approx.), it has a Truss Braced Wing (TBW) structure to enhance the aircraft range as it enables to employ a wing structure with exceptionally high aspect ratio. The analysis performed includes the aerodynamic characteristics of the aircraft and technical specifications of it along with the performance characteristics.
Keywords
Aircraft Design, Sustainable Aviation, Transonic Truss Braced Wing (TTBW), Long Range Transport

I. INTRODUCTION

Innovation has long served as a compass directing advancements in the everchanging aviation industry. The need for innovative aircraft design is greater than ever now, given the competing demands of technical progress and environmental stewardship. The arrival of a Truss Braced Winged Aircraft design, which has the potential to completely reshape the definition of air travel, is signalled by this introduction. An aircraft wing's performance and efficiency can be improved by using a structural member known as a truss-braced wing. To provide the wing more support, this creative design integrates a truss structure, which is made up of several connected bars or struts. Usually, the truss bracing is placed diagonally between the leading or trailing edge and the primary spar of the wing.

This project aims to overcome the constraints of traditional aircraft and tackle the most pressing problems of our day by combining innovative engineering with sustainable principles. Driven by an insatiable need for novelty and an unwavering commitment to the environment, our group has set out to imagine, create, and design an aircraft that not only soars high in the skies but also sets a new standard for the aviation industry. Fundamentally, this aircraft design is a combination of innovative technologies, audacious aerodynamic theories, and sustainable propulsion mechanisms. Our goal is to reign in a new era of efficiency and environmental responsibility for aviation. Our goal is to develop a harmonic balance between performance, safety, and sustainability through demanding engineering and comprehensive analysis.

II. LITERATURE STUDY

Ohad Gur et.al, outlined the advantages of a truss-braced-wing design for transonic transport aircraft when compared to designs with cantilever wings and strut-braced wings. It employs multidisciplinary design optimization techniques to create aircraft with three wing designs, each increasing in complexity: cantilever, one-member truss (strut), and three-member truss. Through multidisciplinary design optimization, the study explores various combinations of cases, including: 1) three wing designs: cantilever, single-member strut (SBW), and jury truss (TBW); 2) three design objectives: minimum take-off gross weight, minimum fuel consumption and emissions, and maximum lift-to-drag ratio; and 3) two drag scenarios: advanced technology (TF 1, Korn factor of 0.95, and fairing factor of 0.02) and current technology (TF 0, Korn factor of 0.91, and fairing factor of 0.1). This results in a total of 18 design scenarios. The study includes visualizations of nine of these designs. The three design objectives of interest are: minimum take-off gross weight, minimum fuel consumption and emissions, and maximum lift-to-drag ratio. A mission with a range of 7730 miles at a cruise speed of 0.85 Mach is considered.

Manav Bhatia et. al. explored the structural elements involved in refining the design of a Truss Braced Wing (TBW) structure. The TBW structure's wings have the potential to greatly enhance performance in fuel economy, yet they present difficulties for those tasked with designing the structure. The specifics of the structural analysis and design process are outlined in this document. It covers two distinct design strategies: designing based on simplified beam models and a more complex approach that accounts for aeroelastic effects using finite element analysis. The document covers every detail of these two strategies, including how design parameters are set, the geometry of the model, and the generation of the mesh for analysis and optimization.

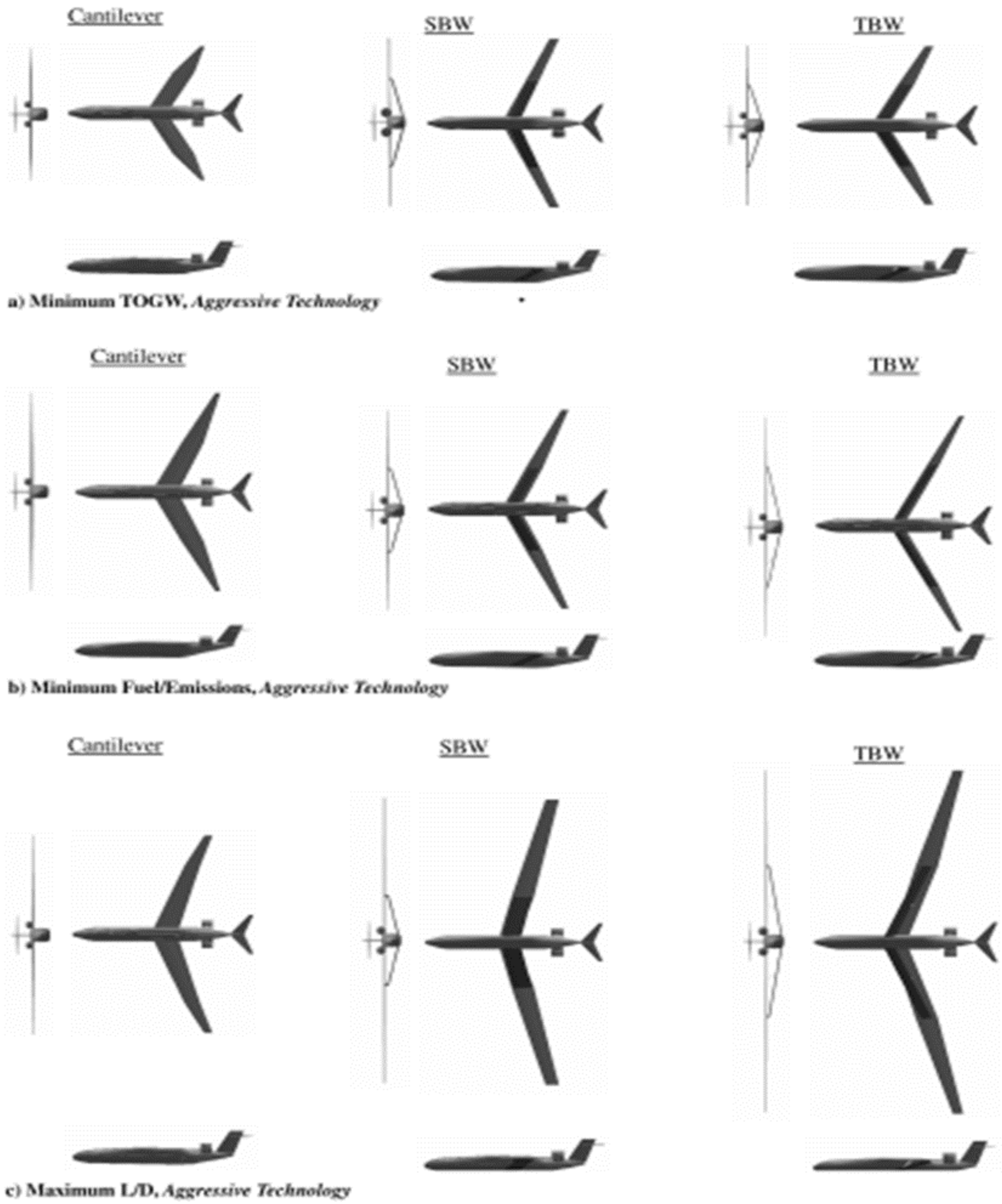
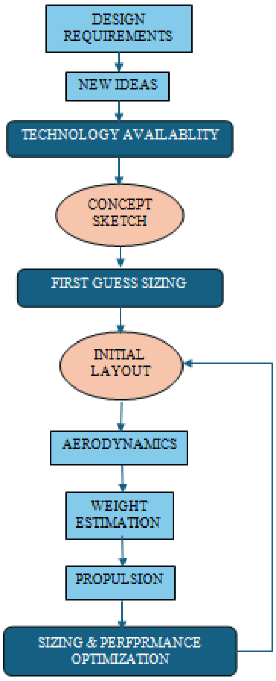


Figure Design study

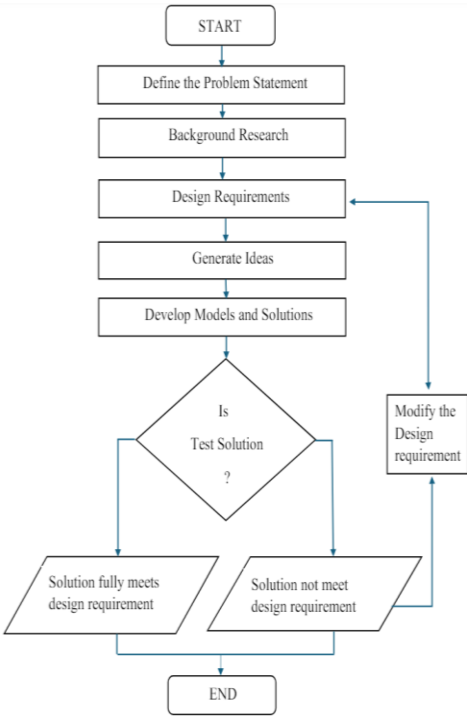
III. METHODOLOGY

The following methodologies were developed and followed during the research process. During the entire aircraft designing process, the following methodology was used and software such as CATIA V5, Solid Works, Open VSP, XFLR5 and Ansys were extensively used for CAD modelling and aerodynamic analysis, whereas some theoretical calculations were done to determine the performance characteristics.

E-ISSN: 2584-0657



Aircraft Design Methodology



Research Methodology

IV. EXPERIMENTAL DETAILS

The experimentation begins with the detailing of the conceptual aircraft design and ends with the conceptual analysis for the same. The designing includes the selection of the suitable airfoil for the aircraft and then proceeds with the dimensional sizing, mesh generation and weight estimation of the aircraft along with the determination of the fuel fraction and the power plant selection. Below given are the images that were detailed during the experimental process.

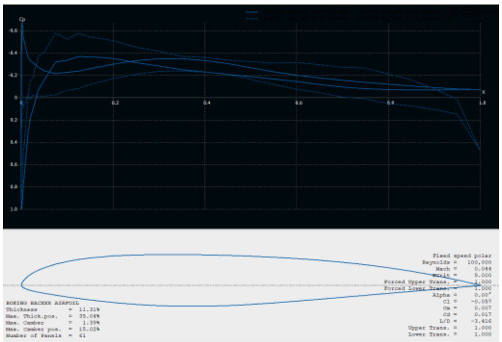


Figure 1: Airfoil Selected: BACXXX

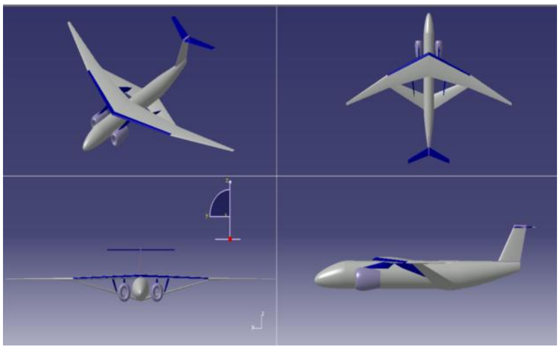


Figure 2: Aircraft Conceptual Design

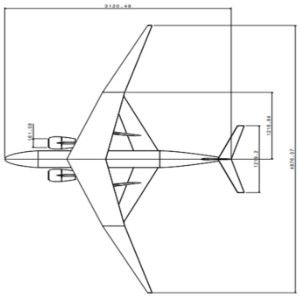


Figure 3: Aircraft Preliminary Design

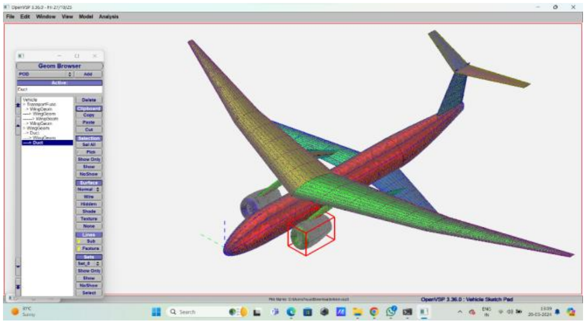


Figure 4: Mesh Generation

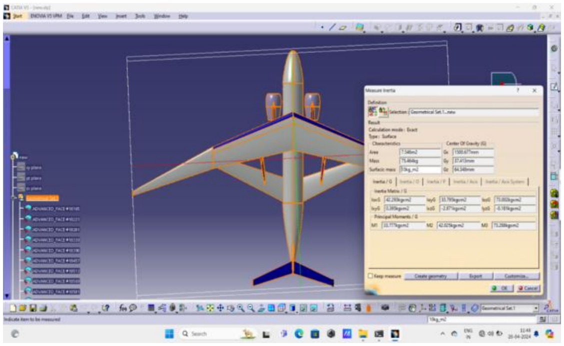


Figure 5: Sizing and Weight Calculation

V. RESULT ANALYSIS AND DISCUSSIONS

Advanced Aerodynamic analysis for pressure, wake, wakes to infinity, dynamic pressure under transonic effect, are simulated using OpenVSP software.

Pressure Analysis at Mach 0.9

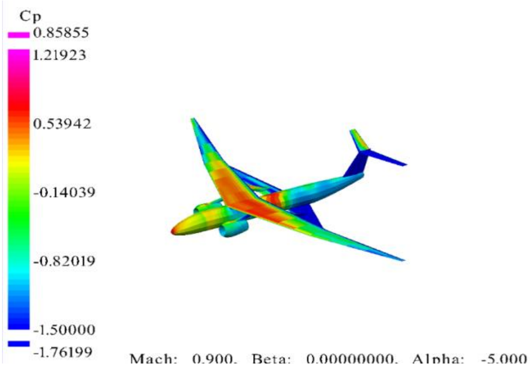


Figure 6: AOA -5 DEGREE

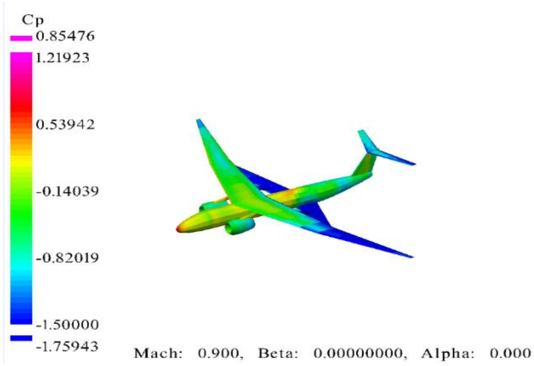


Figure 7: AOA 0 DEGREE

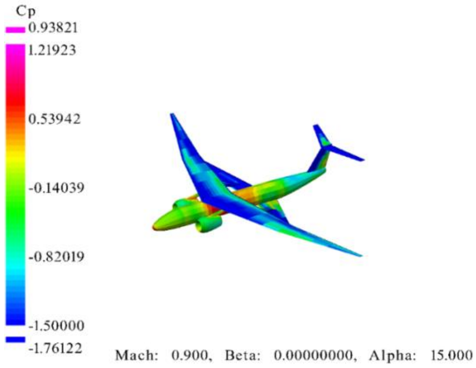


Figure 8: AOA 15 DEGREES

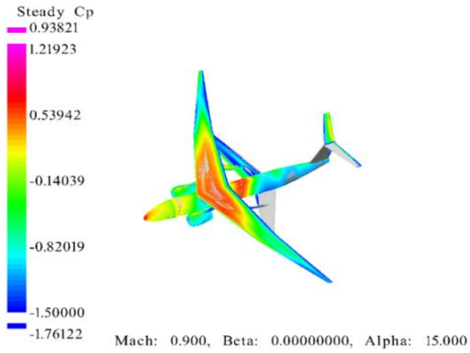


Figure 9: Viscous effect under transonic MACH number

Wake Analysis

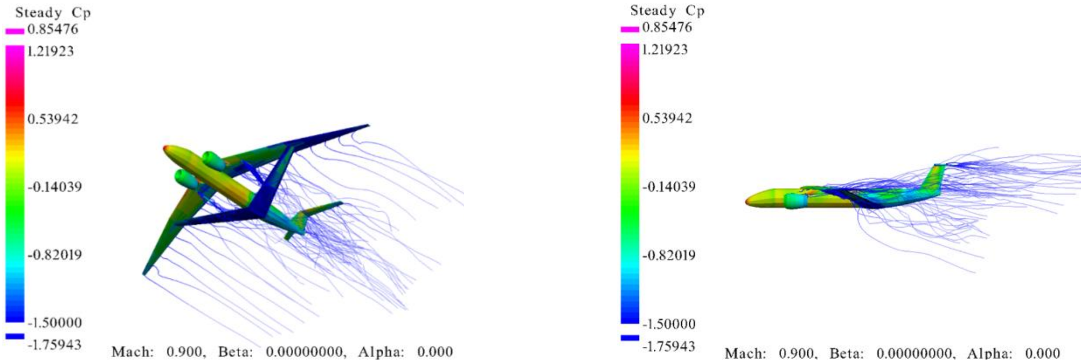


Figure 10: AOA 5 Degrees

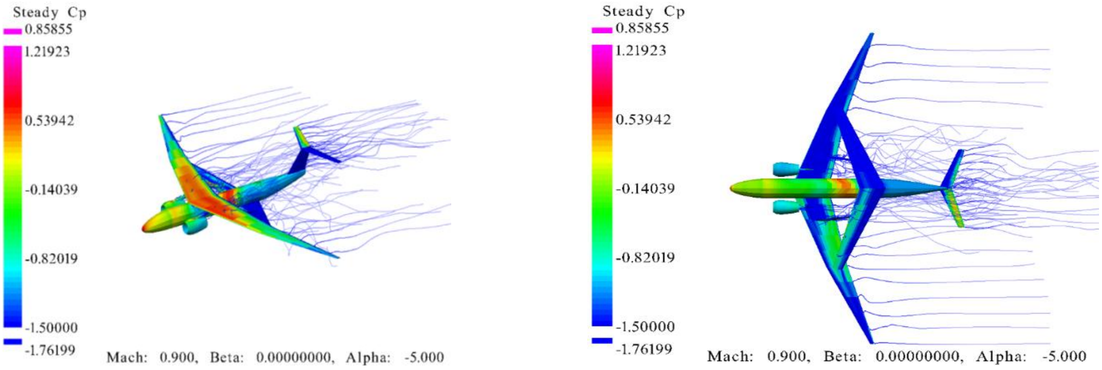


Figure 11: AOA -5 DEGREES

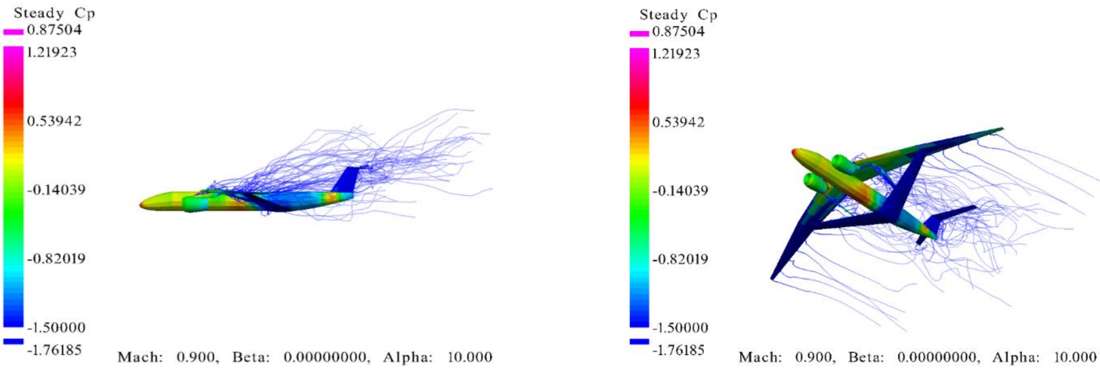


Figure 12: A0A 10 DEGREES

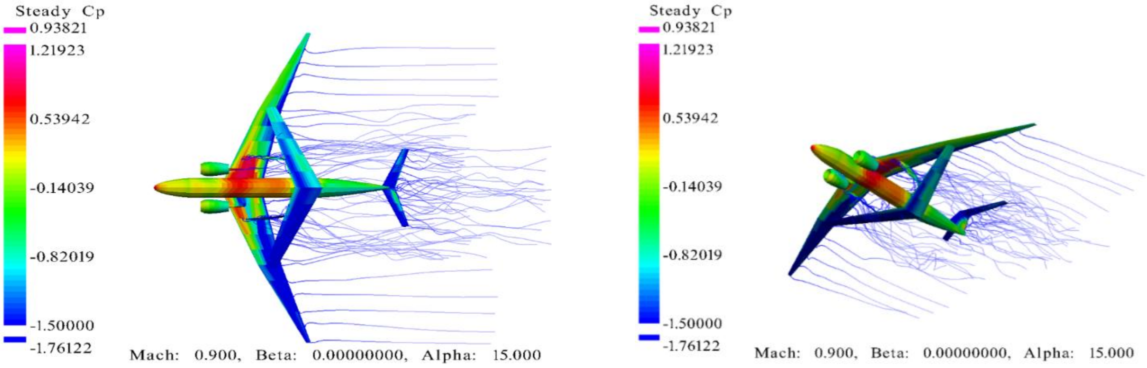


Figure 13: A0A 15 DEGREES

Wakes upto Infinity

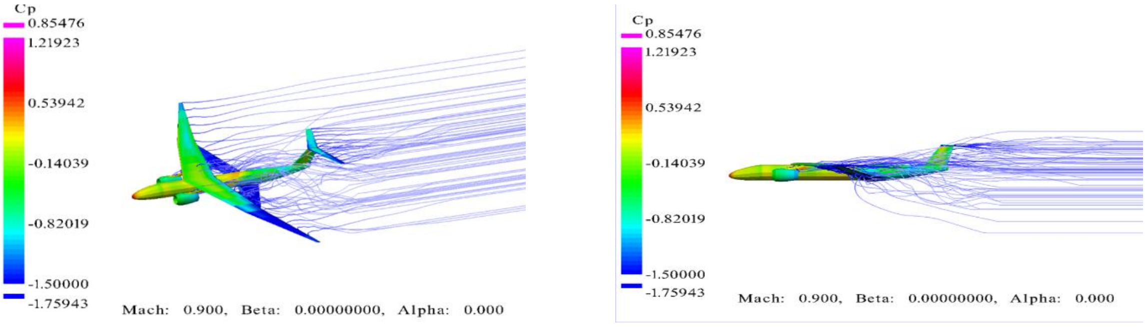


Figure 14: A0A 0 DEGREES

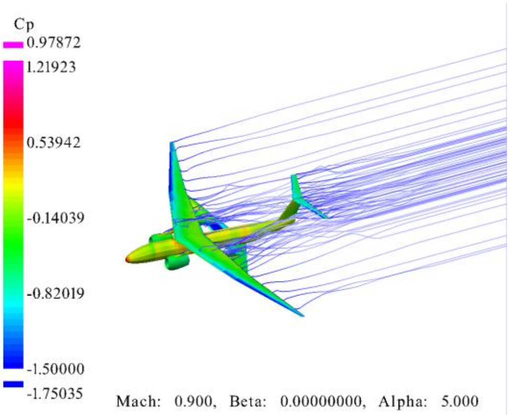


Figure 15: AOA 5 DEGREES

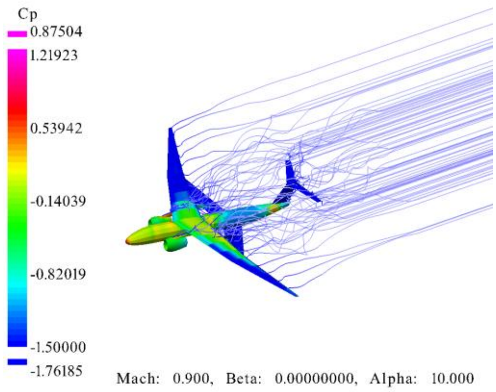


Figure 16: AOA 10 DEGREES

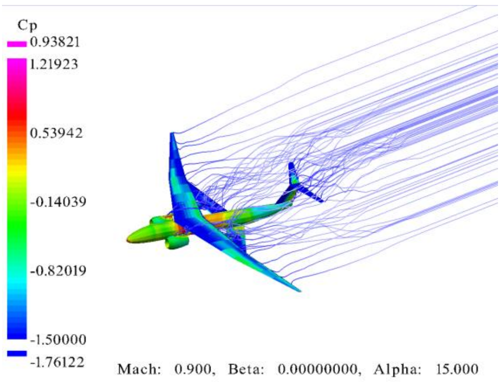


Figure 17: AOA 15 DEGREES

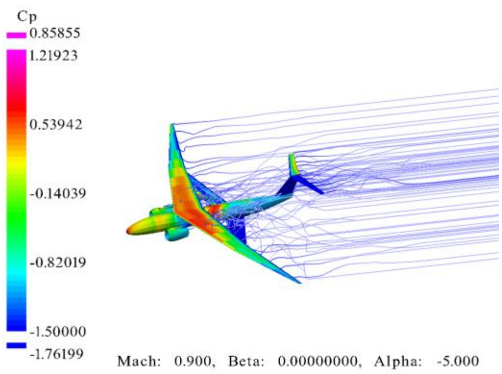


Figure 18: AOA - 5 DEGREES

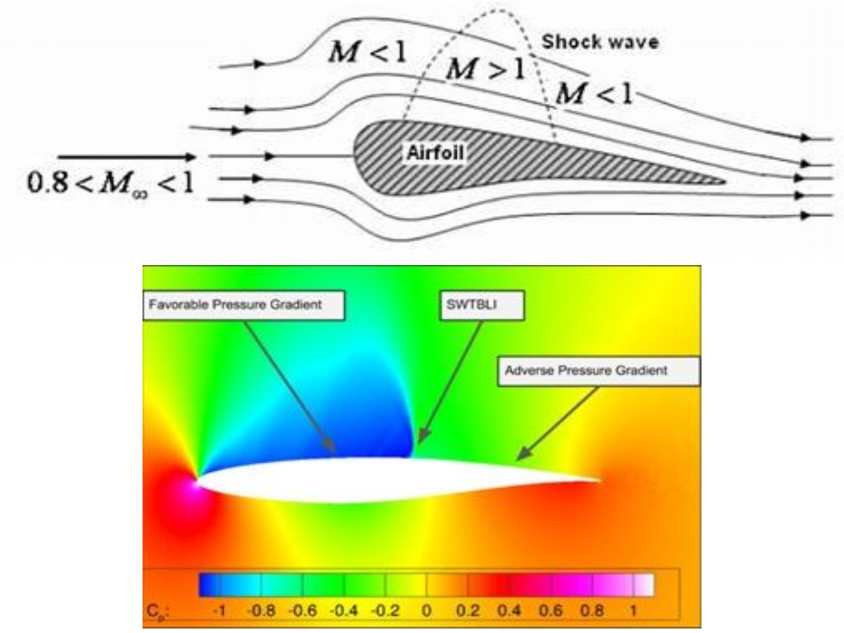


Figure 19: Transonic Flow

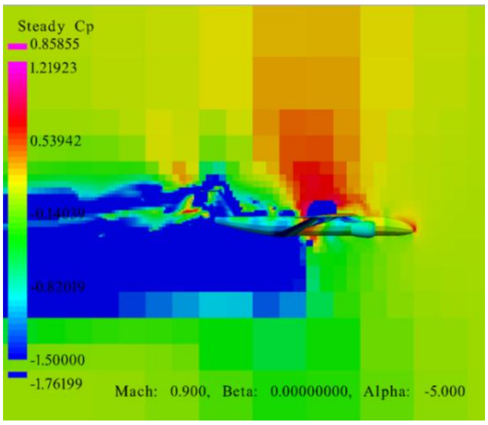


Figure 20: AOA -5 DEGREES

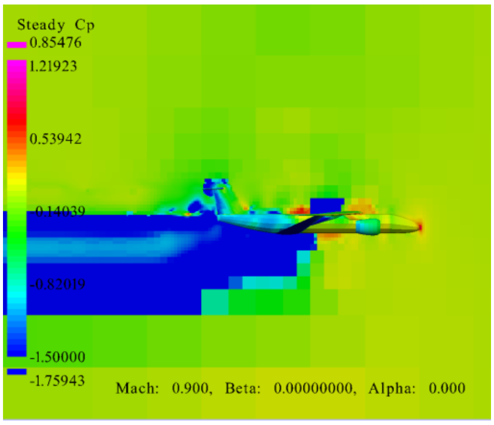


Figure 21: AOA 0 DEGREE

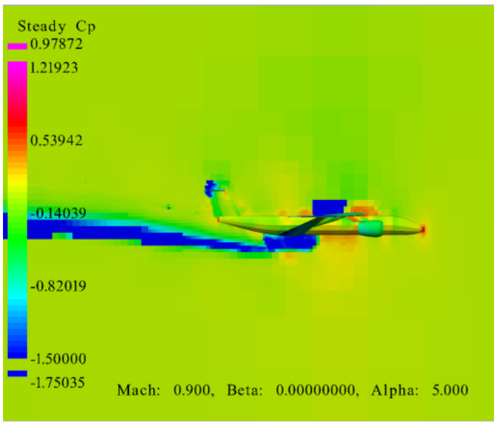


Figure 22: AOA 5 DEGREES

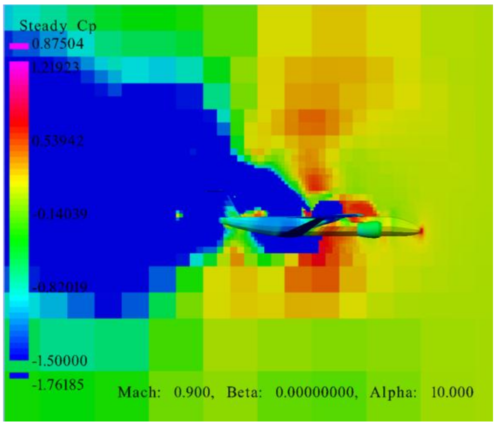


Figure 23: AOA 10 DEGREES

Throughout the detailed analysis, under transonic flight condition. The mathematical model is being tested under different angle of attack, Aerodynamic parameters such as boundary layer separation, wake analysis over the trailing edge of the surface and flow transition from laminar to turbulent has been studied.

Also, the effect of fluid dynamic pressure over the model has been considered and structural behaviour of each component has been noted and later critical components have been optimized for reasonable structural compensation and for better strength to weight ratio.

Since from the detailed analysis report with the knowledge of incorporation of truss under the wing, by adopting the supercritical aerofoil has resulted capable to sustain under transonic flight condition while maintaining passenger comfort this can lead significant potential to unlock the future trend technology.

Aircraft Weight Estimation

The designed aircraft belongs to the Narrow Body Medium Range Airliner category with a seating capacity of 150-200 Passengers approximately. Therefore, from the historical trends and current standards the aircraft weight was determined as followed,

W_{Empty}= 44,450 Kg / 97,995 lb, W_{Crew}= 600 Kg / 1,322 lb,

$W_{Payload}$=20,550 Kg / 45,304 lb, W_{Fuel}=21,050 Kg / 46,407 lb.

$W_O = W_{Crew} + W_{Payload} + W_{Empty} + W_{Fuel}$

W_O=86,650 Kg / 191,030 lb.

Table 1: Comparison of Narrow Body Aircraft

Aircraft Type	Dimensions		Pax (Approx.)	Fuel Weight (Kg)	Empty Weight (Kg)	Max Tow (Kg)
	L (m)	S (m)				
B 737-800	39.47.	34.32	189	18,000	41,150	79,015
B 737 MAX 8	39.52	35.56	189	20,720	65,770	82,191
B 737 MAX 10 (Under Development)	43.8	35.56	230	(Not Disclosed)	(Not Disclosed)	92,079
B TTBW (Conceptual)	31.20	48.76	150	21,050	44,450	86,650

Powerplant

For the given aircraft specifications, the compatible engines were researched, and the most suitable engine was selected. Engine Selected: CFM LEAP-1B. SFC: 0.520 lb/lbf/h.

Aircraft Range and Endurance Estimation

Using the above data and at the standard cruise conditions for a suitable powerplant compatible with the current aircraft specifications the range can be calculated as followed,

The Breguet range equation for jet aircraft is given by,

$$R = \frac{V}{C} \cdot (0.866)\frac{L}{D} \cdot \ln\left(\frac{W_i}{W_f}\right)$$

we have, C=0.52 lb/lbf/h, V=0.85 M ≈ 291.55 m/s, W_i=86,650 kg, W_f= 65,600 kg.

Converting the known values to SI units we found the range to be,

$$R = \frac{291.55}{6.406\times10^{-5}} \times 0.866 \times 15 \times 0.276$$

$R \approx 16{,}435$ km.

Therefore, the range of the aircraft is approximately 16,435 kilometres.

For the same data we use Breguet Endurance equation for jet aircraft is given by,

$$E = \frac{1}{C} \cdot \frac{L}{D} \ln\left(\frac{w_i}{w_f}\right)$$

$E = \frac{1}{6.406 \times 10^{-5}} \times 15 \times 0.276$ [(L/D) is assumed to be 15 typically for a modern Jetliner]

$E \approx 64450.51 \text{sec} \approx 17.9$ hours

Therefore, the endurance of the aircraft is approximately 17.9 hours.

It is to be noted that the Range and Endurance are determined totally based on assumed values.

VI. Conclusion

The proposed approach centers on the idea of a transonic truss braced wing, which offers improved aerodynamic performance and enhanced maneuverability in transonic flight conditions. Following the completion of the Nth design cycle, we refined the commercial aircraft design with the goal of maintaining transonic flight characteristics, resulting in a significant progression from the initial conceptual to the preliminary design phase. During the project, we meticulously analyzed the dynamic pressure forces acting on the wing in transonic conditions. The results validate the model's ability to maintain flight in the transonic zone.

VII. References

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