

DESIGN AND OPTIMISATION OF WING USING SMART MATERIAL

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in

Aeronautical Engineering

By

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DEPARTMENT OF AERONAUTICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC

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DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **ANGADALA GANESH** (Reg. No. 38260002) and **RUPESH VILLAS NAVLE** (Reg. No. 38260026) who carried out the project entitled **DESIGN AND OPTIMISATION OF WING USING SMART MATERIAL** under our supervision from September 2018 to April 2022.

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DECLARATION

We **ANGADALA GANESH** (Reg. No. 38260002) and **RUPESH VILLAS NAVLE** (Reg. No. 38260026) hereby declare that the Project Report entitled **DESIGN AND OPTIMISATION OF WING USING SMART MATERIAL** done by us under the guidance of **Dr.GOKULNATH, M.E., Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE: 04 .03.2022

SIGNATURE OF THE CANDIDATE

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ABSTRACT

Aerodynamics and aerospace applications require strong control surfaces to control the movement of aircraft. In these fields, control surfaces play a crucial role in controlling aircraft motion. Control surfaces are used to control the airplane's direction by creating moments around an appropriate axis. They can be broadly divided into two categories.:

1) There are two types of flight control surfaces on a fixed-wing aircraft: primary or main control surfaces, and secondary or auxiliary control surfaces. The primary flight control surfaces on a fixed-wing aircraft are: ailerons, elevators, and rudders. The ailerons are hinged at either side of the wing. Aircraft are prone to roll and pitch about longitudinal axis during automatic movements. Elevator and rudder are prone to yaw and pitch about lateral axes during manual movements. These could be controlled by hydraulic or electric systems using mechanical linkage. Smart materials have a unique nature which can easily be controlled externally using electric, actuators, sensors, and so forth. The primary objective of this research is to create a motion control mechanism that operates without the use of mechanical links. Starting from the existing design of conventional sub-sonic aircraft wing using aileron is do Smart materials have a unique nature which can easily be controlled externally using electric, actuators, sensors, and so forth. The primary objective of this research is to create a motion control mechanism that operates without the use of mechanical links. cumented in literature, the corresponding proposed design of an aileron using smart materials is modelled with understanding the

. The aircraft wing with control surface is computationally analyzed using ANSYS CFX and then numerically simulated using ANSYS' finite element software. The pressure and temperature distribution are obtained from the fluid environment. Towards the end, Considering the constraints of fuel consumption, this analysis compares the existing conventional aileron with the proposed aileron made of smart materials. Smart materials are more likely to improve the structural and functional integrity of the aileron, as well as reduce its weight.

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CHAPTER-1

INTRODUCTION

History dates back to the summer of 1901 to Kill Devil Hills, 4 mi south of Kitty Hawk, North Carolina. Efficiency is an important component of any aircraft operation. Their first glider design, which was a resounding failure the year before, is now proving difficult for Wilbur and Orville. Architect Samuel Pierpont Langley, secretary of the Smithsonian institute - the most prestigious scientific position in the United States - designed the wing for the glider in the 1890s using aerodynamic data published by Otto Lilienthal, the pioneer of German aviation, and by Samuel Pierpont Lilienthal. Because their first glider in 1900 produced no meaningful lift, the Wright brothers have increased their wing area from 165 to 290 ft² and have increased the wing camber. The Wright brothers' attempted to alter the lift characteristics of their biplane. They used the technique of wrapping the wing

Wing camber can be viewed as a measure of how curved the airfoil shape is - that is, a greater camber indicates a more rounded shape. Modern aircraft can have operating costs approaching fifty percent if their wings are cambered a factor of two. If all the trailing edges of the wings can be optimized, drag can be significantly reduced within the flight envelope with a 3-percent reduction of fuel consumption. This can save each aircraft up to \$300,000/year. Although leading and trailing edge devices will improve low-speed takeoffs and landings, variable-camber aircraft will face a challenge in including cruise flight in order to maximize the benefits associated with full envelope variable-camber aircraft. It is possible to realize fuel savings by controlling the wing's camber throughout flight, which reduces drag. Besides the fuel savings, reduced fuel consumption reduces atmospheric emissions, which becomes increasingly important to mitigate global warming. In many ways, optimizing the lift-to-drag ratio can reduce aircraft drag. This can be done by varying the aircraft configurations and flying conditions. The mission can, for example, be flown at a faster speed to save fuel versus a slower speed without optimization. As less fuel is required for the mission, an increased payload, and thus revenue, can be generated from the weight reduction, as 1lb of payload generates 30 times the equivalent value of 1lb of fuel. Thus, the benefit continues. For aircraft limited by payload or range, small increases in can lead to considerable revenue increases. The camber advantages are applicable to civilian flights as well as military aircraft that operate on a relatively constant angle of attack.

Transport aircraft have very large flight envelopes, so variable camber geometry provides significant benefits. Benefits can approach ten percent when flying under nonstandard circumstances.

1.1 INITIAL APPROACHES:

Wright brothers' glider in 1901 had a poor design, so they decided to determine what constituted good design. It was built during the fall of 1901 using two blade fans and a gasoline engine to power a 6ft long, 16 in long square wind tunnel. There have been 200 different airfoil shapes tested in this wind tunnel, including flat plates, curved plates, rounded leading edges, rectangular and curved plan shapes and various monoplane and multiplane configurations. Wind tunnel data was gathered carefully and logically. This data departed significantly from the existing "state of the art"..

In 1902, the Wrights designed a new glider based on the new information. The new glider is more efficient, with the airfoil's maximum rise positioned closer to the leading edge of the wing. However, the most obvious change is when the length of the wing or wingspan is compared to the chord length, also known as the distance between the front and back of an airfoil. They increased this length from 3 to 6. Over a thousand flights were logged by Orville and Wilbur in the summer and fall of 1902.

Using smart materials in aerospace is the subject of the following literature review.

CHAPTER-2

LITERATURE SURVEY

This advanced fighter technology integration system was designed for the F-111 or 'aardvark'. As part of the program, mission adaptive wings (MAWs) were developed to demonstrate how variable-camber controls could be utilized to optimize cruise and maneuver flight conditions for fighter aircraft. The goal was to maintain a smooth and continuous airfoil surface in flight while actively modifying airfoil camber, span wise camber distribution, and wing sweep during flight. This wing had features that enhanced straight-and-level flight efficiency through cruise camber control, maneuver camber control, maneuver load control, maneuver enhancement, and gust reduction.

By integrating cruise camber control, maneuver camber control, maneuver load control, maneuver enhancement, and gust reduction, this wing enhanced straight-and-level flight efficiency. The onboard flight management system in all large transport aircraft aims to optimize the flight trajectory to minimize costs as a function of flight time and fuel price. However, all these algorithms have one thing in common: their models are based on predetermined base configurations; no ability is provided to use variable-geometry features that would have been available with redundant control surfaces.

Research work at Dryden:

NASA Dryden flight research center located in California has drag-reduction technologies for transport aircraft. Transport aircraft typically have smaller achievable performance advantages than fighter aircraft, which makes the task challenging. Utilizing variable geometry principles such as redundant control effects, these technologies utilize measurement-based optimum control for performance enhancement.

By using symmetrical aileron deflection, the wing can be re-cambered in a manner that minimizes drag for all aircraft configurations and flight conditions.

For fly-by-wire transports, the modification requires only the installation of new flight management software and the modification of the control console. But mechanical transport aircraft require additional control hardware modifications. Additionally, they explored the advantages of aircraft with variable-camber capabilities.

Teaming up of the giants:

Lockheed Martin and Rockwell investigated flexible wings for high performance fighter aircraft as part of a feasibility study. The aircraft in this study was a conventional takeoff and landing generic strike fighter with a single engine and a single seat. A conventional wing and an advance flexible wing were designed with the same plan form, chord thickness ratio, and control surface geometry. In terms of degree of flexibility and control scheme used to vary camber and generate roll, there were significant differences between the two wings.

An 8.7% reduction in empty weight can be achieved by reducing the gross takeoff weight by 7.1%. Structure is sized by a maneuver point of Mach 0.9 and excess power requirements of Mach 1.5 in the advanced flexible wing case to achieve the majority of the weight savings.

Testing process at Langley:

The NASA Langley research center tested a wind tunnel model of a flexible wing in 1991. Two forward-facing wing leading edges and two forward-facing wing trailing edges were used. There have been several key accomplishments of this program, such as:

- * Flutter suppression in single and multimode modes,
- * Load alleviation, load control, and multiple input, multiple output, multiple function active control tests above the open loop flutter boundary, and
- * Implementation of active control tests in a vast array of configurations.

The testing process included a methodology for evaluating the performance of the on-line controllers.

2.1 PROJECT ANALYSIS

2.1.1 EXISTING SYSTEM:

The navy developed many fighters during the 1950's that could fly at high subsonic speeds, but very few could fly at supersonic speeds. Mach 1.75 at 35,000 feet and Mach 1.0 at sea level were the maximum Mach numbers that the Crusader could reach. The F-8R, which started as the XF8U-1, has been a model of what a successful aircraft development should look like. The F7U at Chance Ought served as the prototype, and it was determined conclusively that selection can be based on a design's merits rather than the record of previous attempts.

A single-engine fighter with a single seat and variable incidence wing, the F8U's wing was distinctive for its high wing and increased landing speed. A carrier-based fighter, the Crusader was initially designed as an air superiority fighter for clear-weather conditions, but later became limited all-weather capable.

2.1.2 EXISTING DESIGN:

During the Wright brothers' time, wing flexibility was a concept that was successfully accomplished in their biplane design. The biplane was also designed with lateral stability in mind, so the ropes and pulleys on the rear were used to twist it. Due to the wood and cloth covering the wings, they were

sufficiently flexible to allow for this twist. Biplane wings.

By moving sideways, the pilot caused the rope to move and resulted in the twisting of the wings. The ropes were attached to a movable cradle from which the pilot could move laterally. Wing levels were maintained by the Wright brothers to minimize lateral upsets caused by wind gusts. However, with aircraft control surfaces, this method has been rendered obsolete.

A unique aspect of the F8U Crusader is the wing's two positions, allowing the pilot to hydraulically raise the angle of incidence up to 7 degrees for a smooth and efficient landing and takeoff at slow speeds. The F-8 is equipped with an all-moving horizontal tail mounted below the extended chord plane of the wing, as well as a chin inlet for air flow to the turbojet engine. The wing is fitted with variable incidence and spans 35 feet. In accordance with transonic rules, the F-8 fuselage is shaped in accordance with the wings' two-position variable incidence. Because the F-8A has a low-aspect-ratio wing, it is necessary to maintain a high angle of attack to reach the desired lift coefficient in carrier approaches and landings. The landing gear configuration of the aircraft severely restricts the aircraft's ability to land safely. The aircraft pitch angle was maintained within the desired range throughout the approach in order to achieve the required angle of attack and improve visibility for the pilot.

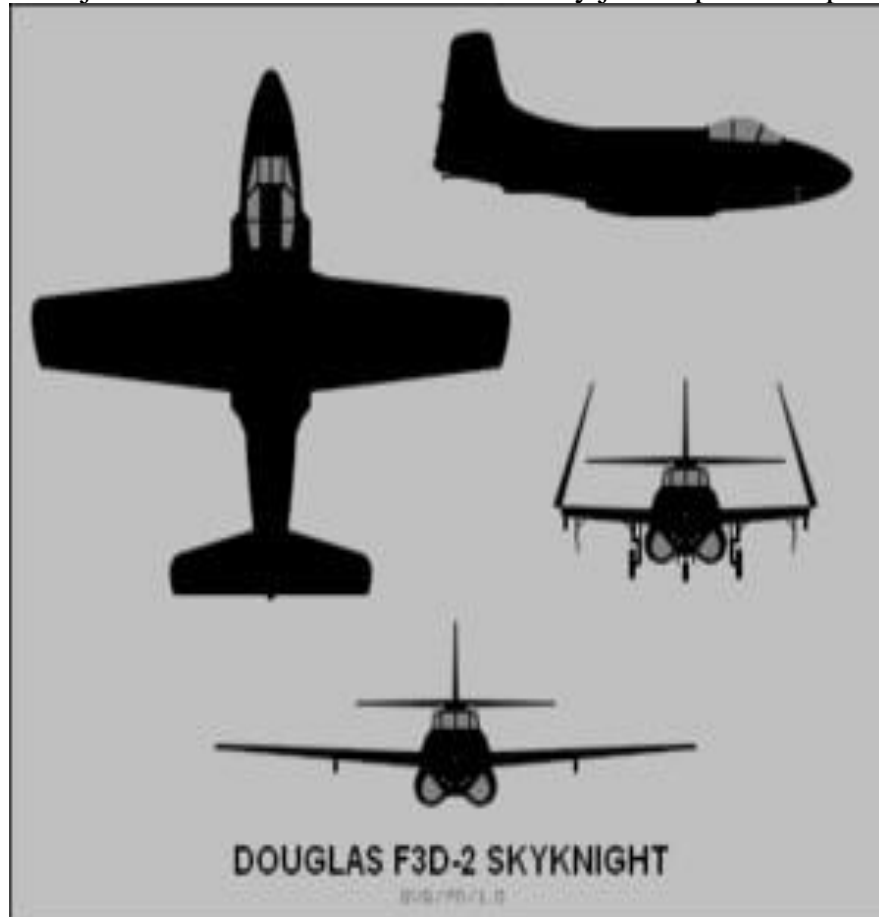
When the wing moved from low to high, the incidence changed by seven degrees. A chord extension, sometimes called a dogtail or snag, which began about midway along the semispan and extended to the wingtip was also one of the notable features of the approximately 6-percent-thick wing. High lift devices were typically inboard leading-edge flaps as well as plain trailing-edge flaps. A vortex is generated at the start of the snag to alleviate pitch-up. To increase the maximum lift coefficient, the capability of the trailing edge flap was enhanced by blowing boundary-layer control with engine bleed air. For lateral control, small inboard ailerons were used; these surfaces could also be deflected symmetrically to increase lift at low speeds.

The Martin XB-51 was a tri-jet aircraft designed by the United States Air Force. It was originally intended to be an attack aircraft. It was a unique ground-attack plane and one of the most advanced aircraft at the time. Two jet engines were carried in pods near the nose, with a third buried beneath the tail. The pilot could change the angle of incidence of the thin wing in the air, making takeoffs and landings easier. The variable-incidence wing allowed for a very long fuselage with two bomb bays, all fuel tanks, and bicycle-style landing gear.

2.1.3 PROPOSED DESIGN:

We created a design that includes an airfoil that varies along the chordwise direction. It also includes a change in the airfoil's angle of incidence. Our design primarily focuses on controlling an aircraft, specifically by deflecting the wings with controlled movements. Our wing required an aircraft that could serve as a model. All tests pertaining to our design are conducted in relation to the reference aircraft in question. Following a thorough analysis and survey, we selected the F3D as our reference aircraft.

The F3D sky knight, later known as the F-10 sky knight, was a twin-engine, mid-wing jet fighter aircraft produced by the Douglas Aircraft Company in California. The F3D was intended to be a carrier-based all-weather aircraft. It saw service with the US Navy, shooting down several MiG-15s over Korea and thus serving as an electronic warfare platform during the Vietnam War. Various research projects with the F3D aircraft resulted in an aeroplane with a broad, deep, and roomy fuselage. An escape tunnel was used instead of ejection seats. Two Westinghouse J34 turbojets mounted in the roots of the early jet era provided power.



ARMAMENT:

- Guns: 4 × 20 mm Hispano-Suiza M2 cannon(4,000 lbs)
- Missiles: 4× sparrow I air to air missiles (510 lbs)

→ Bombs: $2 \times 2,000$ lb bombs

2.1.4 SPECIFICATIONS:

→ Crew: 2

→ Length: 45 ft 5 in (13.85 m)

→ Wingspan: 50 ft 0 in (15.24 m)

→ Height: 16 ft 1 in (4.90 m)

→ Wing area: 400 ft² (37 m²)

→ Aspect ratio: 6.25

→ Empty weight: 14,989 lb (6,813 kg)

→ Loaded weight: 21,374 lb (9,715 kg)

→ Max take-off weight: 28,800 lb (13,064 kg)

→ Power plant: $2 \times$ Westinghouse WE-36 turbojets, 3,400 lbf (15 kN) each

PERFORMANCE:

→ Maximum speed: 529 mph (460 kn, 852 km/h) at sea level.

: 516 mph (448 kn, 830 km/h) at 35,000 ft

→Cruise speed: 454 mph (395 kn, 731 km/h)

→Specific fuel consumption: 1.04 lb/hr-lb

→Stall speed: 93 mph (81 kn, 149 km/h)

→Range: 1,374 mi (1,195 nmi, 2,212 km) (with $2 \times$
150 gal/568 l tanks)

→service ceiling: 36,700 ft (11,200 m)

→rate of climb: 2,970 ft/min (15.1 m/s)

→wing loading: 53.4 lb/ft² (383 kg/m²)

→thrust/weight: 0.32

2.2 RESEARCH ORIENTED LITERATURE SURVEY AERO-STRUCTURAL WING DESIGN OPTIMIZATION USING HIGH-FIDELITY SENSITIVITY ANALYSIS

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This research proposes and implements a system for computing coupled aero-structural sensitivities, which are necessary for the design of aircraft with significant aero elastic interactions. All aero-structural sensitivities are calculated using high-fidelity models of the wing's aerodynamics and structure, as well as a coupled-adjoint approach that employs single discipline sensitivity information to derive the coupled system's sensitivities. The aero-structural adjoint approach is used to compute drag sensitivities with respect to a collection of shape design variables, and the results are compared to those obtained using the complex-step derivative approximation and finite-differences. When the gradient of a small number of functions with respect to each other is small, the aero-structural adjoint is demonstrated to be both precise and efficient, as well as having a large cost advantage. The results of two drag minimization problems with 190 shape design variables are shown to demonstrate the utility of computing aero-structural sensitivity with the proposed method. Even in a traditional swept-wing design, these findings highlight the relevance of aero-structural coupling.

Multi Disciplinary Optimization (MDO) and its application to aircraft design have been the subject of a lot of research. Sobieski's survey paper includes a thorough examination of much of the work in this field. The activities discussed there vary from the invention of inter-disciplinary coupling approaches through their application to real-world design issues. Because some strategies, such as sequential discipline optimization, were unable to converge to the genuine optimum of a connected system, sound coupling and optimization methods were found to be particularly significant in most circumstances. Wakayama, for example, demonstrated that in order to get realistic wing plan form forms through aircraft design optimization, many disciplines must be combined with a comprehensive set of real-world constraints.

Traditionally, aero-structural analysis has been done on a cut-and-try basis. The shape of a "ideal" load distribution is pre-conceived by aircraft designers, who then tweak the structure's jig shape so that the deflected wing shape under a 1-g load produces the required distribution. While this method is usually adequate for traditional swept-back wing designs, the intricacy of aero-structural interactions can lead to sub-optimal designs in more sophisticated designs where little experience has been gained or if many design points are required. This is true in the design of both small and large supersonic transports, where simple wing beam theory models are unable to adequately represent the structure's behaviour. In some situations, these aircraft must also cruise at different Mach values for considerable sections of their trip. Furthermore, a number of studies have shown that this type of aircraft configuration exhibits a number of undesired aero elastic phenomena that can only be avoided if aero-structural interactions are considered early in the design process.

2.3 OPTIMIZATION OF A SIMPLE AIRCRAFT WING

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Two instances are considered while optimising a wing-like structure made up of spars, ribs, reinforcements, and skin: (i) weight reduction and (ii) critical load maximisation. The load is dispersed elliptically across the span of the wing. The design variables are the placement of spars and ribs, as well as the dimensions of various elements of the structure. The optimization processes resulted in a significant improvement in terms of objective function, according to the findings. In recent years, structural and transdisciplinary optimization have gotten more attention for their recognised contributions to design enhancement, particularly in the early stages of product development. The aircraft sector has pioneered applications where lightweight structural components are required for cost savings or increased payload. In a study reported by Grihon and Mahé (1999), a simplified formulation of the operational cost was minimised by combining cruise drag and wing weight. Their approach has the distinct advantage of working directly with wing plan shape, which allows designers to evaluate product efficiency early in the development process, as well as modelling the full wing structure using finite elements. A different perspective (Garcelon and Balabanov, 1999) Garcelon, Balabanov, and Sobieski (1999) divide the optimization problems into structural and aerodynamic optimization, and design an approach that solves one at a time, iterating until the convergence condition is fulfilled. The problem is that interface difficulties arise.

Because wing deformation usually results in a change in aerodynamic load, it comes into play. All of the above optimization strategies are largely based on cutting-edge algorithms and codes that take a significant amount of computational work to solve. Traditional continuous approaches such as viable directions, sequential linear programming, and sequential quadratic programming are used in the MSC Nastran commercial structure optimization package (Vanderplaats, 1999). Weight reduction and increased critical loads, as well as structure quality and reliability, are all considered important factors in the design of aircraft structures.

In these situations, structural optimization proves to be a viable option for creating efficient structural components. The Sequential Quadratic Programming algorithm is used to address the non-linear constrained optimization problem (Powell, 1978). Because it produced better findings for the current investigations, this strategy was chosen above others accessible in commercial codes.

Despite the fact that design optimization has been proven to be effective, it is not frequently employed as a conventional design technique for a variety of reasons. Non-technical causes include the difficulty of creating design data and the lack of time available to train engineers on optimization techniques. Rather of altering designs using optimization approaches, those engineers spend the majority of their time modifying and studying their designs and making incremental adjustments. However, due to the immense demand to reduce "time to market" while simultaneously improving product quality, those views are gradually evolving and/or under pressure to change. It is the obligation of academics and software developers to constantly improving the state of the art in optimization technologies and to produce easy-to-use, user-friendly software.

friendly optimization techniques, in order to pique the interest and curiosity of as many engineers as possible.

2.4 ORNITHOPTER WING OPTIMIZATION SANDRA MAU

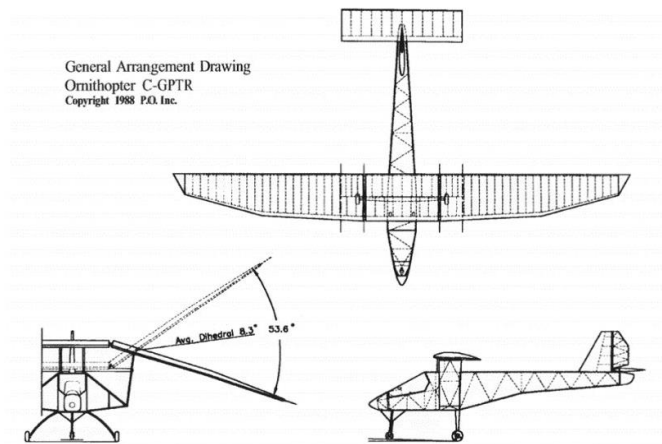
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Aug. 2003

Using mathematical software, a new ornithopter wing was built to theoretically produce enough lift and push to put an engine-powered manned aircraft into sustained flight. After generations of wishing to fly like the birds, the Wright brothers succeeded in building and flying the first successful powered and piloted aeroplane in 1903. However, the fantasy of being able to fly like the birds continues to elude us. Ornithopters have been envisioned by visionaries like Leonardo DaVinci since before the 1500s, much before rigid-wing aircraft like the Wright Brothers'. They're motorised flapping-wing aircraft with mechanical flapping wings that mimic the flapping wings of a bird. Throughout history, people have attempted to replicate this form of flight. Alphonse Penaud's rubber-powered model ornithopter in 1984, Alexander Lippisch's gliding human-powered ornithopter in 1929, and Percival Spencer's series of engine-powered, free-flying models in the 1960s were all notable advancements in flapping-wing flight.

Jeremy Harris and James DeLaurier's objectives resulted in the most recent important improvement in flapping wing flight. They successfully launched the first engine-powered, remotely piloted ornithopter in 1991. This craft, dubbed Mr. Bill, was used to create a quarter-scale model for a full-scale piloted ornithopter. The Harris/DeLaurier engine-powered piloted aircraft was able to self-accelerate to lift-off speeds by flapping its wings alone in 1999. It hasn't been able to maintain a constant flight, though.

One of the significant issues was that the full-scale ornithopter's wing could barely create adequate lift despite delivering enough thrust to self-propel the plane. The wing was designed to support roughly 600 pounds of aircraft weight, while the actual plane weighed closer to 700 pounds. The method of analysing and modifying the ornithopter wing to potentially offer the best lift and propulsion for flapping-wing flying is detailed in this work. Full Wing and Rambod Larijani's Newmark, two algorithms that forecast the performance of flapping wing craft given specific parameters, were used in the analysis. A new optimum plan form for the ornithopter wing was devised based on available data. The wing design on the modern Harris/DeLaurier full-scale ornithopter is quite distinctive. The wing is made up of three hinged panels: a constant chord centre panel and symmetrical, double tapering outside panels. The outer panels can be further separated. Between the centre panel and the hinged pivot coupled to the outboard vertical links, which give support and a pivot point for the flapping panel, is the "stiff part" of the outer panel. The panel chord continues at the same tapering angle as the rigid portion beyond this hinge, then tapers out further along the wing.



2.5 SUBSONIC WING PLANFORM DESIGN USING MULTIDISCIPLINARY OPTIMIZATION

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The fundamental results of wing plan form optimization for least drag with structural weight and maximum lift limitations are presented in this article. To achieve successful wing plan form shape optimization, analyses in each of these fields are produced and combined. Weight limitations, compressibility drag, maximum lift, and static aero elasticity all have an impact on wing shape, and modelling these effects is required to achieve realistic optimum plan forms.

Optimization can be a powerful tool in the conceptual and preliminary phases of wing design; however, successful plan form optimization has been an elusive goal, with the imposition of designer expertise often necessary to avoid unrealistic results. This lack of success comes from the high sensitivity of wing shape to off-design considerations. By casting these considerations as

constraints and selecting a reasonable performance objective, realistic plan forms can be attained; the problem is then to build an optimization analysis that appropriately models the aerodynamic and structural design drivers.

Different levels of analysis have been used for wing optimization, ranging from simple analytic or empirical expressions for conceptual design, to complex finite element structural models. The difficulty is to find or develop analyses that are sufficiently simple to be called thousands of times during optimization, but are sophisticated enough to capture considerations that determine local geometry. With a simplified objective, such as minimum-induced and section profile drag with structural weight constraints, the optimization can be cast as a linear problem that can be solved directly to obtain optimal load distributions for given plan form. Some extension of this can be made toward determining chord or thickness distributions. These methods are very fast, but cannot be extended to plan form variables such as sweep, span, or dihedral.

This article describes extensions to the aerodynamic and structural analyses and presents new optimization results. This forms a methodology for plan form optimization of subsonic wings. Basic results of this method are presented here, demonstrating wing characteristics driven by many considerations, including induced, profile, and compressibility drag, bending and buckling weight, section maximum lift constraints, and static aero elasticity. The results strongly indicate that drag, weight, and maximum lift must be carefully analyzed to obtain reasonable plan form shapes.

2.6 DESIGN AND OPTIMIZATION OF A JOINED-WING AIRCRAFT

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The American Institute for Aeronautics and Astronautics (AIAA) hosts the annual Design, Build and Fly (DBF) competition. Teams of students from universities around the world compete to engineer a radio-controlled aircraft capable of successfully completing the mission designated by AIAA for that year. The 2007-2008 seasons required that the aircraft must be able to take off in 75 feet and have a wingspan no greater than 5 feet. Since the aircraft must also carry a significant payload, a crucial engineering challenge arose for designing an aircraft which has a short ground run, small wings and a high-lift capacity. The team from the University of Colorado at Boulder determined that the best design for this mission was a joined-wing configuration, in which there are two separate sets of wings that are connected to each other. This paper provides an overview of the processes involved in determining the span, plan form area, incidence, dihedral and sweep of the wings. The final design allows for high efficiency in a compact package. The two wings produce an interference effect that bolsters the lift generated, produces outstanding stall characteristics and is also quite stable.

The aerodynamic configuration of the aircraft consists of two main lifting surfaces: the upper forward wing which is swept back and the lower aft wing which is swept forward. The two wings are joined by vertical surfaces and there is no dedicated horizontal stabilizer. The large effective wing area promotes a high efficiency in terms of lift and wingspan, and the design can be both responsive and stable. However, this unorthodox approach to aircraft design presents certain difficulties when computing the appropriate geometry and stability matrices. The focus of this paper will be the procedure used for the determination and optimization of the wing geometry, its theoretical and experimental stall characteristics and an analysis of the dynamic stability.

2.7 Morphing Wing Using Shape Memory Alloy: A Concept Proposal

The concept of a morphing wing able to adapt itself for different aerodynamic characteristics during flight is where aircraft research is mostly heading to. This investigation looks for the development of an actuation mechanism using the smart material Nitinol to twist the body of a wing in three different sections. We engineered a concept of this mechanism using bended SMA strips connected from the supporting shaft of a NACA 0015 wing to the lower back side of the wing. Actuation was gained by heating the bended material and obtaining twist angles when the material straightens in austenite form. This twisting alters the aerodynamic properties of the wing, raising the lift coefficient among other gains. The first section of the wing was able to twist approximately 5.50° without being fix to the shaft using only two SMA strips. Further addition of SMA strips would increase the twisting force on the wing.

Another purpose of this research is to leave this idea in the hands of other researchers for further development of this concept. More experimentation on this mechanism could be made and obtain far more convincing results. The development of a locking mechanism on each section of the wing, the addition of all 6 SMA mechanisms on all the sections, the development of control algorithms for deflection are just some of the ways this concept has room to improve.

2.8 Utilization of Optimization for Design of Morphing Wing Structures for Enhanced Flight.

The agility of conventional aircraft control surfaces is limited. This research provides a thorough examination of both smart and traditional materials.

wing twist actuation systems that use minimum actuation energy while permitting minimal wing deformation under aerodynamic loads to potentially increase flight capability. A continuous wing is utilised to reduce drag while also allowing the aircraft to mimic the wing deformation seen in birds while loitering. The skin of the morphing wing for this project is supported by an underlying truss structure, with the purpose of achieving a given roll moment with less actuation energy than traditional control surfaces. To accomplish minimal wing deformation under aerodynamic loading while permitting wing twist during actuation, a structural optimization code was built. The optimization's multi-objective cost function includes terms that ensure minimal deformation under aerodynamic loads and minimal change in weight.

This chapter begins with providing the designs utilised as case studies in this study, which were published by previous researchers. Initially, the skin thickness was estimated using beam theory. Along with the designs, this was given. The expenses for Case I designs were reasonable, but the expenditures for Case II were not. The shell theory was then utilised to estimate the thickness of the skin.

displayed after that. For Case I, the designs that resulted were satisfactory. However, this was not the case with the Case II designs. As a result, nodal density, rib count, structural type, and skin material were all different. However, none of these changes resulted in a considerable cost reduction. The cost of the support structure was significantly reduced when the material was changed from aluminium to steel. However, the resulting design proved insufficient. During the optimization routine, a variable cooling rate and re-seeding were incorporated, and an acceptable design was found. The resultant designs were compared to other researchers' designs, demonstrating that the code used in this study generated better wing designs.

2.9 SMART MATERIAL WING MORPHING FOR UNMANNED AERIAL VEHICLES

Since the Wright Brothers' first powered flight, morphing, or geometric adaptation to off-design situations, has been studied in aircraft design. Smooth, bio-mimetic form variation for control of aerodynamic forces is still elusive decades later.

Unmanned Aerial Vehicles (UAVs) are prime targets for morphing implementation because they must adapt to large changes in flight conditions caused by locally varying wind or large changes in mass caused by payload delivery. The Spanwise Morphing Trailing Edge (SMTE) concept was developed to locally vary the trailing edge camber of a wing or control surface, acting as a modular replacement for conventional ailerons without changing the spar box. The SMTE design was realised by alternating active sections of Macro Fiber Composites (MFCs) driving internal elastomeric compliant mechanisms and passive sections of anisotropic, elastomeric skin with an anisotropic, elastomeric skin with an anisotropic, elastomeric skin with an anisotropic, elastomeric skin with an anisotropic,

Additive manufacturing produces tailorable stiffness. Due to asymmetric voltage constraints, experimental investigations of the modular design using a new scaling methodology for reduced-span test articles revealed that increased use of more MFCs within the active section did not improve aerodynamic performance. The comparative mass and aerodynamic gains for the SMTE concept are assessed for a representative finite wing versus a conventional, articulated flap wing. Experiments based on a simplified system model and measured control derivatives revealed a reduction in the adaptive drag penalty of up to 20% at off-design conditions.

To investigate the potential for improved aeroelastic performance and actuation range, the Synergistic Smart Morphing Aileron (SSMA) is introduced as a hybrid multiple-smart material morphing concept. The SSMA takes advantage of the properties of two different smart material actuators to outperform the constituent materials. The resultant design achieves the desired goals while providing additional control authority at stall and for unsteady conditions due to the relatively higher work density and phase transformation of Shape-Memory Alloys combined with the larger bandwidth and conformal bending of MFCs through synergistic use of reflex actuation. These advancements highlight and motivate new morphing structures for the expanding field of unmanned aerial vehicles (UAVs), where adaptation involves advanced compliance tailoring of complex geometry with synergistic actuation of embedded, smart materials.

2.10 Aerodynamic Performance Optimization of Smart Wing Using SMA Actuator

Today's commercial, private, and military aeroplanes have fixed wings that allow them to fly. The aircraft's unique aerodynamic qualities are determined by the diverse shapes of wings, camber angles, texturing, and other factors. These characteristics enable the aeroplane to do the purpose for which it was designed. New technology and development, on the other hand, has pushed forward the idea of a wing that can change its shape and form to have diverse aerodynamic properties. It would be able to adapt to various flight situations as a result of this. The current research project's major goal is to increase the aerodynamic performance of an experimental aircraft wing that operates in a variety of cruise circumstances. The improvement is achieved by producing a broad laminar flow to reduce viscous drag. To attain this aerodynamic ability, the wing upper surface is subjected to regulated and well-studied deformation (in-flight morphing) to keep the drag at its lowest feasible value, regardless of the flow circumstances. In this study, the wing is outfitted with novel morphing actuation mechanism hardware and appropriately engineered controls. The goal of this experiment was to create a device that used Shape Memory Alloys (SMA) to change the wing's camber thickness. The NACA0021 airfoil was used in this experiment. The manufacture of the morphing wing was completed, and two-dimensional analysis was performed using computational fluid dynamics (CFD), as well as aerodynamic experiments in an open-circuit wind tunnel. This morphing wing was put through its paces.

For this morphing wing, new morphing actuation mechanism hardware with adequately designed controllers was used in the construction, as well as two-dimensional analysis utilising computational fluid dynamics (CFD) and aerodynamic experiments in an open-circuit wind tunnel. The lift-to-drag ratio of this morphing wing was established at various angles of attack during the tests. The findings of the CFD and experimental analyses were then reviewed, revealing that the morphing wing configuration had superior aerodynamic performance when compared to the traditional wing configuration. It is obvious from the pressure and velocity distribution diagrams that the morphing wing configuration outperforms the conventional wing configuration.

2.11 A Numerical Study on Smart Material Selection for Flapped and Twisted Morphing Wing Configurations

Innovative adaptable structures on Unmanned Aerial Vehicles (UAVs), such as morphing wings, have the ability to reduce system complexities by eliminating control surfaces and auxiliary equipment. By maintaining an optimal airfoil section over a range of speeds for different segments of a mission profile, this technique has the potential to allow a UAV to adapt to different mission requirements or to execute a specific mission more effectively. To achieve wing morphing, studies on a number of smart materials candidates are currently accessible in the free literature. The choice of material is based on a number of variables, including fast dynamic response, low weight, and the ability to function across a wide temperature range.

Low power consumption and flying conditions A review of smart materials technologies for UAV morphing wings is presented in this research. A numerical analysis of the power needs for two morphing wing concepts is also presented: flapped and twisted wing planforms. A two-step approach was used to calculate the energy for both morphing configurations. The first phase involves using an in-house Vortex-Lattice (VL) based algorithm to calculate the aerodynamic energy. Following that, the first-step pressure field is mapped onto a finite element mesh, and the structural strain energy is determined. The computational results showed that flapped morphing wings outperform twisted wings in terms of aerodynamic performance, and that different morphing levels may be achieved utilising lighter smart materials with reduced weight.

This study presented and analysed a review of smart materials technologies and concepts for morphing wing structures. For both flapped and twisted morphing wing planforms, a formulation based on the Vortex Lattice Method (VLM) was proposed to compute the pressure distribution, lift generation, and aerodynamic energy. MATLAB software has been used to implement the proposed formula. For a typical small UAV, numerical simulations were run with two morphing notions in mind: flapped and twisted wing shapes. For the same deflection range, the flapped wing created more lift than the twisted wing, according to the numerical data. To maintain the twisted wing against the aerodynamic loads, however, less aerodynamic power was required. These data suggest that flapped wing configurations have superior aerodynamic performance than twisted wing configurations; nevertheless, more research is needed to evaluate global twisting rather than twisting only part of the wing. A stronger aerodynamic performance indicates that the deformable sections of the vehicle are less likely to distort.

Lighter smart materials with lower specific energy can be used to make the wing, allowing for the manufacture of lighter aircraft with improved performance and lower fuel consumption. Due to its fast response with maximum efficiency for all morphing configurations evaluated in this work, the preliminary analysis presented in this paper proposes Single Crystal (PZN-PT) materials as possible options for smart morphing wing structures.

2.12. CAE TOOLS

- • **Ansys Mechanical software is a complete product solution for structural linear and nonlinear analysis, as well as dynamics analysis. For a wide range of engineering issues, the software includes a complete set of element behaviour, material models, and equation solvers. Thermal analysis and coupled-physics capabilities comprising acoustic, piezoelectric, thermal–structural, and thermoelectric analysis are also available with ANSYS Mechanical.**
- □ • **Nastran is a finite element analysis (FEA) application that was developed for NASA in the late 1960s with financing from the US government for the aerospace sector.**
- **The automobile, aerospace, and industrial products industries all use Abaqus. Academic and research institutions prefer the product because of its extensive material modelling capabilities and ability to be customised. Abaqus also has a good collection of multiphysics features, such as linked acoustic-electrical-mech**

- • **Ls-Dyna is a multi-physics simulation package with extensive capabilities. Its origins and core competencies are in highly nonlinear transient dynamic finite element analysis (FEA) employing explicit time integration, and it continues to contain more and more possibilities for the calculation of many complicated, real-world situations. The automotive, aerospace, construction, military,**

manufacturing, and biotechnology industries all employ LS-DYNA.

- **Pam-Crash is an ESI Group software programme for crash simulation and occupant safety system design, primarily in the automotive industry. PAM-Collision allows automotive engineers to evaluate the possibility for injury to vehicle occupants in various crash situations by simulating the performance of a proposed vehicle design.**
- **Matlab (matrix laboratory) is a fourth-generation programming language and numerical computing environment. Matrix manipulations, graphing of functions and data, implementation of algorithms, construction of user interfaces, and interfacing with programmes written in other languages, such as C, C++, Java, and Fortran, are all possible with MATLAB, which was developed by Math Works.**
- **Ansys Fluent software has the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications ranging from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from blood flow to semiconductor manufacturing.**

- To wastewater treatment plants, clean room design is used. Special models have been added to the software to allow it to model in-cylinder combustion, aero acoustics, turbo machinery, and multiphase systems.

2.13 COMPUTATIONAL FLUID DYNAMICS

We chose computational fluid dynamics as our external aerodynamics optimization technology from the list above. The discipline of determining a numerical solution to the governing equations of fluid flow while advancing the solution through space and time to get a numerical description of the entire flow field of interest is known as computational fluid dynamics (CFD).

Since the invention of the digital computer, CFD has gotten a lot of attention as an emerging science all across the world. The subject has two aspects that appeal to me. To begin with, there is a desire to be able to represent physical fluid phenomena that are difficult to mimic or detect using physical experiments, such as weather systems or hypersonic aerospace aircraft. Second, the need to be able to explore physical fluid systems in a more cost-effective and time-efficient manner than is possible using experimental approaches.

The development and application of CFD to all elements of fluid dynamics has seen significant progress. CFD programmes are currently widely used in industry and are regarded standard numerical tools in design and development. As a result, there is a significant demand for experts in the field to implement and improve CFD methodologies across engineering firms and research institutions.

CFD's current situation in industry is comparable to that of structural analysis a decade ago, when it was also in its infancy. The average company selling Finite Element structural analysis products at the time had a turnover that was an order of magnitude more than the largest CFD provider. Finite Element programmes are now widely used in industry as part of the standard design and analysis process, and they are available on nearly every computing platform. Similarly, Computational Fluid Dynamics has evolved into a mainstream industry tool that now sits alongside CAD and FE software.

Both business and research organisations use CFD as a tool for design analysis. The course provides a solid foundation for graduates to be able to use CFD as a design tool for engineering applications in an educated manner. For graduates who want to pursue a doctorate. The course provides a good foundation for subsequent specialisation in both numerical methods and physical models development and implementation.

PREPROCESSING:

- **Geometry clean up and fluid domain extraction:**

The geometry clean phase is the initial step in the CFD process, and it removes any undesired thickness or geometry that does not affect the results.

- To a considerable extent, fluid flow is eliminated. This is known as fluid domain extraction, and it ensures that the fluid domain is completely closed.
- **Domain discrimination:**
- Grid generation is the next step in the process. The discretization of a fluid domain into finite volumes is known as grid generation. Discretization is the process of transforming partial differential equations into algebraic equations. To improve the quality of the volume mesh, a surface mesh for the domain is generated first, followed by the final volume mesh after the appropriate surface mesh adjustments.
- **Boundary conditions:**

Setting the boundary conditions is the last step in the preprocessing procedure. The mesh is examined and resized, and the domain's boundary conditions are specified.

SOLUTION

- The solution is produced after setting the solution monitors, convergence criteria, and the number of iterations.

POSTPROCESSING

The answers are shown as needed graphs, contour plots, vector plots, path lines, or numerical reports can be generated.

2.14 MESHING SOFTWARES

ANSYS ICEM CFD

The powerful CAD/geometry readers and repair tools in ANSYS ICEM CFD meshing software allow the user to quickly progress.

to a number of geometry-tolerant meshers and quickly generate high-quality volume or surface meshes. ANSYS ICEM CFD is a complete meshing solution with advanced mesh diagnostics, interactive and automatic mesh editing, output to a broad variety of computational fluid dynamics (CFD) and finite element analysis (FEA) solvers, and various physics post-processing capabilities. ANSYS aims to provide a set of versatile tools that can take a model from any geometry to any solver in a modern, scriptable environment.

- Mesh huge, complicated models efficiently using dirty CAD and/or faceted geometry such as STL
- Advanced hex mesh control (organised or unstructured)
- Advanced mesh diagnostics and interactive mesh editing
- Output to a range of CFD and FEA solvers as well as neutral formats

GAMBIT

Fluent's geometry and mesh generation software is called GAMBIT. The unified interface for geometry creation and meshing in GAMBIT brings together the majority of Fluent's preprocessing tools in one place. Advanced journaling capabilities allow you to edit and playback model building sessions for parametric research with ease. The combination of GAMBIT's CAD interoperability, geometry cleanliness, decomposition, and meshing tools results in one of the simplest, fastest, and most straightforward preprocessing approaches from CAD to excellent CFD meshes.

HYPERMESH

Altair Hyper Mesh is a high-performance CFD pre- and post-processor for major finite element solvers that enables engineers to investigate design situations in a highly interactive and visual environment. The user interface of Hyper Mesh is simple to learn and allows for the direct usage of CAD geometry and existing finite element models, ensuring robust compatibility and efficiency. Users can use Hyper Mesh's advanced automation features to optimise meshes based on a set of quality criteria, morph existing meshes, and generate mid-surfaces from models of different thickness.

ANSA

ANSA is a multidisciplinary CAE pre-processing tool that provides all of the necessary capabilities for full-model build-up in a single integrated environment, from CAD data to ready-to-run solver input file. ANSA is the preferred choice of users because to its extensive set of features and tools that fulfil their requirements. The number of useful and adaptable characteristics is large, and the jobs and processes that may be accomplished with them are numerous.

2.15 SOLVER AND POST PROCESSING SOFTWARES

FLUENT

ANSYS Fluent software has the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications ranging from air flow over an aeroplane wing to furnace combustion, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants. Models that provide the software the ability to model in a specific way-

Its scope has been expanded by cylinder combustion, aero acoustics, turbo machinery, and multiphase systems.

CFX

ANSYS CFX is a high-performance, general-purpose fluid dynamics application that has been used to address a variety of fluid flow issues for more than 20 years. The sophisticated solver technology in ANSYS CFX is the key to quickly and reliably obtaining trustworthy and accurate solutions. The contemporary, highly parallelized solver serves as the foundation for a wide range of physical models that may describe practically every form of fluid flow phenomenon. The solver and its various physical models are housed in a modern, intuitive, and adaptable user interface and environment, with considerable customization and automation capabilities via session files, scripting, and a sophisticated expression language.

ACU-SOLVE

AcuSolve is a durable, fast, and accurate general-purpose finite element-based Computational Fluid Dynamics (CFD) flow solver. AcuSolve is a standalone tool that may be used by designers and research engineers of all levels of competence, or it can be effortlessly integrated into a strong design and analysis programme. Users may get quality answers quickly with AcuSolve without iterating on solution techniques or worrying about mesh quality or topology.

OPENFOAM

OPEN FOAM includes a wide range of characteristics that can be used to handle a wide range of problems, including chemical processes, turbulence, and heat transport, as well as solid dynamics and electromagnetism. It provides meshing and pre- and post-processing tools, including the snappy Hexmesh, a parallelized mesher for complicated CAD shapes. Almost everything (including meshing and pre- and post-processing) happens in parallel as a matter of course, allowing users to make the most of their computer capabilities.

CHAPTER 3

3.1 Motivation

3.2 Despite the numerous applications of control surfaces in the aircraft industry, there is relatively little work documenting smart materials on such applications, according to the literature. Implementing smart materials on the control surface is particularly advantageous for aeronautical applications. The goal of this study is to apply smart materials technique to a variety of situations. This would not only minimise aircraft drag, but it would also be economically beneficial in terms of fuel usage. The current research aims to build an aileron structure built of smart material that may be actuated externally using electric or other sources. It is anticipated that such a methodology will provide useful physical knowledge while also being simple to implement.

3.3 Objective

The following are the precise aims of the current effort in this regard.

1. Using smart materials, build an aeroplane control surface that is fixed at the trailing edge of the wing.

2. Analytical computations for specific aerodynamic loading circumstances are also necessary to get the airfoil design of the control surface.

3. Investigate the design's structural integrity. Existing and proposed designs are subjected to computational fluid analysis, which is followed by structural analysis.

4. Pressure and velocity distributions for both designs will be provided based on aerodynamic loading conditions. Fluid structural interaction will be studied for existing and proposed design.

3.4 Comparative analysis to prove that the suggested design is more useful and structurally sound than the current wing design.

3.5 Scope:

1. For numerical simulations, a rectangular wing with a twist at the wing tip will be used.
2. Analytical computations are based on steady-state flight circumstances.
3. The aircraft's speed is slower than the speed of the speed.
i.e. a subsonic situation.

Simulations were carried out in the commercial software packages CFX and ANSYS for hydrodynamic and structural analysis, respectively.

3.6 RESEARCH METHODOLOGY:

STEPS

1. Scope & Objective defining.

2. Literature summary study.
3. Problem identification & CAE analysis methodology study.
4. Project plan & resource allocation.
5. Initial Design Phase: Conventional Wing (Flap and Aileron twisted condition) & Smart wing (Flap and Aileron twisted condition).
6. Design documentation & detailing wing internal and external structure.
7. Computational Fluid Dynamic Analysis over both the wing configuration.
8. Steady level flight conditions considered for numerical calculations.
9. Velocity of aircraft is less than speed of sound. ie subsonic condition.
10. Simulations performed in commercial package software CFX.
11. Structural analysis is performed using ANSYS for fluid pressure load obtained from Computational Fluid Dynamic Analysis.
12. Flow parameters over both the wing configurations are studied.
13. Structural load distribution on the wing structures are studied.

3.7 CAD Model – Design-

The development of the CAD model, followed by geometrical clean up, is the first stage in any analysis. CAD software CREO.4 was used to create a CAD model of the existing and suggested design. The CAD model's detailed design and dimensioning are presented below.

Normal Wing

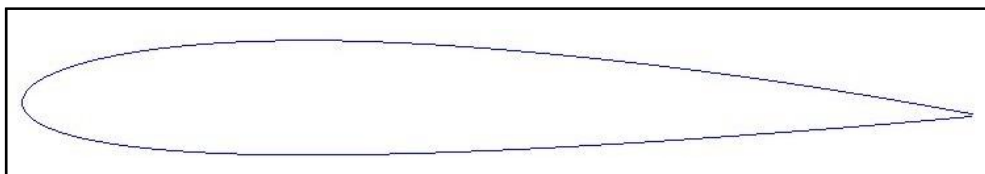


Figure: 1 NACA 1412 Left side of the wing

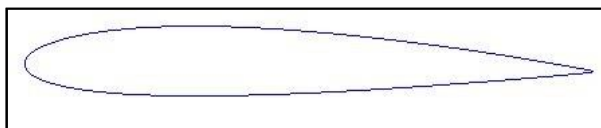


Figure: 2 NACA 1412 Right side of the wing

Smart Wing

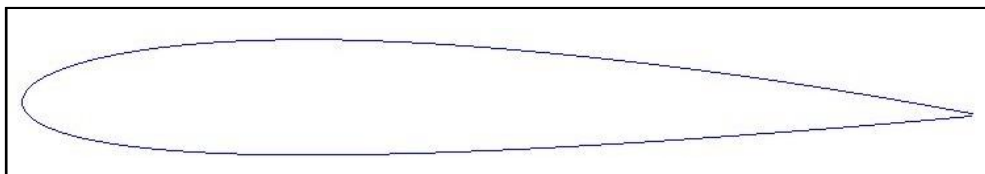


Figure: 3 NACA 1412 Left side of the wing

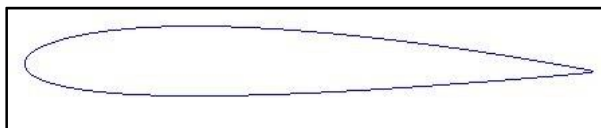


Figure: 4 NACA 1412 Right side of the wing

NACA Airfoil co-ordinates of left and right airfoil cross section

X	Y	Z
1000	1.26	0
950.25	9.66	0
900.4	17.53	0
800.58	31.78	0
700.61	44.13	0
600.51	54.53	0
500.29	62.67	0
400	68.03	0
299.25	69.4	0
248.89	67.99	0
198.57	64.86	0
148.33	59.51	0
98.24	51.18	0
73.3	45.37	0
48.45	37.86	0
23.78	27.33	0
11.58	19.54	0
0	0	0
13.42	-18.3	0
26.22	-24.91	0
51.55	-33.18	0
76.7	-38.57	0
101.76	-42.42	0
151.67	-47.33	0
201.43	-49.86	0
251.11	-50.81	0
300.75	-50.64	0
400	-48.03	0
499.71	-43.21	0
599.49	-36.75	0
699.39	-29.13	0
799.42	-20.66	0
899.6	-11.41	0
949.75	-6.46	0
1000	-1.26	0

X	Y	Z
300	0.378	0
285.075	2.898	0
270.12	5.259	0
240.174	9.534	0
210.183	13.239	0
180.153	16.359	0
150.087	18.801	0
120	20.409	0
89.775	20.82	0
74.667	20.397	0
59.571	19.458	0
44.499	17.853	0
29.472	15.354	0
21.99	13.611	0
14.535	11.358	0
7.134	8.199	0
3.474	5.862	0
0	0	0
4.026	-5.49	0
7.866	-7.473	0
15.465	-9.954	0
23.01	-11.571	0
30.528	-12.726	0
45.501	-14.199	0
60.429	-14.958	0
75.333	-15.243	0
90.225	-15.192	0
120	-14.409	0
149.913	-12.963	0
179.847	-11.025	0
209.817	-8.739	0
239.826	-6.198	0
269.88	-3.423	0
284.925	-1.938	0
300	-0.378	0

CAD Model Normal Wing:

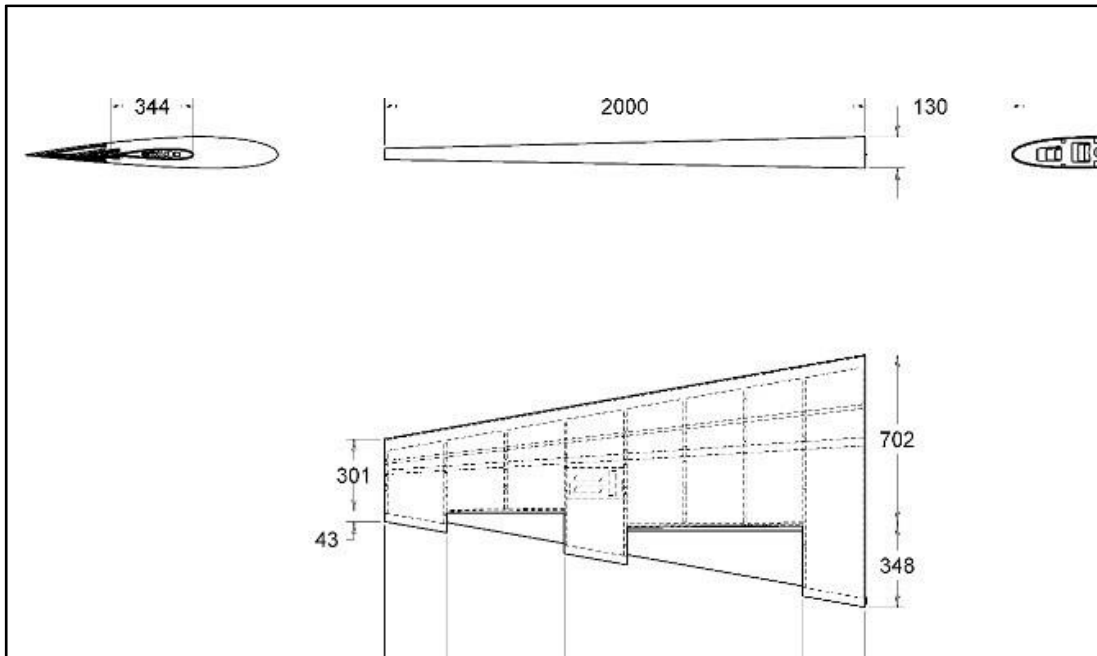


Figure: 5 Wing assemblies

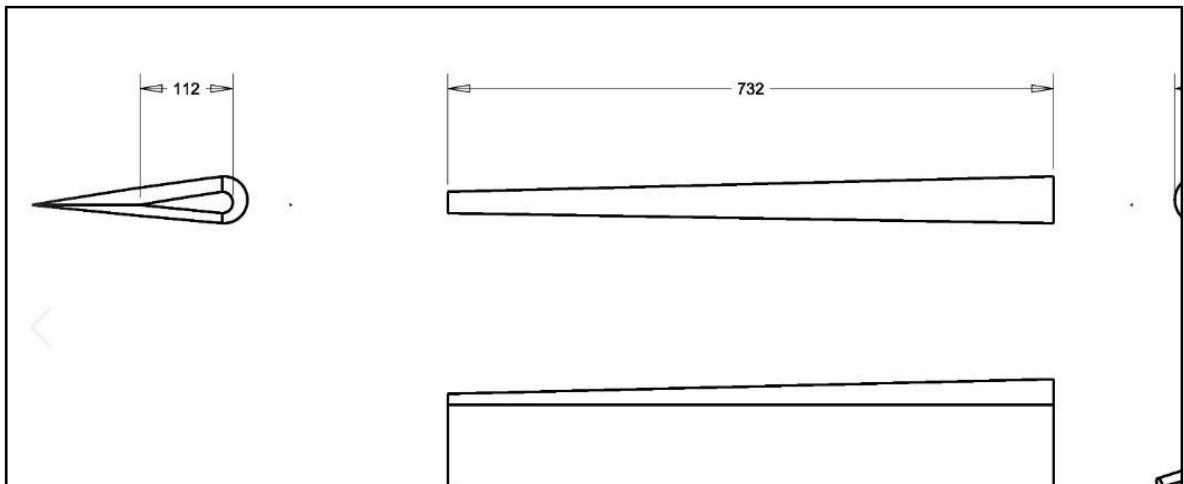


Figure: 6 Flaps

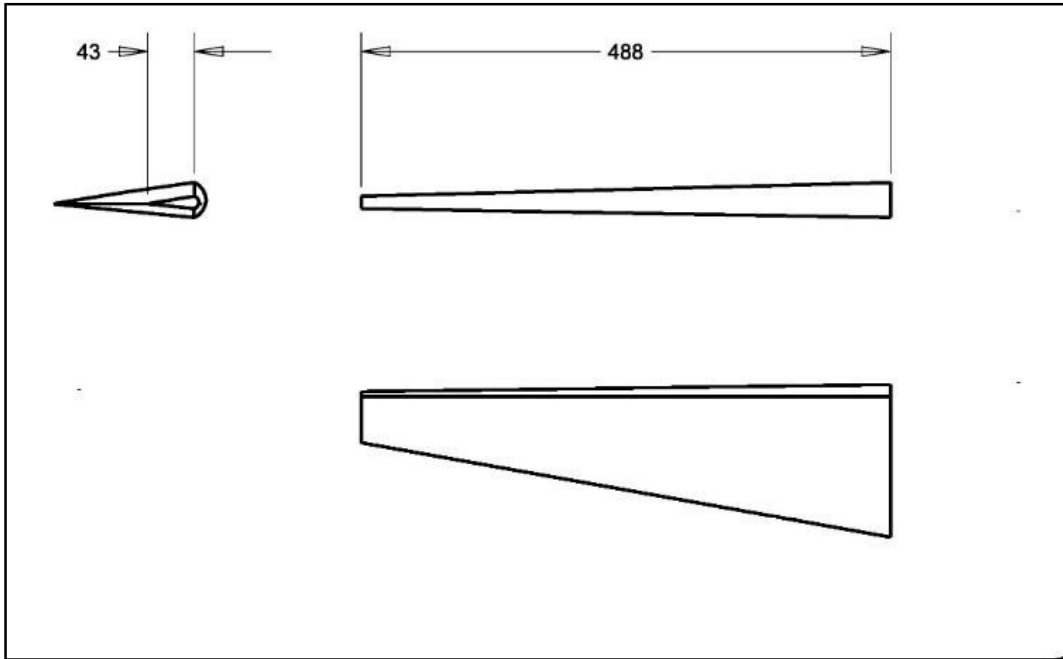


Figure: 7 Ailerons

Smart Wing

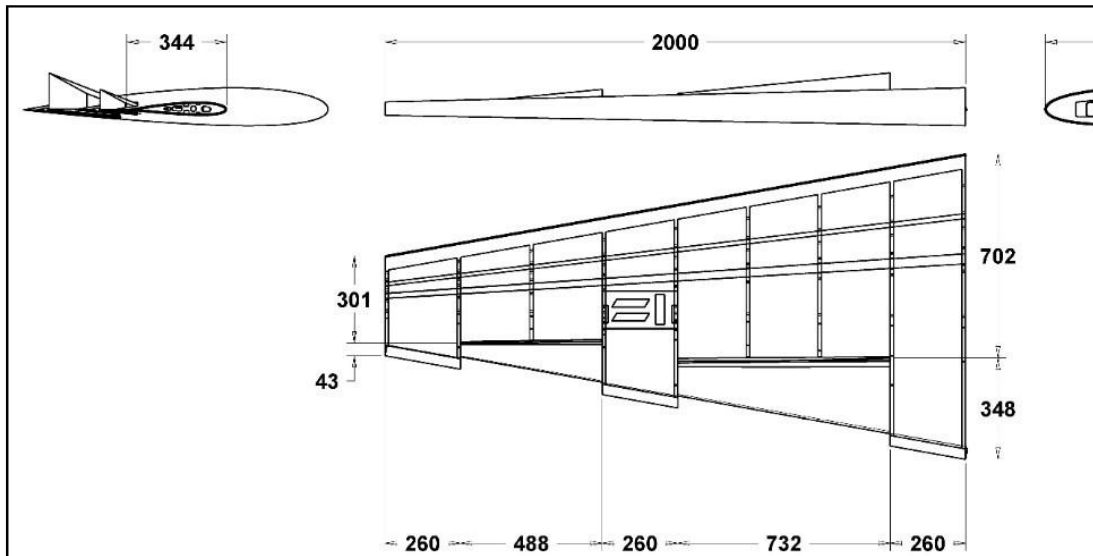


Figure: 8 Smart Wing assemblies

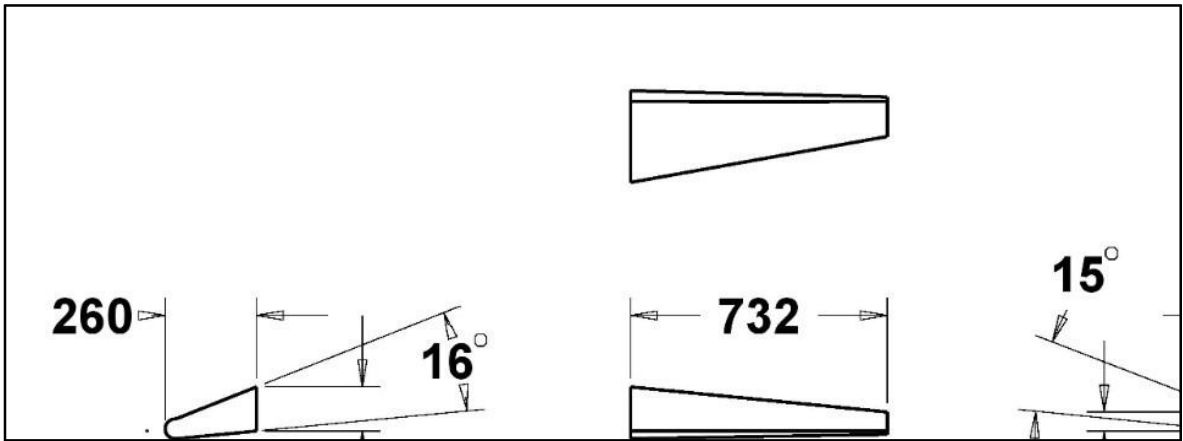


Figure: 9 Flaps

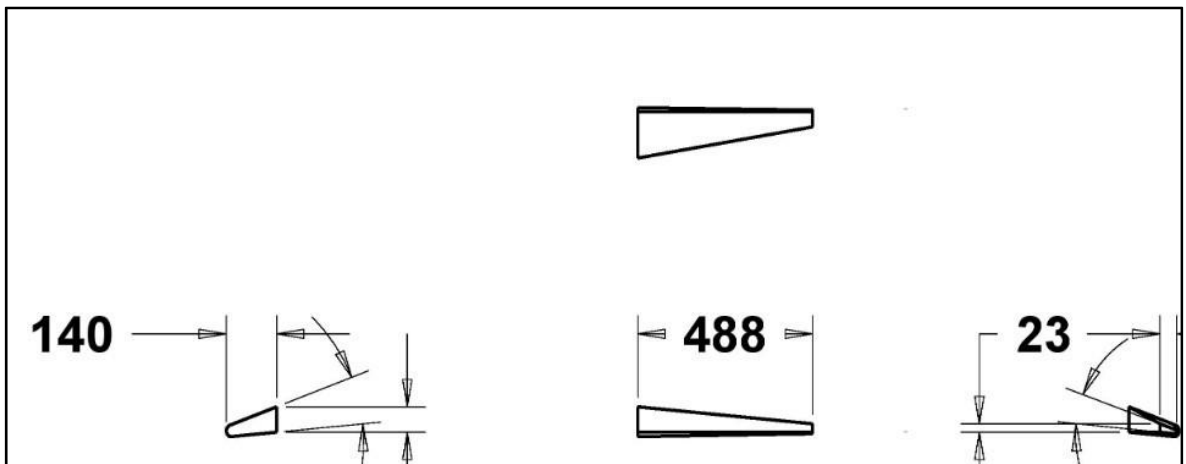


Figure: 10 Ailerons

3.8 CFD METHODOLOGY

PREPROCESSING:

- **Geometry clean up and fluid domain extraction:**

- The first phase in the CFD process is geometry clean, which involves removing any undesired thickness or geometry that does not have a significant impact on fluid flow. This is known as fluid domain extraction, and it ensures that the fluid domain is completely closed.

- **Domain discrimination:**

Grid generation is the next step in the procedure. The discretization of a fluid domain into finite volumes is known as grid generation. Discretization is the process of transforming partial differential equations into algebraic equations. To improve the quality of the volume mesh, a surface mesh for the domain is generated first, followed by the final volume mesh after the appropriate surface mesh adjustments.

- **Boundary conditions:**

Setting the boundary conditions is the last step in the preprocessing procedure. The mesh is examined and resized, and the domain's boundary conditions are specified.

SOLUTION:

- The solution is produced after setting the solution monitors, convergence criteria, and the number of iterations.

3.9 FEA METHODOLOGY

For structural analysis, the 3Dmodel was meshed with SOLID parts.

SOLID185 Element: SOLID185 is a programme for modelling solid structures in three dimensions. It is made up of eight nodes, each of which has three degrees of freedom: translations in the nodal x, y, and z directions. Plasticity, hyperelasticity, stress stiffening, creep, huge deflection, and big strain capacities are all features of this element. It can also simulate deformations of virtually incompressible elasto-plastic materials and fully incompressible hyper elastic materials using mixed formulations.

Boundary Conditions: A static structural analysis is followed by a modal analysis to perform a pre-stress modal analysis. For linear static analysis, pressure is uniformly distributed across the exterior surface of the skin. The stresses and displacements created during static analysis are saved and used as input for the modal analysis that follows.

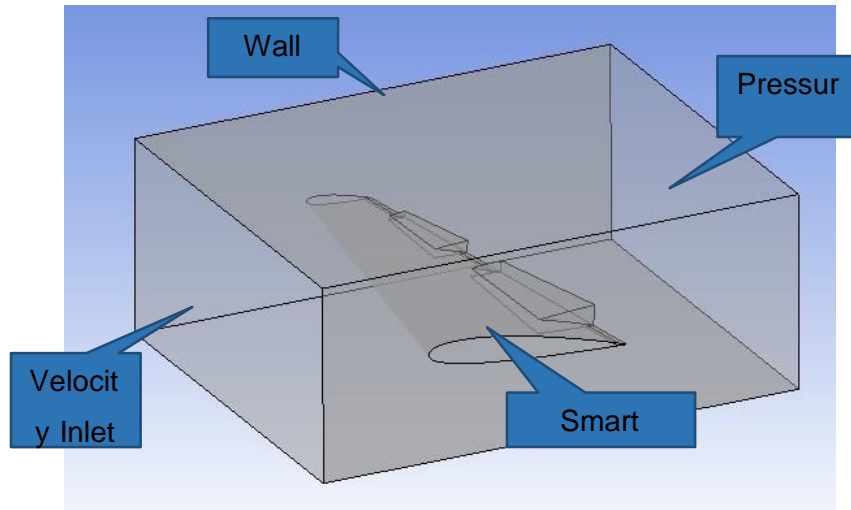
POSTPROCESSING

The answers are shown as needed graphs, contour plots, vector plots, path lines, or numerical reports can be generated.

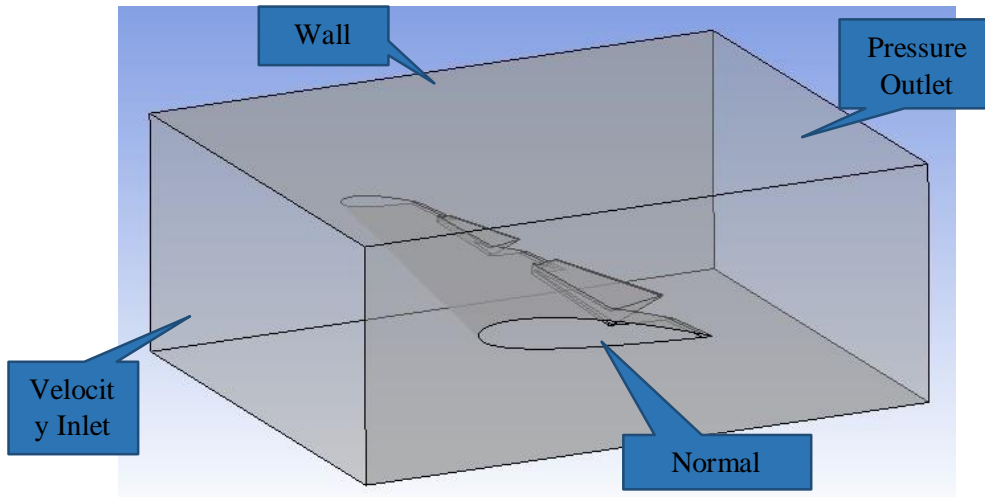
GRID GENERATION

Extracted fluid volume:

Geometry-Smart Wing

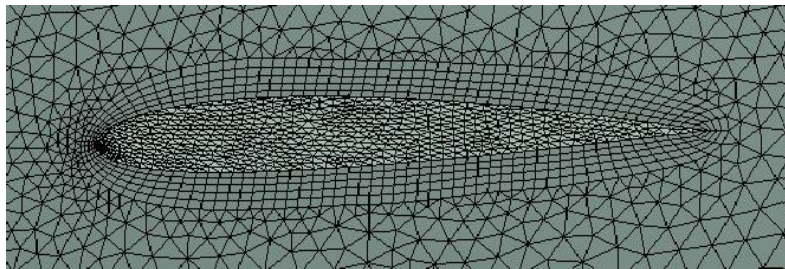
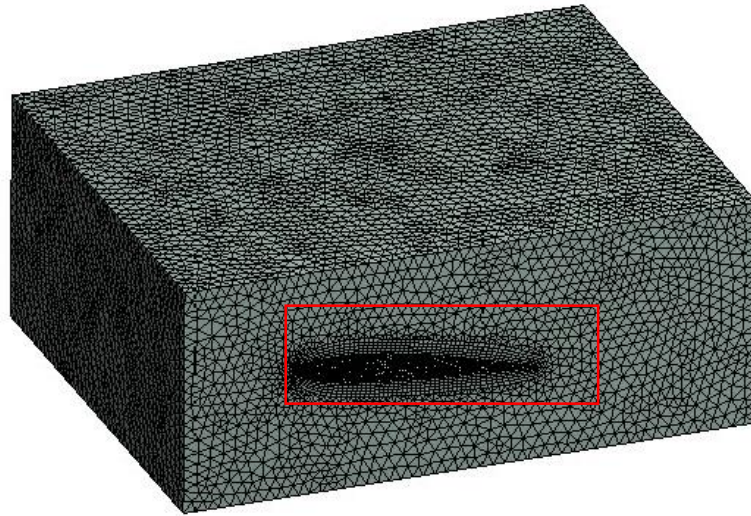


Geometry- Smart Wing



Geometry- Normal Wing

CFD Mesh Model:



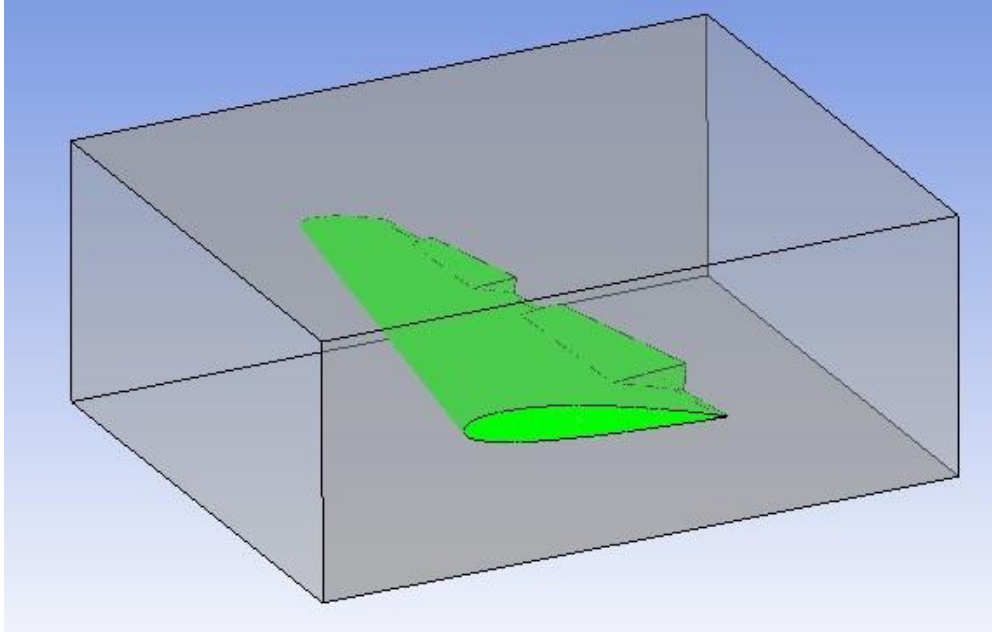
BOUNDARY CONDITIONS APPLIED:

Normal & Smart wing

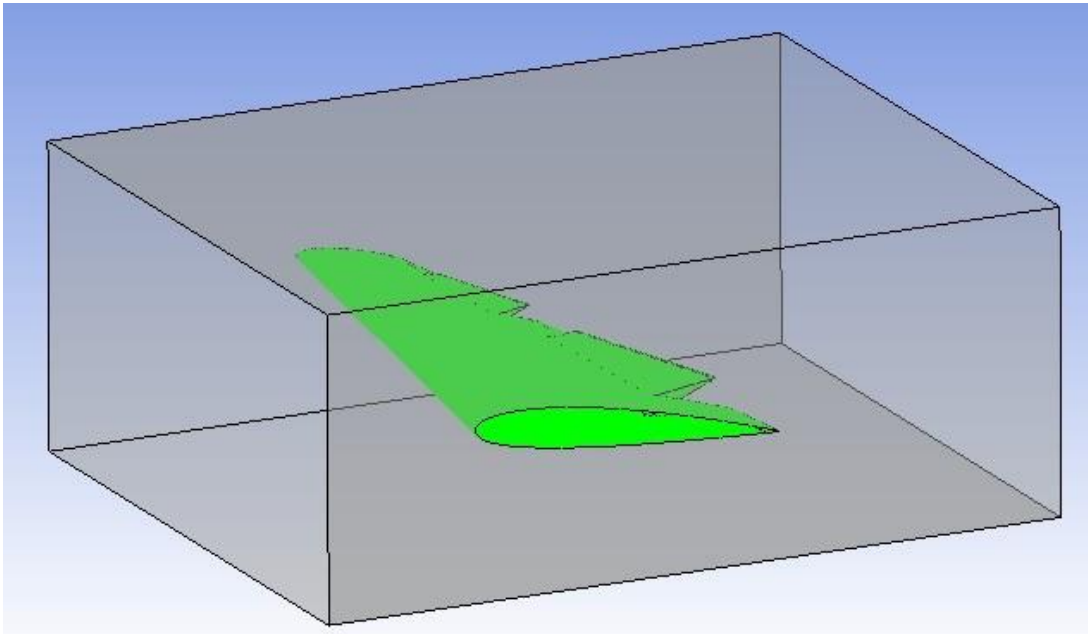
Velocity Inlet: 300 m/s

Pressure Outlet: Atmospheric Pressure

Turbulence Model: Standard k-epsilon, Standard wall function



Smart Wing in Fluid Domain



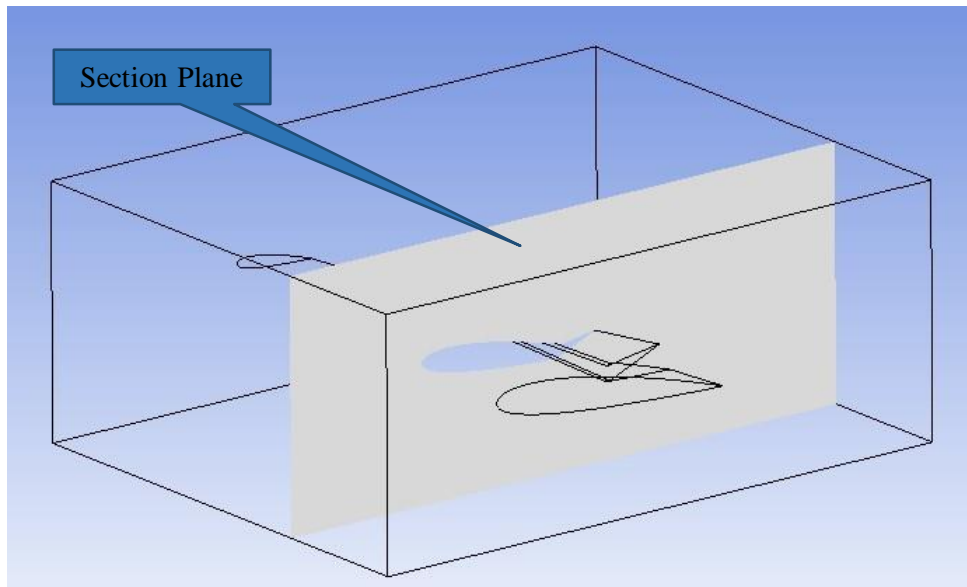
Normal Wing in Fluid Domain

Chapter 4 CFD Analysis - Results

Normal Wing

Plane at normal wing having ailerons:

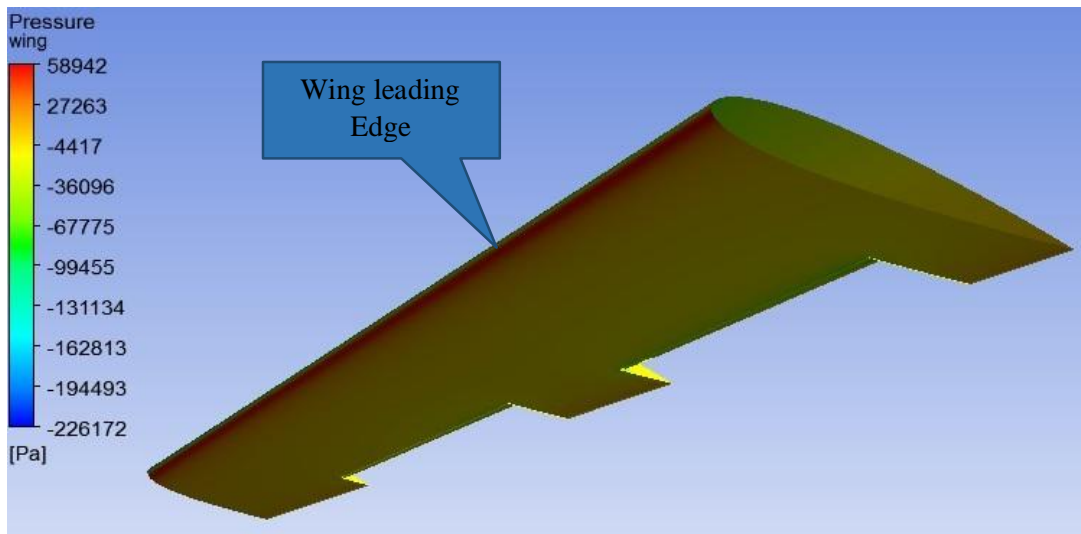
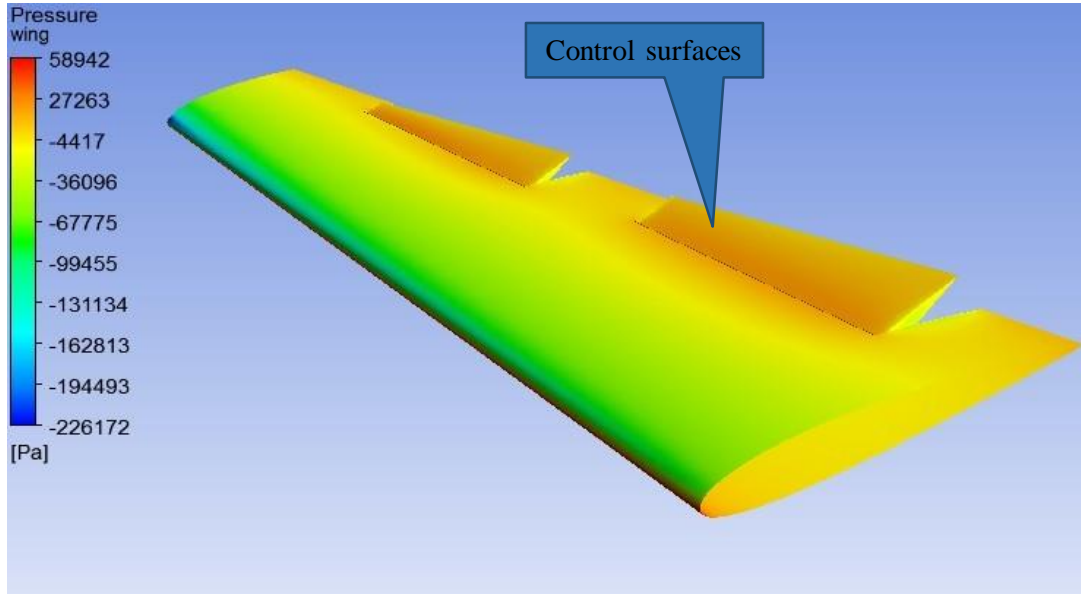
To see the effect, we made a section plane along the wing's lateral axis, as shown above. We can see the contour plots above the wing and below the wing from here.



The plane is constructed at the mid-section of the aileron to examine the flow distribution over the wing due to aileron up. Throughout the domain, the plane is designed.

Normal Wing:

Contours of static pressure on wing surface

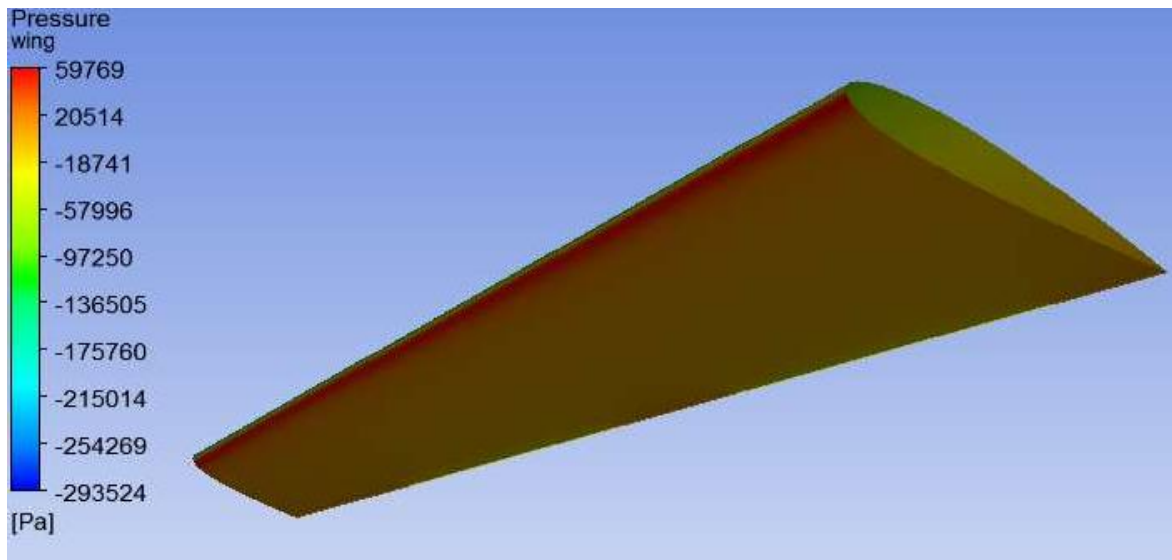
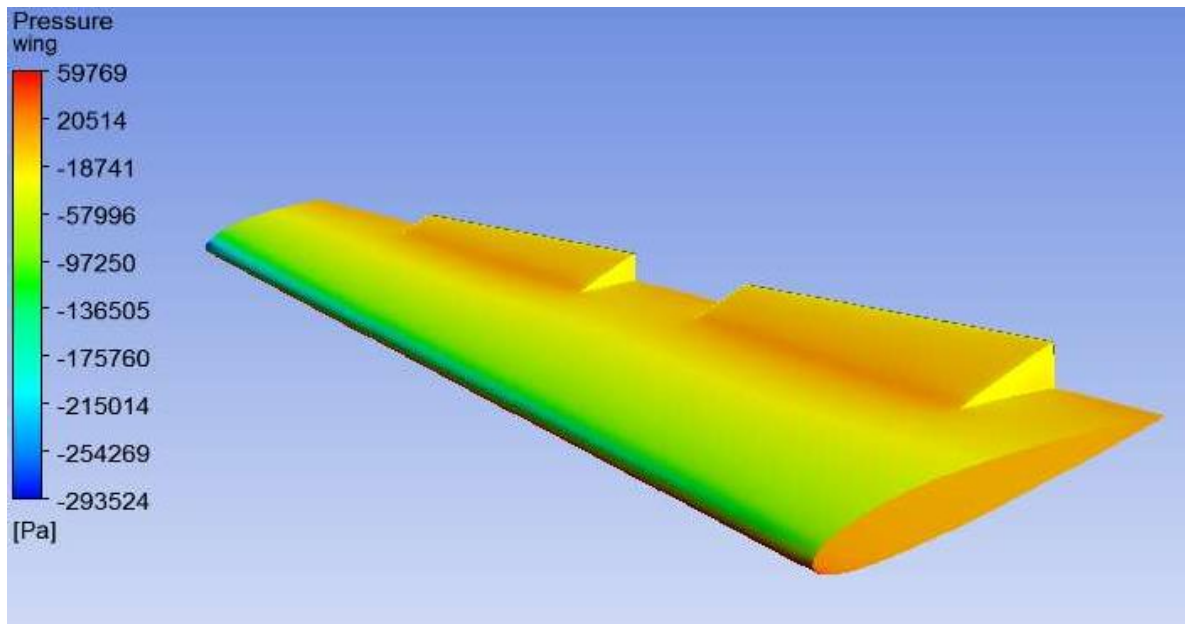


Above is a graph of the static pressure distribution. The pressure distribution over the wing can be seen from this result. During the effect of rolling

At control surfaces, there is a lot of pressure. At the leading edge of the wing, the greatest pressure is obtained.

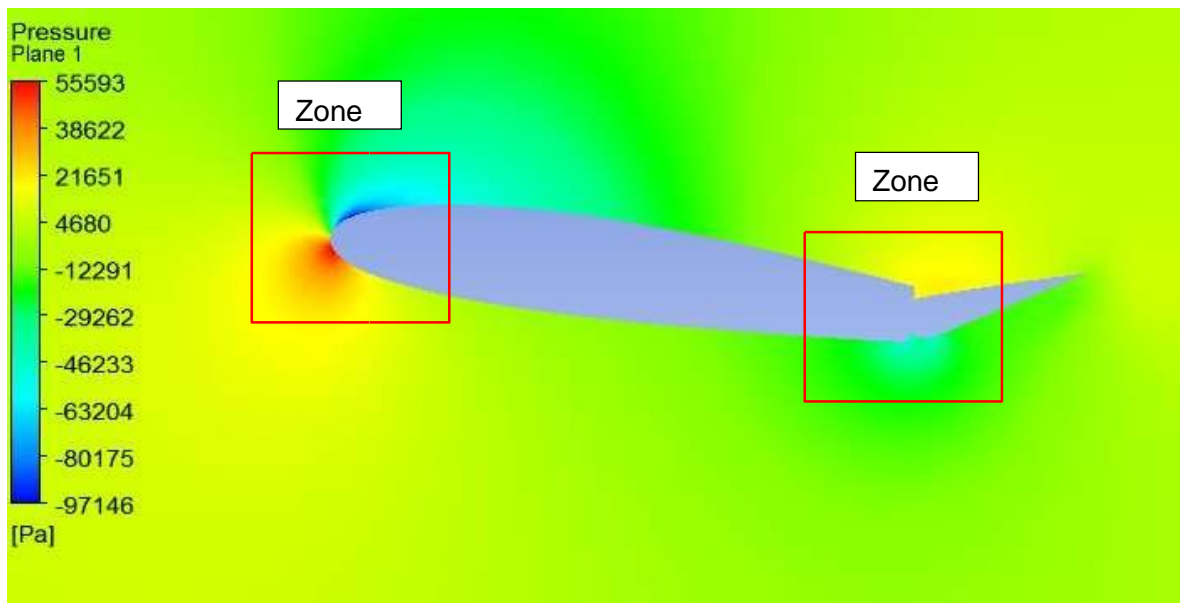
Smart Wing:

Contours of static pressure on wing surface



The static pressure distribution plot in the smart wing model, like the conventional wing model, shows that during roll effect, the pressure is high at control surfaces and the maximum pressure is obtained at the leading edge of the wing.

Contours of Static Pressure at section plane



Section Plane- normal wing

The flow distribution over the wing at the control surface is illustrated using the section plane shown above. The pressure appears to be strong at the wing tip (zone 1) and the control surface (zone 2), as seen in the CFD result.

plainly. As a result of this,

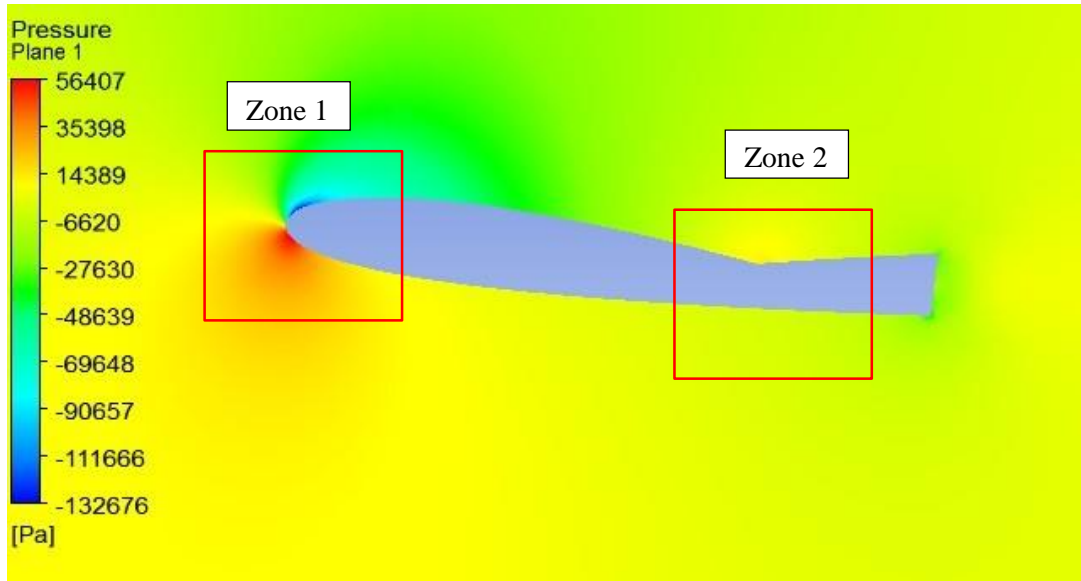
a high level of pressure on the lower surface of the

the command

The aeroplane will tend to roll on the surface.

However, a loss pressure region is detected at zone 2 due to discontinuity between the base wing structure and control surface, resulting in Circulation and

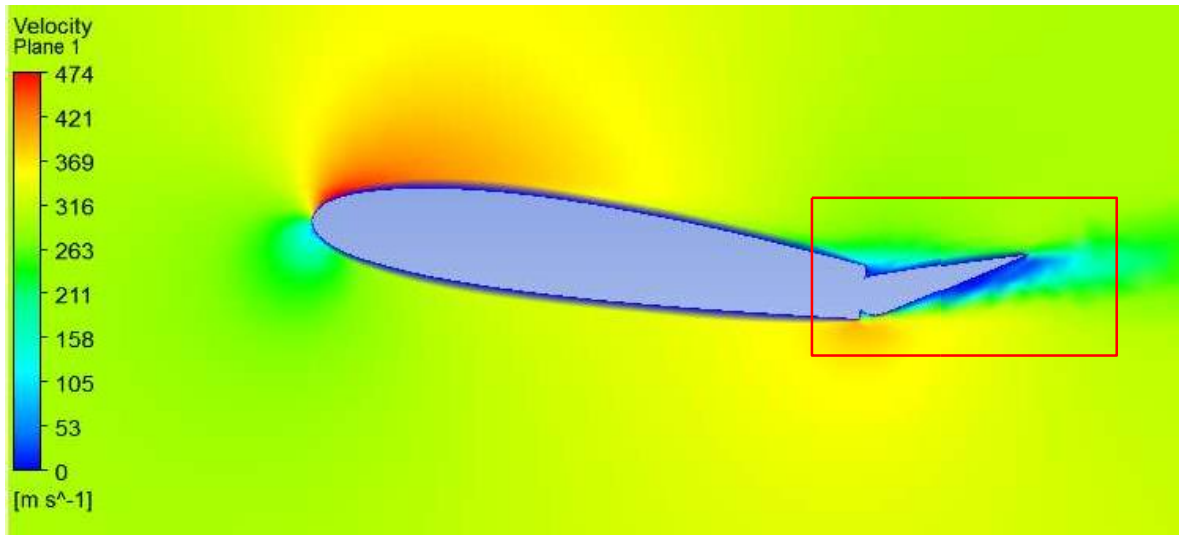
air loss As a result, pressure drag will increase.



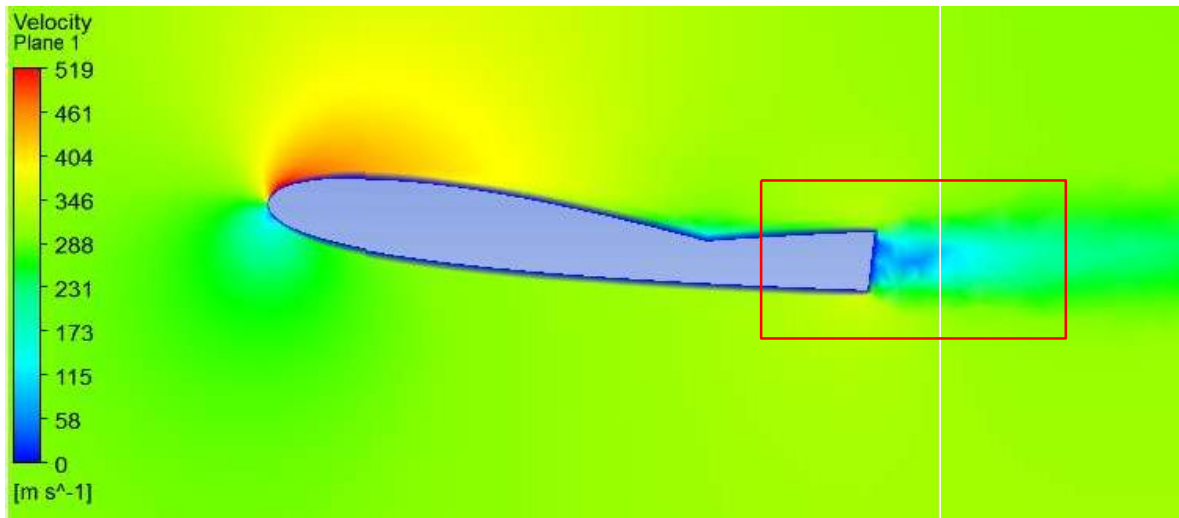
Section Plane- Smart wing

Smart wing, like regular wing, has a higher static pressure at the leading edge of the wing in zone 1. As expected, the top of the control surface has a high pressure region, and air circulation is avoided due to a low pressure region. This is because smart wing and smooth wing continuation were introduced.

Contours of Velocity distribution



Section Plane- Normal wing



Section Plane- Smart wing

The Velocity contour graphs show that, in comparison to a conventional wing, the smart wing has a smooth velocity distribution at the trailing end (as highlighted above). As a result, recirculation is reduced, and induced drag at the trailing edge of the wing is reduced.

5.1 FE ANALYSIS

5.1.1 Fluid Structure Interaction

Fluid-structure interactions (FSI), or interactions of a moveable or deformable structure with an interior or surrounding fluid flow, are one of the most important and demanding multi-physics challenges in terms of modelling and computing.

Such interactions can be either stable or oscillatory, and they are an important factor in the design of many technical systems, particularly aircraft. Failure to consider the consequences of FSI can be disastrous, especially in large-scale structures and those made up of materials prone to failure.

Fluid-structure interactions can be classified into three groups:

- Interactions with zero strain, such as the transport of suspended solids in a liquid matrix.
- Interactions with constant strain steady flow, such as the transport of suspended solids in a liquid matrix.

The constant force acting on an oil pipeline as a result of viscous friction between the pipeline walls and the fluid.

- Interactions between oscillators:

The strain created in the solid structure leads it to move, reducing the source of strain, and the structure returns to its original state, only to repeat the process.

We modelled the fluid pressure load as a constant strain steady flow interaction in this research. The wing and its control surfaces are subjected to a load known as lift load or aerodynamic load when the control surface is deployed.

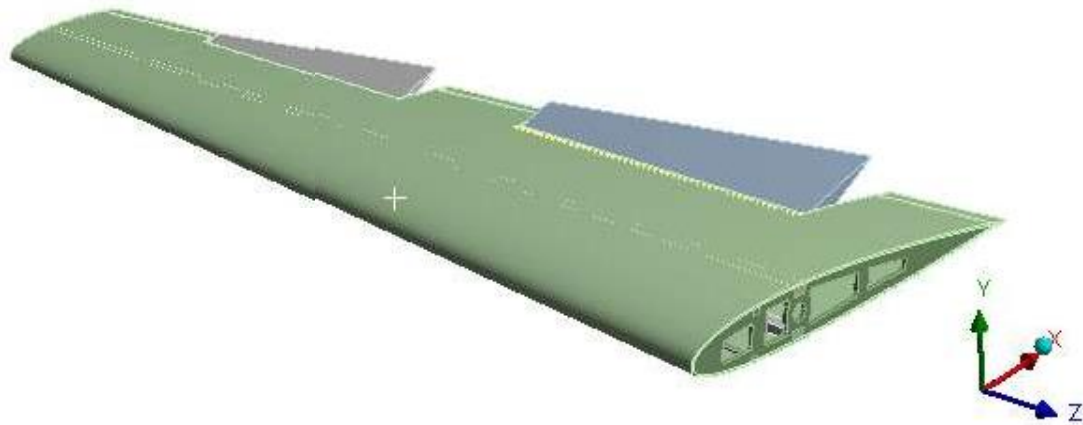
Constant strain steady flow fluid structure interaction analysis is used to assess structural deformation caused by this aerodynamic force.

The wing assembly is structurally validated using the loads acquired from the CFX-CFD analysis findings, which are loaded into the Ansys structural analysis deck.

The FE modeling approach and results are discussed in this section.

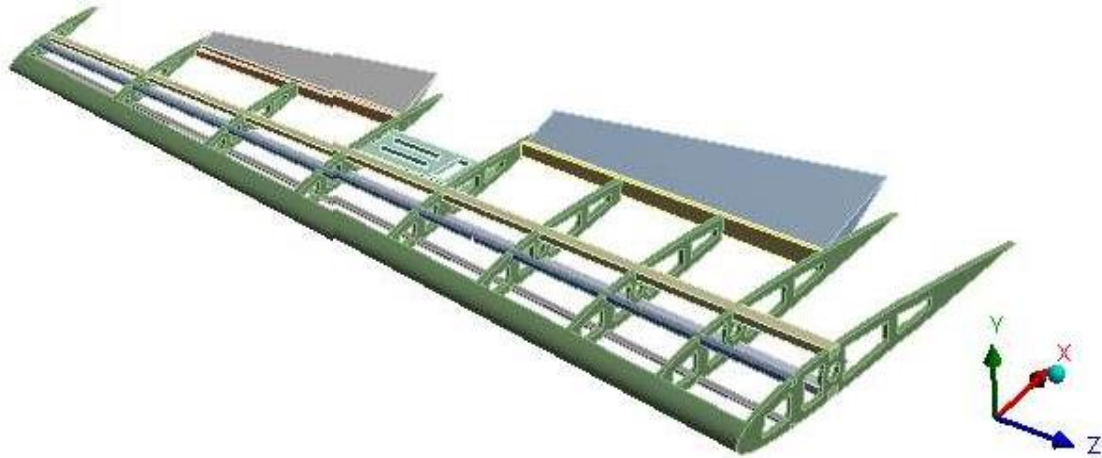
FE model

Geometry



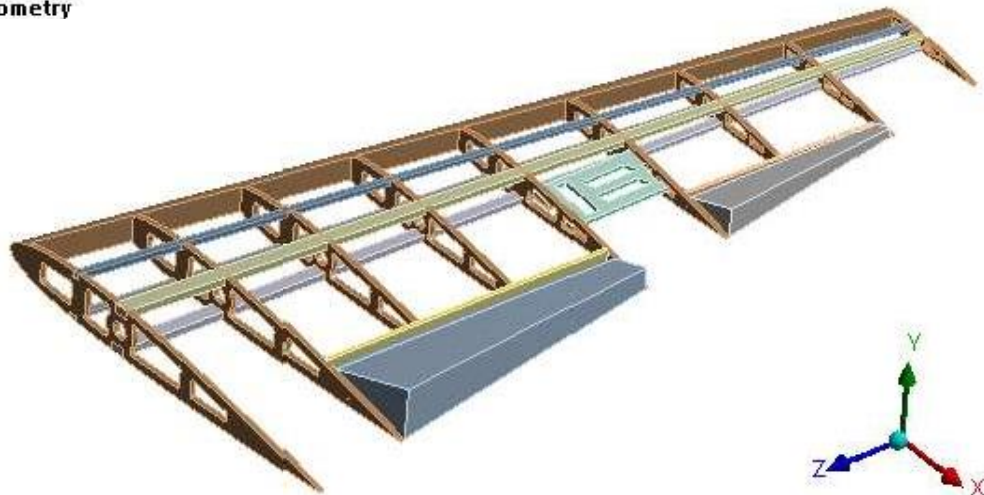
Normal wing structure

Geometry



Normal wing skeleton (Ribs, struts, longerons etc)







Geometry



Smart wing skeleton (Ribs, struts, longerons etc)

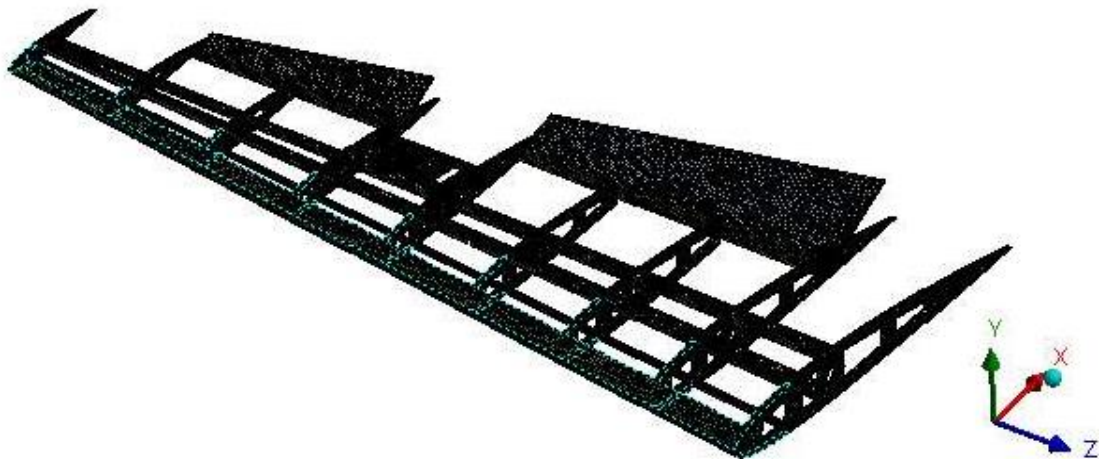
Aluminum alloy is used for all structural components, including the Smart wing skin and the standard wing structure.

Material properties of Aluminum alloy:

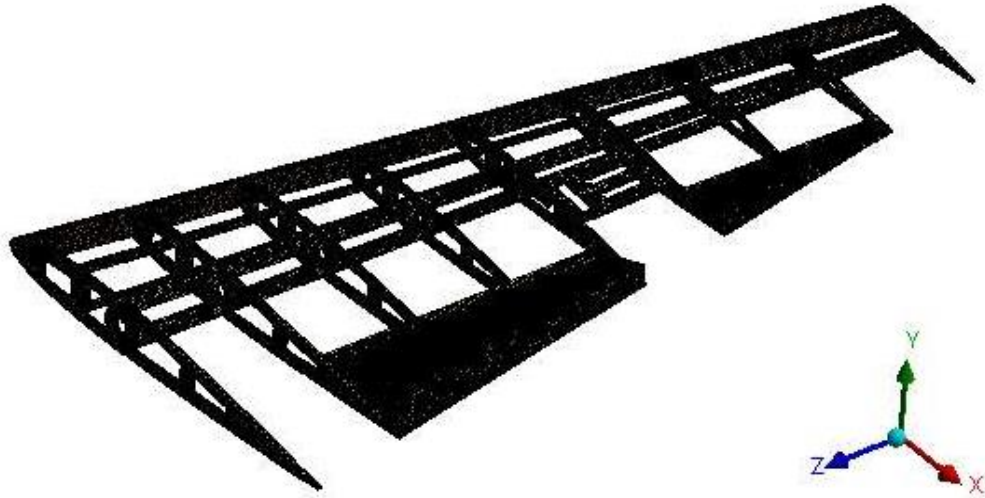
A	B	
Property	Value	
 Density	2770	kg m ⁻³
 Isotropic Secant Coefficient of Thermal Expansion		
 Coefficient of Thermal Expansion	2.3E-05	C ⁻¹
 Reference Temperature	22	C
 Isotropic Elasticity		
Derive from	Young's Modulu... 	
Young's Modulus	7.1E+10	Pa
Poisson's Ratio	0.33	
Bulk Modulus	6.9608E+10	Pa
Shear Modulus	2.6692E+10	Pa

 Tensile Yield Strength	280	MPa
 Compressive Yield Strength	280	MPa
 Tensile Ultimate Strength	310	MPa

Finite Element Mesh Model:



Normal wing structure

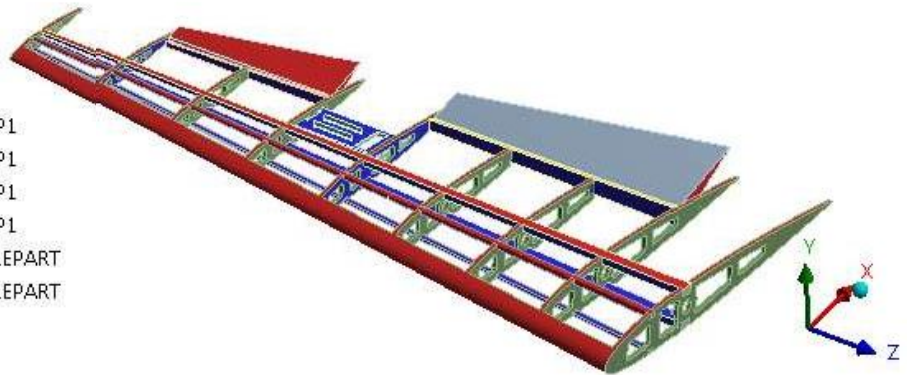


Smart wing skeleton (Ribs, struts, longerons etc)

FE Contacts of Normal wing and smart wing

Bonded - Multiple To CL_PROFILE
 Items: 10 of 15 indicated

- A** Bonded - RIP1 To RIP2
- B** Bonded - RIP1 To RIP4
- C** Bonded - RIP1 To RIP6
- D** Bonded - RIP1 To RIP5
- E** Bonded - Multiple To RIP1
- F** Bonded - Multiple To RIP1
- G** Bonded - Multiple To RIP1
- H** Bonded - Multiple To RIP1
- I** Bonded - RIP1 To MIDDLEPART
- J** Bonded - RIP1 To MIDDLEPART

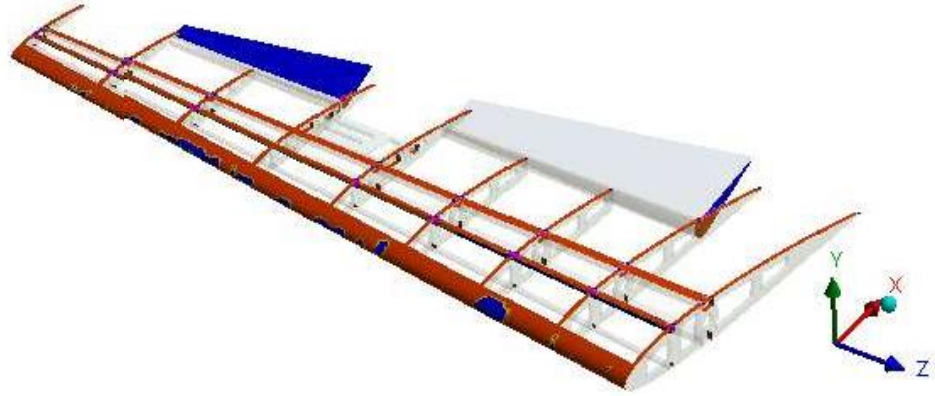


Status

Type: Status

Time: 0

- Over Constrained
- Far
- Near
- Sliding
- Sticking



Wing Structural components contact status plot

Loads and Boundary conditions:

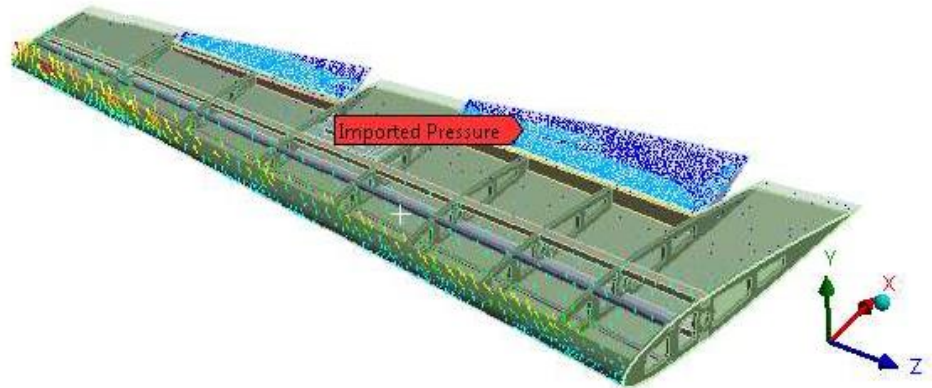
Imported Pressure load from CFD – Normal Wing

E: Static Structural

Imported Pressure

Unit: MPa

- 0.13809 Max**
- 0.12275
- 0.10742
- 0.092083
- 0.076748
- 0.061413
- 0.046078
- 0.030743
- 0.015408
- 7.2565e-5 Min**



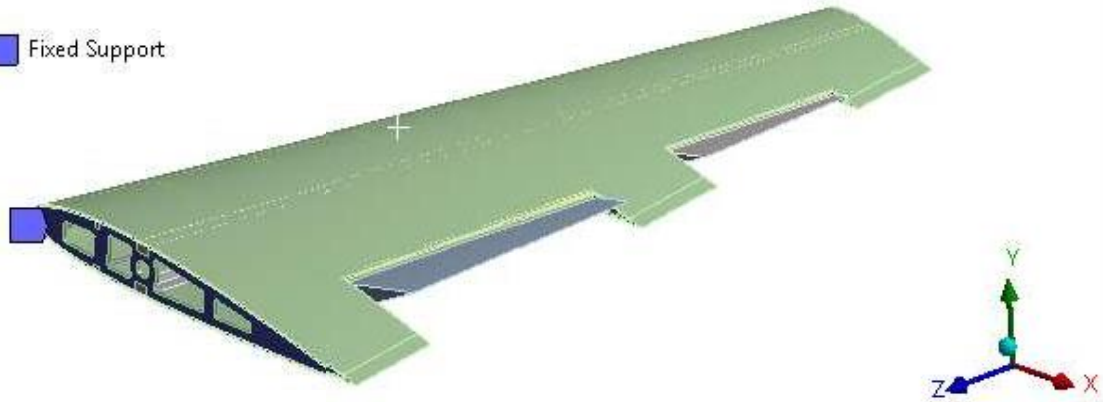
Fixed Support

E: Static Structural

Fixed Support

Time: 1. s

Fixed Support



FE analysis results:

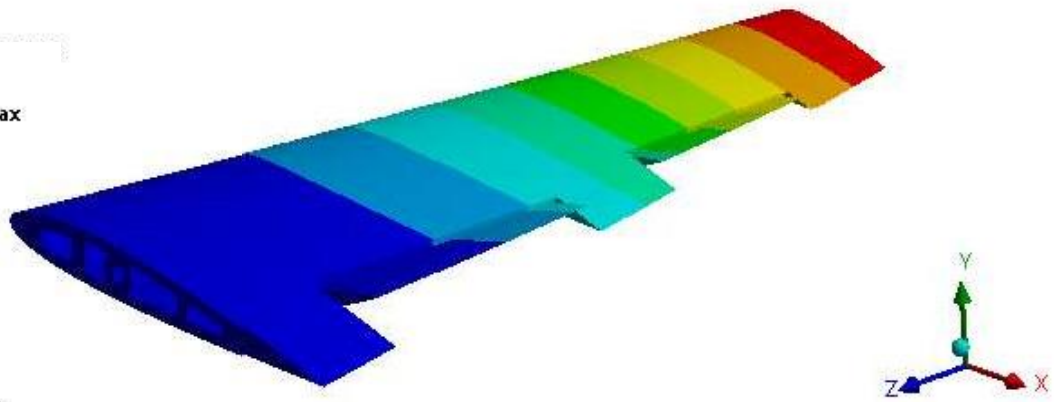
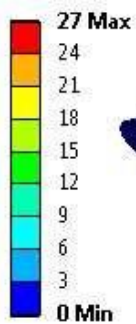
E: Static Structural

Total Deformation

Type: Total Deformation

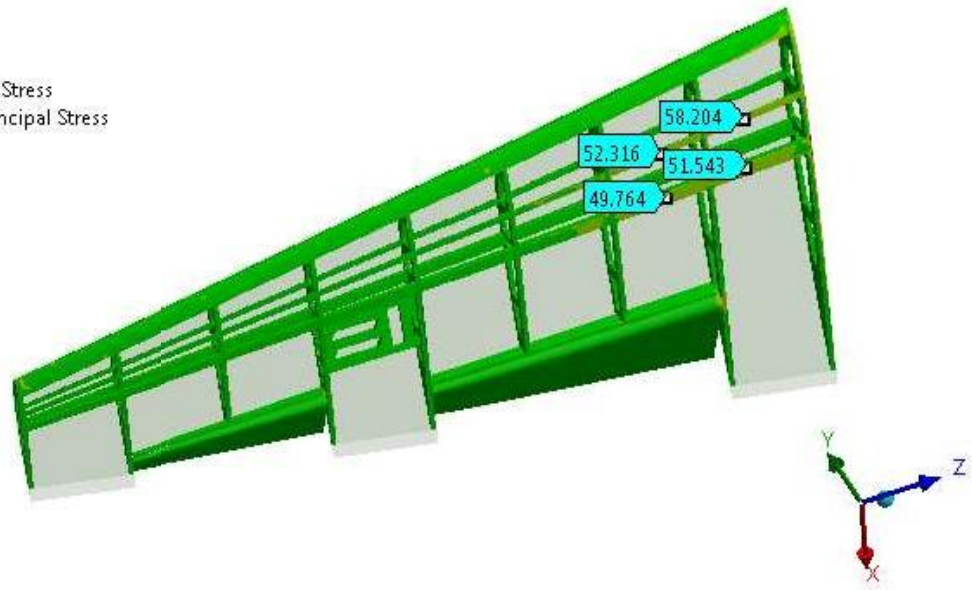
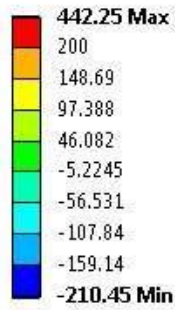
Unit: mm

Time: 1



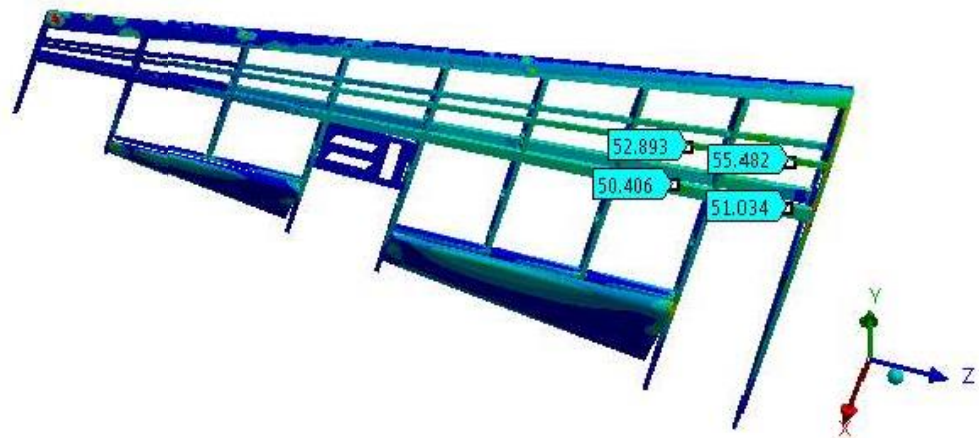
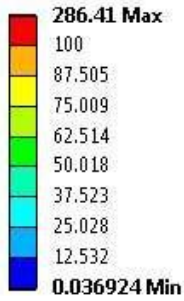
Total Deformation Plot

E: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1



Maximum principal Stress: 58 MPa

E: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1

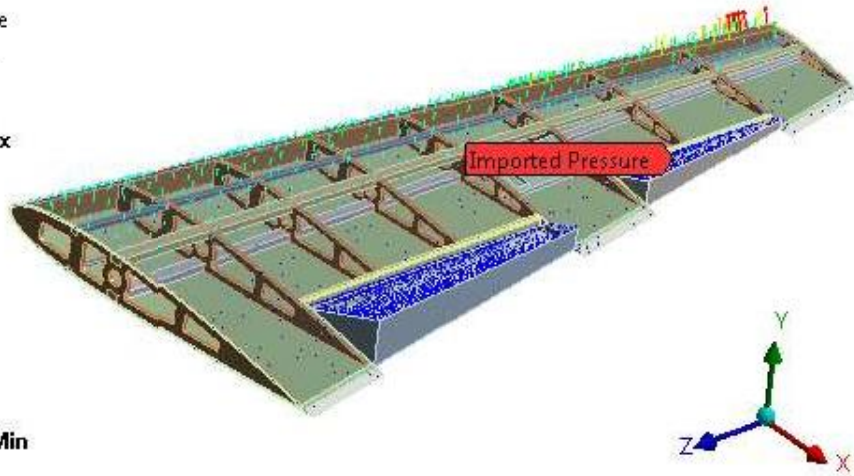
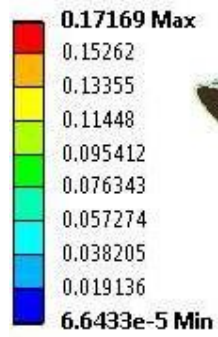


Maximum Equivalent Stress: 55 MPa

Imported Pressure load from CFD – Smart Wing

B: Static Structural

Imported Pressure
Unit: MPa

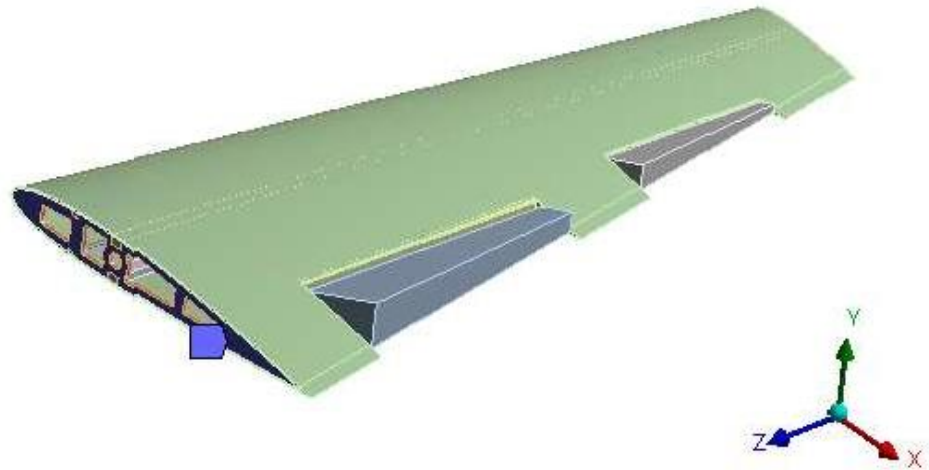


Fixed Support

B: Static Structural

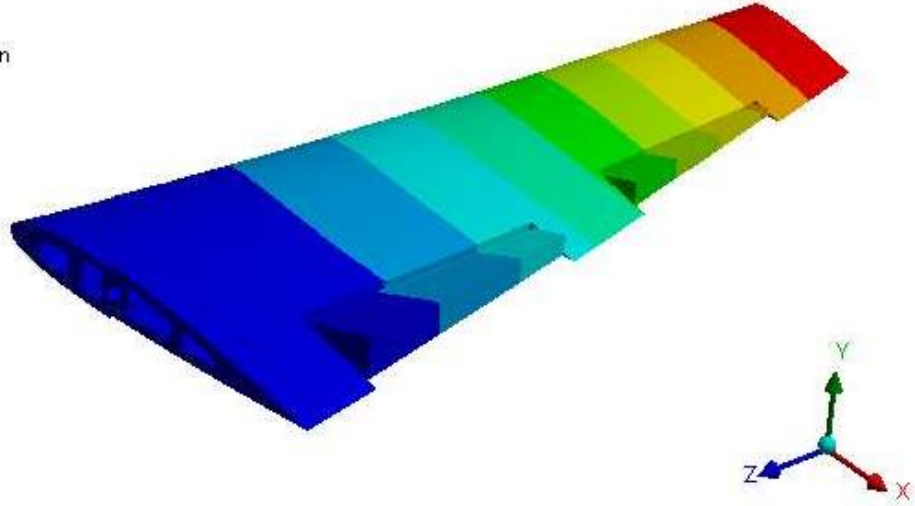
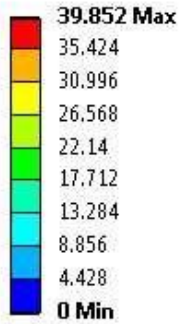
Fixed Support
Time: 1. s

Fixed Support



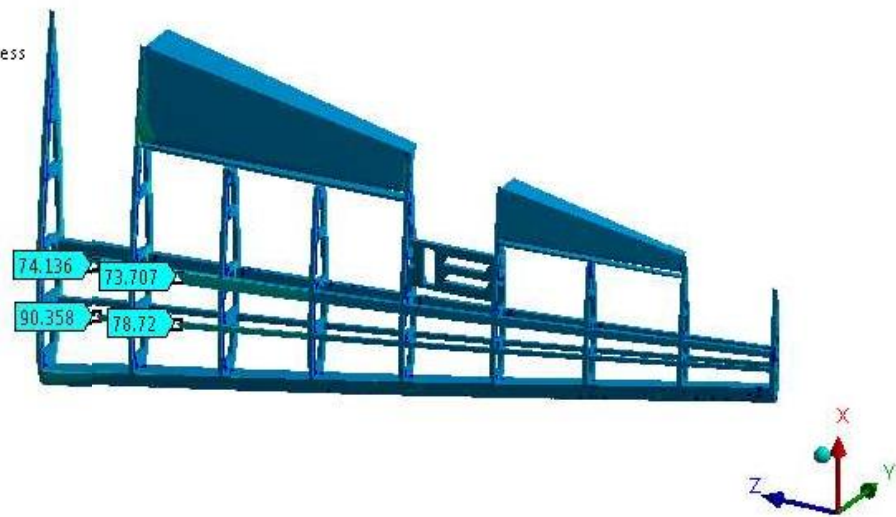
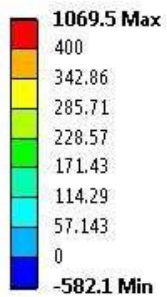
FE analysis results:

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1

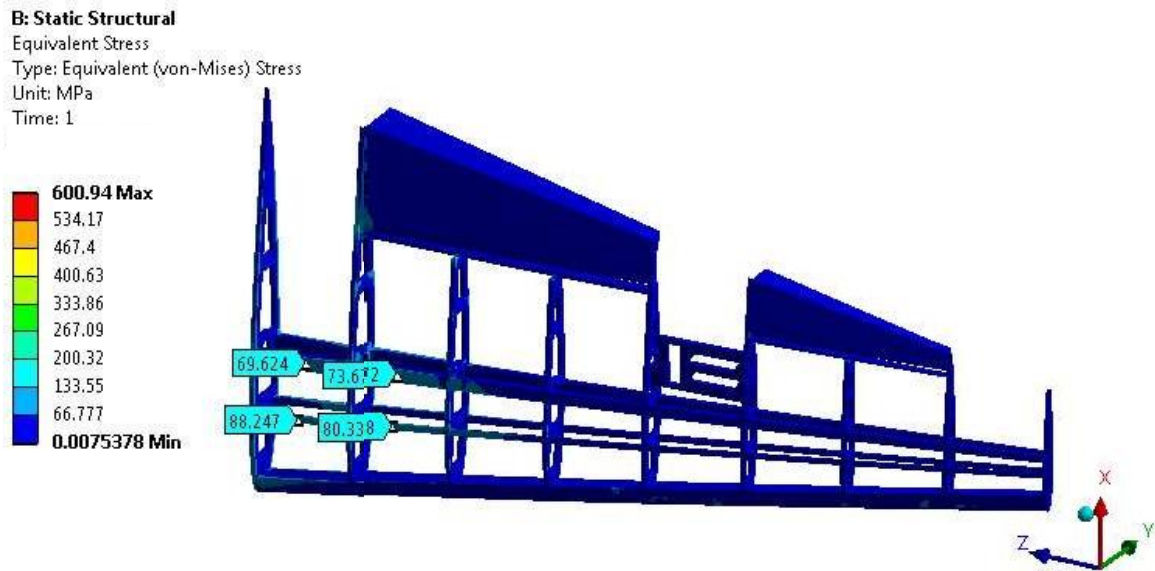


Total Deformation Plot

B: Static Structural
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1



Maximum principal Stress: 90 MPa



Maximum Equivalent Stress: 88 MPa

6.0 Conclusion & Discussions

Aluminum alloy material has a yield tensile strength of 280 MPa. From the start,

Following observations, computational and FE static structural analysis findings for both smart wings are shown.

both typical and

- For a normal wing, the maximum principal stress and maximum equivalent stress are within the material's permissible limits (YTS: 280 MPa).
- The optimised smart wing's maximum principal stress and maximum equivalent stress are both within the material's allowed limits (YTS: 280 MPa).
- According to CFD study, smart wing has a smooth fluid flow transition near control surfaces compared to regular wing, which decreases drag and makes maneuvering smooth.