

EXPERIMENTAL INVESTIGATION OF MODIFIED NACA AIRFOIL UNDER SUBSONIC CONDITIONS

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in
Aeronautical Engineering

By

P. Emmanuel Wilson (Reg. No. 37260012)

Afsal K. (Reg. No. 37260002)



DEPARTMENT OF AERONAUTICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade “A” by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119

APRIL 2021



SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with "A" grade by NAAC
Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119
www.sathyabama.ac.in



DEPARTMENT OF AERONAUTICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of P. EMMANUEL WILSON (Reg. No. 37260012) and AFSAL K. (Reg. No. 37260002) who carried out the project entitled "**EXPERIMENTAL INVESTIGATION OF MODIFIED NACA AIRFOIL UNDER SUBSONIC CONDITIONS**" under our supervision from December 2020 to April 2021.

Internal Guide

Mr. GUNASEKARAN., M.E.,

Head of the Department

Dr. BOOMA DEVI, ME., PhD.,

Submitted for Viva voce Examination held on _____

Internal Examiner

External Examiner

DECLARATION

We AFSAL K. (37260002) and P.EMMANUEL WILSON (Reg.No. 37260012) hereby declare that the Project Report entitled “**EXPERIMENTAL INVESTIGATION OF MODIFIED NACA AIRFOIL UNDER SUBSONIC CONDITIONS**” done by us under the guidance **Mr. GUNASEKARAN., M.E.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE: 30.04.2021

SIGNATURE OF THE CANDIDATE

PLACE: CHENNAI

ACKNOWLEDGEMENT

We are pleased to acknowledge my sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

We convey my sincere thanks to **Dr. S. Prakash, M.E., Ph.D.**, Dean, School of Mechanical Engineering and **Dr. BOOMA DEVI, ME., PhD.** Head of the Department, Dept. of Aeronautical Engineering for providing me necessary support and details at the right time during the progressive reviews.

We would like to express my sincere and deep sense of gratitude to my Project Guide **Mr. GUNASEKARAN., M.E.**, for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

We also express my thanks to all Teaching and Non-teaching staff members of the Department of Aeronautical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The wing of the aircraft is the primary control surface that produces lift and is the chief aerodynamic operator of the aircraft. Over the years many wing modifications have been proposed and studies. In this project work a modified NACA airfoil where a stepwise discontinuity was introduced at a distance from the trailing edge, this new airfoil design concept enables the user to operate at a broader range of angles of attack, it also considerably increases the lift and drag and hence enhancing the overall performance of the aircraft. The enhanced performance has been seen to be very pronounced during the stalling conditions. The stall performance of the unmodified NACA 2412 airfoil and the stall performance of this aircraft with the modification is tested and the modification is seeming to be producing better performance in terms of lift and drag. The computational fluid dynamics analysis was carried out following a smoke test in a subsonic wind tunnel for considerably low Reynold's number. The simulation and experimental results satisfactorily prove that this modification provides better lift and drag characteristics

TABLE OF CONTENTS

CHAPTER No.	TITLE	PAGE No.
	ABSTRACT	v
	LIST OF FIGURES	viii
	LIST OF TABLES	ix
1	INTRODUCTION	1
1.1	WING	1
1.2	WING MODIFICATION	1
1.2.1	Performance during stall	1
1.2.2	Lift and Drag performance	1
1.3	WING	2
1.3.1	Wing Feature	2
1.4	Wing Configuration	3
1.4.1	Number and position of main planes	4
1.4.2	Wing Support	7
1.5	Wing Planform	9
1.5.1	Aspect Ratio	9
1.5.2	Chord variation along span	10
1.6	Wing Sweep	14
1.6.1	Sweep variation along span	15
1.6.2	Asymmetrical	16
1.6.3	Tailplanes and foreplanes	16
1.6.4	Dihedral and Anhedral	18
1.7	Wings vs bodies	20
1.8	Variable geometry	21
1.9	Variable Planform	21
1.10	Variable chord	22
1.11	Polymorphism	23
1.12	Minor independent surfaces	23

CHAPTER No.	TITLE	PAGE No.
	1.13 Variable geometry	24
	1.14 High lift	24
	1.15 Spanwise flow control	25
	1.16 Vortex creation	25
	1.17 Drag reduction	26
	1.18 TESTS CARRIED OUT	27
2	LITERATURE SURVEY	28
3	AIM AND SCOPE	41
	3.1 Existing Modification	41
	3.2 Aim	41
	3.2 Scope of the Project	41
4	METHODOLOGY	42
	4.1 METHODOLOGY	42
5	CFD ANALYSIS	44
	5.1 CAD DESIGN	44
	5.2 CFD ANALYSIS	48
	5.2.1 Design Parameters	48
	5.2.2 Mesh	48
	5.2.3 Boundary Conditions	48
	5.2.4 CFD Results	49
6	WIND TUNNEL EXPERIMENT	56
	6.1 Fabricated Model	56
	6.2 Smoke Test	56
7	RESULTS	58
	7.1 CFD Results	58
	7.1.1 Pressure contour	58
	7.2 Smoke Test Results	59
8	RESULT AND SUMMARY	
	8.1 RESULT	60
	6.2 SUMMARY	60

LIST OF FIGURES

FIGURE No	TITLE	PAGE No.
1.1	Fixed-wing aircraft	5
1.2	Busemann biplane in cross-section	6
1.3	Biplane Configuration	6
1.4	Cruciform Wing	7
1.5	Biplane wings	8
1.6	Other Biplane wings	8
1.7	Other Wing types	9
1.8	Aspect Ratio	10
1.9	Chord Variation	11
1.10	Elliptical and Semi Elliptical Wings	12
1.11	Other Wing types	13
1.12	Delta Wing	14
1.13	Wing Sweep	15
1.14	Sweep along span	16
1.15	Types of asymmetry	16
1.15	Tail Configurations	19
1.16	Wing types	19
1.17	Wing tip types	20
5.1	The Original NACA 2412 airfoil CAD Model	44
5.2	First CAD Modification	44
5.3	Second CAD Modification	46
5.4	Third CAD Modification	46
5.5	Fourth CAD Modification	47
5.5	Fifth CAD Modification	47
5.6	Enclosure Visualisation	48
5.7	Mesh with enclosure	48
5.8	The Coefficient of Lift vs Alpha for the NACA airfoil	50
5.9	The Coefficient of Lift vs Alpha for the First modification airfoil	50

FIGURE No	TITLE	PAGE No.
6.1	Fabricated Modified Model	56

LIST OF TABLES

TABLE No	TITLE	PAGE No.
5.1	NACA 2412 Computational Results	49
5.2	First Modification Computational Results	52

CHAPTER 1

INTRODUCTION

One of the basic requirements of an airfoil is to produce a more lift and reduced drag. Over the years there had been many wing modifications that were suggested and were aimed at this particular requirement. In this project a similar modification – a stepwise discontinuity was introduced and the flow conditions were tested when the wing was operated at high angles of attack – even during stall

1.1 WING

A Wing is the primary control surface of the aircraft which produces lift – the upward force in an aircraft. It has a leading edge at the front and a trailing edge at the bottom. The concept of stalling occurs at that point when even as the angle of attack increases the lift co-efficient keeps dropping

1.2 WING MODIFICATION

The new modification is the introduction of a stepwise aerodynamics discontinuity on the top surface of the airfoil. This modification produces an improvement in lift, drag and lift to drag ratio and overall better aerodynamic performance.

1.2.1 Performance during stall

This new stepwise discontinuity which is introduced in the top surface of the wing introduces a turbulence at the top surface which will eliminate the stall angle of the NACA airfoil and produces a much smoother stall transition and a much more smoother flow separation even at stall and higher angle of attack

1.2.2 Lift and Drag performance

This stepwise discontinuity which is introduced in the top surface of the wing introduces a turbulence at the top surface increases the lift, drag performance and the highlight is it is done even during the high angles of attack

1.3 WING

A wing is a type of fin that produces lift, while moving through air or some other fluid. As such, wings have streamlined cross-sections that are subject to aerodynamic forces and act as airfoils. A wing's aerodynamic efficiency is expressed as its lift-to-drag ratio. The lift a wing generates at a given speed and angle of attack can be one to two orders of magnitude greater than the total drag on the wing. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wings through the air at sufficient lift.

Lifting structures used in water include various foils, such as hydrofoils. Hydrodynamics is the governing science, rather than aerodynamics. Applications of underwater foils occur in hydroplanes, sailboats and submarines.

1.3.1 Wing Feature

Aircraft wings may feature some of the following:

- A rounded leading edge cross-section
- A sharp trailing edge cross-section
- Leading-edge devices such as slats, slots, or extensions
- Trailing-edge devices such as flaps or flaperons (combination of flaps and ailerons)
- Winglets to keep wingtip vortices from increasing drag and decreasing lift
- Dihedral, or a positive wing angle to the horizontal, increases spiral stability around the roll axis, whereas anhedral, or a negative wing angle to the horizontal, decreases spiral stability.

Aircraft wings may have various devices, such as flaps or slats that the pilot uses to modify the shape and surface area of the wing to change its operating characteristics in flight.

- Ailerons (usually near the wingtips) to roll the aircraft clockwise or counterclockwise about its long axis
- Spoilers on the upper surface to disrupt the lift and to provide additional traction to an aircraft that has just landed but is still moving.

- Vortex generators mitigate flow separation at low speeds and high angles of attack, especially over control surfaces.
- Wing fences to keep flow attached to the wing by stopping boundary layer separation from spreading roll direction.
- Folding wings allow more aircraft storage in the confined space of the hangar deck of an aircraft carrier
- Variable-sweep wing or "swing wings" that allow outstretched wings during low-speed flight (i.e., take-off and landing) and swept back wings for high-speed flight (including supersonic flight), such as in the F-111 Aardvark, the F-14 Tomcat, the Panavia Tornado, the MiG-23, the MiG-27, the Tu-160 and the B-1B Lancer warplanes
- Strakes to improve flight characteristics
- Chine, which may blend into the wing
- Leading-edge droop flap, a high-lift device
- Fairings, structures whose primary function is to produce a smooth outline and reduce drag. For example, flap track fairings

Wings may have other minor independent surfaces.

1.4 Wing Configuration

The wing configuration of a fixed-wing aircraft (including both gliders and powered aeroplanes) is its arrangement of lifting and related surfaces.

Aircraft designs are often classified by their wing configuration. For example, the Supermarine Spitfire is a conventional low wing cantilever monoplane of straight elliptical planform with moderate aspect ratio and slight dihedral.

Many variations have been tried. Sometimes the distinction between them is blurred, for example the wings of many modern combat aircraft may be described either as cropped compound deltas with (forwards or backwards) swept trailing edge, or as sharply tapered swept wings with large leading edge root extensions (or LERX). Some are therefore

duplicated here under more than one heading. This is particularly so for variable geometry and combined (closed) wing types.

Most of the configurations described here have flown (if only very briefly) on full-size aircraft. A few significant theoretical designs are also notable.

1.4.1 Number and position of main planes

Fixed-wing aircraft can have different numbers of wings:

- Monoplane: one wing plane. Since the 1930s most aeroplanes have been monoplanes. The wing may be mounted at various positions relative to the fuselage:
- Low wing: mounted near or below the bottom of the fuselage.
- Mid wing: mounted approximately halfway up the fuselage.
- Shoulder wing: mounted on the upper part or "shoulder" of the fuselage, slightly below the top of the fuselage. A shoulder wing is sometimes considered a subtype of high wing
- High wing: mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing mounted on a projection (such as the cabin roof) above the top of the main fuselage.
- Parasol wing: raised clear above the top of the fuselage, typically by cabane struts, pylon(s) or pedestal(s).

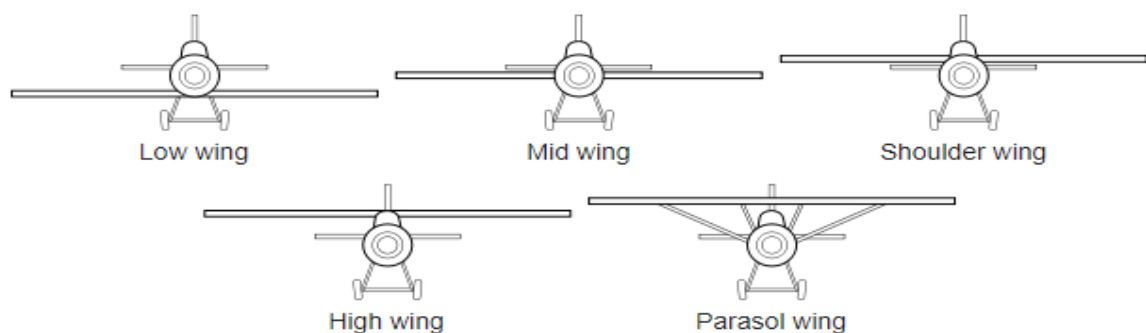


Fig 1.1 Fixed-wing aircraft

A fixed-wing aircraft may have more than one wing plane, stacked one above another:

- Biplane: two wing planes of similar size, stacked one above the other. The biplane is inherently lighter and stronger than a monoplane and was the most common configuration until the 1930s. The very first Wright Flyer I was a biplane.
- Unequal-span biplane: a biplane in which one wing (usually the lower) is shorter than the other, as on the Curtiss JN-4 Jenny of the First World War.
- Sesquiplane: literally "one-and-a-half planes" is a type of biplane in which the lower wing is significantly smaller than the upper wing, either in span or chord or both. The Nieuport 17 of World War I was notably successful.
- Inverted sesquiplane: has a significantly smaller upper wing. The Fiat CR.1 was in production for many years.
- Busemann biplane: a theoretical supersonic wing configuration, in which shock waves between the wing planes interfere to reduce their energy and wave drag.

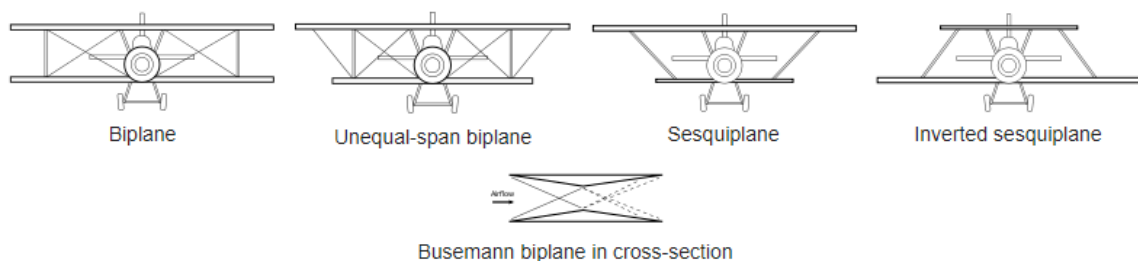


Fig 1.2 Busemann biplane in cross-section

- Triplane: three planes stacked one above another. Triplanes such as the Fokker Dr.I enjoyed a brief period of popularity during the First World War due to their manoeuvrability, but were soon replaced by improved biplanes.
- Quadruplane: four planes stacked one above another. A small number of the Armstrong Whitworth F.K.10 were built in the First World War but never saw service.
- Multiplane: many planes, sometimes used to mean more than one or more than some arbitrary number. The term is occasionally applied to arrangements stacked in tandem as well as vertically. The 1907 Multiplane of Horatio Frederick Phillips flew successfully with two hundred wing foils. See also the tandem wing, below.

A staggered design has the upper wing slightly forward of the lower. Long thought to reduce the interference caused by the low pressure air over the lower wing mixing with the high pressure air under the upper wing; however the improvement is minimal and its primary benefit is to improve access to the fuselage. It is common on many successful biplanes and triplanes. Backwards stagger is also seen in a few examples such as the Beechcraft Staggerwing.

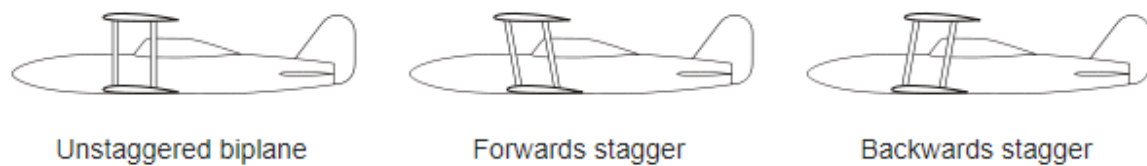


Fig 1.3 Biplane Configuration

A tandem wing design has two wings, one behind the other: see Tailplanes and foreplanes below. Some early types had tandem stacks of multiple planes, such as the nine-wing Caproni Ca.60 flying boat with three triplane stacks in tandem.

A cruciform wing is a set of four individual wings arranged in the shape of a cross. The cross may take either of two forms:

- Wings equally spaced around the cross-section of the fuselage, lying in two planes at right angles, as on a typical missile.
- Wings lying together in a single horizontal plane about a vertical axis, as in the cruciform rotor wing or X-wing.

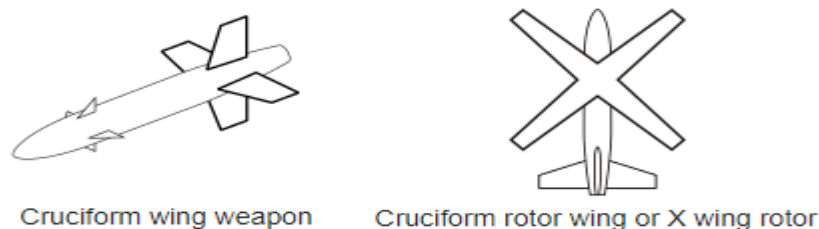


Fig 1.4 Cruciform Wing

1.4.2 Wing Support

To support itself a wing has to be rigid and strong and consequently may be heavy. By adding external bracing, the weight can be greatly reduced. Originally such bracing was always present, but it causes a large amount of drag at higher speeds and has not been used for faster designs since the early 1930s.

The types are:

- Cantilevered: self-supporting. All the structure is buried under the aerodynamic skin, giving a clean appearance with low drag.
- Braced: the wings are supported by external structural members. Nearly all multi-plane designs are braced. Some monoplanes, especially early designs such as the Fokker Eindecker, are also braced to save weight. Braced wings are of two types:
 - Strut braced: one or more stiff struts help to support the wing, as on the Fokker D.VII. A strut may act in compression or tension at different points in the flight regime.
 - Wire braced: alone (as on the Boeing P-26 Peashooter) or, more usually, in addition to struts, tension wires also help to support the wing. Unlike a strut, a wire can act only in tension.

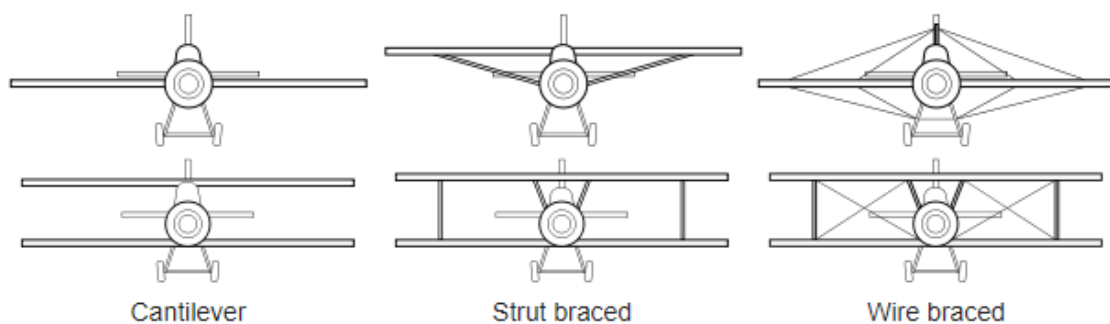


Fig 1.5 Biplane Wings

A braced multiplane may have one or more "bays", which are the compartments created by adding interplane struts; the number of bays refers to one side of the aircraft's wing panels

only. For example, the de Havilland Tiger Moth is a single-bay biplane where the Bristol F.2 Fighter is a two-bay biplane

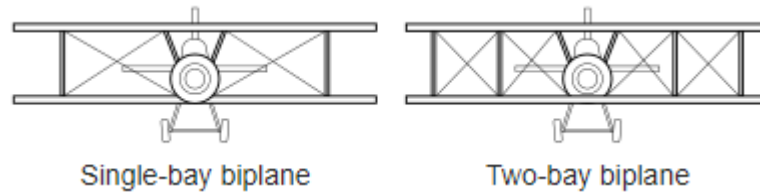


Fig 1.6 Other Biplane Wings

- Closed wing: two wing planes are merged or joined structurally at or near the tips in some way. This stiffens the structure and can reduce aerodynamic losses at the tips. Variants include:
 - Box wing: upper and lower planes are joined by a vertical fin between their tips. The first officially witnessed unaided take off and flight, Santos-Dumont's 14-bis, used this configuration and some Dunne biplanes were of this type as well. Tandem box wings have also been studied (see Joined wing description below).
 - Annular box wing: A type of box wing whose vertical fins curve continuously, blending smoothly into the wing tips. An early example was the Bleriot III, which featured two annular wings in tandem.
 - Annular (cylindrical): the wing is shaped like a cylinder. The Coléoptère had concentric wing and fuselage. It took off and landed vertically, but never achieved transition to horizontal flight. Examples with the wing mounted on top of the fuselage have been proposed but never built.
 - Annular (planar): the wing is shaped like a disc with a hole in it. A number of Lee-Richards annular monoplanes flew shortly before the First World War.
 - Joined wing: a tandem layout in which the front low wing sweeps back and/or the rear high wing sweeps forwards such that they join at or near the tips to form a continuous surface in a hollow diamond or triangle shape. The Ligeti Stratos is a rare example.

- Rhomboidal wing: a joined wing consisting of four surfaces in a diamond arrangement. The Edwards Rhomboidal biplane of 1911 had both wings in the same plane and failed to fly.

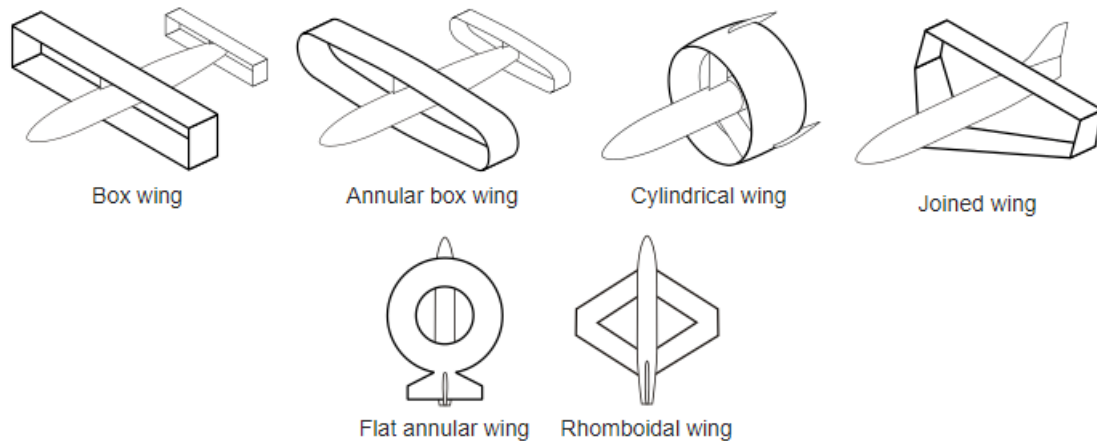


Fig 1.7 Other Wing types

1.5 Wing Planform

The wing planform is the silhouette of the wing when viewed from above or below.

1.5.1 Aspect ratio

The aspect ratio is the span divided by the mean or average chord. It is a measure of how long and slender the wing appears when seen from above or below.

- Low aspect ratio: short and stubby wing. More efficient structurally and higher instantaneous roll rate. They tend to be used by fighter aircraft, such as the Lockheed F-104 Starfighter, and by very high-speed aircraft including the North American X-15.
- Moderate aspect ratio: general-purpose wing, very widely used, for example on the Douglas DC-3 transport.
- High aspect ratio: long and slender wing. More efficient aerodynamically, having less induced drag. They tend to be used by high-altitude subsonic aircraft such as

airliners like the Bombardier Dash 8 and by high-performance sailplanes such as the Glaser-Dirks DG-500.

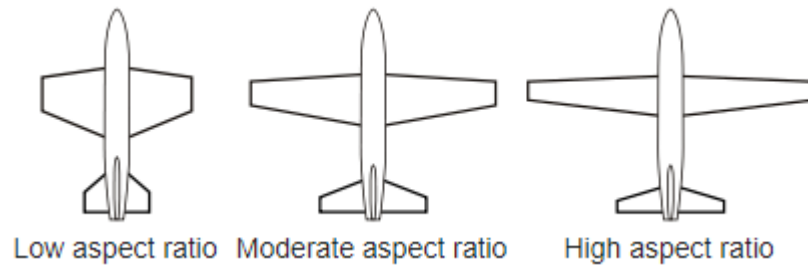


Fig 1.8 Aspect Ratio

Most variable geometry configurations vary the aspect ratio in some way, either deliberately or as a side effect.

1.5.2 Chord variation along span

The wing chord may be varied along the span of the wing, for both structural and aerodynamic reasons.

- Constant chord: parallel leading & trailing edges. Simplest to make, and common where low cost is important, such as on the Piper J-3 Cub but inefficient as the outer section generates little lift while adding both weight and drag. Sometimes known as the Hershey Bar wing in North America due to its similarity in shape to a chocolate bar.
- Tapered: wing narrows towards the tip. Structurally and aerodynamically more efficient than a constant chord wing, and easier to make than the elliptical type.
 - Trapezoidal: a tapered wing with straight leading and trailing edges: may be unswept or swept. The straight tapered wing is one of the most common wing planforms, as seen on the Messerschmitt Bf 109.
 - Inverse tapered: wing is widest near the tip. Structurally inefficient, leading to high weight. Flown experimentally on the XF-91 Thunderceptor in an attempt to overcome the stall problems of swept wings.

- Compound tapered: taper reverses towards the root. Typically braced to maintain stiffness. Used on the Westland Lysander army cooperation aircraft to increase visibility for the crew.
- Constant chord with tapered outer section: common variant seen for example on many Cessna types.

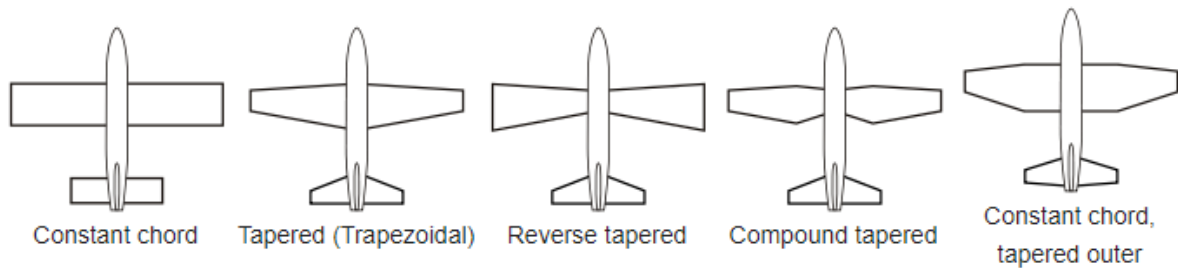


Fig 1.9 Chord Variation

- Elliptical: leading and trailing edges are curved such that the chord length varies elliptically with respect to span. Theoretically the most efficient, but difficult to make. Famously used on the Supermarine Spitfire. (Note that in aerodynamics theory, the term "elliptical" describes the optimal lift distribution over a wing and not its shape).
 - Semi-elliptical: only the leading or trailing edge is elliptical with the other being straight, as with the elliptical trailing edges of the Seversky P-35.

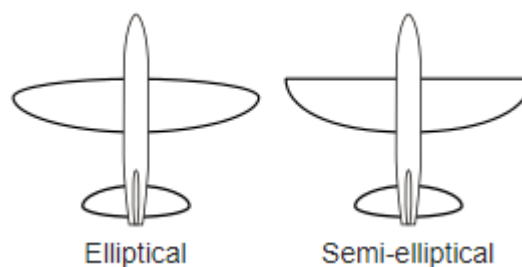


Fig 1.10 Elliptical and Semi Elliptical Wings

- Bird wing: a curved shape appearing similar to a bird's outstretched wing. Popular during the pioneer years, and achieved some success on the Etrich Taube where its planform was inspired by the zanonina (*Alsomitra macrocarpa*) seed.

- Bat wing: a form with radial ribs. The 1901 Whitehead No. 21 has been the subject of claims to the first controlled powered flight.
- Circular: approximately circular planform. The Vought XF5U used large propellers near the tips which Vought claimed dissipated its wingtip vortices and had an integral tail plane for stability.
- Flying saucer: circular flying wing. Inherently unstable, as the Avrocar demonstrated.
- Disc wing: a variant in which the entire disc rotates. Popular on toys such as the Frisbee.
- Flat annular wing: the circle has a hole in, forming a closed wing (see above). The Lee-Richards annular monoplanes flew shortly before the First World War

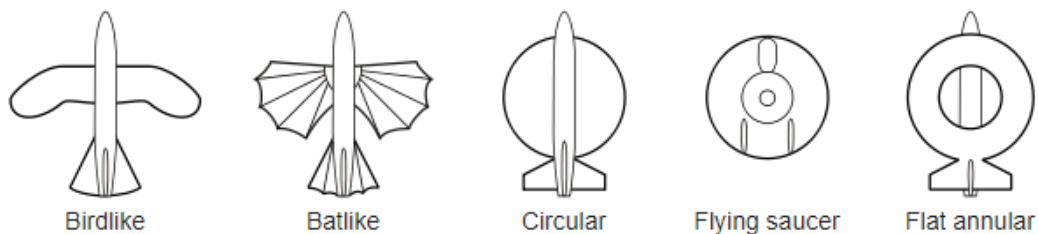


Fig 1.11 Other Wing types

- Delta: triangular planform with swept leading edge and straight trailing edge. Offers the advantages of a swept wing, with good structural efficiency and low frontal area. Disadvantages are the low wing loading and high wetted area needed to obtain aerodynamic stability. Variants are:
 - Tailless delta: a classic high-speed design, used for example in the Dassault Mirage III series.
 - Tailed delta: adds a conventional tailplane, to improve handling. Used on the Mikoyan-Gurevich MiG-21.
 - Cropped delta: wing tips are cut off. This helps avoid tip drag at high angles of attack. The Fairey Delta 1 also had a tail. At the extreme, merges into the "tapered swept" configuration.
 - Compound delta or double delta: inner section has a (usually) steeper leading edge sweep as on the Saab Draken. This improves the lift at high angles of

attack and delays or prevents stalling. By contrast, the Saab Viggen has an inner section of reduced sweep to avoid interference from its canard foreplane.

- Ogival delta: a smoothly blended "wineglass" double-curve encompassing the leading edges and tip of a cropped compound delta. Seen in tailless form on the Concorde supersonic transports.

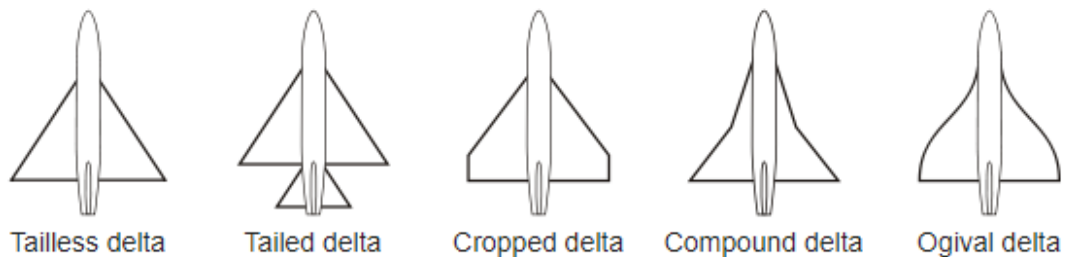


Fig 1.12 Delta Wing

1.6 Wing sweep

Wings may be swept back, or occasionally forwards, for a variety of reasons. A small degree of sweep is sometimes used to adjust the centre of lift when the wing cannot be attached in the ideal position for some reason, such as a pilot's visibility from the cockpit. Other uses are described below.

- Straight: extends at right angles to the line of flight. The most structurally-efficient wing, it has been common for low-speed designs since the very first days of the Wright Flyer.
- Swept back (aka "swept wing"): The wing sweeps rearwards from the root to the tip. In early tailless examples, such as the Dunne aircraft, this allowed the outer wing section to act like a conventional empennage (tail) to provide aerodynamic stability. At transonic speeds swept wings have lower drag, but can handle badly in or near a stall and require high stiffness to avoid aeroelasticity at high speeds. Common on high-subsonic and early supersonic designs such as the Hawker Hunter.
- Forward swept: the wing angles forward from the root. Benefits are similar to backwards sweep, also it avoids the stall problems and has reduced tip losses

allowing a smaller wing, but requires even greater stiffness to avoid aeroelastic flutter as on the Sukhoi Su-47. The HFB 320 Hansa Jet used forward sweep to prevent the wing spar passing through the cabin. Small shoulder-wing aircraft may use forward sweep to maintain a correct CoG.

Some types of variable geometry vary the wing sweep during flight:

- Swing-wing: also called "variable sweep wing". The left and right hand wings vary their sweep together, usually backwards. Seen in a few types of military aircraft, such as the General Dynamics F-111 Aardvark.
- Oblique wing: a single full-span wing pivots about its midpoint, so that one side sweeps back and the other side sweeps forward. Flown on the NASA AD-1 research aircraft.

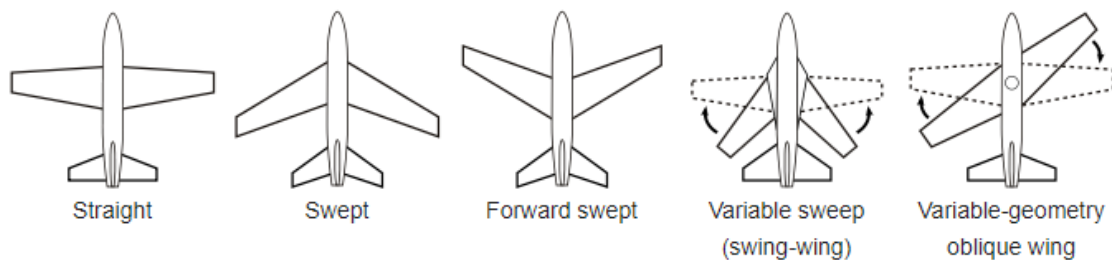


Fig 1.13 Wing Sweep

1.6.1 Sweep variation along span

The angle of a swept wing may also be varied, or cranked, along the span:

- Crescent: wing outer section is swept less sharply than the inner section, to obtain a best compromise between transonic shock delay and spanwise flow control. Used on the Handley Page Victor.
- Cranked arrow: aerodynamically identical to the compound delta, but with the trailing edge also kinked inwards. Trialled experimentally on the General Dynamics F-16XL.

- M-wing: the inner wing section sweeps forward, and the outer section sweeps backwards. Allows the wing to be highly swept while minimising the undesirable effects of aeroelastic bending. Periodically studied, but never used on an aircraft.
- W-wing: A reversed M-wing. Proposed for the Blohm & Voss P.188 but studied even less than the M-wing and in the end never used.

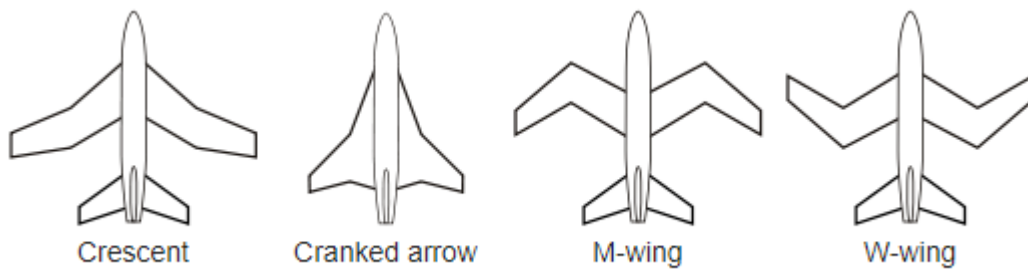


Fig 1.14 Sweep along span

1.6.2 Asymmetrical

On a few asymmetrical aircraft the left and right hand sides are not mirror-images of each other:

- Asymmetric layout: the Blohm & Voss BV 141 had separate fuselage and crew nacelle offset on either side to give the crew a good field of view.
- Asymmetric span: on several Italian fighters such as the Ansaldo SVA, one wing was slightly longer than the other to help counteract engine torque.
- Oblique wing: one wing sweeps forward and the other back. The NASA AD-1 had a full-span wing structure with variable sweep.

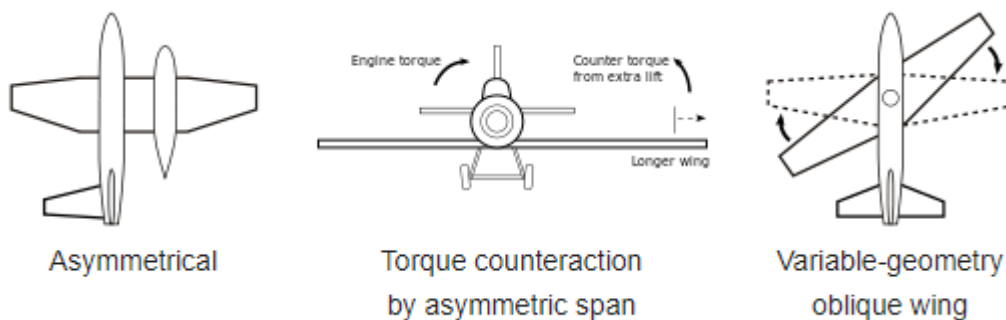


Fig 1.14 Types of asymmetry

1.6.3 Tailplanes and foreplanes

The classic aerofoil section wing is unstable in pitch, and requires some form of horizontal stabilizing surface. Also it cannot provide any significant pitch control, requiring a separate control surface (elevator) mounted elsewhere.

- Conventional: "tailplane" surface at the rear of the aircraft, forming part of the tail or empennage. It did not become the convention for some years after the Wrights, with the Blériot VII of 1907 being the first successful example.
- Canard: "foreplane" surface at the front of the aircraft. Common in the pioneer years, but from the outbreak of World War I no production model appeared until the Saab Viggen in 1967.
- Tandem: two main wings, one behind the other. Both provide lift; the aft wing provides pitch stability (as a usual tailplane). An example is the Rutan Quickie. To provide longitudinal stability, the wings must differ in aerodynamic characteristics: typically the wing loading and/or the aerofoils differ between the two wings.
- Three surface: both conventional tail and canard auxiliary surfaces. Modern examples include the Sukhoi Su-33, while pioneer examples include the Voisin-Farman I.
- Outboard tail: split in two, with each half mounted on a short boom just behind and outboard of a wing tip. It comprises outboard horizontal stabilisers (OHS) and may or may not include additional boom-mounted vertical stabilisers (fins). In this position, the tail surfaces interact constructively with the wingtip vortices to significantly reduce drag. Used for the Scaled Composites SpaceShipOne.
- Tailless: no separate surface, at front or rear. The lifting and stabilizing surfaces may be combined in a single plane, as on the Short SB.4 Sherpa whose whole wing tip sections acted as elevons. Alternatively the aerofoil profile may be modified to provide inherent stability, as on the Dunne D.5. Aircraft having a tailplane but no vertical tail fin have also been described as "tailless".

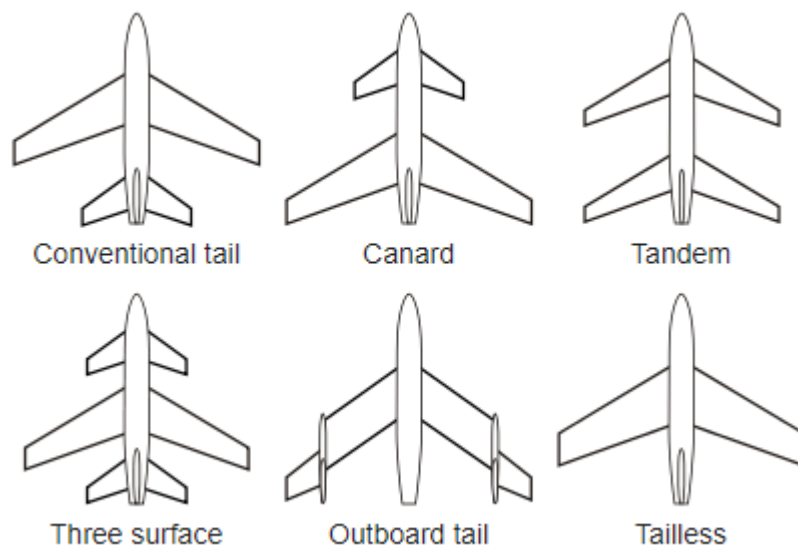


Fig 1.15 Tail Configurations

1.6.4 Dihedral and anhedral

Angling the wings up or down spanwise from root to tip can help to resolve various design issues, such as stability and control in flight.

- Dihedral: the tips are higher than the root as on the Santos-Dumont 14-bis, giving a shallow 'V' shape when seen from the front. Adds lateral stability.
- Anhedral or catahedral: the tips are lower than the root, as on the first Wright Flyer; the opposite of dihedral. Used to reduce stability where some other feature results in too much stability.

Some biplanes have different degrees of dihedral/anhedral on different wings. The Sopwith Camel had a flat upper wing and dihedral on the lower wing, while the Hanriot HD-1 had dihedral on the upper wing but none on the lower.

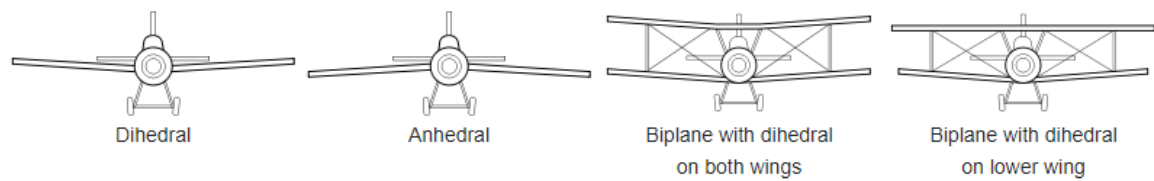


Fig 1.16 Wing types

In a cranked or polyhedral wing the dihedral angle varies along the span.

- Gull wing: sharp dihedral on the wing root section, little or none on the main section, as on the PZL P.11 fighter. Sometimes used to improve visibility forwards and upwards and may be used as the upper wing on a biplane as on the Polikarpov I-153.
- Inverted gull wing: anhedral on the root section, dihedral on the main section. The opposite of a gull wing. May be used to reduce the length of wing-mounted undercarriage legs while allowing a raised fuselage, as on the German Junkers Ju 87 Stuka dive bomber.
- Cranked or canted tip: tip section dihedral differs from the main wing. The tips may have upwards dihedral as on the F-4 Phantom II or downwards anhedral as on the Northrop XP-56 Black Bullet.

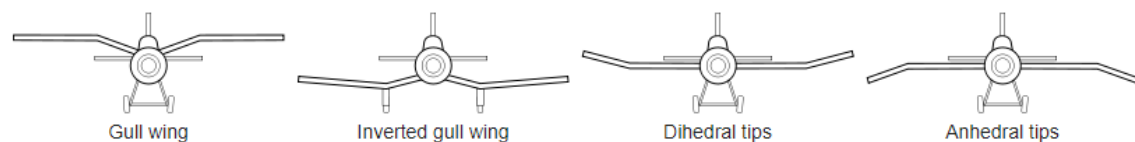


Fig 1.17 Wing tip types

- The channel wing includes a section of the wing forming a partial duct around or immediately behind a propeller. Flown since 1942 in prototype form only, most notably on the Custer Channel Wing aircraft.



Fig 1.18 Channel Wing

1.7 Wings vs. bodies

Some designs have no clear join between wing and fuselage, or body. This may be because one or other of these is missing, or because they merge into each other:

- Flying wing: the aircraft has no distinct fuselage or horizontal tail (although fins and pods, blisters, etc. may be present) such as on the B-2 stealth bomber.
- Blended body or blended wing-body: a smooth transition occurs between wing and fuselage, with no hard dividing line. Reduces wetted area and can also reduce interference between airflow over the wing root and any adjacent body, in both cases reducing drag. The Lockheed SR-71 spyplane exemplifies this approach.
- Lifting body: the aircraft lacks identifiable wings but relies on the fuselage (usually at high speeds or high angles of attack) to provide aerodynamic lift as on the X-24.

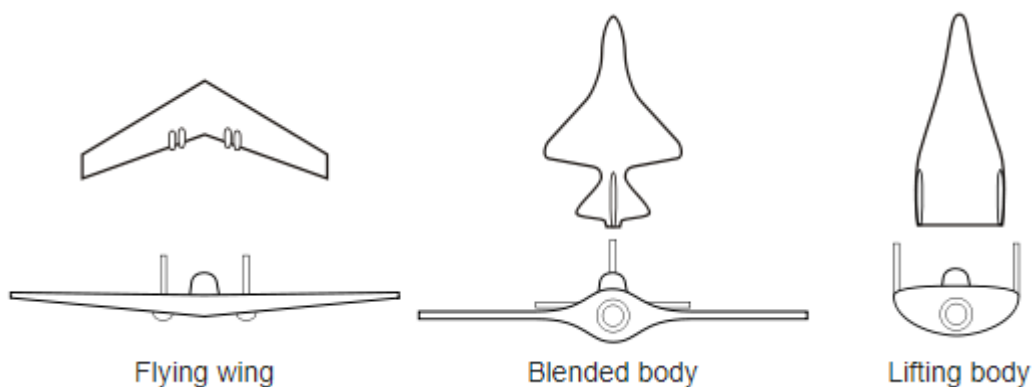


Fig 1.19 Wing Bodies

Some designs may fall into multiple categories depending on interpretation, for example many UAVs or drones can be seen either as a tailless blended wing-body or as a flying wing with a deep centre chord.

1.8 Variable geometry

A variable geometry aircraft is able to change its physical configuration during flight.

Some types of variable geometry craft transition between fixed wing and rotary wing configurations.

1.9 Variable planform

- Variable-sweep wing or Swing-wing. The left and right hand wings vary their sweep together, usually backwards. The first successful wing sweep in flight was carried out by the Bell X-5 in the early 1950s. In the Beech Starship, only the canard foreplanes have variable sweep.
- Oblique wing: a single full-span wing pivots about its midpoint, as used on the NASA AD-1, so that one side sweeps back and the other side sweeps forward.
- Telescoping wing: the outer section of wing telescopes over or within the inner section of wing, varying span, aspect ratio and wing area, as used on the FS-29 TF glider.
- Detachable wing. The WS110A study proposed a long wing for subsonic takeoff and cruise, which then detached the outer panels to drop away, leaving a short-span wing for supersonic flight.
- Extending wing or expanding wing: part of the wing retracts into the main aircraft structure to reduce drag and low-altitude buffet for high-speed flight, and is extended only for takeoff, low-speed cruise and landing. The Gérin Varivol biplane, which flew in 1936, extended the leading and trailing edges to increase wing area.

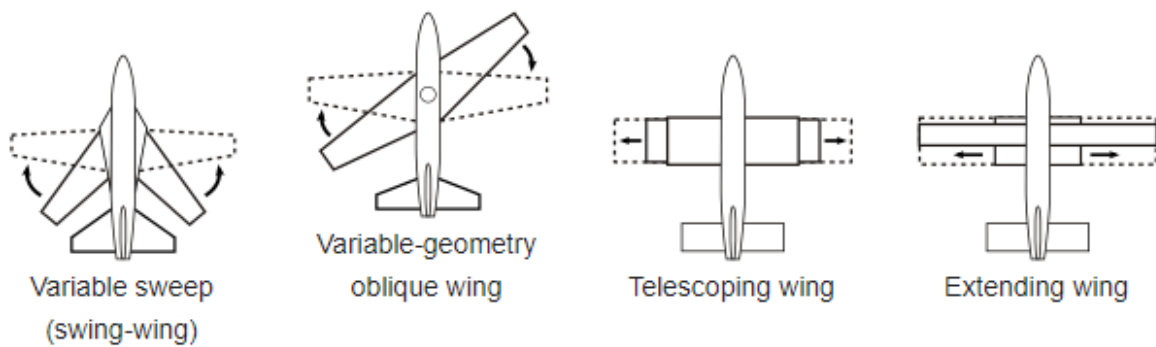
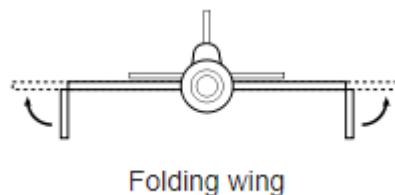


Fig 1.21 Variable Planform

- Folding wing: part of the wing extends for takeoff and landing, and folds away for high-speed flight. The outer sections of the XB-70 Valkyrie wing folded down during supersonic cruise. (Many aircraft have wings that may be folded for storage on the ground or on board ship; these are not folding wings in the sense used here.)



1.10 Variable chord

- Variable incidence: the wing plane can tilt upwards or downwards relative to the fuselage. The wing on the Vought F-8 Crusader was rotated, lifting the leading edge on takeoff to improve performance. If powered prop-rotors are fitted to the wing to allow vertical takeoff or STOVL performance, merges into the powered lift category.
- Variable camber: the leading and/or trailing edge sections of the whole wing pivot to increase the effective camber of the wing and sometimes also its area. This enhances manoeuvrability. An early example was flown on the Westland N.16 of 1917.

- Variable thickness: the upper wing centre section can be raised to increase wing thickness and camber for landing and take-off, and reduced for high speed. Charles Rocheville and others flew some experimental aircraft.



Fig 1.22 Variable airfoil

1.11 Polymorphism

A polymorphic wing is able to change the number of planes in flight. The Nikitin-Shevchenko IS "folding fighter" prototypes were able to morph between biplane and monoplane configurations after takeoff by folding the lower wing into a cavity in the upper wing.

The slip wing is a variation on the polymorphic idea, whereby a low-wing monoplane was fitted with a second detachable "slip" wing above it to assist takeoff, which was then jettisoned once aloft. The idea was first flown on the experimental Hillson Bi-mono.

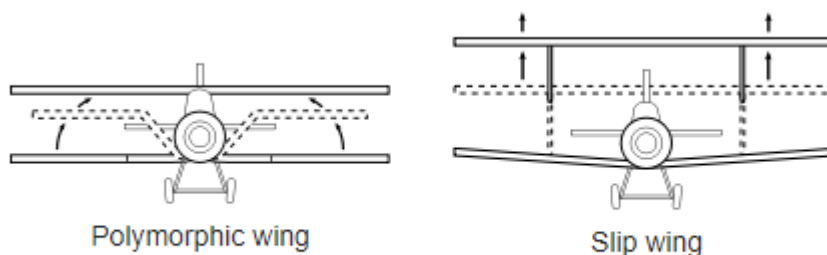


Fig 1.23 Wing Types

1.12 Minor independent surfaces

Aircraft may have additional minor aerodynamic surfaces. Some of these are treated as part of the overall wing configuration:

- Winglet: a small fin at the wingtip, usually turned upwards. Reduces the size of vortices shed by the wingtip, and hence also tip drag.
- Strake: a small surface, typically longer than it is wide and mounted on the fuselage. Strakes may be located at various positions in order to improve aerodynamic behaviour. Leading edge root extensions (LERX) are also sometimes referred to as wing strakes.
- Chine: sharp-edged profile running along the fuselage. When used aerodynamically it is extended outwards to form a lifting surface, typically blending into the main wing. As well as improving low speed (high angle of attack) handling, provides extra lift at high supersonic speeds for minimal increase in drag. Seen on the Lockheed SR-71 Blackbird.
- Moustache: small high-aspect-ratio canard surface having no movable control surface. Typically is retractable for high speed flight. Deflects air downward onto the wing root, to delay the stall. Seen on the Dassault Milan.

1.14 High lift

High-lift devices maintain lift at low speeds and delay the stall to allow slower takeoff and landing speeds:

- Slat and slot: a Leading edge slat is a small aerofoil extending in front of the main leading edge. The spanwise gap behind it forms a leading-edge slot. Air flowing up through the slot is deflected backwards by the slat to flow over the wing, allowing the aircraft to fly at lower air speeds without flow separation or stalling. A slat may be fixed or retractable.

- Flap: a hinged aerodynamic surface, usually on the trailing edge, which is rotated downwards to generate extra lift and drag. Types include plain, slotted, and split. Some, such as Fowler Flaps, also extend rearwards to increase wing area. The Krueger flap is a leading-edge device.
- Cuff: an extension to the leading edge which modifies the aerofoil section, typically to improve low-speed characteristics.

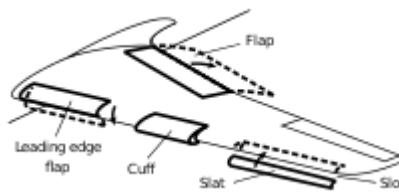


Fig 1.24 High Lift Devices

1.15 Spanwise flow control

On a swept wing, air tends to flow sideways as well as backwards and reducing this can improve the efficiency of the wing:

- Wing fence: a flat plate extending along the wing chord and for a short distance vertically. Used to control spanwise airflow over the wing.
- Dogtooth leading edge: creates a sharp discontinuity in the airflow over the wing, disrupting spanwise flow.
- Notched leading edge: acts like a dogtooth.

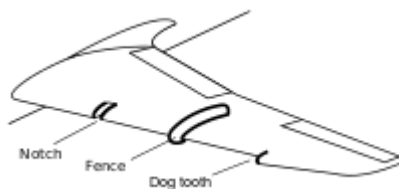


Fig 1.25 Spanwise flow control

1.16 Vortex creation

Vortex devices maintain airflow at low speeds and delay the stall, by creating a vortex which re-energises the boundary layer close to the wing.

- Vortex generator: small triangular protrusion on the upper leading wing surface; usually, several are spaced along the span of the wing. Vortex generators create additional drag at all speeds.
- Vortilon: a flat plate attached to the underside of the wing near its outer leading edge, roughly parallel to normal airflow. At low speeds, tip effects cause a local spanwise flow which is deflected by the vortilon to form a vortex passing up and over the wing.
- Leading-edge root extension (LERX): generates a strong vortex over the wing at high angles of attack, but unlike vortex generators it can also increase lift at such high angles, while creating minimal drag in level flight.

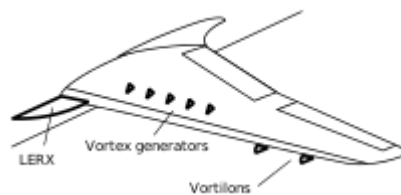


Fig 1.25 Vortex creation

1.17 Drag reduction

- Anti-shock body: a streamlined pod shape added to the leading or trailing edge of an aerodynamic surface, to delay the onset of shock stall and reduce transonic wave drag. Sometimes called a Küchemann carrot.
- Fairings of various kinds, such as blisters, pylons and wingtip pods, containing equipment which cannot fit inside the wing, and whose only aerodynamic purpose is to reduce the drag created by the equipment.
- Fillet, a type of fairing: a small curved infill at the junction of two surfaces, such as a wing and fuselage, blending them smoothly together to reduce drag.

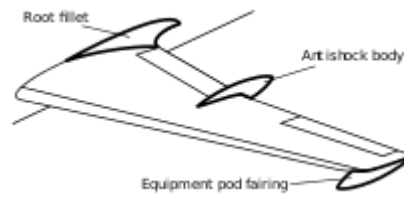


Fig 1.26 Drag reduction

1.18 TESTS CARRIED OUT

The NACA airfoil which was chosen to introduce this stepwise aerodynamic discontinuity is the NACA 2412. First and foremost Computational fluid dynamics was carried out for five different models where this new modification was introduced at different points from the center of the aircraft and the conditions that were tested were low Reynold's number and the velocities which were tested was 30m/s, 60m/s and 90m/s. Then a smoke test was carried out in similar conditions in a subsonic wind tunnel and the turbulence was visualized around the stepwise discontinuity.

The simulation software that was taken for doing the computational fluid dynamics work was ANSYS fluent, the Computer-aided Design model was designed using modelling software CATIA V5

CHAPTER 2

LITERATURE SURVEY

E. V. Laitone (1997) Rectangular planform wings were tried at Reynolds numbers as low as 20 000 of a low disturbance air stream. The lift and drag estimations on a NACA 0012 profile were contrasted and those for slight level and cambered plates. For all Reynolds numbers under 70 000 the best profile was a slim plate with a 5% roundabout curve camber. At all choppiness levels this profile delivered the best lift-drag proportion, and had the most elevated lift coefficient at all approaches. The 5% camber and the entirety of the slim plates tried were generally heartless toward either a variety in the Reynolds number, or an expansion in the air stream disturbance level, though the NACA 0012 was very truly influenced by either, at Reynolds numbers under 50 000.

Marylyn Smith (2001) Expanding on the examination performed during the DARPA/AFRL/NASA Shrewd Wing Stage 1 program (Kudva, J.N. et al. (July 1999). Outline of the DARPA/AFRL/NASA Shrewd Wing System, SPIE Discussion on Keen Constructions and Materials, Newport Sea shore, CA, Vol. 3674, pp. 230 6; Martin, C.A. et al. (1999). Keen Materials and Designs Savvy Wing Stage 1 Last Report, AFRL-ML-WP-TR-1999-4162, Air Vehicles Directorate, Flying corps Exploration Research facility, Wright-Patterson Aviation based armed forces Base, Goodness.) looked to improve vehicle streamlined effectiveness utilizing control surfaces activated by brilliant materials, the objective of the Stage 2 exertion was to create bigger scope, shrewd hingeless control surfaces able to do high-rate incitation and measure their presentation benefits at test conditions illustrative of operational flight conditions. To accomplish this objective, a 30-percent mathematical scale, full-range air stream model of a proposed Northrop Grumman Organization (NGC) Uninhabited Battle Air Vehicle (UCAV) was planned and tried. The model joined customary, pivoted control surfaces on the left side and keen, hingeless control surfaces on the option to permit gradual streamlined execution examinations; including lift increase because of unit control surface diversion (CL), and move second because of unit control surface avoidance (Cld). This paper portrays the plan, manufacture, framework mix, and ground test aftereffects of the Shrewd Wing Stage 2 model. Subjects that are covered include: (1) air stream model choice; (2) investigation and plan technique; (3) shrewd control

surface coordination; (4) model instrumentation; and (5) static burden and Ground Vibration Test (GVT) results and connection.

Lee-Rauch (2003) Expanding on the examination performed during the DARPA/AFRL/NASA Shrewd Wing Stage 1 program (Kudva, J.N. et al. (July 1999). Outline of the DARPA/AFRL/NASA Shrewd Wing System, SPIE Discussion on Keen Constructions and Materials, Newport Sea shore, CA, Vol. 3674, pp. 230 6; Martin, C.A. et al. (1999). Keen Materials and Designs Savvy Wing Stage 1 Last Report, AFRL-ML-WP-TR-1999-4162, Air Vehicles Directorate, Flying corps Exploration Research facility, Wright-Patterson Aviation based armed forces Base, Goodness.) looked to improve vehicle streamlined effectiveness utilizing control surfaces activated by brilliant materials, the objective of the Stage 2 exertion was to create bigger scope, shrewd hingeless control surfaces able to do high-rate incitation and measure their presentation benefits at test conditions illustrative of operational flight conditions. To accomplish this objective, a 30-percent mathematical scale, full-range air stream model of a proposed Northrop Grumman Organization (NGC) Uninhabited Battle Air Vehicle (UCAV) was planned and tried. The model joined customary, pivoted control surfaces on the left side and keen, hingeless control surfaces on the option to permit gradual streamlined execution examinations; including lift increase because of unit control surface diversion (CL), and move second because of unit control surface avoidance (Cld). This paper portrays the plan, manufacture, framework mix, and ground test aftereffects of the Shrewd Wing Stage 2 model. Subjects that are covered include: (1) air stream model choice; (2) investigation and plan technique; (3) shrewd control surface coordination; (4) model instrumentation; and (5) static burden and Ground Vibration Test (GVT) results and connection.

Christopher Martin (2004) Expanding on the examination performed during the DARPA/AFRL/NASA Shrewd Wing Stage 1 program (Kudva, J.N. et al. (July 1999). Outline of the DARPA/AFRL/NASA Shrewd Wing System, SPIE Discussion on Keen Constructions and Materials, Newport Sea shore, CA, Vol. 3674, pp. 230 6; Martin, C.A. et al. (1999). Keen Materials and Designs Savvy Wing Stage 1 Last Report, AFRL-ML-WP-TR-1999-4162, Air Vehicles Directorate, Flying corps Exploration Research facility, Wright-Patterson Aviation based armed forces Base, Goodness.) looked to improve vehicle streamlined effectiveness utilizing control surfaces activated by brilliant materials, the

objective of the Stage 2 exertion was to create bigger scope, shrewd hingeless control surfaces able to do high-rate incitation and measure their presentation benefits at test conditions illustrative of operational flight conditions. To accomplish this objective, a 30-percent mathematical scale, full-range air stream model of a proposed Northrop Grumman Organization (NGC) Uninhabited Battle Air Vehicle (UCAV) was planned and tried. The model joined customary, pivoted control surfaces on the left side and keen, hingeless control surfaces on the option to permit gradual streamlined execution examinations; including lift increase because of unit control surface diversion (CL), and move second because of unit control surface avoidance (Cld). This paper portrays the plan, manufacture, framework mix, and ground test aftereffects of the Shrewd Wing Stage 2 model. Subjects that are covered include: (1) air stream model choice; (2) investigation and plan technique; (3) shrewd control surface coordination; (4) model instrumentation; and (5) static burden and Ground Vibration Test (GVT) results and connection.

Lucy Gagrighaldi (2006) The conduct of the stream over slim delta wings under transonic conditions is profoundly perplexing. With the event of various stuns in the stream the conduct of vortex breakdown is very extraordinary to that for subsonic stream. This examination considers this conduct over the 65° sharp driving edge delta wing utilized in the second Global Vortex Stream Test (VFE-2) utilizing Computational Liquid Elements. Three foundation engaged with the VFE-2 have teamed up to think about the wing under states of $M = 0.85$ and $Re = 6 \times 10^6$ at two rates: $\alpha = 18.5^\circ$ and 23° . The stream arrangements are contrasted with existing test information and show great understanding for the cases considered. Be that as it may, an error with the test information is shown where the basic rate for the beginning of vortex breakdown on the wing is under-anticipated. From investigation of the arrangements, it is resolved that the beginning of vortex breakdown is profoundly subject to the vortex strength and the strength and area of the stuns in the stream. The event of a basic connection between these boundaries is recommended for vortex breakdown to happen and is utilized to clarify the errors between the computational and trial results dependent on the under-foresee particle of the vortex center pivotal speed. An affectability investigation of the stream to various computational elements, for example,

choppiness model, is additionally embraced. In any case, it is tracked down that these boundaries have little impact on the general conduct of the transonic stream.

A.Y.N. Sofla (2010) In this paper, the new movement in applied plan, model manufacture, and assessment of shape transforming wing is briefly arranged. Of exceptional interest are ideas which incorporate shrewd materials such as shape memory compounds (SMA), piezoelectric actuators (PZT), and shape memory polymers (SMP). We will likewise give a few ideas that have been created and assessed by the creators. Our work indicates that adversarial SMA-activated flexural structures structure a potential empowering innovation for wing transforming of little airplane. The utilization of SMA-incited structures fit as a fiddle transforming wing plans diminishes the weight punishment because of the activation frameworks, in light of the fact that such SMA-incited structures convey aerodynamic loads.

Vladimir Popov (2010) This paper presents the displaying and exploratory testing of the streamlined exhibition of a transforming wing in open-circle engineering. We show the technique used to secure the pressing factor information from the outside surface of the adaptable wing skin, utilizing fused Kulite pressure sensors and the instrumentation of the transforming regulator. The gained pressure information are examined through quick Fourier changes to recognize the greatness of the commotion in the surface wind stream. Therefore, the information are separated by methods for high-pass channels and handled by ascertaining the root mean square of the sign to get a plot outline of the clamor in the wind stream. This sign preparing is important to eliminate the innate clamor electronically instigated from the Tollmien–Schlichting waves, which are liable for setting off the change from laminar to violent stream. The adaptable skin is needed to transform the state of the airfoil through two incitation focuses to accomplish an improved airfoil shape dependent on the hypothetical stream conditions like those tried in the air stream. Two shape memory combination actuators with a nonlinear conduct drive the relocation of the two control points of the adaptable skin toward the enhanced airfoil shape. Every one of the shape memory actuators is enacted by a force supply unit and

controlled utilizing the Simulink/MATLAB® programming through a self-tuning fluffy regulator. The strategy and the outcomes got during the air stream test demonstrated that the idea and legitimacy of the framework progressively are talked about in this paper. Constant securing and sign handling of pressing factor information are required for additional improvement of the shut circle regulator to acquire a completely programmed transforming wing framework.

Ryan Gerkpulos (2010) The lift and detachment bubble attributes of a NACA 0018 airfoil are examined tentatively. Surface pressing factor estimations are introduced for Reynolds numbers from 80×10^3 to 200×10^3 and approaches from 0° to 18° . These information were utilized to describe the division bubble and decide lift coefficients. From these outcomes, two particular locales in the lift bends can be distinguished: an area of quick and direct development of the lift coefficients at low approaches and a district of more progressive and straight development at higher pre-slow down points. Moreover, the slant of the lift bend in every locale is discovered to be connected to the paces of progress in division, change, and reattachment areas with the approach. These discoveries are validated by an investigation of the accessible exploratory information for a NACA 0012 airfoil.

Vladmir Kopov (2010) In this paper, air stream aftereffects of an ongoing enhancement of a transforming wing in the air stream for postponing the change toward the following edge are introduced. A transforming rectangular limited viewpoint proportion wing, having an air stream trial airfoil reference airfoil cross segment, was thought of, with its upper surface made of an adaptable composite material and instrumented with Kulite pressure sensors and two savvy memory compounds actuators. A few air stream trials for different Mach numbers, approaches, and Reynolds numbers were acted in the 6' x 9' air stream at the Foundation for Aviation Exploration at the Public Exploration Gathering

Canada. Shaky pressing factor signals were recorded and utilized as input continuously control while the transforming wing was mentioned to repeat different enhanced airfoils by changing consequently the two actuators' strokes. This paper shows the advancement technique executed into the control programming code that permits the transforming wing to change its shape to an ideal arrangement under the air stream wind current conditions

Juan Murcia (2011) Obtuse following edge airfoil alteration strategies have shown that a trade off between streamlined execution and underlying advantages can be accomplished. Two adjustment techniques are examined: the cutting off strategy and the additional thickness strategy. Twodimensional recreations were gotten in Ansys CFX® for an average Reynolds number of 3.2 million. A Taguchi Technique analyze is led for the investigation of the four-digit NACA airfoil family with the proposed alteration strategies. An itemized concentrate for the NACA 4421 changed with a few following edge thickness esteems was finished. The outcomes acquired show that the increment in the most extreme lift coefficient, the deferred slow down and the drag coefficient increment are regular to all adjustment strategies examined, though it is demonstrated that for the cutting off technique the lift coefficient bend removal to higher approaches is brought about by the deficiency of camber. At long last, it was demonstrated that the additional thickness technique produces bigger most extreme lift coefficients and bigger basic approaches than the cutting off strategy.

E. Livya (2015) The principle objective of airplane streamlined features is to improve the streamlined attributes and mobility of the airplane. This improvement remembers the decrease for drag and slow down wonder. The airfoil which contains dimples will have nearly less drag than the plain airfoil. Presenting dimples on the airplane wing will make choppiness by making

vortices which defers the limit layer detachment bringing about decline of pressing factor drag and furthermore increment in the point of slow down. Also, wake decrease prompts decrease in acoustic emanation. The by and large objective of this paper is to improve the airplane mobility by deferring the stream partition point at slow down and along these lines diminishing the haul by applying the dimple impact over the airplane wing. This venture incorporates both computational and test examination of dimple impact on airplane wing, utilizing NACA 0018 airfoil. Dimple states of Semi-circle, hexagon, chamber, square are chosen for the examination; airfoil is tried under the gulf speed of 30m/s and 60m/s at distinctive approach (5° , 10° , 15° , 20° , and 25°). This investigation favors the dimple impact by expanding L/D proportion and accordingly giving the most extreme streamlined proficiency, which gives the improved execution for the airplane.

Andreea Koreanschi. (2016) A test approval of a streamlined wing calculation in the Price-Paidoussis subsonic breeze burrow is introduced. Two wing models were fabricated utilizing upgraded glass fiber composite and tried at three rates and different approaches. These wing models were built dependent on the first airfoil state of the ATR 42 airplane and a streamlined form of a similar airfoil for a flight state of Mach number equivalent to 0.1 and approach of 0° . The airfoil's improvement was acknowledged utilizing an 'in-house' hereditary calculation combined with a cubic spline remaking schedule, and was dissected utilizing XFoil streamlined solver. The streamlining was focused on improving the laminar stream on the upper surface of the wing, somewhere in the range of 10% and 70% of the harmony. XFoil-anticipated pressing factor disseminations were contrasted and test information acquired in the breeze burrow. The progress position was assessed from the trial pressure information

utilizing a second subsidiary strategy and was contrasted and the progress anticipated by XFoil code. The outcomes have shown the arrangement among mathematical and exploratory information. The air stream tests have shown that the improvement of the laminar progression of the upgraded wing is higher than the worth anticipated mathematically.

Naveen R (2018) In the new years, the analysts zeroed in on the improvement of long-range airplane with the business help of nonconventional plan ideas. The C-wing ideas for huge airplane are exceptionally liked to beat the plan limitations like range, angle proportion, and similarity. The range effectiveness of the C-wing is roughly equivalent to that of the shut wing and subsequently a more noteworthy decrease in vortex drag is gotten than on account of the planar wing. The vacillate speed qualities of the C-wing are examined utilizing Computational Liquid Elements (CFD) solver and the C-wing is retrofitted to the A340-200 airplanes. In the CFD investigation the Navier Stroke conditions are acquired as administering conditions and underlying vibration recurrence is determined by a Computational Primary Elements (CSD) solver. Moreover, multi-matrix method is utilized to register the streamlined powers with better precision. The proposed aeroelastic examination comprises of a fractional coupling of CFD and CSD solvers. In the streamlined examination, hypothetical outcomes show that there is a 20% of drag decrease for the C-wing when contrasted with the regular wing. The mathematical outcomes for the areas of the C-wing are approved by utilizing the test consequences of the NACA report.

Demeter G. Fertis (2019) The exploration in this paper is the consequence of a trial study concerning new airfoil-plan idea, which is created to deliver more prominent lift coefficients over a lot more extensive scope of operational approaches, to improve or then again kill slow down at for all intents and purposes every single operational velocity, to increment practical lift-to-drag proportions over a more noteworthy scope of operational approaches, and to be versatile for airplane of both the fixed-wing and the turning wing types. The essayist has consolidated his work with L. L. Smith, and a U.S. Patent, named "Airfoil," Patent No. 4,606,519, was gotten on August 19, 1986. Licenses were likewise gotten or on the other hand are forthcoming in different nations. The test results, gotten by utilizing the new airfoil plan idea, have been contrasted and exploratory outcomes obtained from a traditional NACA 23012 airfoil. Flight execution tests by utilizing a 2.134-m (7.0 ft) model and controller

gadgets, just as stream detachment contemplates, were likewise performed. The outcomes were contrasted and the ones got by utilizing the NACA 23012 airfoil.

Wirachman Wisnoe (2009) This paper talks about the streamlined features conduct of a benchmark plan of a Mixed Wing Body (BWB) airplane created at MARA College of Innovation (UiTM). Two strategies for investigation are introduced, for example Consistent state, three-dimensional Computational Liquid Elements (CFD) of the BWB at Mach 0.3 and Air stream probes 1/6 scaled half model of the BWB at Mach 0.1. In the two techniques for investigation, Lift Coefficient (CL), Drag Coefficient (Compact disc) and Pitching Second Coefficient (CM) are estimated and contrasted at particular Mach numbers and regard to variety of approach. Pressing factor forms and Mach number shapes are plotted and the disturbance zone is anticipated, both separated from CFD examination. Perception utilizing scaled down tuft during air stream tests is additionally executed to finish the investigation where the slow down movement examples can be plainly noticed. The introduced BWB UAV configuration here has accomplished an extraordinary ability regarding manageability of trip at high approach, low parasite drag coefficient and respectable greatest lift coefficient. A few proposals for future improvement of the BWB are given.

J.Vale (2011) An air foundational layout and investigation of an adjustable wing with a conformal camber transforming ability is introduced. A streamlined examination of an extending wing, first with a high velocity airfoil followed by an investigation with a low speed airfoil is performed. The information got from these investigations is utilized to decide the ideal polar bends for drag decrease at various paces. This data thus gave the foundation to conceiving an ideal transforming system for drag decrease accepting that the extending wing airfoil has the ability to step transform between the high and low speed airfoils. Then, a conformal camber transforming idea is presented. The idea depends on a non-uniform thickness appropriation along the harmony of a wing shell area that distorts from an even airfoil shape into a cambered airfoil shape under incitation. Primary advancement dependent on limited component models is utilized to get the shell thickness appropriation for least shell area weight and best airfoil shape change. At long last, an examination concentrate between the exhibition of an airplane furnished with a

transforming wing (adjustable wing joined with conformal camber transforming) and the presentation of a similar airplane outfitted with a streamlined fixed wing for 30 m/s journey speed and 100 N weight is introduced. Streamlined advancement dependent on computational liquid elements models is utilized for the ideal fixed wing mathematical boundaries counts. The ideal wing setups for different execution boundaries are determined. The transforming wing for the most part beats the ideal fixed wing except for a 10% decrease in pace of climb and 4% drag punishment at 30 m/s journey speed.

Yuguang Bai (2011) Mathematical streamlined reproductions are introduced for a Public Warning Advisory group for Aviation (NACA) airfoil that is fixed and pitching at high Reynolds numbers. Another improved CFD technique dependent on block-iterative coupling is utilized with a computational plan for liquid construction cooperation, in which a type of two-condition RANS choppiness model is embraced. Right off the bat, fundamental recreations were performed utilizing the proposed CFD strategy and disturbance model, which gives great expectation of the airfoil power coefficients and ripple subsidiaries contrasted and the notable exploratory estimation and logical plan. At that point, expanded airfoil stream recreations were done to look at the conceivably critical impacts on aeroelasticity from a few affecting variables, including non-zero harmony approaches, expanded constrained vibration amplitudes and huge Reynolds number. Both the essential and expanded reenactments uncover that utilizing the proposed CFD strategy can give successful appraisal of streamlined and aeroelastic execution of airfoils in any event, for working conditions past those a research center test can approach, demonstrating the chance of broadening the system proposed for reasonable streamlined and aeroelastic forecast of 3D full-scale airplane structures.

Eleni Duovi (2012) The investigation of the forecast of the stream field and streamlined qualities of a NACA 0012 airfoil in mimicked hefty downpour, utilizing a computational liquid elements code is introduced. The recreation of downpour is cultivated by utilizing the two-stage stream Discrete Stage Model, which is accessible in the CFD code. Circular particles are followed through the two-dimensional, incompressible wind stream field over a NACA 0012 airfoil, at a recreated downpour pace of 1000 mm/h and working at Reynolds numbers $Re=1 \times 10^6$ and $Re=3 \times 10^6$. To approve the CFD created model, the outcomes are contrasted and grounded and distributed test information, showing great

understanding. The point of the work was to show the conduct of the airfoil at these conditions and to set up a checked arrangement strategy. Lift and drag coefficients are processed at different approaches in both dry and wet conditions and the outcomes are contrasted with show the impacts of downpour at airfoil execution. The effect of downpour on wind turbine execution is likewise examined. It is inferred that downpour causes debasement of streamlined execution, particularly lift is diminished and drag is expanded.

S Murugan (2014) A logical aeroelastic model to examine the aeroelastic soundness of a range mor-phing airplane is inferred. Primary and aeroelastic models are inferred with the dad rameteric varieties presented by a range transforming wing. Dynamic aeroelastic stabilityanalysis is performed with meager airfoil hypothesis and CFD. A CFD investigation of range mor-phing shows the lift expansions in a non-straight style during the transforming cycle, andafter the transforming is finished. The flutter examination, in light of the CFD results, showsa significant decrease in flutter speed during transforming because of inertial, versatile andaerodynamic varieties, and because of the flow development after the transforming time frame. Thisstudy shows that the advancement of low fidelity aeroelastic models of transforming wings,supplemented with high fidelity examination, can measure the wonders related withthe transforming and furthermore fill in as forerunner to a computationally costly, completely coupledhigh fidelity reproduction of flutter due to transforming.

R.K. Ganesh Ram (2014) *CFD strategy is reasonable technique for investigation of stream over streamlined construction. It consolidates numerical relations and calculations to dissect and take care of the issues in regards to liquid stream. CFD investigation of an airfoil produces results, for example, lift and drag powers which decides the capacity of an airfoil. Improvement of an airfoil includes improving the plan of the airfoil to control the lift and drag coefficients as indicated by the prerequisites. It is a typical strategy utilized on the whole fields of designing. MATLAB is a mathematical figuring climate which underpins interface with other programming. XFoil is airfoil investigation programming which figures the lift and drag attributes for various Reynolds numbers, Mach numbers and approaches. MALAB is interfaced with XFoil and the improvement of NACA 0012 airfoil is done and the outcomes are investigated. The exhibition of upgraded air foil is broke down utilizing ANSYS Familiar programming.*

Olivu Gabor (2016) This paper presents the outcomes got from the mathematical recreation and test air stream testing of a transforming wing furnished with an adaptable upper surface and controllable impelled aileron. The innovation demonstrator is illustrative of a genuine airplane wing tip area, and it was created following a complex, multidisciplinary configuration measure. The model was fitted with a composite material upper skin whose shape can be transformed, as an element of the flight condition, by four electrical actuators set inside the wing structure. The advancements were performed with the point of controlling the degree of the laminar stream district, and the subsequent shapes were filtered utilizing high-exactness photogrammetry. The mathematical reenactments were performed utilizing Computational Liquid Elements (CFD) and incorporated a model for foreseeing the laminar-to-fierce stream change over the whole wing surface. The investigations included cases with three aileron diversion points and approaches arranged inside five degrees range. The CFD results were contrasted and infrared thermography estimations as far as progress area, surface pressing factor estimations and equilibrium loads estimations procured during subsonic air stream tests performed at the Public Exploration Gathering Canada.

Srikanth Narasimalu (2017) The current work mathematically investigates the presentation attributes of Darrieus turbine with NTU-20-V and NACA 0018 airfoils. The NTU-20-V airfoil was cut out to improve the exhaustion life of the aluminum expelled cutting edges by building up with glass fiber material in standard shapes. The prior examinations by the creators incorporate imagining the airfoil profile through hereditary calculation streamlining followed by exploratory streamlined portrayal regarding lift and drag coefficients. The target of the current examination is to assess the presentation of Darrieus rotor with NTU-20-V airfoil as far as force coefficient and force coefficient for various Reynolds number and contrast it and standard NACA0018 airfoil from which the new airfoil was determined. The computational investigation is expected to reveal insight into the stream qualities as for NACA 0018 airfoil.

Dumitru Pepelea (2016) The scope of automated ethereal airplane (UAV) is growing ceaselessly producing new useful arrangements from little size and mass to those, which are tantamount to steered airplane. The primary explanation of UAV use is because of lower cost of plan, acknowledgment and procedure (on flight hour) in correlation with human

guided airplane. This paper presents the CFD examination on a UAV tailless, after a 3D filtered genuine model

Cees Bill (2017) Airplane transforming is alluded to as the capacity for an airplane to change its math in flight. Officially, folds, spoilers, and control gadgets are considered transforming, however by and large, transforming in aviation is related with mathematical changes utilizing brilliant materials, for example, shape memory amalgams. Shape memory composite is a material that changes shape under warming and creates power and diversions, which make it expected actuator for a wing transforming framework. The inspiration driving this investigation is the application to little estimated and medium-sized automated air vehicles and the possibility to expand reach or perseverance for a given fuel load through improved lift-to-drag proportion. The camber line of an airfoil segment, the overwhelming boundary influencing lift and drag, is changed by resistive warming of a shape memory combination actuator and cooling in the encompassing air. Tests were directed under air stream conditions to confirm examination and to research the impacts of its application on the streamlined conduct of the wing. This examination researched three control techniques: the customary corresponding vital subordinate regulator, relative indispensable subsidiary with vigorous compensator, and corresponding fundamental subsidiary with against windup compensator. The last demonstrated to have unrivaled execution in accomplishing and keeping a necessary degree of transforming. Furthermore, the force needed to the shape memory amalgam actuators under streamlined burden, and the impact of encompassing temperature was additionally researched.

CHAPTER 3

AIM AND SCOPE OF THE PRESENT INVESTIGATION

3.1 Existing Modification

At the present there are many modifications in the wing's shape which is aimed and believed to produce extra lift and drag. Like the introduction of slats, flaps and other control surface which is aimed to increasing the stall performance. This modification is created at the upper surface conditions were tested at low Reynold's number.

3.2 AIM

The main aim of this analysis is to modify the original NACA airfoil and test the modification under subsonic condition. First step involves the CFD Analysis of a small version of this airfoil and the charecteristics like lift and drag are to be measured. The next step is to fabricate the model and perform wind tunnel tests to further validate the result

3.3 SCOPE of the Project

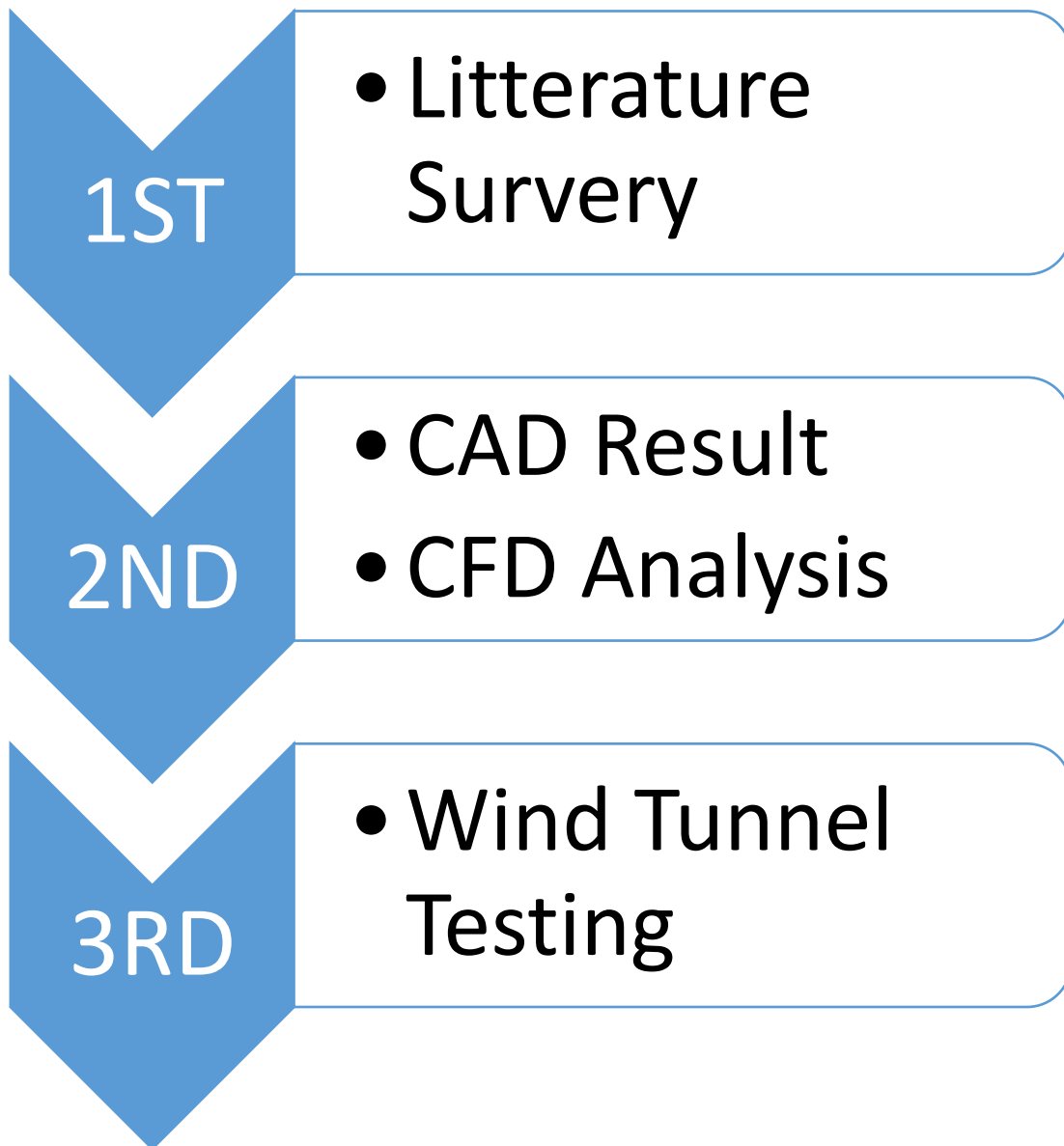
Currently stall performance of any wing without is very poor and the Lift vs Alpha graph for a typical airfoil shows. The graph shows a decline in the lift after the stall angle is achieved. This modified airfoil will provide better lift even during stall conditions and increase the over all performance

CHAPTER 4

METHODOLOGY

4.1 METHODOLOGY

- A appropriate NACA airfoil is to be chosen
- A miniature model wing of any NACA Configuration with the modification could be fabricated
- Model of the wing could be designed in modelling software
- The model could be tested under various conditions using simulation software
- Further, the fabricated model could be used to test pressure in the wing in wind tunnel under all three sonic conditions
- The pressure and other experimental results could be used to calculate stall lift and compare it with a normal wing



CHAPTER 5

CFD ANALYSIS

5.1 CAD DESIGN

The first step in performing the computational fluid dynamics analysis is the CAD design. The CAD design was performed in CATIA software. The following pictures show the modified and unmodified design files

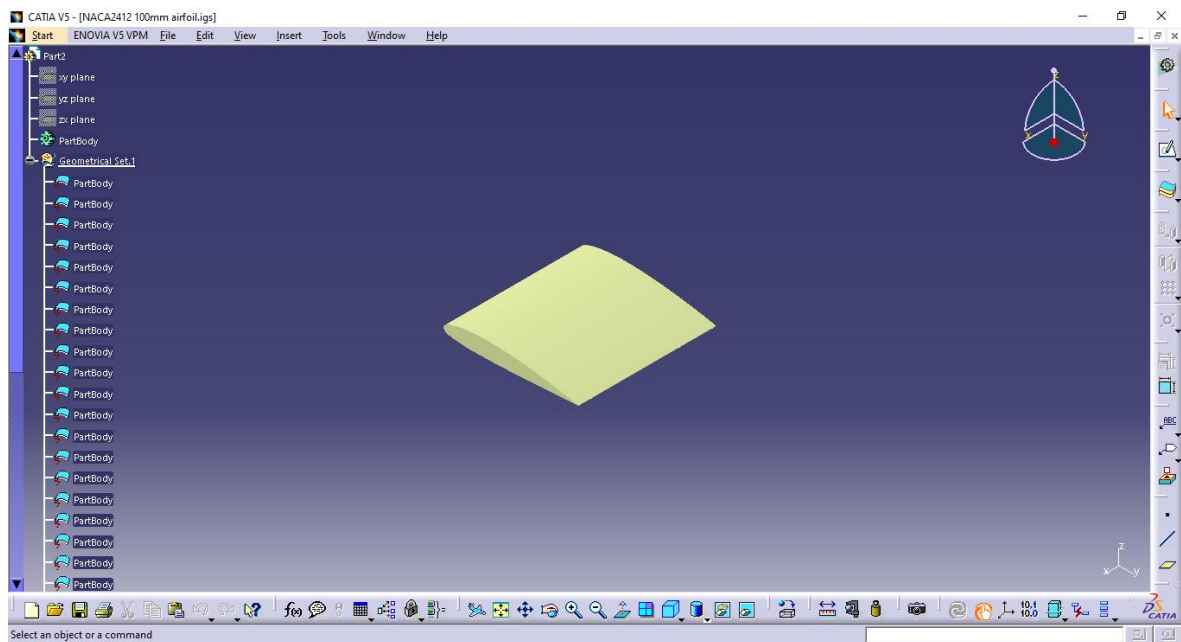


Fig 5.1 The Original NACA 2412 airfoil CAD Model

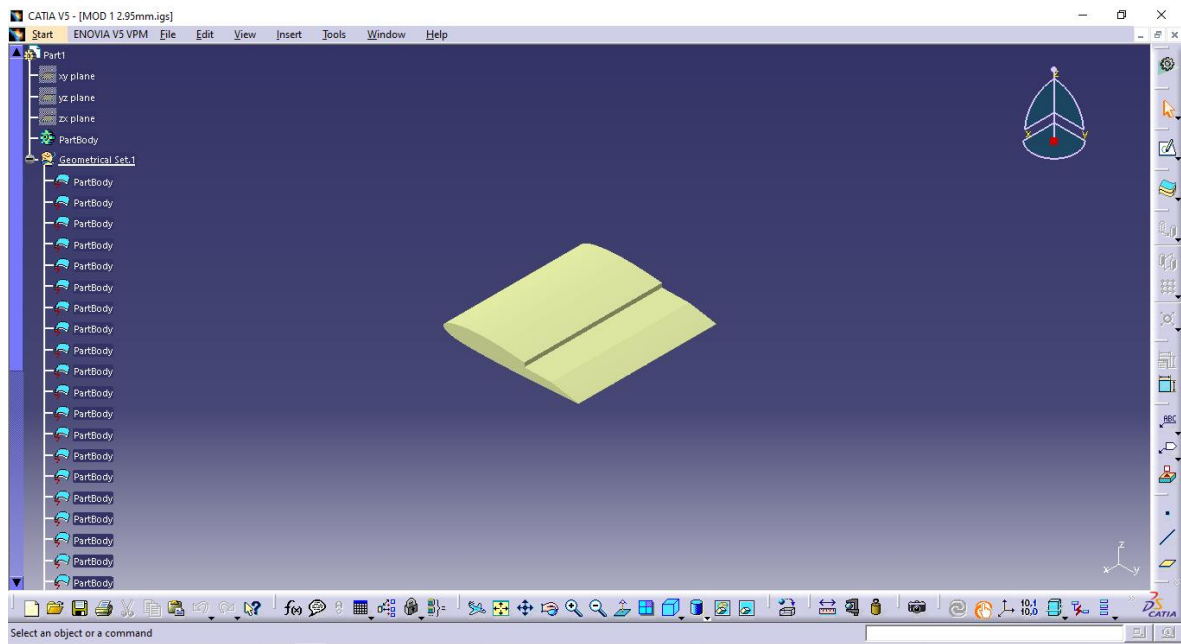


Fig 5.2 First CAD Modification

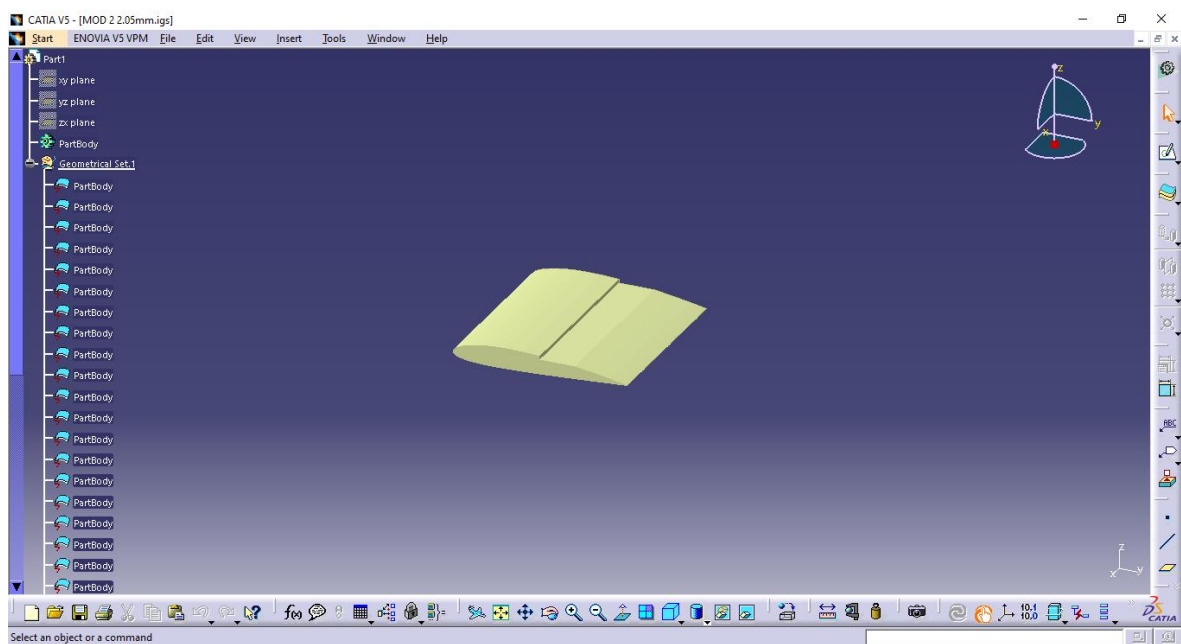


Fig 5.3 Second CAD Modification

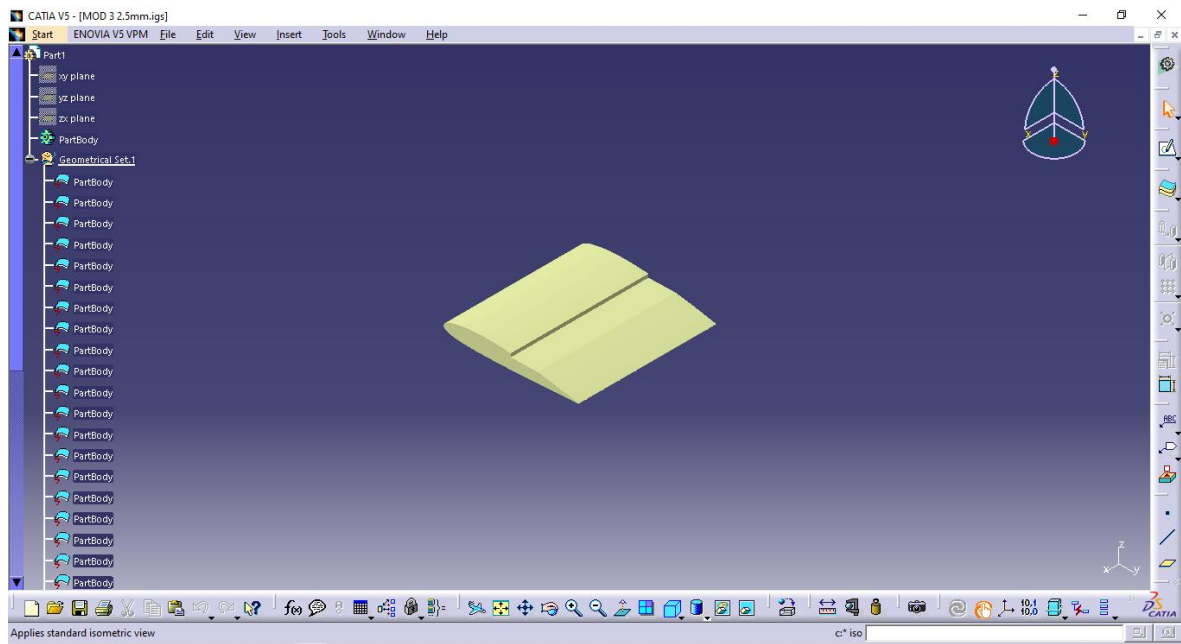


Fig 5.4 Third CAD Modification

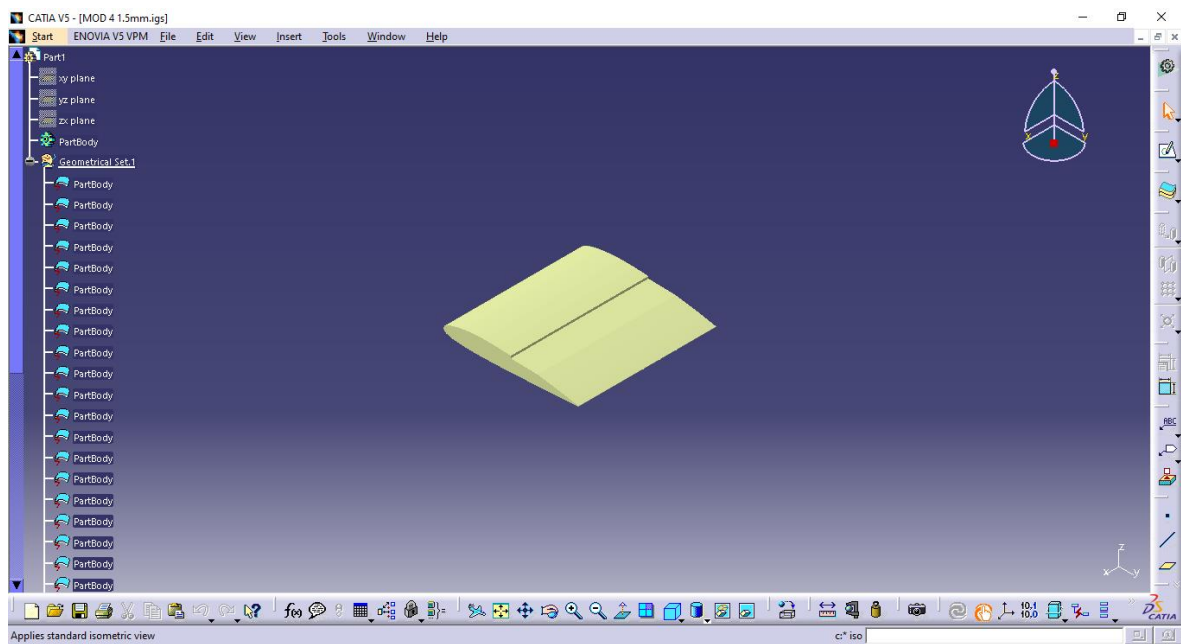


Fig 5.5 Fourth CAD Modification

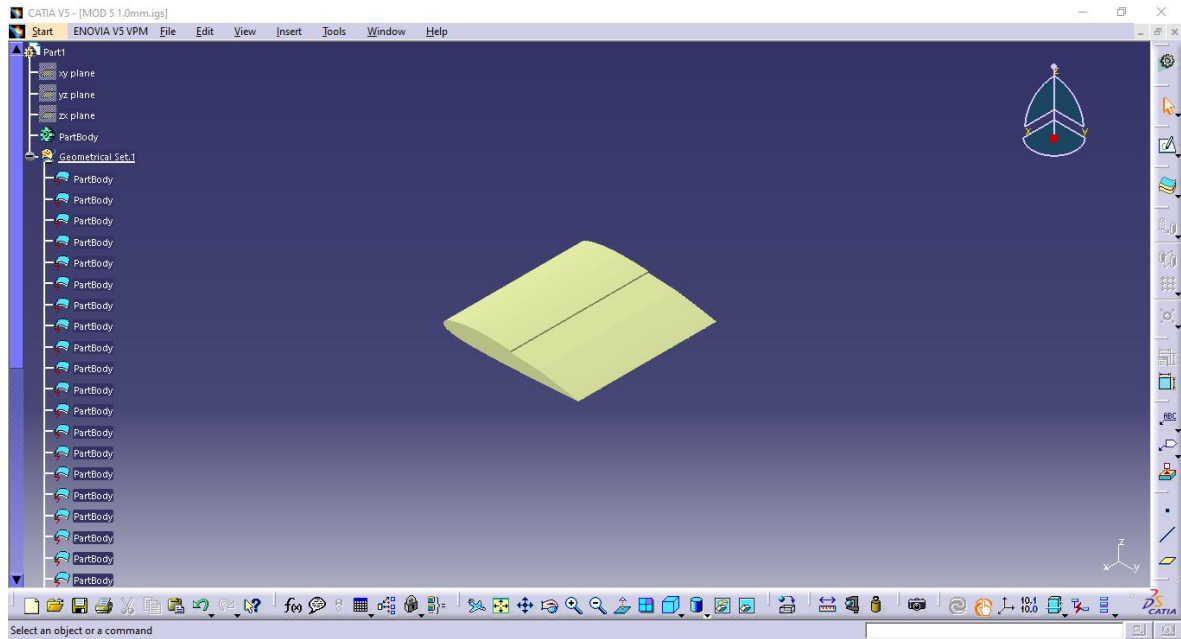


Fig 5.5 Fifth CAD Modification

5.2 CFD Analysis

Using CFD, we are able to analyze complex problems involving fluid-fluid, fluid-solid or fluid-gas interaction. Engineering fields where CFD analyses are frequently used are for example aerodynamics and hydrodynamics, where quantities such as lift and drag or field properties as pressures and velocities are obtained.

5.2.1 Design Parameters

- Enclosure Size : 0.5m x 1m x 0.5m

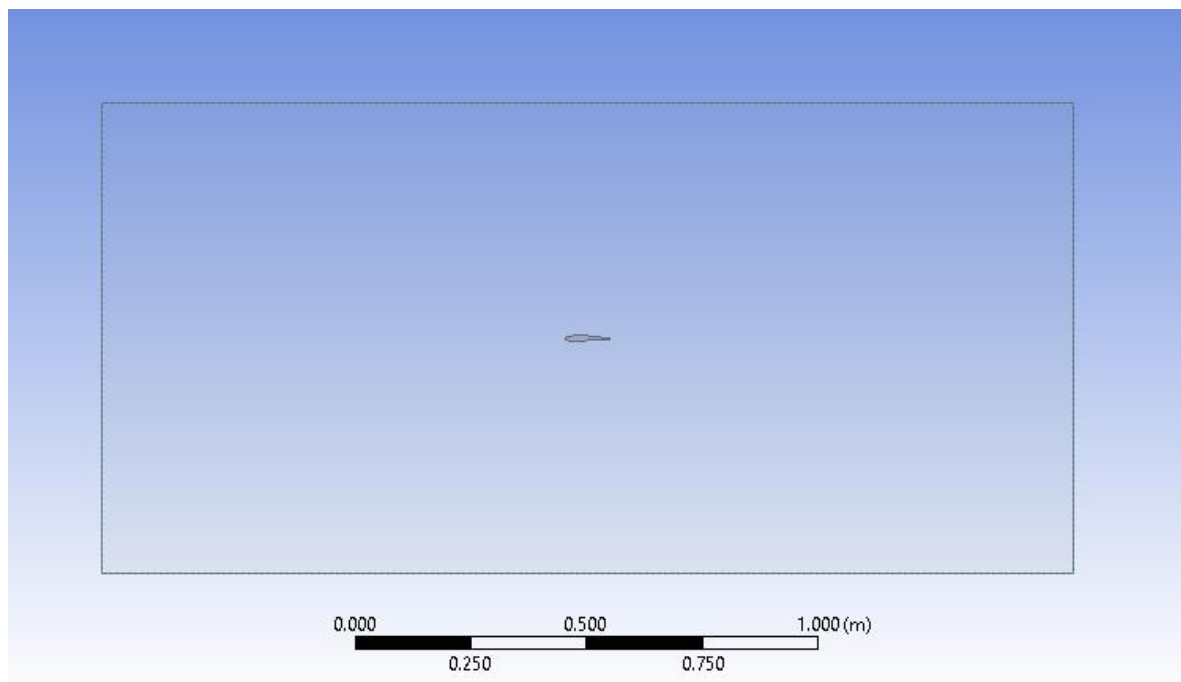


Fig 5.6 Enclosure Visualisation

5.2.2 Mesh

- Smoothing : High
- Curvature Min Size: 0.001m
- Defeature size : 0.0005m
- Node : 8199
- Elements : 43915

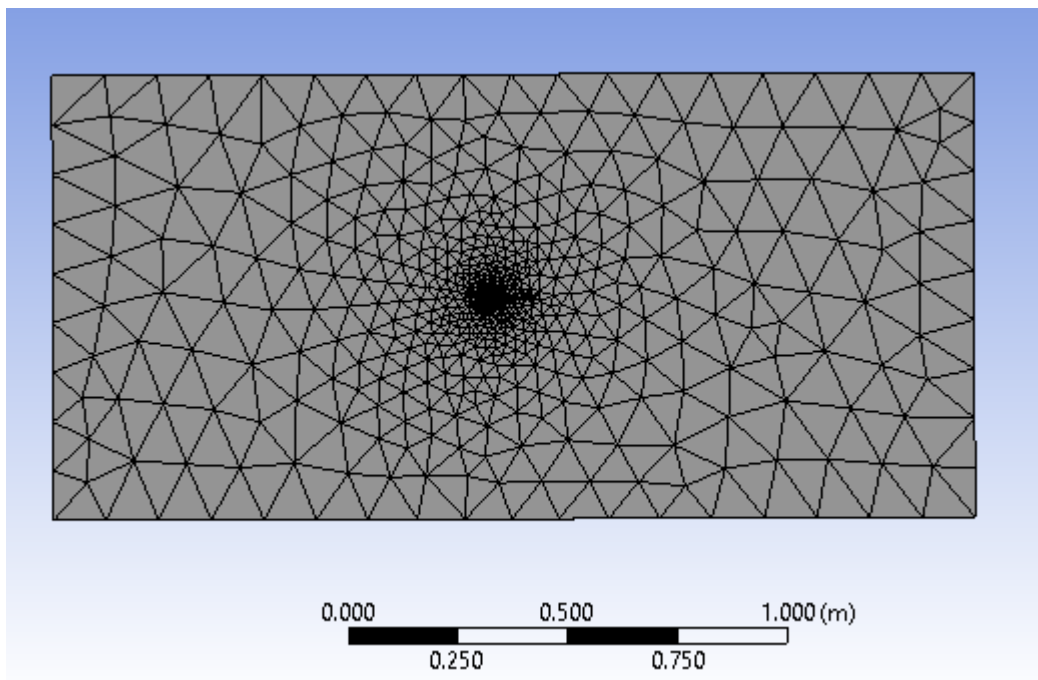


Fig 5.7 Mesh with enclosure

5.2.3 Boundary Conditions

- Viscous Model: SST K-omega
- Inlet Velocity: 30m/s, 60m/s and 90m/s
- Solver Method:
 - Scheme: Coupled
 - Turbulent KE: Second Order Upwind
 - Dissipation Rate: Second Order Upwind
- Solution Settings
 - Number of iterations: 500

- Automatic time step method

5.2.4 CFD Results

NACA 2412 Computational Results

The computational results obtained using the computational fluid dynamics results for the NACA 2412 model of the same chord length is shown in this table 5.1 and the plot between Coefficient of lift and alpha is shown in Fig 5.8

Table 5.1 NACA 2412 Computational Results

Angle of Attack	Lift	Drag	Cl	Cd	Velocity
0	0.19706609	0.056975354	0.32174056	0.093020986	30
3	0.40632244	0.065242285	0.66338357	0.10651802	30
5	0.56054192	0.096687049	0.91517048	0.15785641	30
7	0.75845097	0.12480432	1.2382873	0.20376215	30
11	1.1323646	0.23720363	1.8487586	0.38727123	30
15	1.4462466	0.36610389	2.3612189	0.59772063	30
19	1.8537267	0.55242295	3.0264926	0.90191502	30
23	1.95795	0.72662163	3.343544	1.186321	30
27	2.3458926	1.020709	3.8300287	1.6664637	30
31	2.3216875	1.111903	3.994573	1.8153518	30
35	2.5772034	1.4308733	4.207679	2.3361196	30
39	2.1400244	1.4911207	3.4939174	2.4344827	30

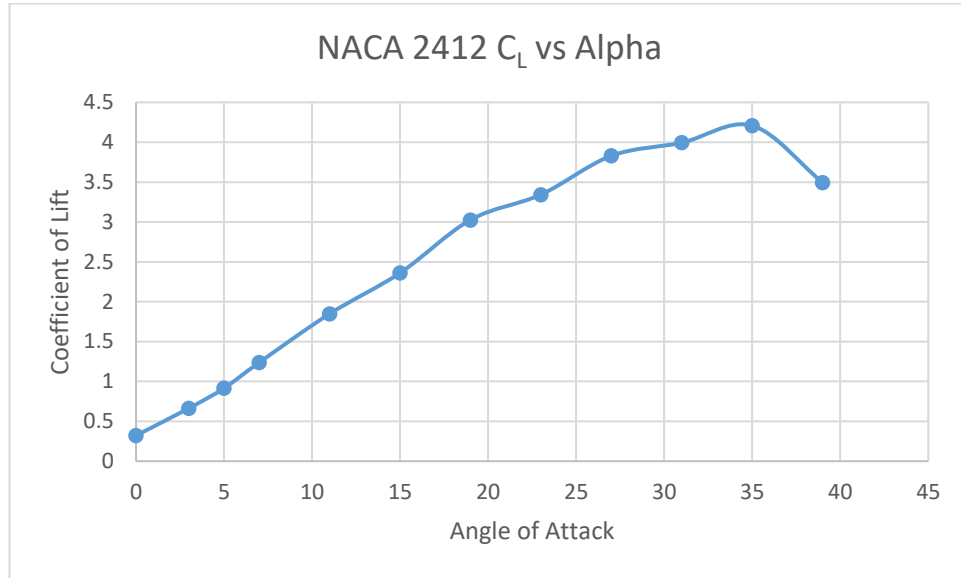


Fig 5.8 The Coefficient of Lift vs Alpha for the NACA airfoil

Modification 1 Computational Results

The computational results obtained using the computational fluid dynamics results for the first modification model of the same chord length is shown in this table 5.2 and the plot between Coefficient of lift and alpha is shown in Fig 5.9

Table 5.1 First Modification Computational Results

Angle of Attack	Lift	Drag	Cl	Cd	Velocity
0	0.308244	0.089122	0.50327	0.145504	30
3	1.198962	0.19252	1.957545	0.314319	30
5	1.641454	0.28314	2.680001	0.462269	30
7	1.7091	0.327082	2.790448	0.534011	30
11	2.118884	0.443869	3.459502	0.724684	30
15	3.51876	0.890767	5.745079	1.454313	30
19	3.821476	0.923109	6.239324	1.507116	30
23	5.555893	1.97134	9.071106	3.218514	30
27	7.465775	2.97113	12.18937	4.850825	30
31	7.451204	3.386331	12.16558	5.528703	30

35	4.653512	2.583722	7.59779	4.218322	30
39	5.555893	1.97134	7.285391	5.886648	30

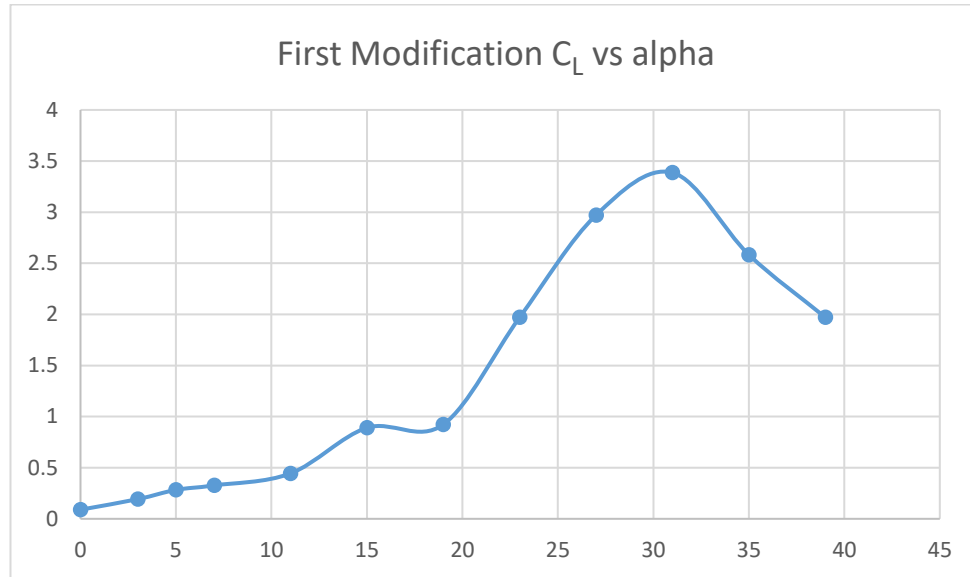


Fig 5.9 The Coefficient of Lift vs Alpha for the First modification airfoil

Modification 2 Computational Results

The computational results obtained using the computational fluid dynamics results for the second modification model of the same chord length is shown in this table 5.3 and the plot between Coefficient of lift and alpha is shown in Fig 5.10

Table 5.2 First Modification Computational Results

Angle of Attack	Lift	Cl	Drag	Cd	Velocity
0	0.300332	0.490338	0.060937	0.1289	30
3	1.227513	2.004103	0.158524	0.285028	30
5	1.6381	2.674449	0.212517	0.358875	30
7	2.536725	4.141592	0.330319	0.539296	30
11	3.764381	6.145928	0.623392	1.017783	30
15	4.321047	7.054771	0.856848	1.398935	30
19	4.439425	7.248041	1.138696	1.859096	30

23	7.467938	12.75282	2.210429	3.608863	30
27	8.643494	14.11183	3.201126	5.226328	30
31	6.115878	10.52266	2.224325	3.631551	30
35	5.911848	9.651997	2.518796	4.112321	30
39	6.943254	11.33593	2.829093	4.618927	30
43	5.958024	9.727386	2.53847	4.144441	30

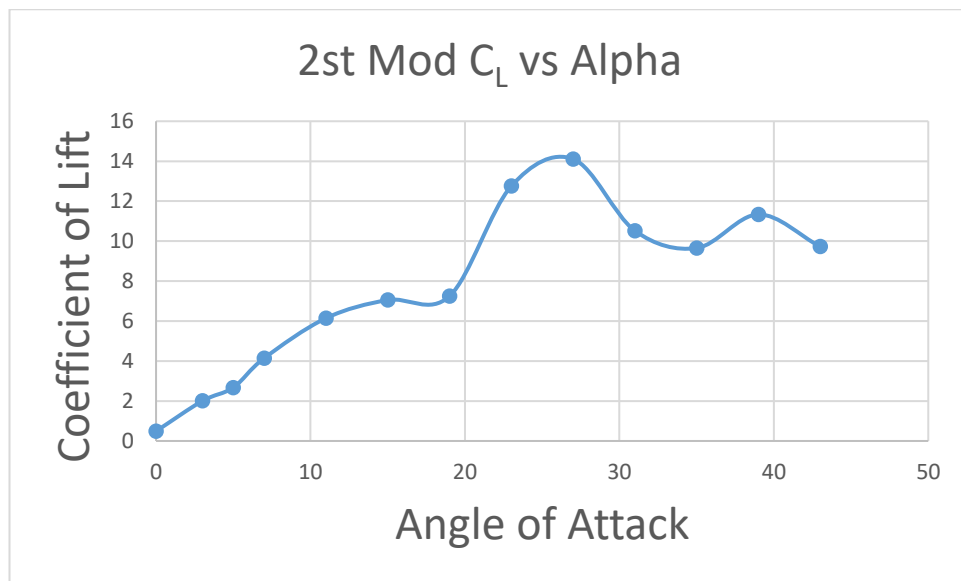


Fig 5.10 The Coefficient of Lift vs Alpha for the Second modification airfoil

Modification 3 Computational Results

Table 5.2 First Modification Computational Results

Angle of Attack	Lift	Drag	Cl	Cd	Velocity
0	0.243377	0.070365	0.39735	0.114881	30
3	0.5977	0.095971	0.975837	0.156688	30
5	0.825118	0.142323	1.347131	0.232365	30
7	1.105063	0.18184	1.804185	0.296881	30
11	1.354308	0.283696	2.211115	0.463176	30
15	2.127429	0.538539	3.473353	0.879247	30

19	2.204081	0.656831	3.5985	1.072377	30
23	2.322129	0.861773	3.965443	1.406977	30
27	3.331167	1.449407	5.438641	2.366378	30
31	3.396629	1.626714	5.84406	2.65586	30
35	3.376136	1.874444	5.512059	3.060317	30
39	2.749931	1.91609	4.489684	3.12831	30

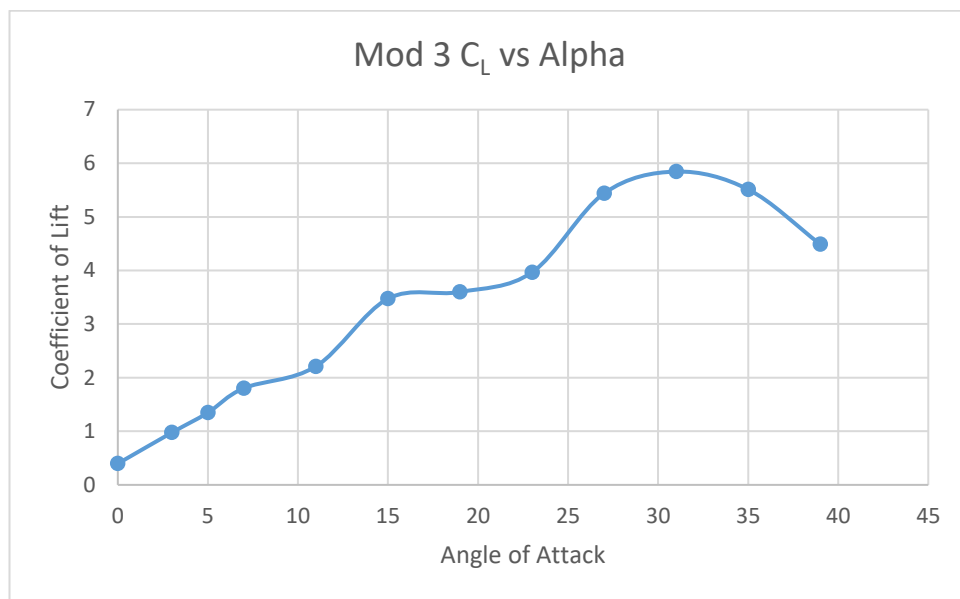
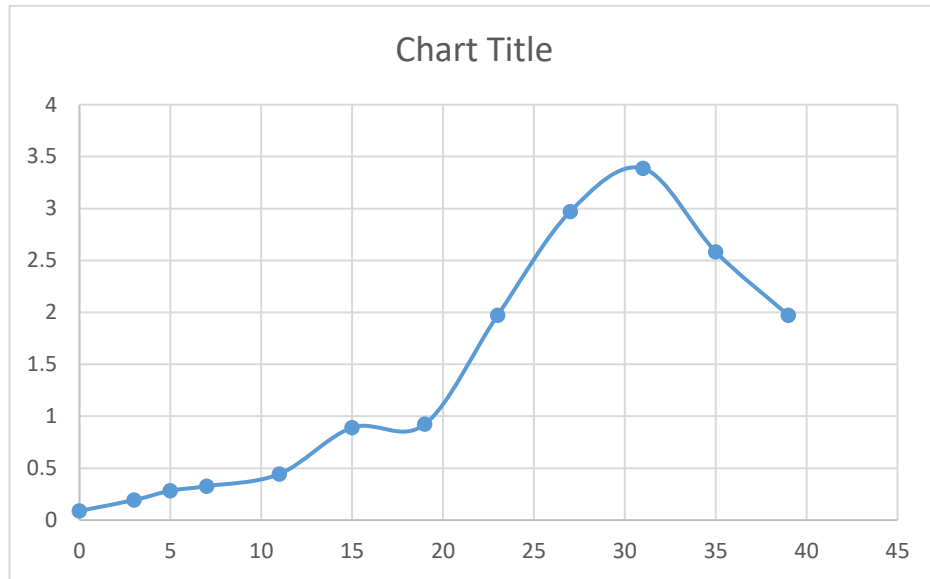


Fig 5.11 The Coefficient of Lift vs Alpha for the Third modification airfoil

Modification 4 Computational Results

Angle of Attack	Lift	Drag	Cl	Cd	Velocity
0	0.277198	0.080145	0.452581	0.130849	30
3	0.780574	0.125339	1.274443	0.204635	30
5	1.371306	0.236541	2.238932	0.38619	30
7	1.503167	0.287671	2.45422	0.469666	30
11	1.783573	0.373627	2.912039	0.610003	30
15	2.476256	0.626859	4.042983	1.023444	30
19	3.233059	0.780972	5.278616	1.275056	30

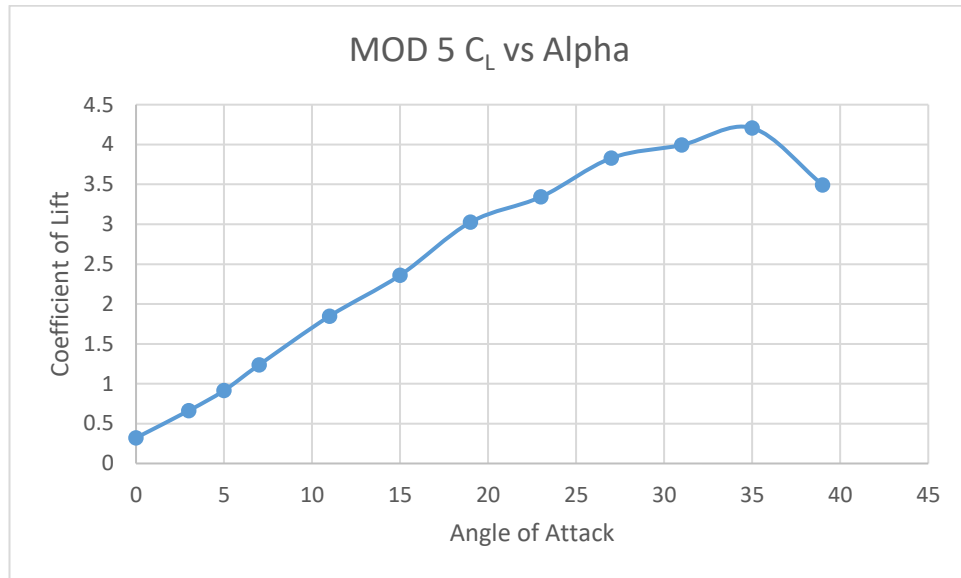
23	4.277054	1.517583	6.983145	2.477686	30
27	4.435992	1.765377	7.242644	2.882249	30
31	4.599508	2.090328	7.509617	3.41278	30
35	4.07488	2.262454	6.653056	3.693802	30
39	3.836779	3.100234	6.264308	5.061606	30



Modification 5 Computational Results

Angle of Attack	Lift	Cl	Drag	Cd	Velocity
0	0.21673487	0.353852854	0.043975354	0.093020986	30
3	0.45873487	0.748954884	0.059242285	0.10651802	30
5	0.72054192	1.176394969	0.0934787	0.15785641	30
7	0.95845097	1.564817913	0.12480432	0.20376215	30
11	1.4323646	2.338554537	0.23720363	0.38727123	30
15	1.8462466	3.014280114	0.36610389	0.59772063	30
19	2.1537267	3.516288523	0.55242295	0.90191502	30
23	2.454893	4.192161578	0.72662163	1.186321	30

27	2.7560593	4.499688612	1.020709	1.6664637	30
31	3.0572256	5.260101041	1.111903	1.8153518	30
35	3.3583919	5.48308879	1.4308733	2.3361196	30
39	3.6595582	5.974788919	1.4911207	2.4344827	30
43	3.3583919	5.48308879	1.4308733	2.3361196	30



CHAPTER 6

WIND TUNNEL EXPERIMENT

6.1 Fabricated Model



Fig 6.1 Fabricated Modified Model

The above Fig 6.1 shows the modified fabricated model

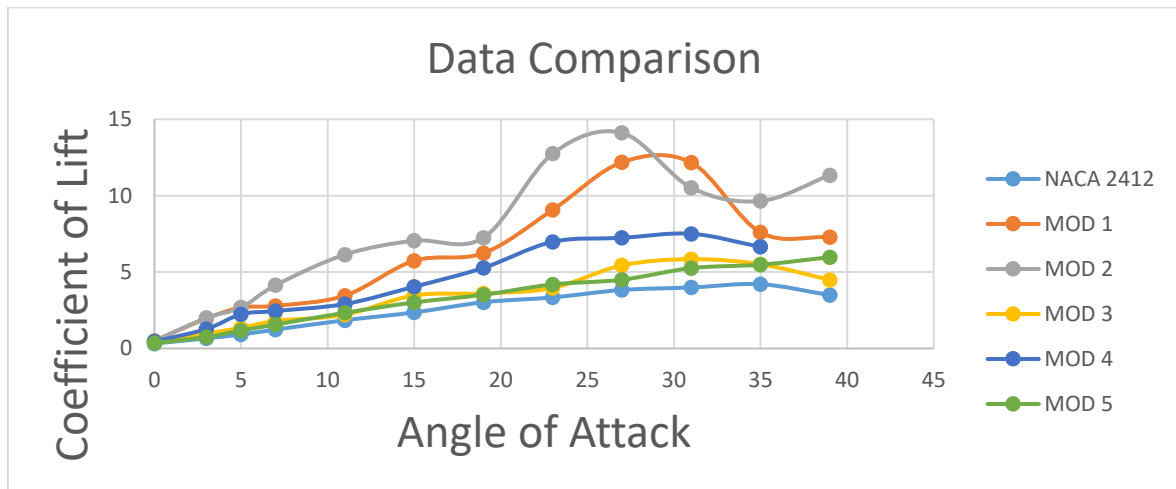
6.2 Smoke Test



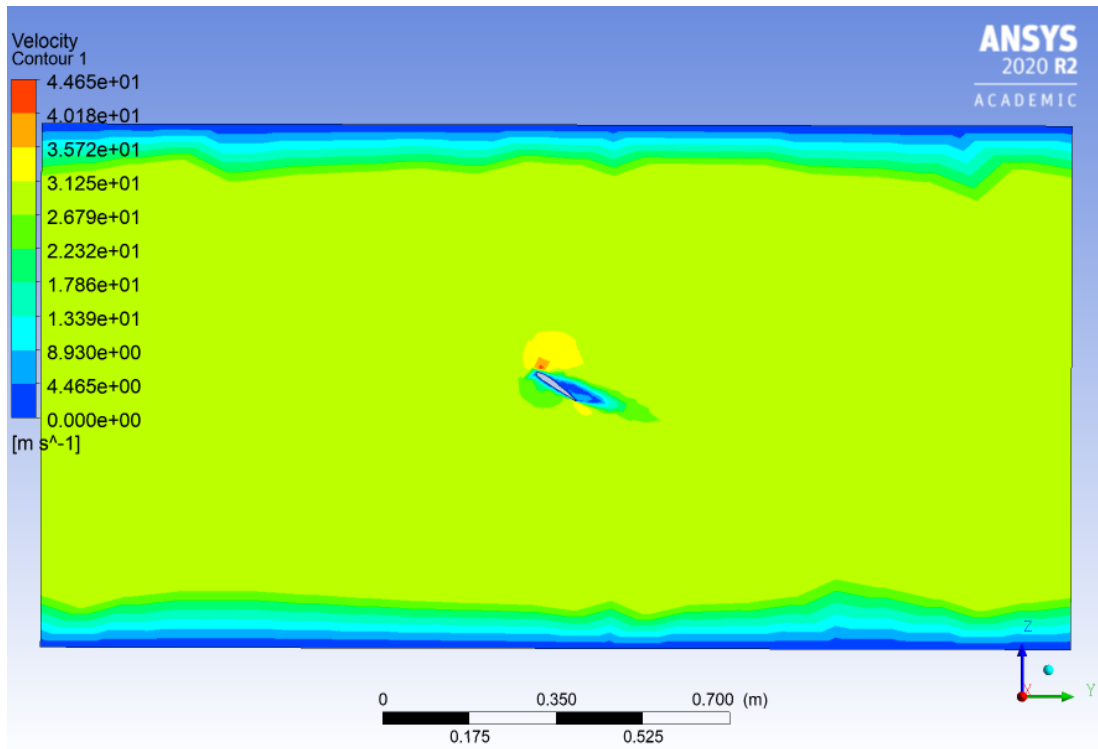
CHAPTER 7

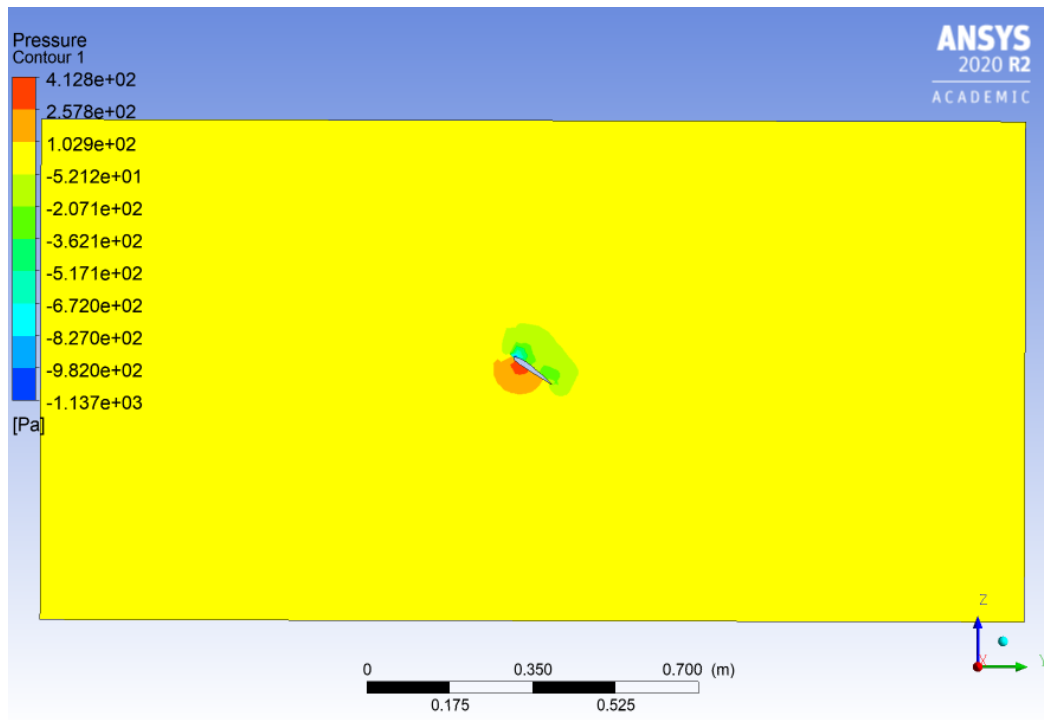
RESULT

7.1 CFD Results



7.1.1 Pressure contour





7.2 Smoke Test Results

- The smoke was more streamlined around the introduced stepwise continuity
- The flow seemed more attached to the body and the vortices and less when compared to the original NACA 2412 model without any modification
- The smoke test reveals the flow to be smooth and hence can be concluded that the modification impacts the aerodynamics around the wing in a positive way

CHAPTER 8

RESULT AND SUMMARY

8.1 RESULT

The modification provided more lift and reduced drag as anticipated at the beginning of the project the results could be published as a journal.

8.2 SUMMARY

CAD Design was carried out at first followed by the CFD analysis and then the model was fabricated and smoke test was carried out. The lift and drag of the modified NACA airfoil was compared to that of the existing NACA airfoil and the results were found to be positive and the lift were reduced.