Qualitative Study of Aircraft Wings and Associated Structures from Aerodynamic Perspective

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ABSTRACT

The modern day Aviation Industry has seen enormous competition is varied aspects ever since the advent of consumer friendly air travel and economic air transport. The key challenge before Engineers is to meet the structural as well as aesthetic requirements of their clients in such a manner that the design is cost effective and meets the desires and requirements of the end users. From the first principles, there are a number of methods of achieving the same, one being Design of the Wings of the Aircraft from the Aerodynamic perspective. Design of any system involves a number of considerations and boundary conditions which link to the performance parameters. Thus the process of Aerodynamic Design has gained importance in the recent times. This study highlights certain basic aspects of flight of an aircraft and thereafter provides details of certain supporting structures that aid a smooth flight. The Physics of flight mainly involves the manner in which, a pressure differential is developed on the wings of an aircraft due to the very shape of the aircraft and its Wings. Initially, classification of parts of a fixed wing aircraft has been elaborated in addition to which, certain key terms used in design are stated. The kinetics of flight involves certain forces which have been discussed qualitatively. These forces include Lift, Weight, Thrust and Drag. Although each of these forces is physically independent, a collective effect that is the resultant is what leads to a successful flight. Advances in the aerod ynamic design have led to design of Military Fixed Wing Aircraft which have the capability to land vertically on Aircraft Carriers in the mid sea. This is indeed the summit of engineering capabilities. Innovations can indeed lead to strengthening the Technical capabilities with the underlying principle being sound design and complete adherence to the first principles. Finally, certain Advantages and Limitations of Aerodynamic Design of Wings and associated process have been stated. A conclusion has been drawn towards the end stating the importance of Aerodynamic Design of Aircraft Wings.

Keywords: Aerodynamic, Qualitative Study, Aircraft,Design.

1. Introduction

An aircraft is basically defined as a machine that is heavier than air and one which is capable of flying with or without power. This means any structure that is capable of flying is an aircraft. Right from the Paper planes made by children to the Jumbo Jets that fly in the sky, one common aspect is the ability to fly. The question is, what makes an aircraft fly? The answer to this question is the very shape of the aircraft. Supplementing this is the shape of the wing of the aircraft. 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 aerofoils. 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, including hydrofoils. Hydrodynamics is the governing science, rather than aerodynamics .Applications of underwater foils occur in hydroplanes, sailboats and submarines. Lift creation can be described in two ways. Firstly in the form of a Pressure differential where the air pressure on the bottom surface of the wing is higher than the air pressure of the top surface. This pressure difference creates a net upward force. Secondly, Newton's Third law of motion according to which, the wing pushes air downwards and as a consequence, the air itself pushes the wing upwards, thereby generating lift.

2. Literature Survey

The work described in this paper titled ―Airfoil Optimization Using Practical Aerodynamic Design Requirements‖ follows from the investigation of multipoint optimization applied to practical aerodynamic design problems undertaken by Zingg and Billing. Their goal was to demonstrate that multipoint optimization techniques can be applied to complex aerodynamic design problems that encompass a broad range of requirements extending beyond typical *drag minimization over a range of cruise conditions*. This broad range of design requirements includes high lift at low speed and consideration of Maneuverability under dive conditions. The current work in progress focuses on several key findings from their investigation:

- Performance at on-design points is compromised by the need to satisfy off-design constraints
- On-design performance may be unnecessarily sacrificed if off-design constraints are over-satisfied.
- Over-satisfaction of off-design constraints can be prevented by appropriate selection of their respective design point weights.

In this project titled ―Investigation of airfoil design‖ an effort has been made to make a detailed study on lift and drag coefficient of various airfoil sections. The airfoils decide whether the lift force is sufficient to balance the weight of the plane or not and how much drag force is being applied on the plane. Airfoils are basically divided into two categories; The Author has tried to differentiate between the two types i.e., Symmetrical and Asymmetrical airfoils on the basis of their lift and drag coefficient's variation with angle of attack, stall angle of attack and magnitude of the coefficients.

3. Principle of Flight

The flight of an aircraft is determined by the Physics associated with the various forces acting on the aircraft and their effect on the shape of the aircraft and the resultant motion. The following sections deal with certain fundamental concepts regarding the principles of flight

3.1. Parts of an Aircraft

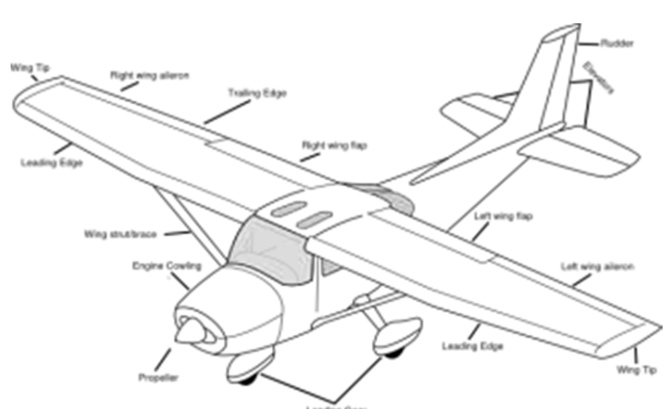


Fig 1: Parts of an Aircraft

- Every Fixed wing Aircraft comprises of four basic parts viz. Fuselage, Main-plane, Tail-plane and Fin.
- Fuselage is that part of the aircraft that carries the cargo, machinery and passengers.

- Main-plane refers to the main Wings of the Aircraft. They are primarily attached with Ailerons and Flaps to control the flight. The purpose of a main-plane is to maintain the horizontal stability of an aircraft.
- Tail-plane refers to the hind wings of the Aircraft. They are dimensionally smaller compared to the main-plane. They are attached with the elevators which aid the altitude control of the aircraft.
- Fin is that part of the Aircraft which aids vertical stability and allows yawing movement of the aircraft with the help of the rudder fitted to it.
- There are some more parts identified as follows:
- Ailerons are attached to the hind portion of the main-plane which is also known as the trailing edge. Their function is to facilitate rolling and banking movement of the aircraft
- Elevators are attached to the trailing edge of the tail-plane. Their function is to facilitate the pitching movement of the aircraft.
- Rudders are attached to the trailing edge of the Fin to control the yawing movement of the aircraft.
- Flaps are attached to the front portion i.e. leading edge of the main-plane. These facilitate reduction of speed of the aircraft.
- At times, trim tabs are used as auxiliary structures to correct alignment errors in the main-plane and to ensure dynamic balance while flying.

3.2. Forces Acting on an Aircraft during Flight

Fig 2: Forces Acting on an Aircraft during Flight

Fig 3: Forces Acting on a Wing

There are four basic forces that act on the airplane. They are: Lift, Drag, Thrust and Weight.

- Lift is the push that lets something move up. It is the force that is the opposite of weight. For an aircraft to move upward, it must have more lift than weight. A hot air balloon has lift because the hot air inside is lighter than the air around it. Hot air rises and carries the balloon with it. Lift is a positive force caused by the difference in air pressure under and above a wing. The higher air pressure beneath the wing creates lift, and is affected by the shape of the wing. Changing a wing's angle of attack affects the speed of the air flowing over the wing and the amount of lift that the wing creates.
- Drag is the resistance of the air to anything moving through it. Drag opposes thrust, and acts rearward parallel to the relative wind. In other words, Drag is a force that pulls back on something trying to move. For example, it is more difficult to walk or run through water than through air. Water causes more drag than air. Different wing shapes greatly affect the drag. Air divides smoothly around a wing's rounded leading edge and flows neatly off its tapered trailing edge. This is called Streamlining.
- Thrust is the force that propels an object forward. Thrust is the force that is the opposite of drag. For an aircraft to keep moving forward, it must have more thrust than drag. A small airplane might get its thrust from a propeller. A larger airplane might get its thrust from jet engines. As a general rule, it is said to act parallel to the longitudinal axis.
- Weight is the combined load of the airplane itself, the crew, the fuel, and the cargo or baggage. Weight is the amount of gra vity multiplied by the mass of an object. It is also the downward force that an aircraft must overcome to fly. A kite has less mass and therefore less weight to overcome than a jumbo jet, but they both need the same thing in order to fly i.e. lift. Weight opposes lift and acts vertically downward through the airplane's center of gravity.

All these forces are of key consideration during the aerodynamic design of wings of an aircraft.

4. Aerodynamic Design and Operation of Aircraft Wings

The study till this point has highlighted the basic requirements for flight. This section emphasizes on the design aspect of the wings of an aircraft.

4.1. Aerodynamics

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Aerodynamics is a subfield of fluid dynamics and gas dynamics, with much theory shared between them. Judging from the story of Daedalus and Icarus, humans have been interested in aerodynamics and flying for thousands of years, although flying in a heavier-than-air machine has been possible only in the last hundred years.Aerodynamics plays an important role in the performance of an Airplane during flight as well as during take-off and landing. For this the wings of an airplane must be properly designed to have a smooth and steady flight. An Airplane having well designed wings according to the aerodynamic modification will have a very good performance at variable atmospheric conditions. Aerodynamic problems can be identified in a number of ways. The flow environment defines the first classification criterion. External aerodynamics is the study of flow around solid objects of various shapes. Evaluating the l ift and drag on an airplane or the shock waves that form in front of the nose of a rocket are examples of external aerodynamics. Internal aerodynamics is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine or through an air conditioning pipe. The design and analysis of the wings of aircraft is one of the principal applications of the science of aerodynamics, which is a branch of fluid mechanics. The properties of the airflow around any moving object can be found by solving the Navier-Stokes equations of fluid dynamics. However, except for simple geometries these equations are notoriously difficult to solve. However, simpler explanations can be described.

For a wing to produce "lift", it must be oriented at a suitable angle of attack relative to the flow of air past the wing. When this occurs the wing deflects the airflow downwards, "turning" the air as it passes the wing. Since the wing exerts a force on the air to change its direction, the air must exert a force on the wing, equal in size but opposite in direction. This force manifests itself as differing air pressures at different points on the surface of the wing.A region of lower-than-normal air pressure is generated over the top surface of the wing, with a higher pressure on the bottom of the wing. These air pressure differences can be either measured directly using instrumentation, or can be calculated from the airspeed distribution using basic physical principles—including Bernoulli's principle, which relates changes in air speed to changes in air pressure.The lower air pressure on the top of the wing generates a smaller downward force on the top of the wing than the upward force generated by the higher air pressure on the bottom of the wing. Hence, a net upward force acts on the wing. This force is called the "lift" generated by the wing.The different velocities of the air passing by the wing, the air pressure differences, the change in direction of the airflow, and the lift on the wing are intrinsically one phenomenon. It is, therefore, possible to calculate lift from any of the other three. For example, the lift can be calculated from the pressure differences, or from different velocities of the air above and below the wing, or from the total momentum change of the deflected air. Fluid dynamics offers other approaches to solving these problems.The flight of an aircraft is determined by the Physics associated with the various forces acting on the aircraft and their effect on the shape of the aircraft and the resultant motion. The following sections deal with certain fundamental concepts regarding t he principles of flight

4.2. Aerofoil Shape

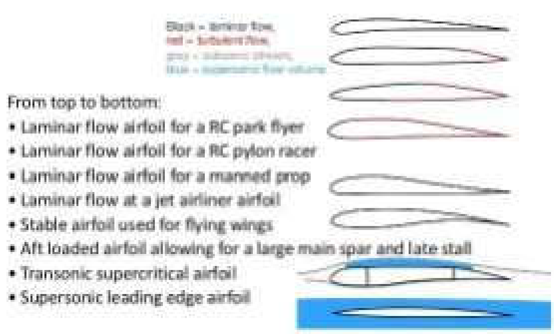


Fig 4: Aerofoil shape of a Wing

Aerofoil design is a major facet of aerodynamics. Various aerofoils serve different flight regimes. Asymmetric aerofoils can generate lift at zero angle of attack, while a symmetric aerofoil may better suit frequent inverted flight as in an aerobatic airplane. In the region of the ailerons and near a wingtip a symmetric airfoil can be used to increase the range of angles of attack to avoid spin-stall. Thus a large range of angles can be used without boundary layer separation. Subsonic aerofoils have a round leading edge, which is naturally insensitive to the angle of attack. The cross section is not strictly circular, however: the radius of curvature is increased before the wing achieves maximum thickness to minimize the chance of boundary layer separation. This elongates the wing and moves the point of maximum thickness back from the leading edge. Supersonic aerofoils are much more angular in shape and can have a very sharp leading edge, which is very sensitive to angle of attack. A supercritical aerofoil has its maximum thickness close to the leading edge to have a lot of length to slowly shock the supersonic flow back to subsonic speeds. Modern aircraft wings may have different aerofoil sections along the wing span, each one optimized for the conditions in each section of the wing.

4.3. Design Features of Aircraft Wings

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 counter clockwise 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 to help prevent flow separation in transonic flow
- 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‖ 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

4.4. Operations

The chord of the slat is typically only a few percent of the wing chord. The slats may extend over the outer third of the wing, or they may cover the entire leading edge. Many early aerodynamicists, including Ludwig Prandtl believed that slats work by inducing a high energy stream to the f low of the main airfoil thus re-energizing its boundary layer and delaying stall. In reality, the slat does not give the air in the slot high velocity (it actually reduces its velocity) and also it cannot be called high-energy air since all the air outside the actual boundary layers has the same total head. The actual effects of the slat are:

- The slat effect: The velocities at the leading edge of the downstream element (main airfoil) are reduced due to the circulation of the upstream element (slat) thus reducing the pressure peaks of the downstream element.
- The circulation effect: The circulation of the downstream element increases the circulation of the upstream element thus improving its aerodynamic performance.
- The dumping effect: The discharge velocity at the trailing edge of the slat is increased due to the circulation of the main airfoil thus alleviating separation problems or increasing lift.
- Off the surface pressure recovery: The deceleration of the slat wake occurs in an efficient manner, out of contact with a wall.
- Fresh boundary layer effect: Each new element starts out with a fresh boundary layer at its leading edge. Thin boundary layers can withstand stronger adverse gradients than thick ones.

5. Associated Structures

There are certain additional structures that are required to increase the operation ability of the Wings of the Aircraft. They include Ailerons, Flaps, Slats and Spoilers. This section provides brief details about the same.

Fig 5: Structures associated with the wings

5.1. Ailerons

Ailerons are mounted on the trailing edge of each wing near the wing tips and move in the opposite directions. When the pilot moves the stick left, or turns the wheel counter-clockwise, the left aileron goes up and the right aileron goes down. A raised aileron reduces lift on that wing and a lowered one increases lift, so moving the stick left, causes the left wing to drop and the right wing to rise. This causes the aircraft to roll to the left and begin to turn to the left. Centring the stick returns the ailerons to neutral maintaining the back angle. The aircraft will continue to turn until opposite aileron motion returns the back angle to zero to fly straight.

5.2. Flaps

Flaps are hinged surfaces mounted on the trailing edges of the wings of a fixed-wing aircraft to reduce the speed at which the aircraft can be safely flown and to increase the angle of descent for landing. They shorten take-off and landing distances. Flaps do this by lowering the stall speed and increasing the drag.

There are four basic types of flaps: plain, split, Fowler and slotted.

The plain flap is simply a hinged portion of the trailing edge increasing its curvature and, therefore, its lift. Split type flaps are hinged at the bottom of the wing and create much more drag than plain flaps. Split flaps generate a lot of drag by disturbing the airflow on the underside of the wing. The slotted flap is similar to a plain flap, but has a slot between the wing's trailing edge and the flap. The air passing through the slot delays the airflow separation and creates a greater increase in lift with a smaller increase in drag than a plain or split flap. Fowler flaps extend aft and down increasing the wings area and provide large increases in lift with a minimum of drag. Following figure depicts the same:

Plain Flap

Split Flap

Fowler Flap

Slotted Flap

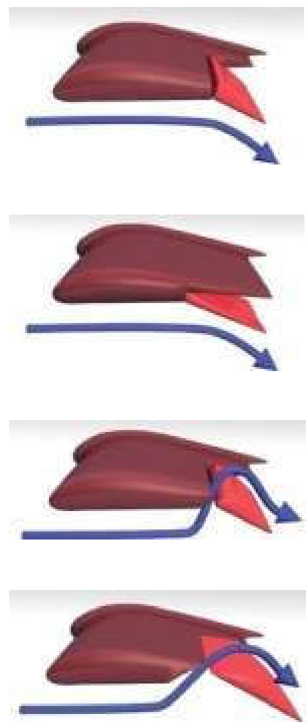


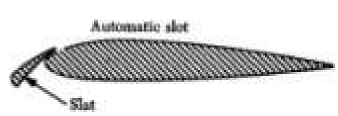
Fig 6: Types of Flaps

5.3. Slats

Slats are aerodynamic surfaces on the leading edge of the wings of fixed-wing aircraft which, when delayed, allow the wing to operate at the higher angle of attack. A higher coefficient of lift is produced as a result of angle of attack and speed, so by deploying slats an aircraft can fly at slower speeds, or take off and land in shorter distances. They are usually used while landing or performing manoeuvres which take the aircraft close to the stall, but are usually retracted in normal flight to minimize drag.

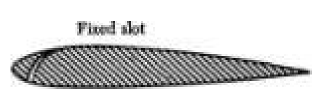
Slats are of three types: Automatic, Fixed and Powered.

Automatic Slat



Automatic slats open and close aerodynamically. They're not managed by the pilot - they're managed by airflow.

Fixed Slat



These slats are permanently extended. This is sometimes used on specialist low-speed aircraft.

Powered Slat

Powered slats appear on many large aircraft and provide the same benefit of an automatic slat. However, they're electrically or hydraulically powered - increasing reliability. The flight crew sets the slat position via cockpit controls.

Fig 7: Types of Slats

5.4. Spoilers

Air brakes are a type of flight control surface used on an aircraft to increase drag or increase the angle of approach during landing. Spoilers are designed to increase drag while making little change to lift. Thus spoilers reduce the lift-to-drag ratio and require a higher angle of attack to maintain lift, resulting in a higher stall speed. Most airplanes are equipped with gliders on their wings in order to adjust their angle of descent during approach to landing.

6. Associated Structures

There are certain additional structures that are required to increase the operation ability of the Wings of the Aircraft. They include Ailerons, Flaps, Slats and Spoilers. This section provides brief details about the same

6.1. Advantages of Aerodynamic Design

- Stable Design
- Improved Efficiency at controlled altitudes
- Reduction in drag
- Reduction in overall Fuel consumption

6.2. Disadvantages of Aerodynamic Design

- Mathematical modeling is complex
- Operation at high altitudes may require supercharging if not accurately designed

7. Associated Structures

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7.1. Designing of Flapping Wings for Aircraft

Fig 8: Model of Flapping Wing Aircraft

The recent interest in flapping wing air vehicle is motivated by the notion that flapping wing may offer some unique aerodynamic advantages over a fixed wing solution. In the future, this technology may be integrated into new plane designs and even retrofitted into existing planes. This is very exciting for the future of flight technology, but more tests are needed before we start seeing these wings on commercial aircrafts.The first test flight was on 6 Nov 2015, conducted to-date included speeds at 0.75 Mach at 20,000 and 40,000ft altitude and various banking maneuvers up to 1.7G (continuous load) and high dynamic pressures subjecting the Flex Foil control surface to various load conditions.The technology has the potential to take aviation to new heights. The adaptive wing significantly increases the fuel economy of the airplanes and thus may decrease the amount of fuel used by as much as 12%. Air travel currently contributes a large amount of pollution to the atmosphere, so this advancement is good news for the environment. People living under air-traffic hotspots can also rejoice: Where old planes with rigid wings have fewer options to reduce drag and as a result are rather noisy, these new sleek wings minimize drag, making them slightly quieter.

7.2. Skyborg

Fig 9: Skyborg

The Air Force Research Laboratory is aiming to field the new prototype autonomous, unmanned combat air vehicle dubbed ―Skybor g‖ by 2023. Skyborg is a vessel for AI technologies that could range from rather simple algorithms to fly the aircraft and control them in airspace to the introduction of more complicated levels of AI to accomplish certain tasks or subtasks of the mission.

8. Conclusion

Thus it can be concluded that Aerodynamic design of Wings of an Aircraft leads to improvement in the overall performance of the aircraft thereby meeting the desired requirements of the end users. The study has thrown light on various facets of aerodynamic design which include basic parts of an aircraft, glossary of certain terms, forces acting on an aircraft, aerodynamic design and operation of Aircraft Wings and study of additional associated structures. Finally, the advantages and limitations highlight the practical significance of the aerodynamic design. The importance of Aerodynamic design is that competitiveness has been introduced in the Aviation Industry whereby, new and innovative ideas are shaping the future of the Industry.

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