iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VII **Month of publication:** July 2020

DOI: https://doi.org/10.22214/ijraset.2020.30573

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

Aerodynamic Principles for Aircraft: A Study

Ashwathy Harikumar[1], Vipin Vibhute[2]
[1, 2]Instrumentation and Control Department, D.Y. Patil College of Engineering, Akurdi, Pune – 411044

Abstract: Aerodynamics is the study of movement of air when the air interacts with a solid object. The study of aerodynamics is needed when resistive forces act on the vehicle, particularly when the vehicle is moving in a fluid medium. The resistive forces such as lift, side force and drag are the causes for the resistance on a vehicle. These above factors are become very important and vital in design of any aircraft. These factors form basics for design of a body of any vehicle such that there is minimum air resistance. The immediate advantages of minimum air resistance are reduction in fuel consumptions, increased speed and many more. In the following review article mainly contains detail knowledge on how aircraft is able to be up there in the air for desired time or estimated time. The different principles used for flying an aircraft are briefly discussed here. This review article also includes the study on how an aircraft actually works.

Nomenclature: Greek

ρ ***Density***

Roman

C ***Coefficient***

m ***Mass***

S ***Surface area***

T ***Thrust***

V ***Velocity***

Index Terms – aerodynamics, aircraft, air resistance, drag, lift, flap, slat

I. INTRODUCTION

What is Aerodynamics? In order to understand this let's recall our basics about atmosphere. Earth's atmosphere is completely covered with different types of gases. Which are Nitrogen(78.084%), Oxygen(21%),Argon(0.93%),Carbon dioxide(0.04%) and other gases in trace amount [1]. Hence, aerodynamics is nothing but resistance induced by air particles on the solid moving objects or vehicles in the air or having a shape which reduces the drag from air moving past. In aerodynamics we mainly mean air dynamics and it is not only a field of air dynamics but also a sub-field of fluid dynamics and gas dynamics. Aerodynamics comprise of different forces acting on an aircraft, different principles working on and in aircraft due to which it successfully flies. The main reason to study aerodynamics is to reduce the air resistance induced by air on a moving solid object. The air resistance is also known as aerodynamic drag and reducing the aerodynamic drag will be advantageous to attend higher top speed but also reduction in the overall fuel consumption of the vehicle [2] and increases in comfortability. A study of aerodynamics also includes forces acting on moving vehicles and even study of undesired lift forces and other causes of instabilities in moving vehicles [3]. The principles of aerodynamics are applied to the designs of many different things, including buildings, bridges and even soccer balls; however, of primary concern is the aerodynamics of aircraft and automobiles [4]. The first ever scientist to discover this force was Sir Issac Newton and he named this force as "Drag". In the early 1800's along with drag other forces like thrust, lift, weight were also added in aerodynamic [5]. With the knowledge of these basics forces gliders were introduced. The first person to make a glider was Otto Lilienthal. After that by upgrading the researches on aerodynamics by others Wright brothers became the first to fly an aircraft with engine.

II. AERODYNAMIC FORCES

A force when exerted on any object will change the motion of that object. A force can be thought of as a push or pull action in any direction. A force is a vector quantity having both a magnitude and a direction. A force causes an object to move even from a state of rest, with mass to change its velocity i.e. to accelerate.

Aircraft is a streamline body in shape of an airfoil. The forces acting on an aircraft, Fig. 1:

1) *Drag:* Drag is the opposing force acting on an aircraft due-to/by the gases in the air. The resistance due to drag greatly depends on the shape of the wings of the aircraft. Also this force depends upon the relative velocity of aircraft with respect to air speed. The streamline shape of aircraft body is a major contribution to the drag force [6].

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

The equation governing drag is:

$$D = \frac{1}{2} \rho V^2 S C_D \quad (1)$$

Were,
ρ = density of air
V = velocity of airplane relative to air
S = Surface area of the wing
C_D = Coefficient of drag.

2) *Lift:* Is a mechanical force generated by a solid object when moving through fluid. When an aircraft flies in air atmospheric pressure acts on it. When this pressure is acted on the wings Low pressure is created at the top of the wings and High pressure beneath the wings. This is because path for air to travel through wings is long on top and short at the bottom.

The equation governing lift is :

$$L s= \frac{1}{2} \rho V^2 S C_L \quad (2)$$

Where,
ρ = density of air
V = velocity of airplane relative to air
S = Surface area of the wing
C_l = Lift coefficient.

3) *Thrust:* is a reaction force described by Newton's third law. When a mass is expelled or accelerated in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction [7]. This force helps the aircraft to move ahead. Turbines play a very important role in producing this force.

The equation governing thrust is:

$$T = V\, dm/dt \quad (3)$$

Where,
T = thrust generated (force)
dm/dt = is the rate of change of mass with respect to time (mass flow rate of exhaust)
V = speed of the exhaust gases measured relative to the aircraft

4) *Weight:* This force is basically produced due to the gravitational force acting on the aircraft. This force is acts in downward direction.

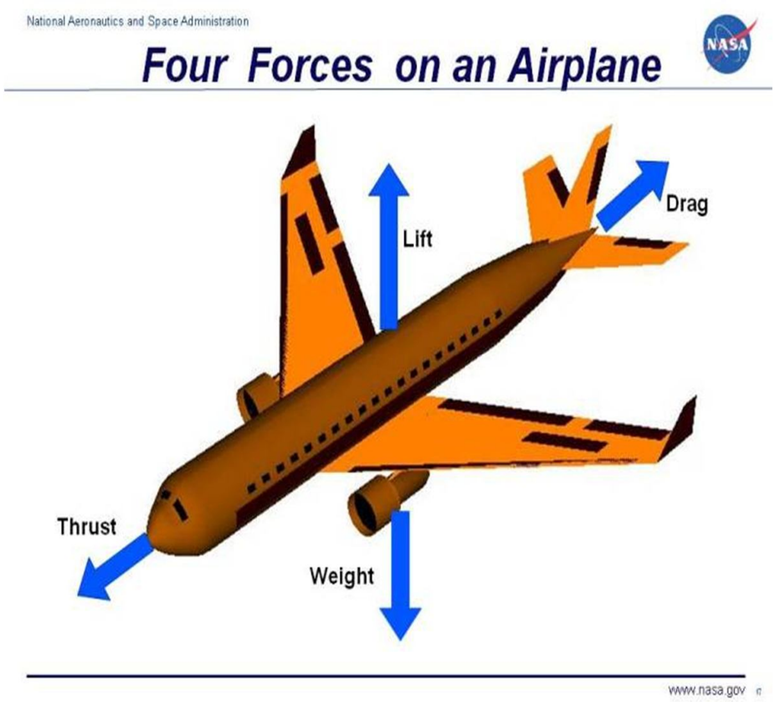

Fig. 1: Forces acting on an aircraft (Courtesy – NASA)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VII July 2020- Available at www.ijraset.com

III. AEROFOIL

An aerofoil creates an aerodynamic force when a cross-sectional shape of an object when moved through a fluid such as air [8]. Aerofoil is used as wings in an aircraft. It is primarily used to produce lift and drag forces. Other aerofoil surfaces include tailplanes, fins, winglets, and helicopter rotor blades. Shape of an aerofoil has a great impact on the forces being produced and also acted upon the aircraft. Different aspects related to aerofoils which play a major role while flying an aircraft is:

A. Chord line is line joining the centres of curvature leading and trailing edge of an aerofoil.
B. Chord length is the length of chord line.
C. Angle of attack is the angle between the chord line and the relative air flow.
D. Angle of incidence is the angle between the chord line and longitudinal axis of aircraft.

While the shape of the aerofoil changes, their aerodynamic characteristics also change [9]. Different aircraft are made for different purpose such as transport, fighter, training, hence by choosing an appropriate aerofoil will help to gain a better efficiency in the desired work.
Aerofils are mainly used to produce more lift than drag. There are different types of aerofoils used for different purpose, they are:
1) *Subsonic Aerofoils:* consists of round leading edge which is insensitive to angle of attack.
2) *Supersonic Aerofoils:* consists of aerofoils which are much more angular in shape S due to which they are sensitive to angle of attack.
3) *Supercritical Aerofoils:* Has maximum thickness close to leading edge

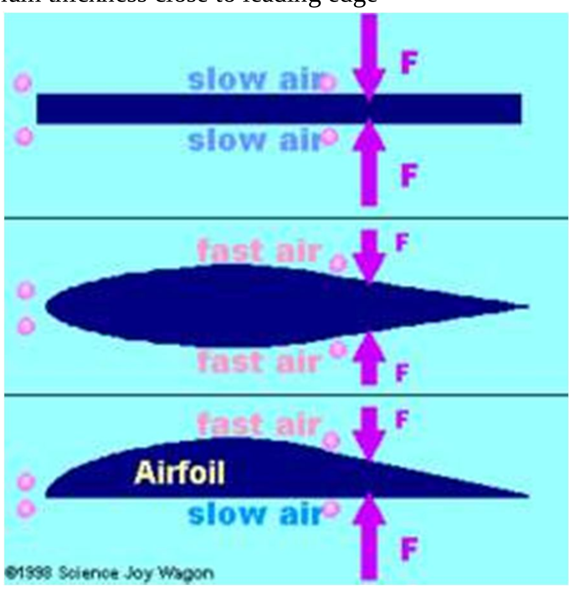

Fig. 2: Effect of shape of aerofoil (Courtesy Science Joy Wagon)

IV. STALLING EFFECT

For an aircraft the angle of attack shouldn't exceed a certain limit and that limit is known as Critical Angle of attack [8]. The lift is the upward force produced in an aircraft due to which it can stay in the air. A stalling condition in an aircraft is the reduction in coefficient of lift and lift begins to decrease. Stalling mainly depends upon the shape of the wings of aircraft, the fluids in aircraft and Reynolds number. When stalling occurs it can be identified be observing that nose of the aircraft is pitching downward.
When stalling starts occurring, the aircraft should immediately pitch down and there should be increase in the speed of aircraft. Failing to pitch up, the aircraft will go into spin / rolling condition and will become highly unstable. Stalling greatly affects the stability of aircraft hence as soon as the pilot feels aircraft is stalling he/she should take the preventive measures.
When an aircraft is taxing on runway and about to take off, the pilot increases angle of attack in order to produce lift but there is also a threat of this stalling effect hence we can say that stalling occurs at low speed. It is not that stalling takes place at low speed only but it can stall at higher speeds also it mainly depends on the critical angle of attack.

It is observed that fighter jets are a bit different about stalling when compared with other aircrafts. A fighter jet performs very fragile and versatile operation at stalling speed. One of the reasons is the weight and compact size of the fighter aircraft. The weight and size of a fighter aircraft is very less and small when compared with other commercial aircrafts like Airbus, Boeing, etc. One more reason is that fighter jets have high thrust to weight ratio, it is almost equal to 1 which helps them to maneuver the aircraft.

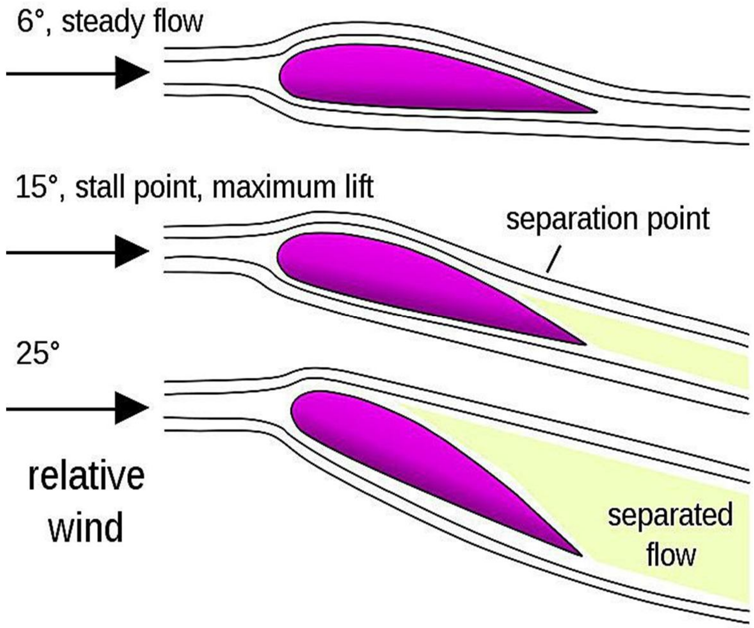

Fig. 3: Stalling effect in aircrafts (Courtesy Sarina Houston)

V. FLAPS

Stalling is one of the causes for fatal accidents in aircrafts, the accident data by the review of the National Transportation Safety Board (NTSB) Briefs of Accidents [10], show that a relatively high number of flap-related accidents occur and with dangerous consequences.

A flap is a high-lift device used to reduce the stalling speed of an aircraft wing at a given weight. Flaps are one of the lift augmenting devices. Flaps are usually situated on the wing trailing edges of a fixed wing aircraft. Flaps are used to reduce the take-off distance and the landing distance [8]. Flaps also cause an increase in drag so they are retracted when not needed. Flaps are another way to reduce the stalling speed of an aircraft. Flaps are operated by the pilot and can be opened anytime whenever needed or at desire of the pilot.

The lift produced to take the aircraft up in the air is directly proportional to the surface area of the wings, hence when the flaps are opened during the take off time it helps in producing greater lift at low speed. When the flaps of an aircraft are opened there is increase in camber also which helps in producing drag, hence during landing a pilot opens the flaps.

The different kinds of flaps used in aircrafts are:

1) *Plain Flap:* the rear portion of airfoil rotates downward on a simple hinge mounted at the front of the flap. These flaps are used for their simplicity in shape. Such surface can be used as an aileron also.
2) *Spilt Flaps:* the ear portion of the lower surface of the airfoil hinges downward from the leading edge of the flap, while upper surface stays immobile. This kind of flap helps in producing more drag than lift. When required, at any point of time, these flaps can produce literally no lift and only drag.
3) *Slotted Flaps:* a gap is there between flap and the wing which forces high pressure below the wings, thus producing great lift. A flap that allows air to pass between the wing and the flap is slotted flap. Basically, these kinds of flaps are used to produce higher amount of lift than drag.
4) *Fowler Flaps:* this is a kind of spilt flap but slides backward flat before hinging downward thereby increasing first chord then camber. These flaps can produce drag and lift equally as the upper portion may or may not behave as plain flap.

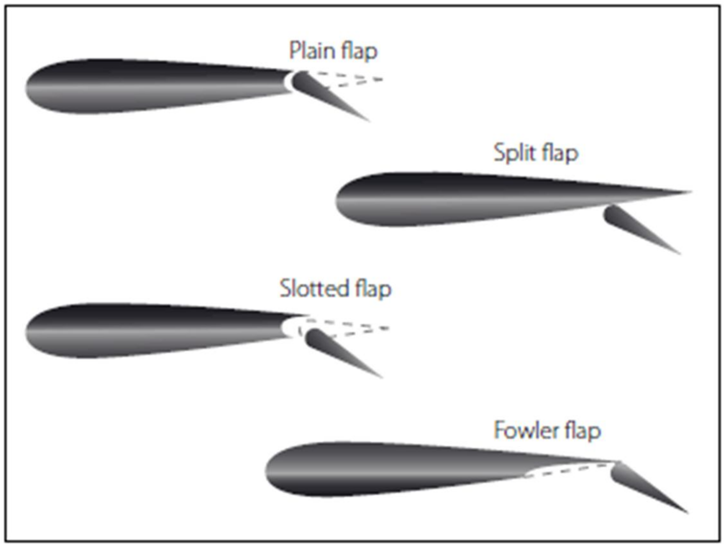

Fig. 4: Flaps (Courtesy www.flight-mechanic.com)

VI. SLATS

Slats are used along with flaps. Slats are situated on the leading edge of the wings that it is on the front side, they are aerodynamic surfaces and for fixed-wing aircraft. A slat helps an aircraft to operate at higher angle of attack when deployed, so that they can maneuver or fly at slower speeds due to a higher coefficient of lift [11] is produced as a result of angle of attack. The slats are operated by pilot by opening and closing when desired, while landing and take-off. When slats operated during landing or take-off, the aircraft can be air-bourne or halted at shorter distances than estimated.

There are different kinds of slats which are:

1) *Automatic:* These slats do not need pilot to control them. They are spring loaded hence as the aerodynamic forces decrease the spring pushes up the slats and they are opened performing their functions. Sometimes referred to as Handley-Page slats.
2) *Fixed:* These slats also don’t need the pilots. They are permanently extended at the leading edge. These are used in low speed aircraft.
3) *Powered:* These are the slats which can be controlled by the pilots. They are opened and closed according to pilot’s orders and controls.

Fig. 4: Slats (Courtesy Airbus A310-300)

VII. PRIMARY CONTROL SURFACE

These are set of controls that a pilot uses to fly an aircraft. In order to take a turn or to go to a higher or lower altitude is done by these control surfaces. When an aircraft takes a left or right turn it is known as Rolling. When an aircraft moves up or down it is known as Pitching. When an aircraft moves towards left or right it is known as Yawing. Hence primary control surfaces control these three important movements of aircraft.

1) *Rolling:* In the front of the pilot he/she has control stick or joy stick with which he/she controls this movement of the aircraft. When the pilot moves the control stick towards left the aircraft turns left with its left wing below and right wing up. If the pilot turns the control stick left with high force aircraft would take a sharp turn and can get unbalanced. Hence one must handle the control stick very lightly and smoothly. Here elevators are used for turning which are situated on the trailing edge .
2) *Pitching:* This motion of the aircraft is also controlled by the control stick itself. But the movement of the joy stick used is different. Pitching means the nose of the aircraft moves up and down. Ailerons on the wings help in pitching. In order to do this movement the control stick is pushed away from pilot and pulled towards pilot. In order to climb i.e. to go up on a higher altitude we have to pitch up the nose of the aircraft i.e pull the control stick towards the pilot. In order to go at lower altitude we need to pitch the nose of an aircraft down i.e push the control stick away from the pilot.
3) *Yawing:* This control is by the pedals which are placed down at the place where the pilot keeps his legs. When pilot press the left rudder the aircraft yaws towards left similarly with right. Rudder is placed on the fin of the aircraft along the vertical axis.

In order to make a perfect left turn two control surfaces are to be used at the same time. For a right turn pilot has to move the control stick towards right as well as press the right rudder, same ways for left turn.

VIII. SECONDARY CONTROL SURFACE

Along with maneuvering the aircraft to left, right, up and down, control of the forces acting on the aircraft is needed.
This control of forces is accomplished by the secondary control surfaces, they are:

1) *Trim Tabs:* it is mainly used to reduce the fatigue of a pilot. These are connected on the trailing edge of a larger control surface of an aircraft. It counteracts the aerodynamic forces acting on an aircraft and stabilizes it in a desired altitude without the pilot keeping a constant eye on it. These are placed on the elevators so once the pilot adjusts the angle of elevator trim tab makes sure that elevator remains in that angle until the next command of the pilot.
2) *Air Brakes and Spoilers:* these control surfaces are used to increase the drag of the aircraft in short used in braking system of the airplane. Air brakes increase the drag by increasing the angle of approach during landing. Whereas spoilers increase drag by playing with lift force. Spoilers reduce the lift to drag ratio.
3) *Slats:* they are placed on the leading edge of the wings. They are used during landing and take-off. Slats make the aircraft to fly at higher angle of attack.
4) *Flaps:* they are placed on the trailing surface of the wings and are used during take-off and landing. They help in increasing the drag so that aircraft can land safely.

IX. CONCLUSION

This paper has deeply detailed on how an aircraft works and the forces acting on an aircraft and also the equations related to it. The study of forces highlighted the necessity of knowledge of forces act on an aircraft and equations to find the forces. An aerofoil is a very implied part of an aircraft and an aerofoil decides how the force will be acting on the aircraft. The studies relieves the stalling effect is the reduction in coefficient of lift and lift begins to decrease. Stalling mainly depends upon the shape of the wings of aircraft, the fluids in aircraft and Reynolds number. Stalling differs in commercial aircraft and fighter aircrafts. The different kinds of flaps and slats are used to control the forces on aircraft. The set of controls for primary and secondary surfaces are necessary to fly an aircraft successfully.

REFERENCES

[1] "Earth's Atmosphere Composition: Nitrogen, Oxygen, Argon and CO2". Earth How. 2017-07-31. Retrieved 2019-10-22.
[2] Abinesh and J Arunkumar, "CFD analysis of aerodynamic drag reduction and improve fuel economy", International Journal of Mechanical Engineering and Robotics Research ISSN 2278 – 0149, Vol. 3, No. 4, October, 2014.
[3] Shobhit Senger and S.D. Rahul Bhardwaj, "Aerodynamic Design of F1 and Normal Cars and Their Effect on Performance", International Review of Applied Engineering Research. ISSN 2248-9967 Volume 4, Number 4, pp. 363-370, 2014.
[4] Jim Lucas, "What Is Aerodynamics?", article on website www.livescience.com, September 20, 2014.

[5] Von Karman, Theodore (2004). Aerodynamics: Selected Topics in the Light of Their Historical Development. Dover Publications. ISBN 0-486-43485-0. OCLC 53900531.
[6] Shalini R Nair and Shyam R Nair, "Study and Comparison of Aerodynamic Forces on an Aircraft and Suspension Bridge", IOSR Journal of Engineering (IOSRJEN), ISSN (e): 2250-3021, ISSN (p): 2278-8719 Vol. 04, Issue 04, PP 43-46, April 2014.|
[7] www.grc.nasa.gov. Retrieved 16 February 2018.
[8] "Cadets hand book SDF/SW". Published by : The Director General, National cadet corps Delhi-110030. Edition-2017,HQ DG NCC, India.
[9] Kondapalli Siva Prasad, Vommi Krishna and B.B. Ashok Kumar, "Aerofoil Profile Analysis and Design Optimisation", Journal of Aerospace Engineering and Technology Volume 3, Issue 2, ISSN: 2231- 038X, January 2013.
[10] Norbert R. Kluga, "A Study of Flap Management, an Analysis of the Consequences of Flap Management, and a Search for Possible Causes", Journal of Aviation/Aerospace Education & Research, Volume 1, Number 3 JAAER Spring 1991.
[11] Vasishta Bhargava, "Importance of slat and flap devices on aircraft wings", MOJ Applied Bionics and Biomechanics, 2019;3(2): pp. nos. 59–61