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MODERN AERODYNAMICS IN WING DESIGN TO ENHANCE FUEL EFFICIENCY BY REDUCING DRAG

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ABSTRACT

Aerodynamics in Wing design is very important while designing the wing. The design and analysis of the wings of an aircraft is one of the principal applications of the science of aerodynamics, which is a branch of fluid mechanics.

The wing may be considered as the most important component of an aircraft. The primary function of the wing is to generate sufficient lift force or simply lift (L).

However, the wing has two other productions, namely drag force or drag (D) and nose-down pitching moment (M). By using flaps, slates, winglets, anhedral-dihedral wing angles drag or drag force can be reduced. New design of wing not only gives more control on aeroplane and increase stability but also increases fuel efficiency.

KEYWORDS: Wing Span, Aspect Ratio, Planform, Anhedral - Dihedral, Upwash-Downwash, Wing Swip, Winglets, Fuel Efficiency, etc

INTRODUCTION

A wing is appendage with a surface that produces lift for flight or propulsion through the atmosphere, or through another gaseous or liquid fluid. A wing is an aerofoil, which has a streamlined cross-sectional shape producing a useful lift to drag ratio. A region of lower-than-normal air pressure is generated over the top surface of the wing, with a higher pressure existing on the bottom of the wing.

Bernoulli's Principle which relates changes in air speed to changes in air pressure. Reduced structural loads permit larger spans for a given structural weight and thus a lower induced drag.

HISTORY

Kites

Kites were used approximately 2,800 years ago in China. Ancient and medieval Chinese sources list other uses of kites for measuring distances, testing the wind, lifting men, signalling, and communication for military operations.

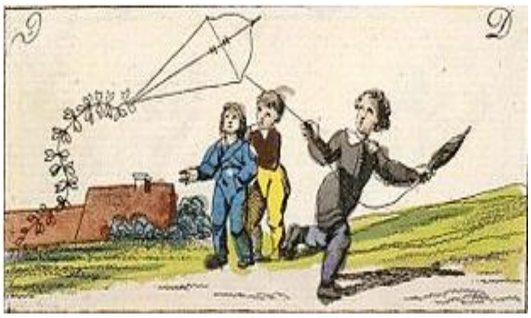


Figure 1(a): Kites

Aeroplane

Figure 1(b): Historical Aeroplane

DESIGN ASPECTS OF WING DESIGN

Bernoulli's Principle

- As the velocity of a fluid increase, its internal pressure decreases
- High pressure under the wing and lower pressure above the wing's surface.

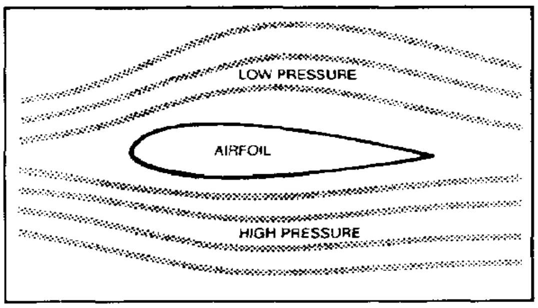


Figure 2: Aerofoil

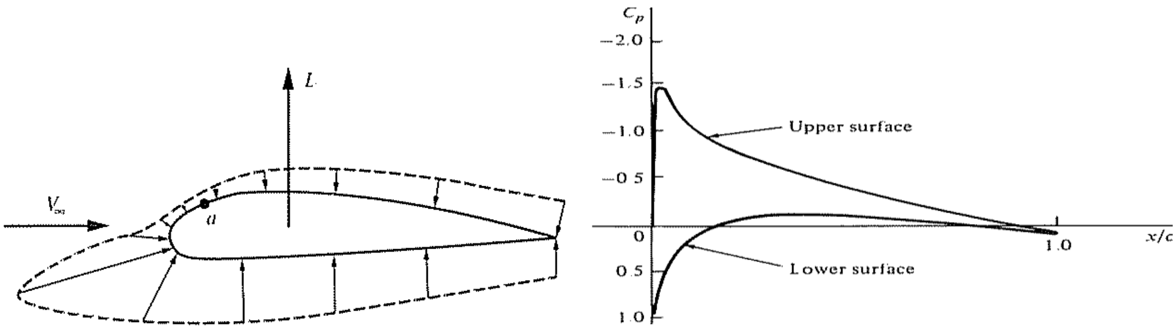


Figure 3: Pressure Distribution on Aerofoil

There are several things that affect the amount of lift created. The first is speed, the faster the wing moves through the air the more air is forced over and under the wing, therefore the more lift is created. Another thing that affects the amount of lift created is the density of the air. The denser the air is the more lift is produced. This is why planes climb better in the winter, the colder air is denser. The final thing that can change the amount of lift created by the wing is the shape of the wing. Certain wings produce more lift.

Wing Span

- Wing span is a distance from one wingtip to the other wingtip.
- It is always measured in a straight line, independently of wing shape or sweep.
- Lift generated from wings is proportional to their area, so the heavier the aircraft the bigger that area must be.

- Wing Area = Span times the width

  = Span * Width

Figure 4: Wing Span

For efficient steady flight the ratio of span to chord, the AR, should be as high as possible because this lowers the lift induced drag associated with the inevitable wingtip vortices.

ASPECT RATIO

- In aerodynamics, the ratio of its Wingspan to its breadth (chord).
- High Aspect ratio = Long , narrow wings (more lift, higher MI, Lower Roll Rate)
- Low Aspect ratio = Short, stubby wings (slightly less lift, lower MI, higher roll rate.)
- AR is defined as the square of the wingspan b divided by the area S of the wing planform

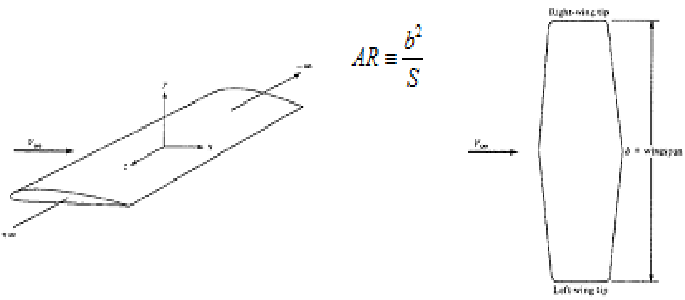


Figure 5: Wing Aspect Ratio

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. More efficient aerodynamically, having less induced drag. They tend to be used by high-altitude subsonic aircraft, subsonic airliners and by high-performance sailplanes.

This property of aspect ratio AR is illustrated in the formula used to calculate the drag coefficient of an aircraft.

$$C_d = C_{d0} + \frac{(C_L)^2}{\pi e AR}$$

C_d=Aircraft drag coefficient

C_{d0}=Aircraft zero lift drag coefficient

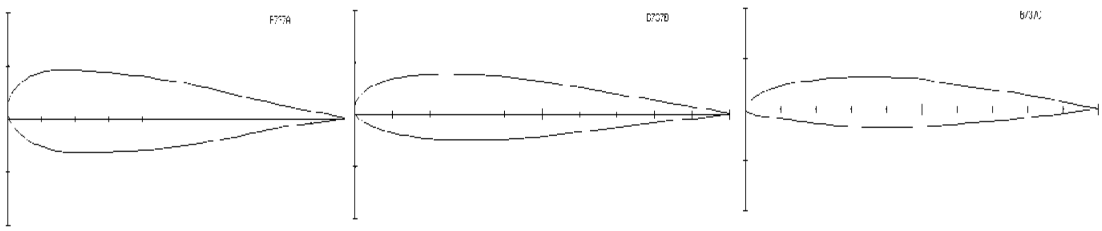
C_L =Aircraft lift coefficient

π =Circumference to dia. ratio of a circle

e =Oswald efficiency number

AR= Aspect ratio.

Figure 6: Varying A.R Ratio



ROOT **MID SPAN** **TIP**

PLANFORM

- In aviation, a planform is the shape and layout of a fixed-wing aircraft's fuselage and wing
- Planform is selected on the basis of Mach Number (It is commonly used to represent the speed of an object when it is traveling close to or above the speed of sound.).

$$Ratio = \frac{Object\ Speed}{Speed\ Of\ Sound} = Mach\ Number$$

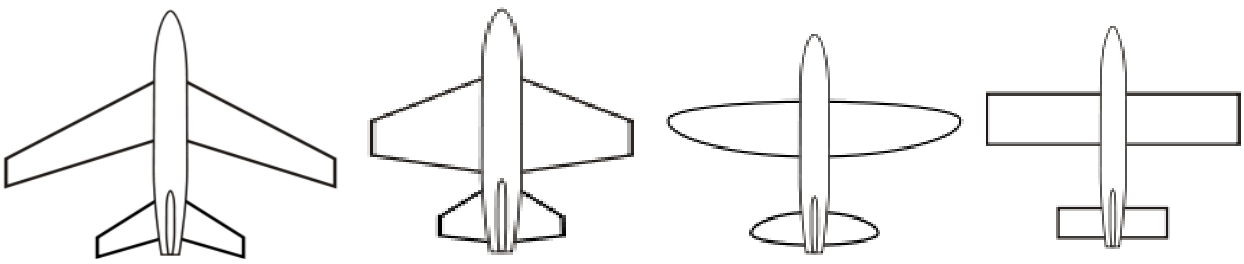
Subsonic = Mach < 1.0

Transonic = Mach = 1.0

Supersonic = Mach > 1.0

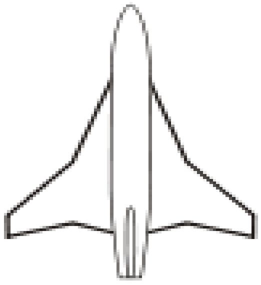
Hypersonic = Mach > 5.0

- **Types of Planform**

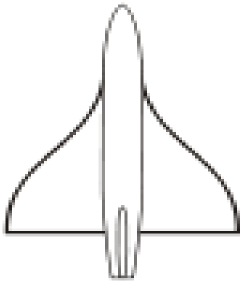


Swept Wing **Trapezoidal Wing** **Elliptical Wing** **Constant Chord Wing**

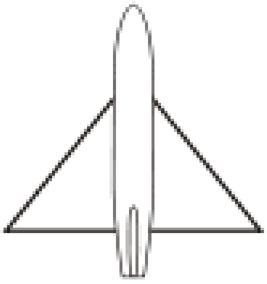
- Delta Wings - Triangular planform with swept leading edge and straight trailing edge.
- Used in supersonic and transonic jets.



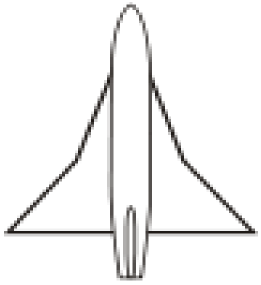
Cranked Delta



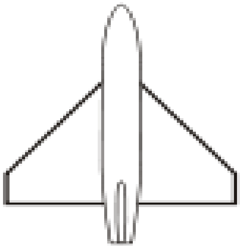
Ogival Delta



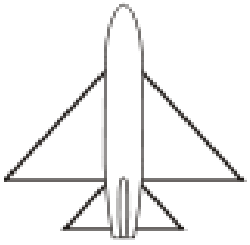
Tailless Delta



Compound Delta



Cropped Delta Wing



Tailed Delta Wing

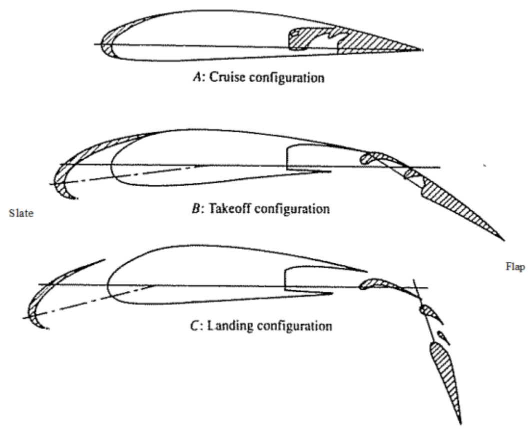
FLAPS AND SLATES

- **Flaps**

In fluid dynamics, a stall is a reduction in the lift coefficient generated by a foil as angle of attack increases. This occurs when the critical angle of attack of the foil is exceeded.

- **Slates**

Slats are aerodynamic surfaces on the leading edge of the wings of fixed-wing aircraft which, when deployed, allow the wing to operate at a 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.



$$L = \frac{1}{2}\rho V^2 S C_L$$

Where,

L = Amount of Lift Produced

ρ = Air Density

S = Surface Area of Wing

C_L= Lift Coefficient

V = Aircraft Velocity

From above equation it can be seen that increasing the area (S) and lift coefficient (C_L) allow a similar amount of lift to be generated at a lower airspeed (V).

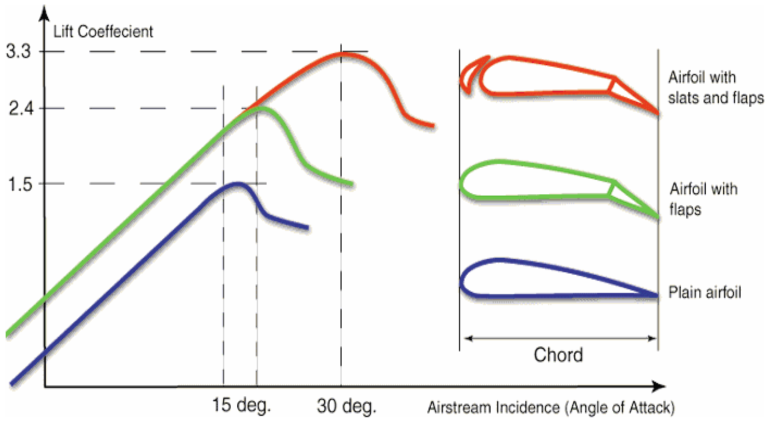


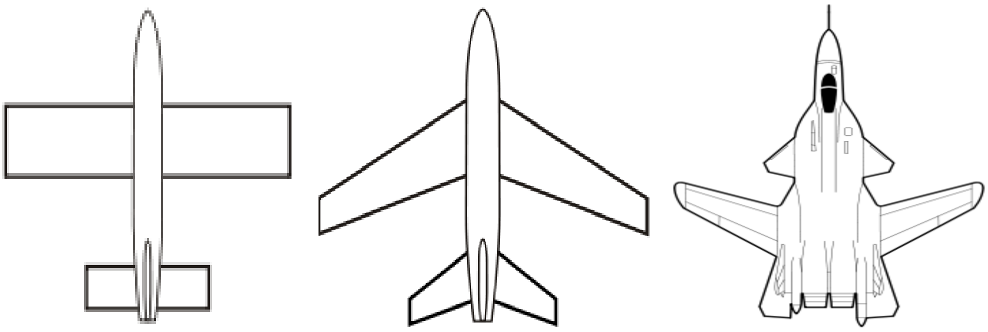
Figure 7: Lift Coefficient Vs Airstream Incident

WING SWEEP

Compared with straight wings common to propeller-powered aircraft, they have a "swept" wing root to wingtip direction angled beyond the span wise axis. This has the effect of delaying the drag rise caused by fluid compressibility near the speed of sound as swept wing fighters were among the first to be able to exceed the speed of sound in a slight dive, and later in level flight.

Unusual variants of this design feature are forward sweep, variable sweep wings and pivoting wings. Swept wings as a means of reducing wave drag were first used on jet fighter aircraft.

- **Straight -** Extends at right angles to the line of flight. The most efficient structurally, and common for low-speed designs. It is found on low-speed planes such as cargo and light planes.
- **Swept Back -** From the root, the wing angles backwards towards the tip. At transonic speeds swept wings have lower drag.
- **Forward Swept**
  - The wing angles forward from the root.
  - Benefits are similar to backwards sweep
  - Reduced tip losses allowing a smaller wing
- **Swing-Wing** - also called "variable sweep wing". The left and right hand wings vary their sweep together. Seen in a few types of military aircraft, such as the General Dynamics.



(a) Straight Wing **(b) Swept Back Wing** **(c) Forward Swept Wing**

(d) Swing Swing

Figure 8: Types of Wing Sweep

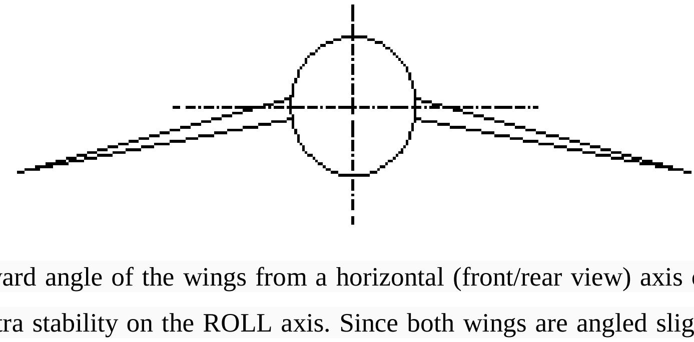
Aspect ratios are changeable.

- Recall M_{CR}
- If $M_\infty > M_{CR}$ large increase in drag
- Wing sees component of flow normal to leading edge
- Can increase M_∞
- By sweeping wings of subsonic aircraft, drag divergence is delayed to higher Mach numbers.

ANHEDRAL AND DIHEDRAL ANGLE

Dihedral Angle

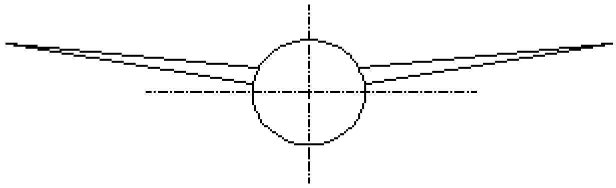
- Dihedral is the wingtip higher than the root.
- Dihedral gives extra stability on the ROLL.
- Dihedral angle is used in commercial airlines to ensure stability.



Dihedral is the upward angle of the wings from a horizontal (front/rear view) axis of the plane. The benefit of a positive dihedral wing is extra stability on the ROLL axis. Since both wings are angled slightly up, and if the right wing were to start rolling down (or clockwise), it will stop when it becomes perpendicular to the horizontal axis. This is because when the wing reaches 0-degree horizontal angle, it produces lift, thus raising the right wing back up. This now causes the left wing to reach 0-degree horizontal angle, thus making it because left and rise again. Because both wings lift back and forth naturally, it keeps the airplane stable on the ROLL (horizontal) axis. This design is used on most commercial airlines today to keep them very stable during flight.

Anhedral Angle

- Highly maneuverable fighter planes have the wing tips lower than the roots
- High roll rate
- It is also called as negative dihedral angle.



Anhedral is the exact opposite. Instead of lifting the wings and stabilizing the plane, anhedral planes lift the wing and keep rolling the plane. This makes the airplane very unstable on the roll (horizontal) axis, but is great for military fighter jets. This allows fighters to be more agile and manoeuvrable, rather than being stable.

DOWNWASH

In aeronautics downwash is the air forced down by the aerodynamic action of a wing or helicopter rotor blade in motion, as part of the process of producing lift an aircraft produces aerodynamic lift by deflecting air downwards as downwash. This generates an equal and opposite upwards force on the wing called lift. When the downwash force exceeds the weight of the aircraft, the aircraft will rise.

UPWASH

Upwash is the relative laminar airflow blowing from underneath the wing which at the trailing edge moves upwards where as downwash is the laminar airflow blowing from the top of the wing moving downwards at the end of the trailing edge, when they meet with each other; it gives rise to vortices or eddies.

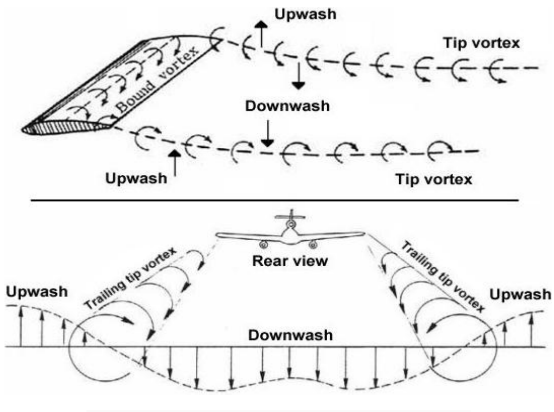


Figure 9: Upwash and Downwash

WINGLETS

Winglets are small vertical or angled surfaces on the edge of wings. They are mainly used to reduce drag on the wing-surface overall. Like a lightning-rod, winglets are small areas where air is redirected, thus causing most drag there rather than over the entire rear-edge of the wing. By reducing drag, the airplane can move forward smoother, thus reducing fuel consumption. This also allows for smaller wingspans because less drag is occurring. Many commercial airliners today use wingtip devices to increase fuel economy. This is noticeable when an aircraft is flying at transonic speeds, where wave drag causes much of the air resistance. Such devices increase the effective aspect ratio of a wing without materially increasing the wingspan.

Wingtip devices increase the lift generated at the wingtip and reduce the lift-induced drag caused by wingtip vortices, improving lift-to-drag ratio. This increases fuel efficiency in powered aircraft and increases cross-country speed in gliders, in both cases increasing range.

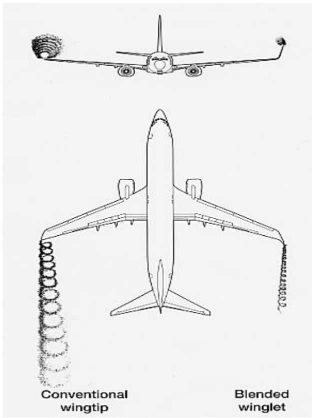
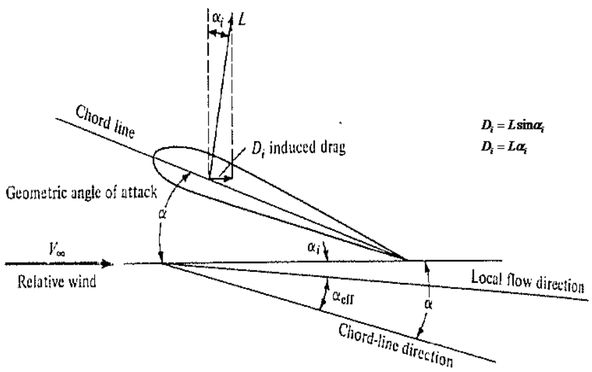


Figure 10: Winglets

HOW TO ESTIMATE INDUCED DRAG

- Local flow velocity in vicinity of wing is inclined downward direction.
- Lift vector remains perpendicular to local relative wind and is tiled back through an angle a_i
- But drag is still parallel to free stream.
- Tilted lift vector contributes a drag component.



- For all wings in general,
- Define a span efficiency factor, e (also called span efficiency factor)
- Elliptical planforms, e = 1
- The word planform means shape as view by looking down on the wing
- For all other planforms, e < 1
- 0.85 < e < 0.99

CONCLUSIONS

New design of wing not only gives more control on airplane and increase stability but also increase fuel efficiency. Recent proposals have been put forward for net tax on aviation fuel from governments and other worldwide bodies have been thought to force the airline companies to produce planes with lower carbon emissions.

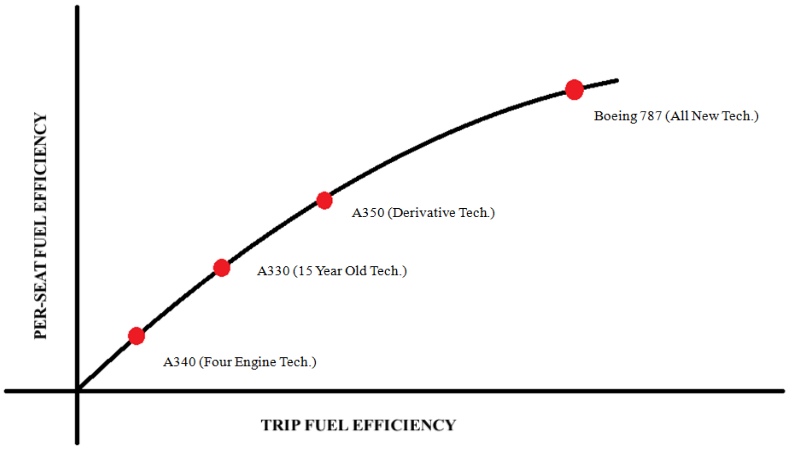


Figure 11: Graph of Per-Seat Fuel Efficiency Vs Trip Fuel Efficiency

Boeing have built a plane with such attributes and will help them save money on their fuel budget with the much improved fuel consumption rate by the help of the carbon composite materials used to build the plane which lighten the plane, resulting in less thrust from the engines to put the plane in the sky. A percentage of fuel will be saved from the state of the art engines due to the technology that the engines possess. These factors should save those millions of pounds per year.

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