Rocket Aerodynamics

Lift:

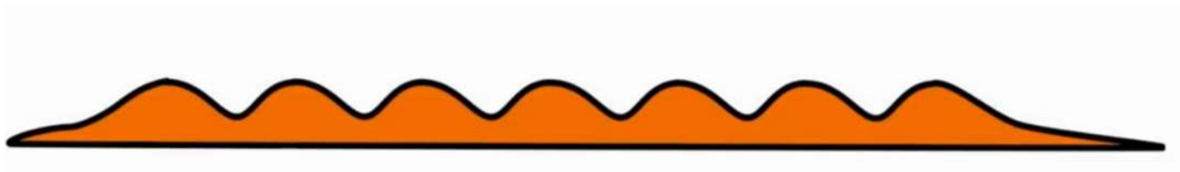
I. Some of the theories that try to explain the generation of lift over wings are:

A. Newton's Third Law
B. Bernoulli's Equation

Incorrect theories includes:

A. "Equal Transit" theory
B. "Skipping Stone" theory
C. "Venturi" theory

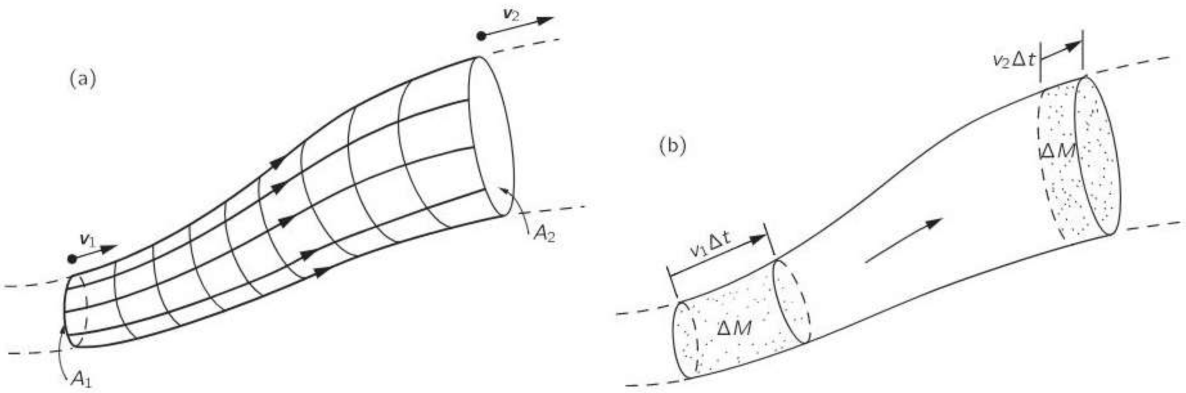
II. In reality this figure doesn't produce lift because of the eddies that form in the u-shaped gaps. Because of the eddies, the pressure difference between the upper and lower faces isn't sufficient to create the lift force.



According to Bernoulli's principle,

- The air molecules closest to the top surface of the aerofoil are kept close to the surface due to there being higher pressure at the top of the particles as opposed to the bottom of them, supplying the centrifugal force.
- The high pressure above the particles pushes them towards the aerofoil, which is why they stay attached to the curved surface instead of continuing on a straight path.
- The curved deflection of the air molecules creates a low pressure above the aerofoil and a high pressure below the aerofoil, and this difference in pressure generates the lift.

III.



The above image is a bundle of adjacent streamlines which form a stream tube.

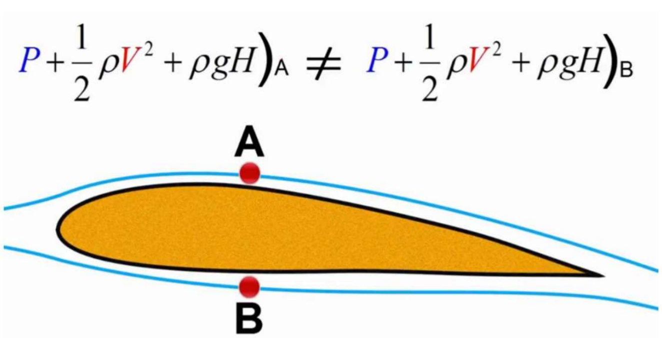
By continuity equation, $A_1v_1=A_2v_2$ (density is assumed constant)
Net Work done by fluid pressure= $p_1A_1v_1\Delta t - p_2A_2v_2\Delta t$
The network is equal to the increase in the energy of a mass ΔM of fluid in going from A_1 to A_2

$$\Rightarrow \quad p_1A_1v_1\Delta t - p_2A_2v_2\Delta t= \Delta M(E2-E1)$$

Where $E=1/2v^2 + \phi + U$

$$\Rightarrow \quad p_1/\rho+1/2v_1^2+ \phi_1+U_1 = p_2/\rho+ 1/2v_2^2+ \phi_2+U_2$$

If the fluid is ***incompressible*** and ***irrotational,*** the internal energy term is the same on both sides, we get $P+½ \rho v^2 +\rho gy$ holds same along any streamline



So, I disagree with the statement which says "Bernoulli's principle cannot be applied between the two points A and B because they lie on two different streamlines."

IV.

A fluid only transmits forces through pressure. If an airfoil generates lift, this must be because the top is at a lower pressure than the bottom in the steady-state flow. The amount of lift can be understood by the rate of deflection of air downward, but the mechanism of lift is always high-pressure on the bottom and low pressure on the top. Low pressure regions speed up a fluid, and high pressure regions slow it down, just because the fluid is doing work to enter the high pressure region and has work done upon it to enter the low pressure region. Therefore the velocity at the top is higher than at the bottom.

The speed at the top and the bottom do not guarantee that the transit time is the same, however, so the explanation that the airfoil lifts because the air above is moving faster is incorrect. But the low-pressure and high-pressure regions exist. Note that if you make the angle of attack of an airfoil such that the air going past it is deflected upward, the pressure at the bottom is less and at the top is more, so the air at the top is moving slower.

V. Can you explain a little technically how lift is generated?

We must look at the molecular level:

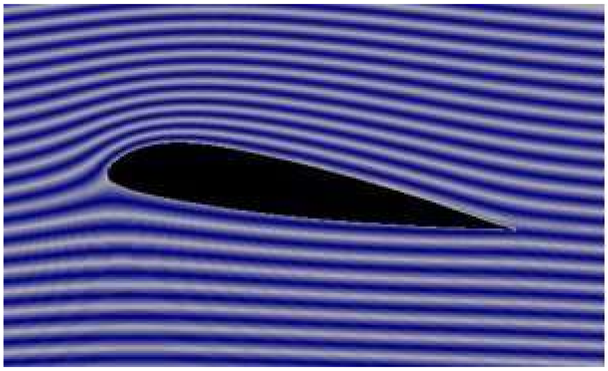
1. Every air molecule is in a dynamic equilibrium between inertial, pressure and viscous effects:
    a. Inertial means that the mass of the particle wants to travel on as before and needs force to be convinced otherwise.
    b. Pressure means that air particles oscillate all the time and bounce into other air particles. The more bouncing, the more force they exert on their surroundings.
    c. Viscosity means that air molecules, because of this oscillation, tend to assume the speed and direction of their neighbors.

Flow over the upper side of the wing

1. When a wing approaches at subsonic speed, the low pressure area over its upper surface will suck in air ahead of it.
2. The packet of air will rise and accelerate towards the wing and be sucked into that low pressure area. Due to the acceleration, the packet will be stretched lengthwise and its pressure drops in sync with it picking up speed.
3. Spreading happens in flow direction - the packet is distorted and stretched lengthwise, but contracts in the direction orthogonally to the flow. This contraction is needed to make space for that wing; in supersonic flow it will decelerate for the same purpose.
4. Once there, it will see that the wing below it curves away from its path of travel, and if that path would remain unchanged, a vacuum between the wing and our packet of air would form.
5. Reluctantly, the packet will change course and follow the wing's contour. This requires even lower pressure, to make the molecules change their direction. This fast-flowing, low-pressure air will in turn suck in new air ahead and below of it, will go on to decelerate and regain its old pressure over the rear half of the wing, and will flow off with its new flow direction.

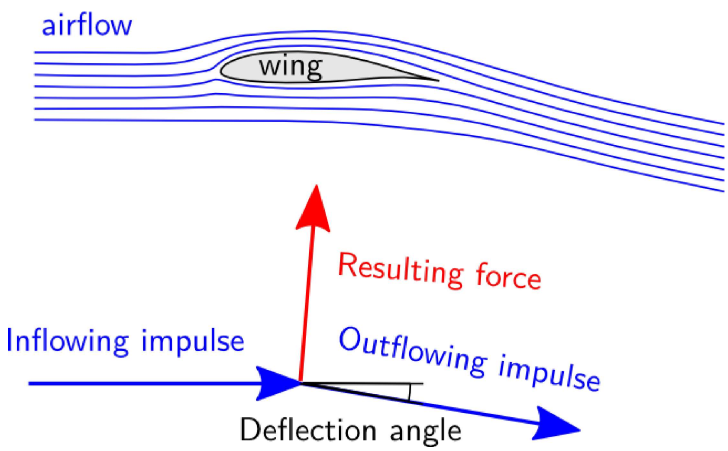
Flow over the lower side of the wing

1. A packet of air which ends up below the wing will experience less uplift and acceleration, and in the convex part of highly cambered airfoils it will experience compression.
2. It also has to change its flow path, because the cambered and/or inclined wing will push the air below it downwards, creating more pressure and more bouncing from above for our packet below the wing. When both packets arrive at the trailing edge, they will have picked up some downward speed.
3. Behind the wing, both packets will continue along their downward path for a while due to inertia and push other air below them down and sideways.
4. Above them, this air, having been pushed sideways before, will now fill the space above our two packets. Macroscopically, this looks like two big vortices. But the air in these vortices cannot act on the wing anymore, so it will not affect drag or lift.



(This flow visualization shows how the air flows up in front of the airfoil. The narrower the smoke lines are to each other, the lower the pressure is and the faster the air flows.)

Lift can be explained in equivalent ways



- Lift is the difference of pressure between the upper and lower surface of the wing. The molecules will bounce against the wing skin more at the lower side than at the upper side, and the difference is lift.
- Looking at the macroscopic level ,A certain mass of air has been accelerated downwards by the wing, and this requires a force to act on that air. This force is what keeps the aircraft up in the air: Lift.
- If you look at the wing as a black box and only pay attention to the impulse of the inflowing and outflowing air, the wing will change the impulse by adding a downward component. The reaction force of this impulse change is lift.

Stability Analysis:

I.

A rocket said to be highly stable or overstable when the distance between the CG and the CP is greater than two times body tube diameters.

Here CG= Centre of Gravity

CP= Centre of Pressure

Drawback of having a highly stable rocket:

1. Overstable rockets tend to "weathercock" or arc upwind as they go up, and the higher they go the more they arc over, the higher the wind speed the quicker the arcing. *(Here arcing means that there will still be a horizontal motion even at apogee, causing increased stress on the laundry)*
2. They have the tendency to "cone" quite a bit, requiring more impulse to achieve the desired altitude.

II.

We have complete assembled model rocket which has a uniform cylindrical body

Diameter of Rocket= 50cm

Distance between CG and CP= 150cm

Static Margin is defined as ratio of Distance between CG and CP to the Diameter of Rocket.

So,Static Margin= 150/50= 3

The ideal distance between the two points should be approximately 2 times the diameter of your rocket or a static margin of 2

So, the given rocket model is highly/overstable.

The simple solution to make it stable is by increasing its diameter to 75cm so that static margin is 150/75=2

Drag:

Techniques required to reduce aerodynamic drag of bluff body:

- Use of Passive methods for reducing drag
- Use of Rear Screen
- Use of Rear Fairing
- Use of Vortex generators
- Selection of optimum vortex generator
- Use of bump shaped vortex
- Use of delta wing shaped vortex generator

All these methods are obtained and verified from experiments that reduce the formation of aerodynamic drag over the surface of the vehicle.
Usually we follow two ways, active or passive way

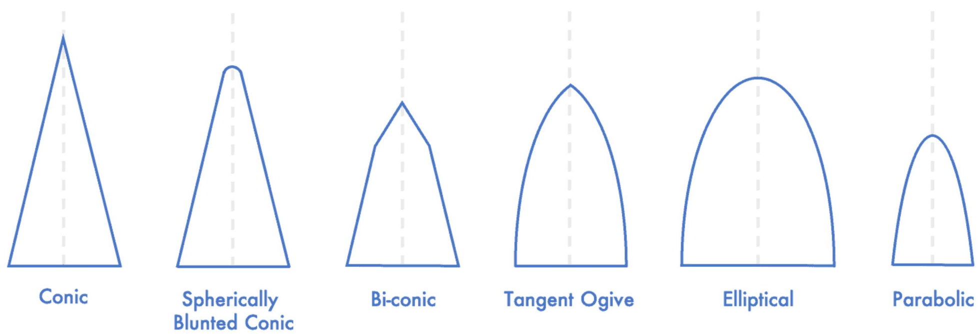
- The aerodynamic design of a vehicle plays a vital role in reducing the drag. If the body is more blunt it can cause greater generation of drag and making it too sharp can also lead to problems.
- Active methods involve the action of an air jet at critical points of the vehicle surface. Such methods require a little or no shape modifications at all.
- Whereas passive methods include the aerodynamic shape changes introduced on the vehicle as well as installation of certain aerodynamic shapes on the vehicle surface.
- Rear screens can be used to reduce drag which is a metal plate fixed at the rear end of the vehicle. By installing such a passive device drag could be reduced up to 6.5%, whereas the use of rear fairing which is another passive device that is the aerodynamic extension of a vehicle’s rear end could yield drag reduction by up to 26%.
- One another method is the usage of vortex generators. Vortex generators are used to create a flow around the vehicle in order to resist the flow separation. Even if vortex generators cause drag by itself overall drag reduction will be obtained after the formation of vortices. Vortex generators are commonly of two shapes – bump shaped and delta wing shaped in which the delta wing shape is more effective.

Nose Cone:

For rockets that fly in low subsonic speeds(Mach Number <1):

1. Aerodynamic forces are minimal
2. Lightweight materials like balsa are sufficient (Balsa's honeycomb-like cell structure, configured into end-grain panels, provide optimal properties including high compressive, flexural and shear strength along with stiffness).

In History, they used many different kinds of nose cone shapes like:



1. The conic shaped are not aerodynamic in nature
2. Elliptical nose cone designs feature a blunt nose and a tangent base, making them popular in low-powered model rocketry because they are very aerodynamic at relatively low speeds

Model rocket nose cones vary in shape, which each have unique properties of drag that affect the overall aerodynamics and efficiency of the model rocket itself. Compared to other designs, elliptical and parabolic nose cones tend to be the most efficient due to their reduced drag.

- Model rocket nose cones affect the drag on a rocket
- The smaller the diameter of a rocket's nose cone, the faster the rocket can be launched in proportion to the amount of thrust provided.
- This means that rockets with pointed nose cones are capable of moving very quickly.
- But in commercial aircrafts, we prefer parabola or elliptical nose cone design due to decreased drag and increased efficiency.

Variable that we should look into for considering model rocket nose cone:

Mission Dependent Variables:

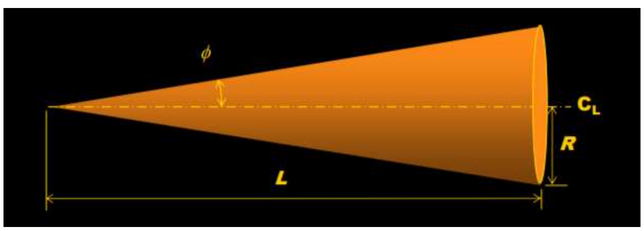
- Payload
- Stability (CP, CG)

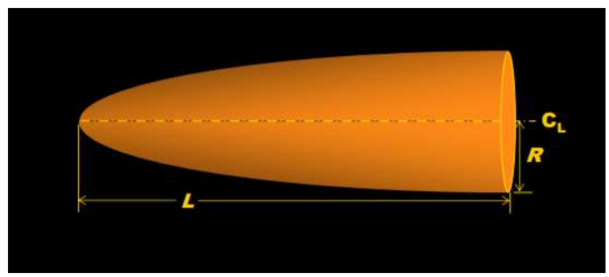
Independent Variables:

- Atmospheric Density
- Temperature
- Wind Conditions
- Surface Finish
- Angle of Attack

Assumptions that we can take are:

- Zero Angle of Attack
- Constant Surface Finish
- No Roll
- No Aerodynamic Heating Effects





Conical	**Elliptical**
The sides of a cone are straight lines, so the diameter equation is simply, $y = Rx/L$	The profile of this shape is one-half of an ellipse, with the major axis being the centerline and the minor axis being the base of the nose cone
$y = x \tan \Phi$, $\Phi = \tan^{-1}(R/L)$	$y = R(1- x^2/L^2)^{.5}$
$Cp = L/3$	$Cp = 3L/2$
$V = \pi R^2 L/3$	$V = 2\pi R^2 L/3$
$S = \pi R(R^2 + L^2)^{.5}$	$S=\pi L^2+[\pi R^2/\sigma[\ln\{(1+\sigma)/(1-\sigma)\}]]/2$ where $\sigma=(L^2+R^2)/L$

So, By comparing all the factors elliptic nose cone is preferred over the other design

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