

# How Airplanes Fly

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## Agenda

- Basic Physics of Flight
- What's happening during a flight
- *Rule of Thumb* airplane design
- Testing the airplane's ability to fly

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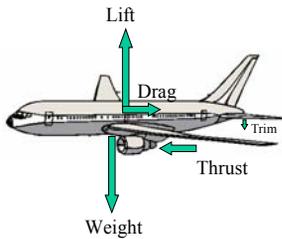
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## Basic Forces



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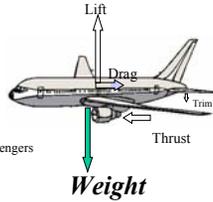
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# What's in Weight?



Airplane Operating Empty Weight (OEW)	<b>Payload</b>	Paying Passengers and Cargo
	Fuel	
	Reserves	
	Operating items	Food, Supplies
	Systems	Navigate, control & support life
	Propulsion	Generate force to move airplane
	Landing Gear	Support airplane on the ground
Body	Enclose the payload	
Wing & Tails	Provide lift	

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# Weight changes during the flight.

## End of flight

Burn off fuel

<b>Payload</b>
Fuel
Operating empty weight

## Start of Flight

<b>Payload</b>
Fuel
Reserves
Operating items
Systems
Propulsion
Landing Gear
Body
Wing & Tails

Food, Supplies  
Navigate, control & support life  
Generate force to move airplane  
Support airplane on the ground  
Enclose the payload  
Provide lift

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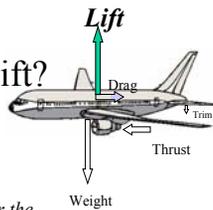
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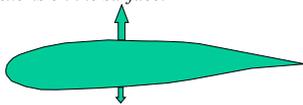
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# How do you make Lift?



Bernoulli:  
*"The faster the air flows over the surface, the lower the pressure air exerts on the surface."*




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## How to Change Lift

- Since Lift is about the same as weight and weight changes, then must be able to change lift.
  - Increase lift by
    - increasing the tilt of the wing
    - increasing the speed of the airplane (actually speed squared)
    - decreasing the altitude of the airplane above the ground.

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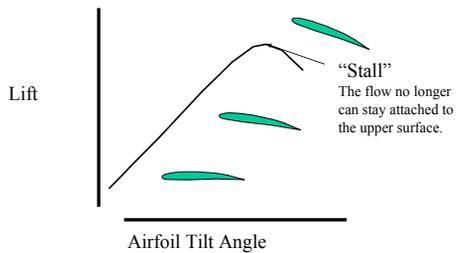
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## But there are Limits to Lift



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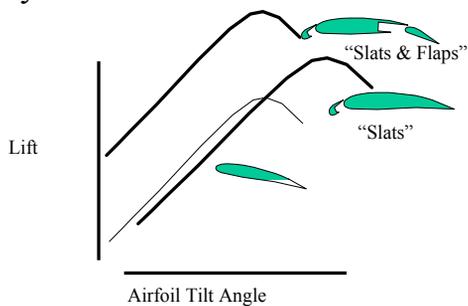
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## Ways around the Limits to Lift



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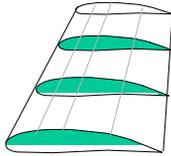
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## Wings are made up of airfoils

Airfoil



Wing



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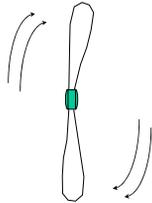
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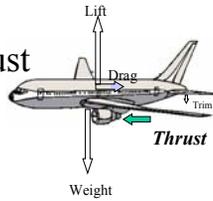
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## How to create Thrust



**A propeller produces thrust like a wing produces lift except:**

- The propeller is a wing rotated 90 degrees
- The speed over the airfoil comes from rotating the prop.



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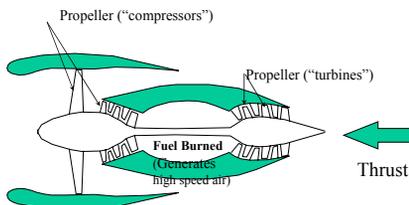
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## How does a jet engine produce thrust?



A jet engine "sucks, squeezes, burns and blows."

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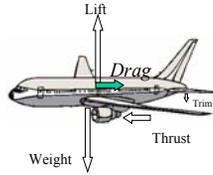
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## What is "Drag"?



Lift and Span  
Aerodynamic  
details  
Smoothness

Induced
"Pressure"
Excrescence
Skin Friction

Due to the influence of an airfoil on those outboard of it  
Due to the rapid growth of the boundary layer  
Due to roughness, gaps & antennas  
Due to the friction in the boundary layer next to the skin to the air flowing over the skin.

Outside surface  
area

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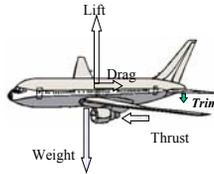
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## What & Why Trim?



- Trim comes from a wing like surface mounted on the back of the airplane
- To change the tilt of the airplane
  - increase down load - airplane nose goes up
  - decrease down load - airplane nose goes down

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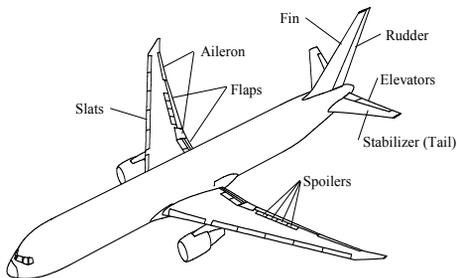
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## Airplane Controls




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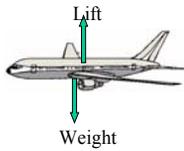
## Airplane Stability

A stable system



Move the ball away from the bottom and it returns to the bottom  
Because ball's center of gravity is above the bottom of the bucket

A stable airplane



Move the nose of the airplane up and the airplane's nose will come back down.  
Because airplane's center of lift is aft of the center of weight

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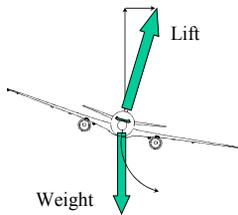
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## How does an airplane turn?

It banks.



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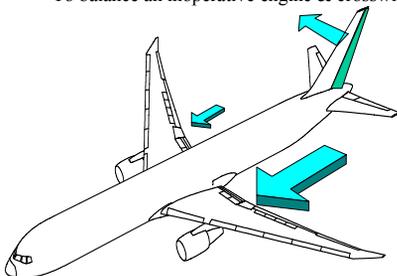
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## Why do airplanes have rudders?

To balance an inoperative engine & crosswinds.



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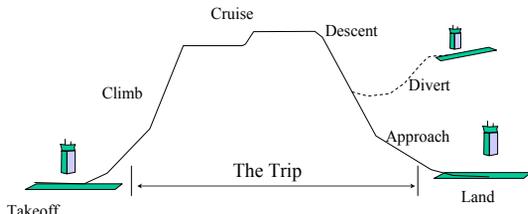
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## Typical Flight



For every trip, load enough fuel to fly to the intended destination, hold and then divert to an alternate airport.

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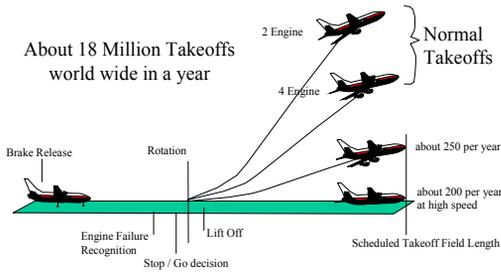
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## How do airplanes takeoff?

About 18 Million Takeoffs world wide in a year



Build up speed at a flat attitude, rotate to flying attitude, liftoff and accelerate to climb speed.

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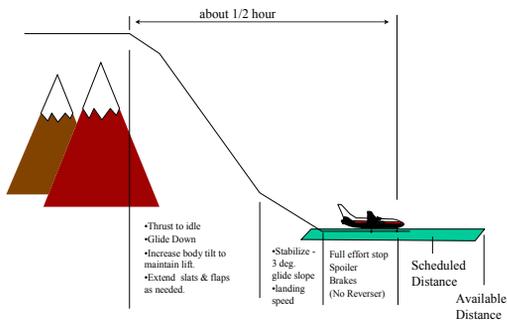
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## Descend and Land




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## Let's Build an Airplane

- Roughly how many passengers?
  - 100, 200, 300, ?
- What type of Range capability?
  - International, Transcon, Local
- What can the engine manufacturers do?

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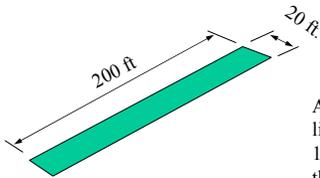
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## Floor Area

For a long range airplane, allow about 13 square feet per passenger. For 305 passengers = 4000 sq. ft.



Aerodynamicists like things that are 10 times longer than they are wide.

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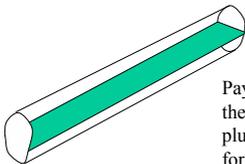
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## Payload Cabin

Cross section of the cabin is a result of experience working with airlines.



Payload weight is 231# times the number of passengers plus 10%. Or, about 78,000# for 305 passengers.

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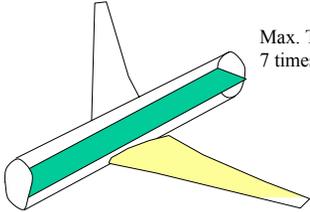
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## Size and install wing

We need 1 sq ft of wing area for every 115# of takeoff weight.



Max. Takeoff weight is 7 times payload.

$TOGW = 550000\#$

$Area = 4800\text{ sq ft}$

Locate wing aft of center of gravity for balance.

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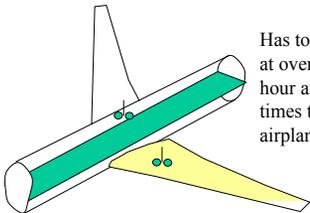
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## Install Landing Gear

Landing gear travels over 300,000 miles in its life



Has to be able to travel at over 250 miles an hour and support 1.5 times the weight of the airplane.

Locate gear so airplane does not tip up while loading.

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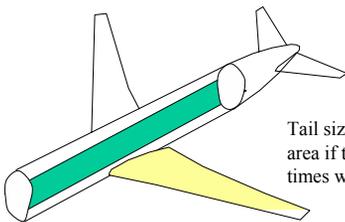
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## Capability to pitch the airplane

Add structure outside the payload area to support the tail.



Tail size is  $1/4$  wing area if tail arm is 4 times wing chord.

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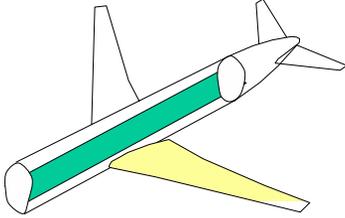
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## Add thrust to make the airplane takeoff

Thrust with one engine not working = 15% Max takeoff weight




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## How Much Thrust?

Thrust to Weight Ratio (with one engine not working) = 0.15 to provide adequate takeoff climb.

Takeoff Weight	Thrust Required (1 engine not working)	Number of engines on airplane	Number of engines Working	Required engine thrust
555,000#	83,000#	4	3	27,700#

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## How Much Thrust?

Thrust to Weight Ratio (with one engine not working) = 0.15 to provide adequate takeoff climb.

Takeoff Weight	Thrust Required (1 engine not working)	Number of engines on airplane	Number of engines Working	Required engine thrust
555,000#	83,000#	4	3	27,700#
555,000#	83,000#	3	2	41,500#

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## How Much Thrust?

Thrust to Weight Ratio (with one engine not working) = 0.15 to provide adequate takeoff climb.

Takeoff Weight	Thrust Required (1 engine not working)	Number of engines on airplane	Number of engines Working	Required engine thrust
555,000#	83,000#	4	3	27,700#
555,000#	83,000#	3	2	41,500#
555,000#	83,000#	2	1	83,000#

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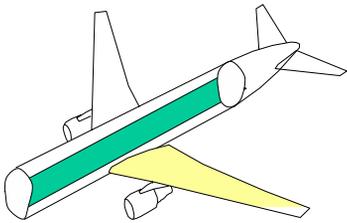
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Two engines are all that is required



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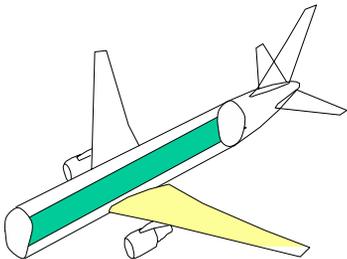
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Add a tail to control the direction with one engine not working



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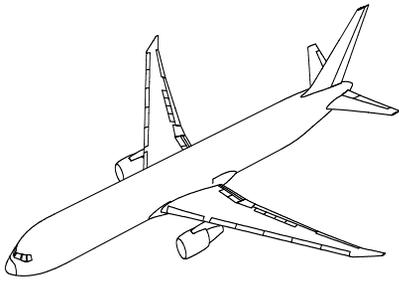
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Add a flight deck to control the whole airplane



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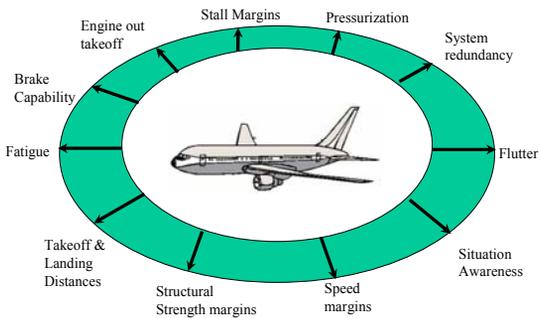
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### Design Envelope



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Testing Airplane to see if it is ready to fly

- Objective to find problems before the airplane gets into service.

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