Introduction to Stability & Control

AE 1350

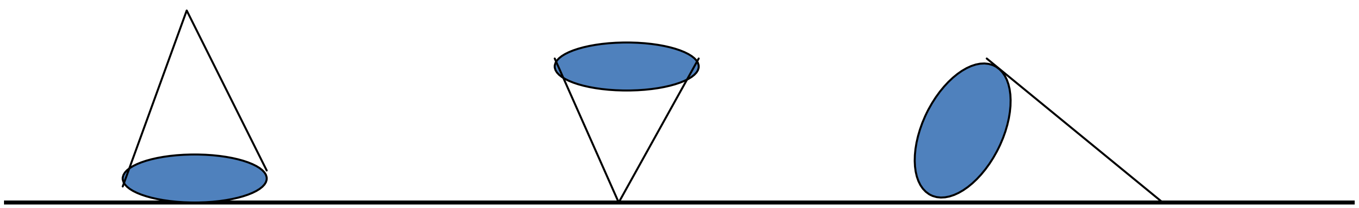
Learning Objectives

1. What is stability?
2. What are the different types of Stability?
3. Why are aircraft shaped like they are?
4. What is control?
5. What does this all mean to Aerospace engineers?

Outline

- What do we mean by aircraft stability and control?
- Static and Dynamic Stability
- Longitudinal, lateral and roll stability
- Necessary Conditions for Longitudinal stability
- Stability Margin
- Relaxed Stability Margin

A system is stable if it can recover from small disturbances



A cone resting on its base is stable

Unstable

Neutrally stable
Assumes new position caused by the disturbance

The axis system

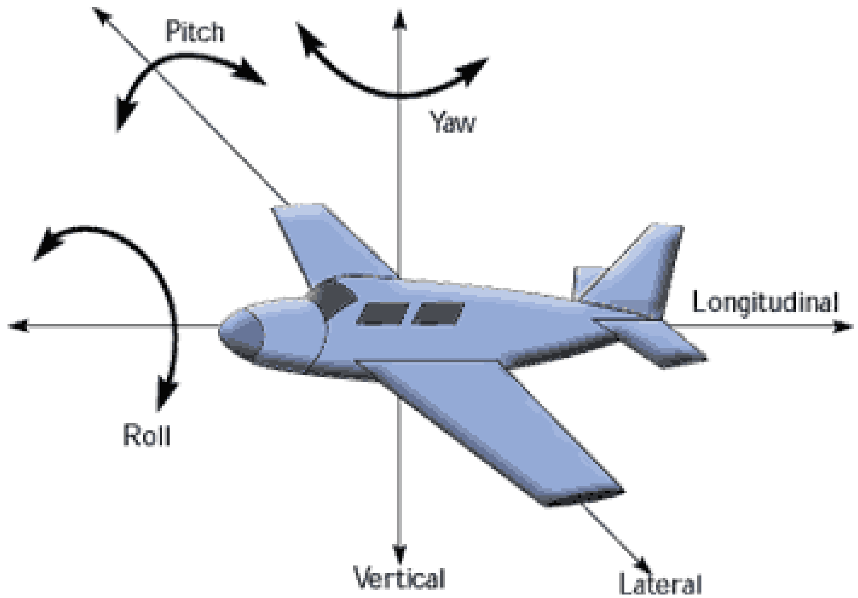


Image borrowed from http://quest.arc.nasa.gov/aero/virtual/demo/aeronautics/tutorial/motion.html

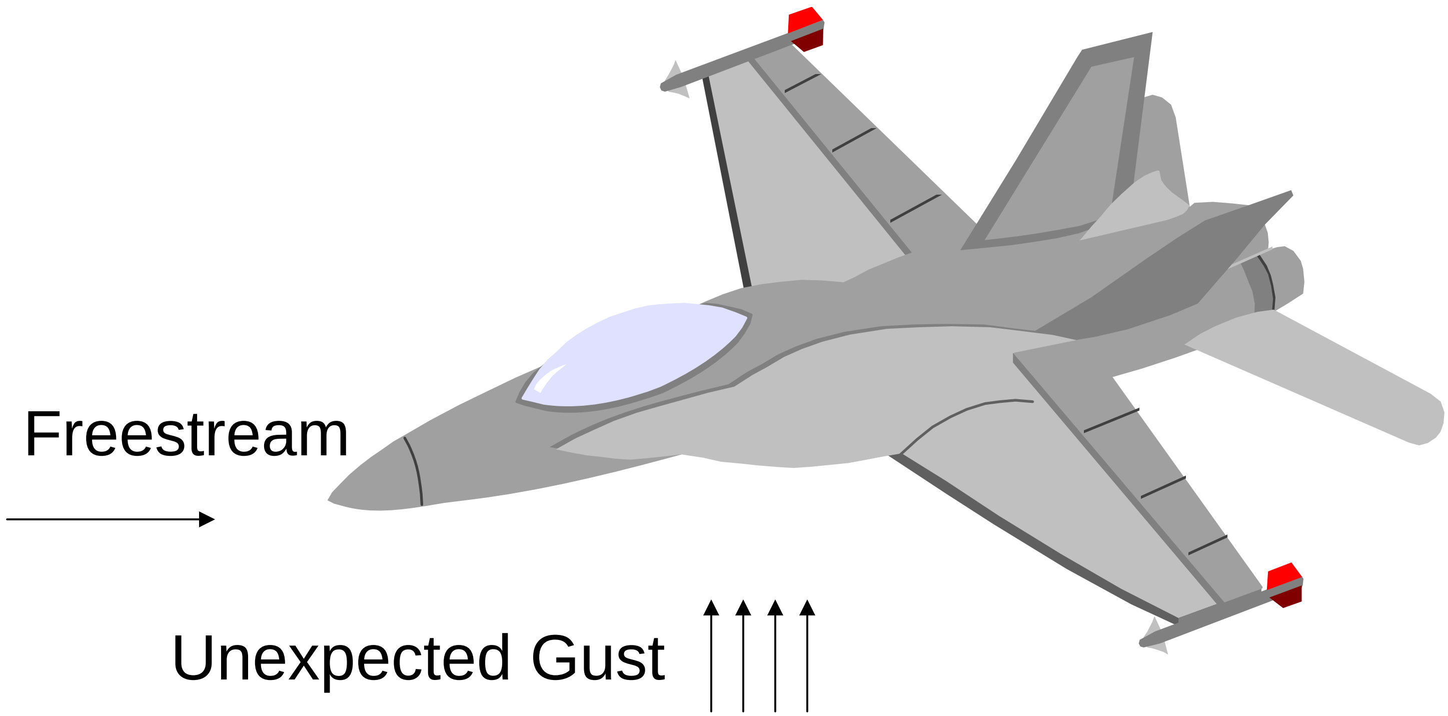
Types of Stability

Static Stability: The spring like **tendency** to return to the equilibrium position

Dynamic Stability: The **property** of returning to the equilibrium position over time

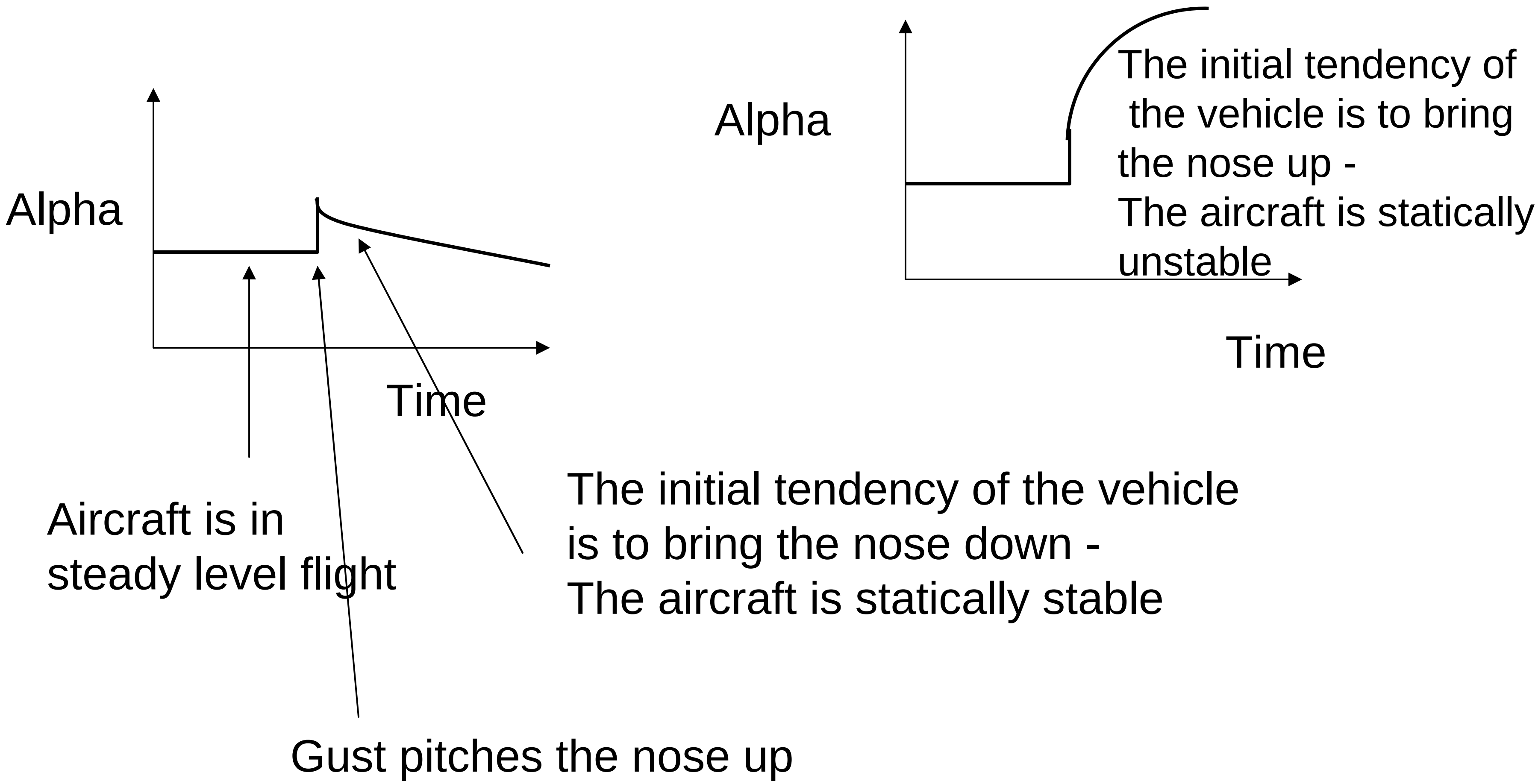
Can an aircraft be statically stable but dynamically unstable?

Aircraft are subjected to disturbances: gusts/turbulence

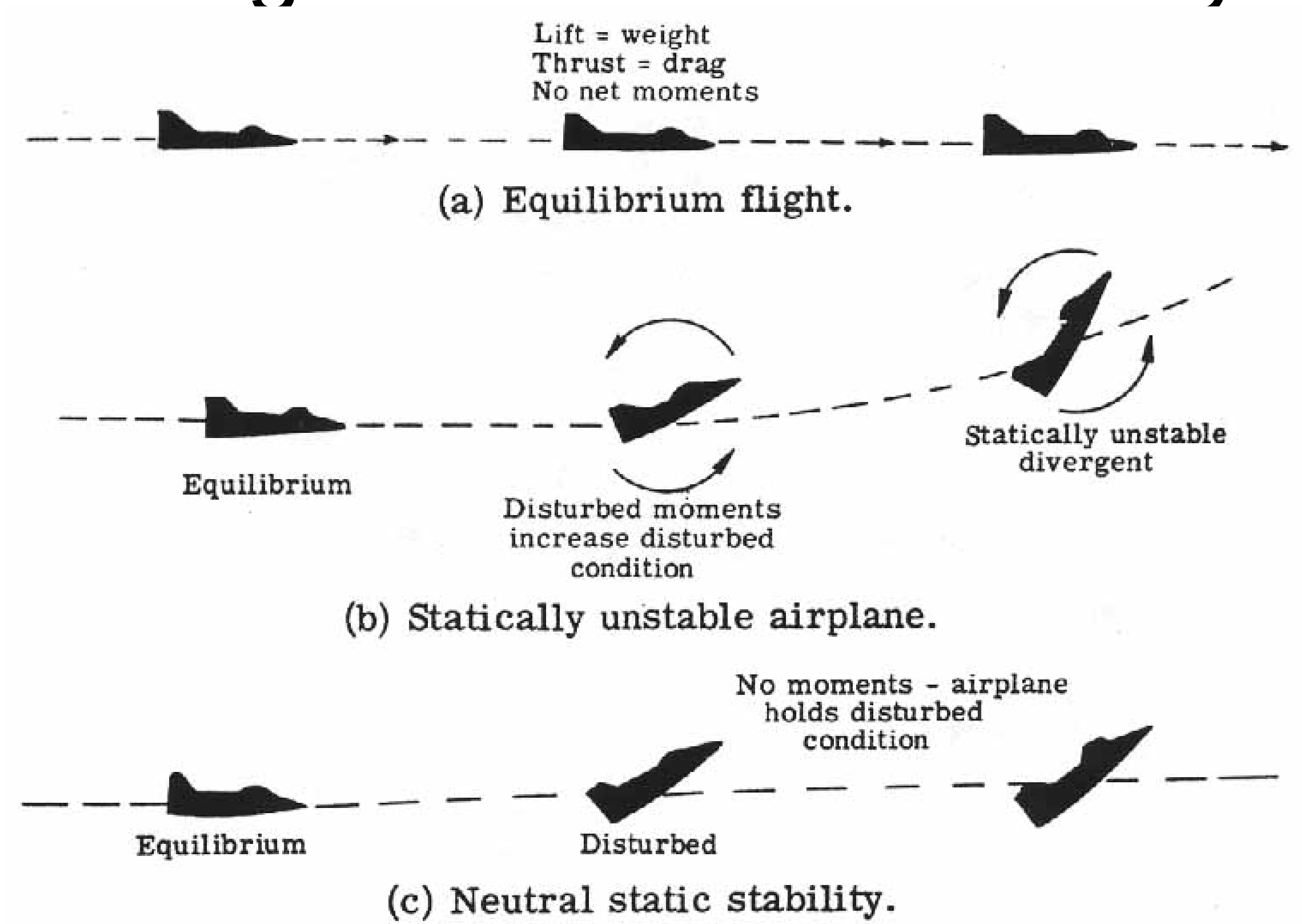


Will it recover automatically, without pilot’s intervention, and resume its original direction of flight?
If yes, then the aircraft is <u>longitudinally</u> stable

Longitudinal Static Stability



Longitudinal static stability



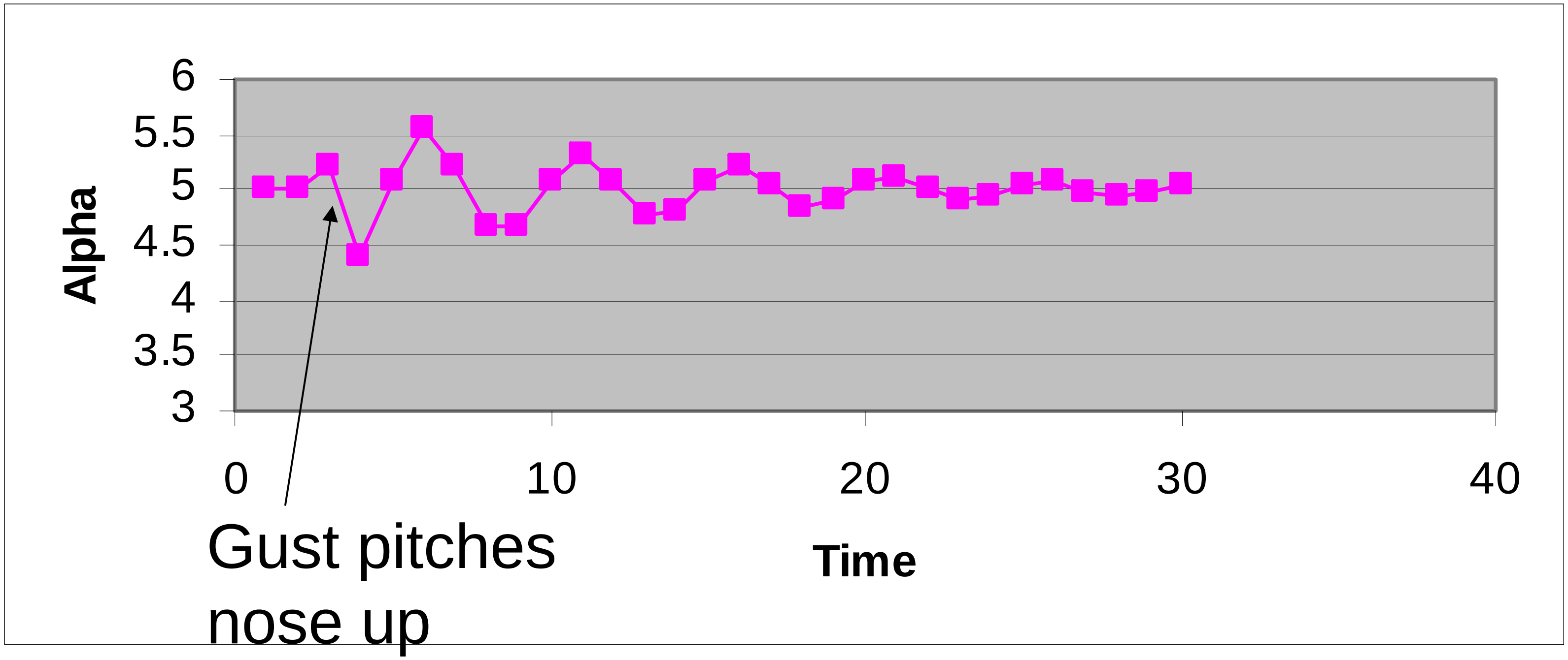
(a) Equilibrium flight.

(b) Statically unstable airplane.

(c) Neutral static stability.

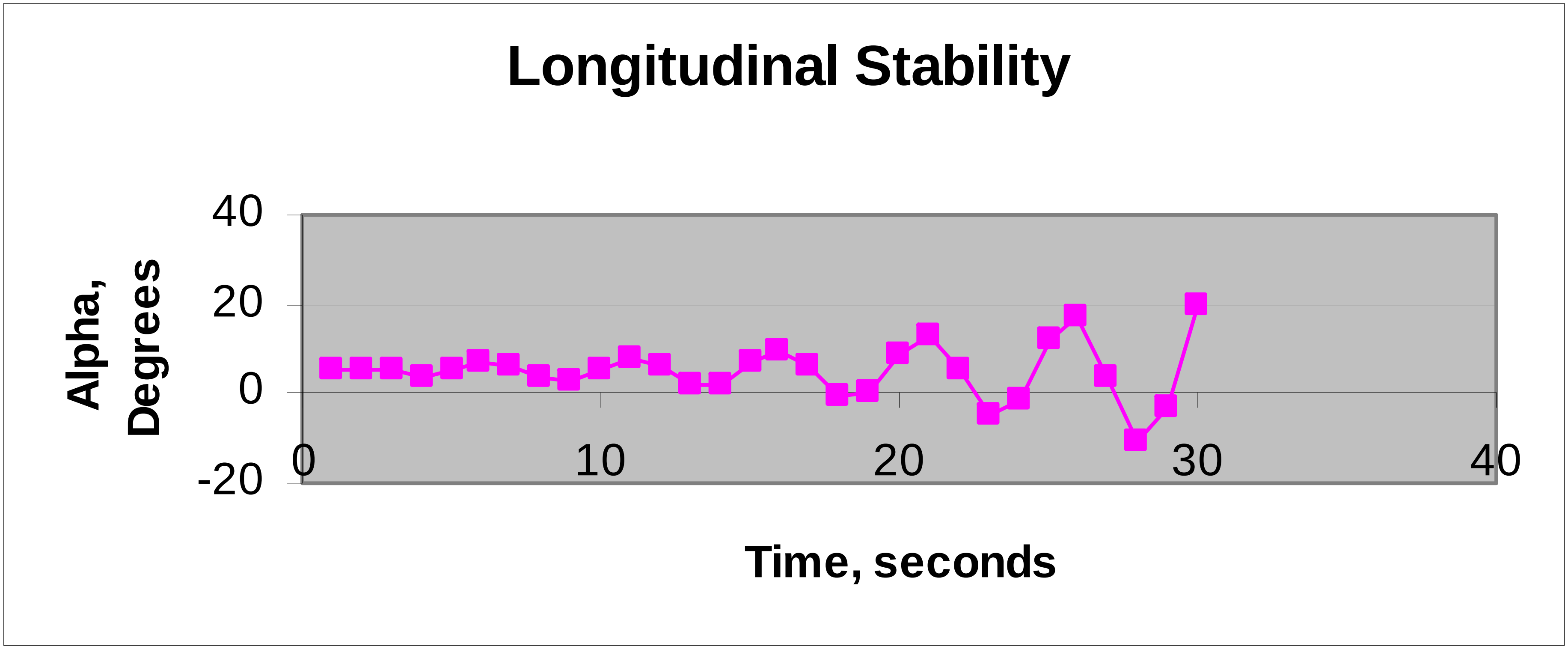
Credit: NASA, can be found at http://www.centennialofflight.gov/essay/Theories_of_Flight/Stability/TH26G1.htm

Aircraft may be statically and dynamically stable

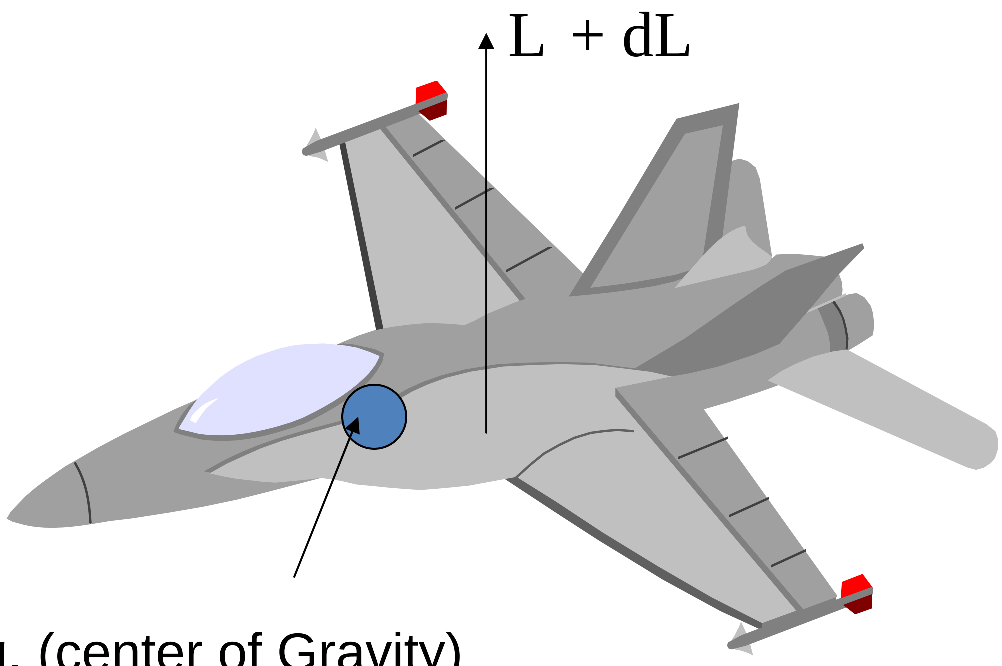


Initial tendency and long-term tendency both are to recover from a gust or disturbance

Aircraft may be statically stable, yet dynamically unstable



Condition for Static Stability



Aircraft c.g. (center of Gravity)

The gust generates a small clockwise Moment about c.g. dM, and a small positive additional lift dL

For static stability, if dL is positive (upward gust),
dM must be negative, causing the nose to drop
Otherwise the wing will pitch up further increasing lift
dM/dL must be negative for static stability

Nondimensionalization

Lift and pitching moment M are usually non-dimensionalized.

L is divided by $[1/2\ \rho\ V_\infty^2\ S]$ to yield C_L

M is divided by $[1/2\ \rho\ V_\infty^{\ 2}\ S\ c]$ to yield C_M

Here, c is a reference length, e.g. "average" chord

From previous slide, dM/dL must be negative for static stability

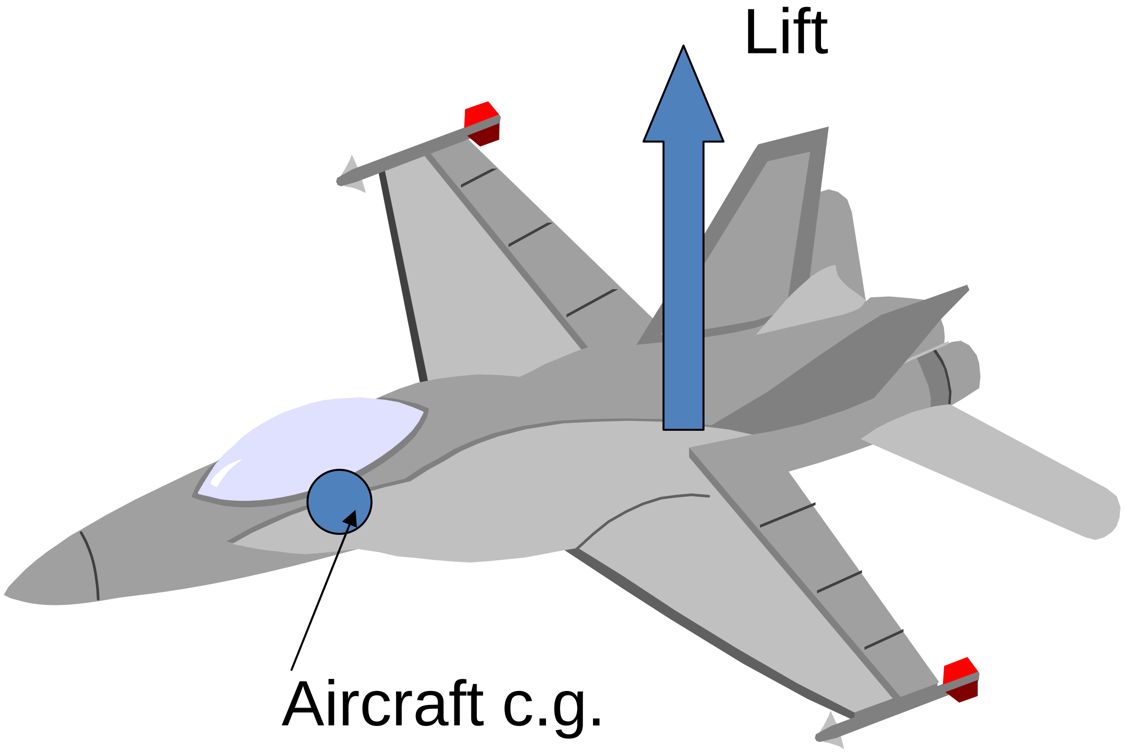
In nondimensional form, dC_M/dC_L must be negative for static stability

The quantity $-dC_M/dC_L$ is called the static <u>stability margin</u>

Notice the negative sign!

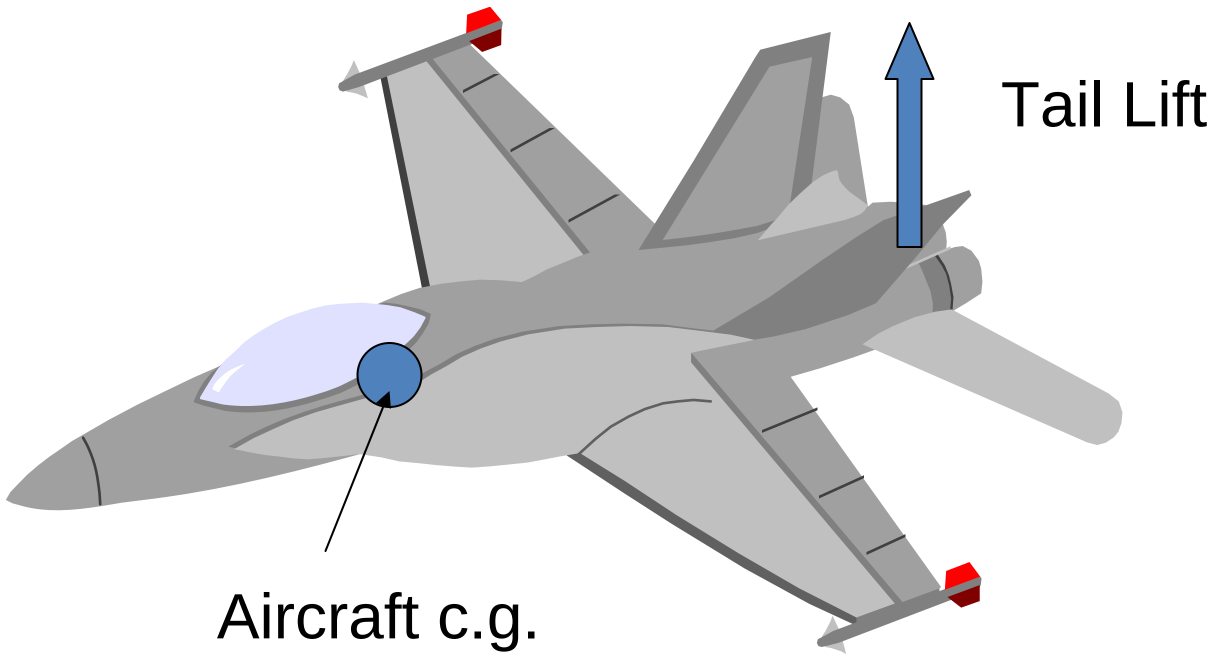
The more positive it is, the more longitudinally stable the aircraft

How can a Designer Ensure Longitudinal Static stability?



Rule #1 : Place the c.g. as far forward as possible - This will cause the nose to drop, if lift increases due to a gust, reducing α, and lift / The opposite will occur if there is downward gust

How can a Designer Ensure Longitudinal Static stability?



Rule #2 : Place the horizontal tail as far aft as possible - This will cause the nose to drop, if there is a vertical gust, reducing α, and lift / The opposite will occur if there is downward gust

A canard is a tail upstream of the c.g., reduced static stability (move wing aft or c.g. forward to compensate)

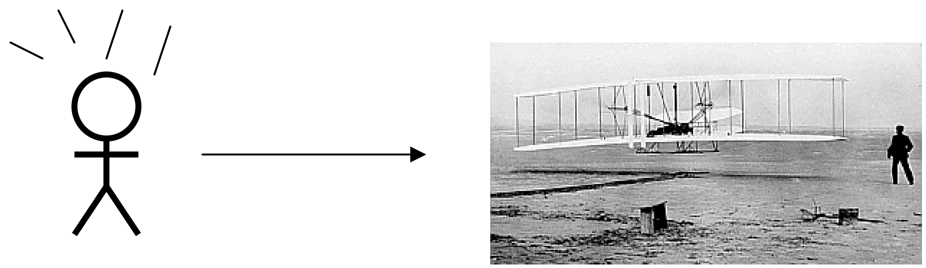
The price paid for a large static stability margin

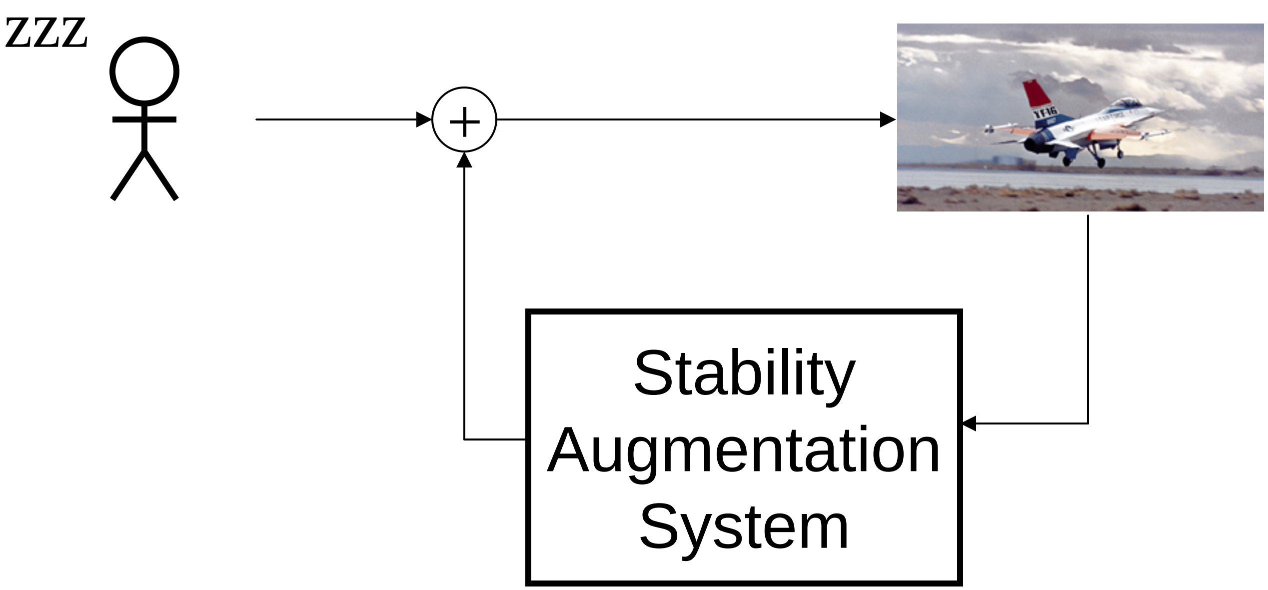
- The aircraft may become sluggish, hard to maneuver; The tail will resist the pilot’s attempt to change the aircraft “angle of attack”
- A large tail adds to aircraft weight, and cost
- Tail generates drag!
- A smaller tail will require a long fuselage (equivalent torque by applying force farther away) to generate enough pitching moment to bring the nose up or down

Relaxed Static Stability

- For improved maneuverability, some aircraft sacrifice the static stability margin: relaxed static stability
- Some fighter aircraft are statically unstable
  - Their nose will continue to pitch up, the lift will continue to go up after an upward gust is encountered; Result: A/C will stall, “flip over”
- These aircraft must be actively controlled by the pilot, or an onboard computer
- Redundant computer systems are present in case a computer based flight control fails

Artificial Stability Augmentation

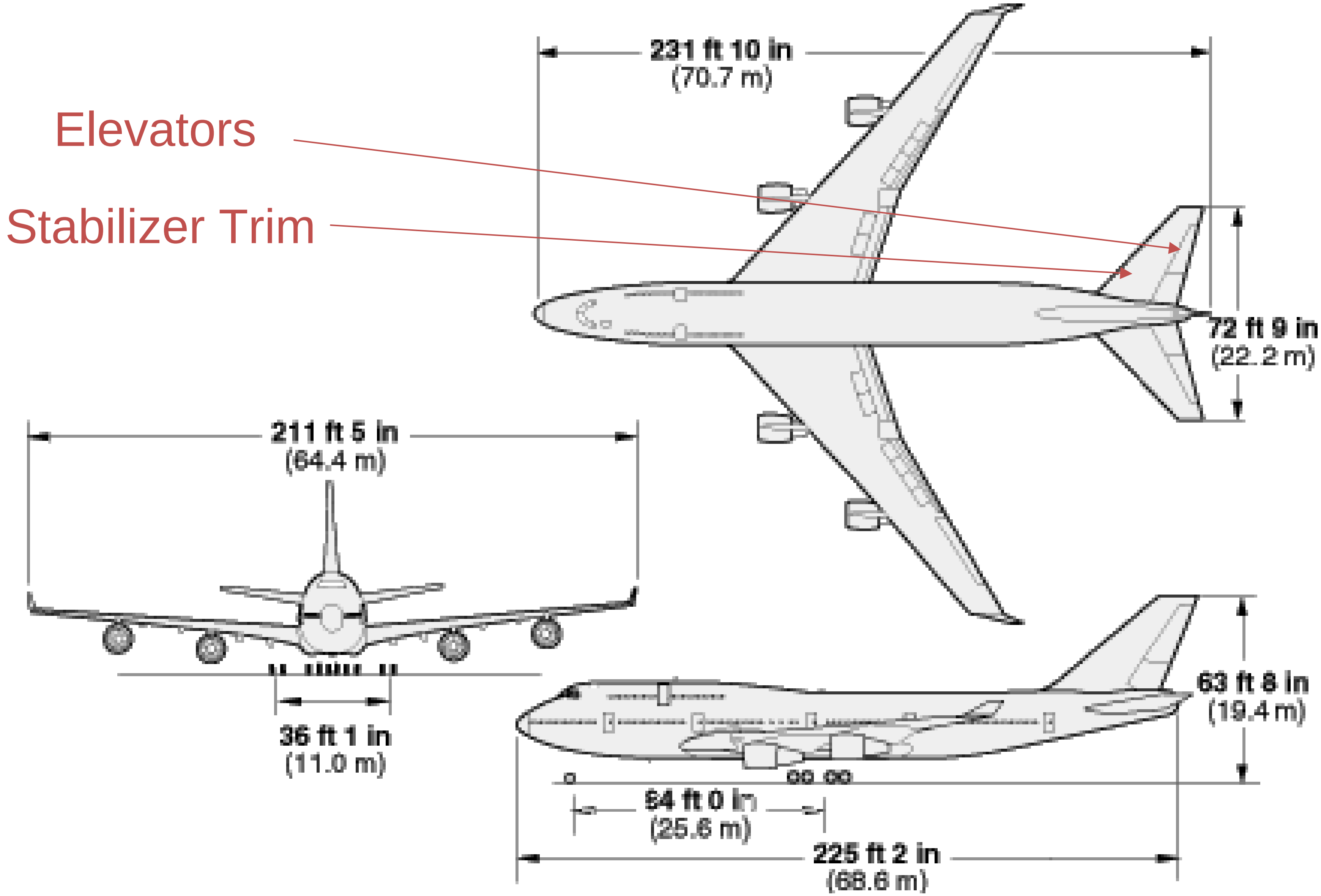




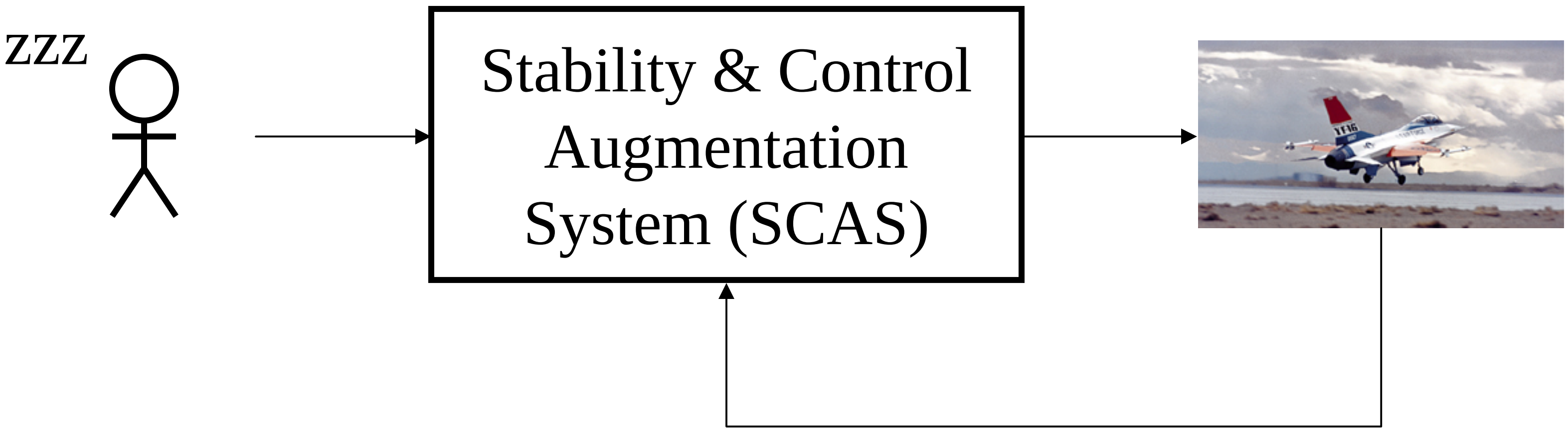
Air Transports, Boeing 747-400

Can Reduce Stability (and therefore drag) in Cruise by Pumping Fuel to Tail

Elevators/Stab Trim: B747



Stability and Control Augmentation



Super-augmented Aircraft

F-16

X-29

Dryden Flight Research Center EC91-491-6 Photographed 13Sep1991
X-29 smoke test. NASA photo.

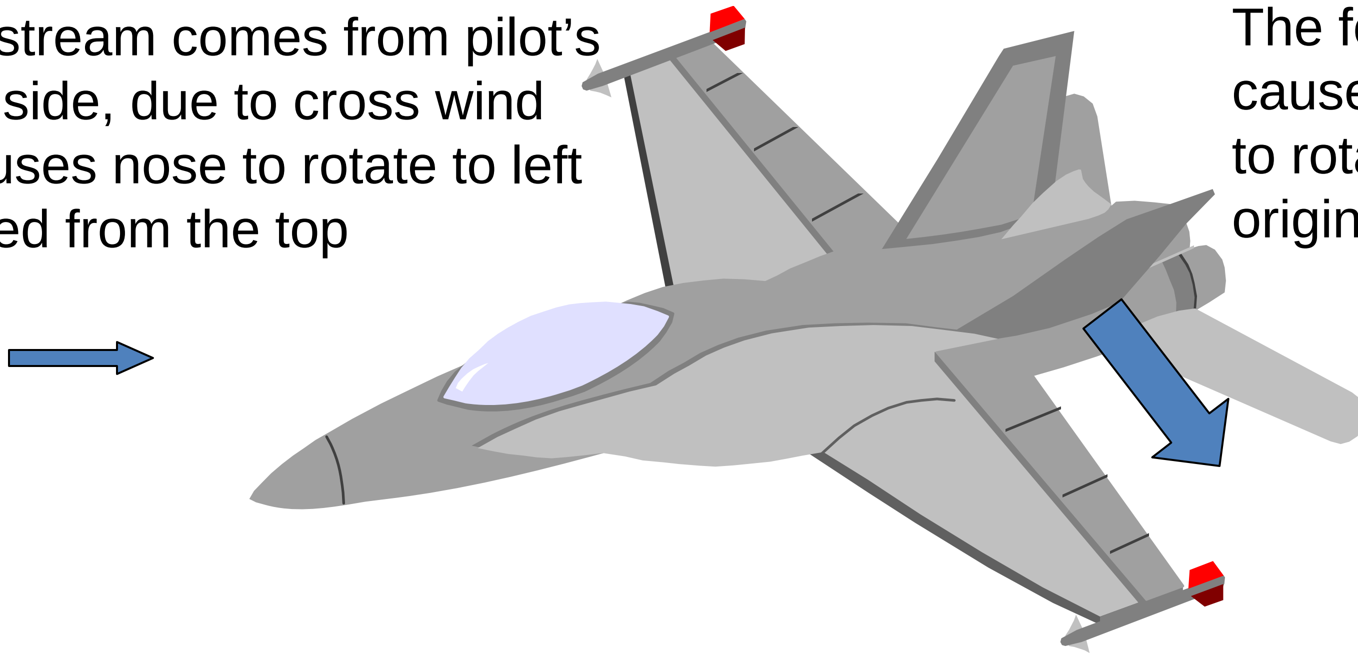
Saab Gripen (JAS-39B)

Digital Fly-by-wire:
Reduced Drag at High-G

When the Actuators Saturate…

Directional Stability

Freestream comes from pilot's right side, due to cross wind
It causes nose to rotate to left viewed from the top



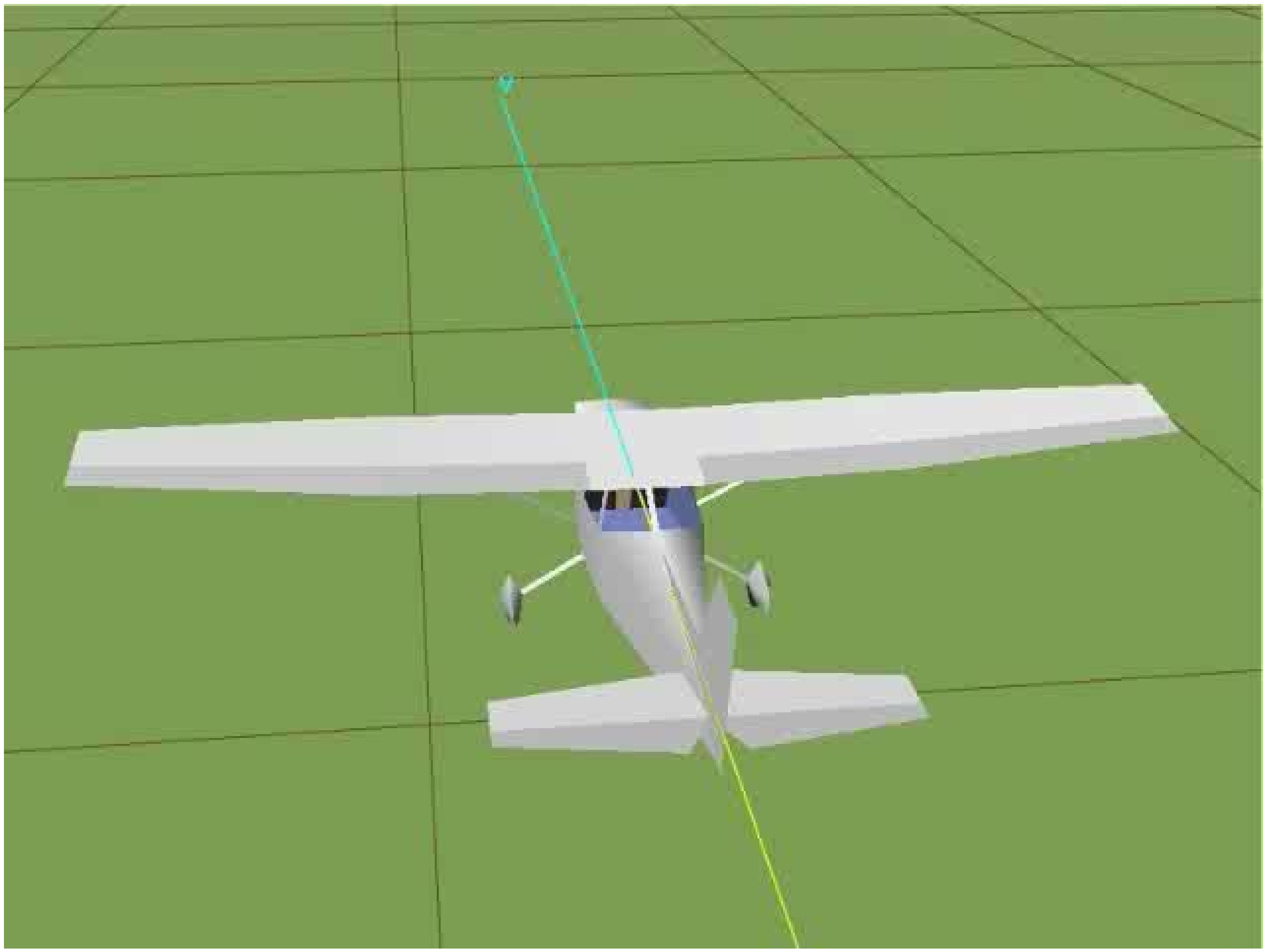
The force on the tail causes the aircraft to rotate back to original direction

A cross wind may cause the nose to rotate about the vertical axis, changing the flight direction

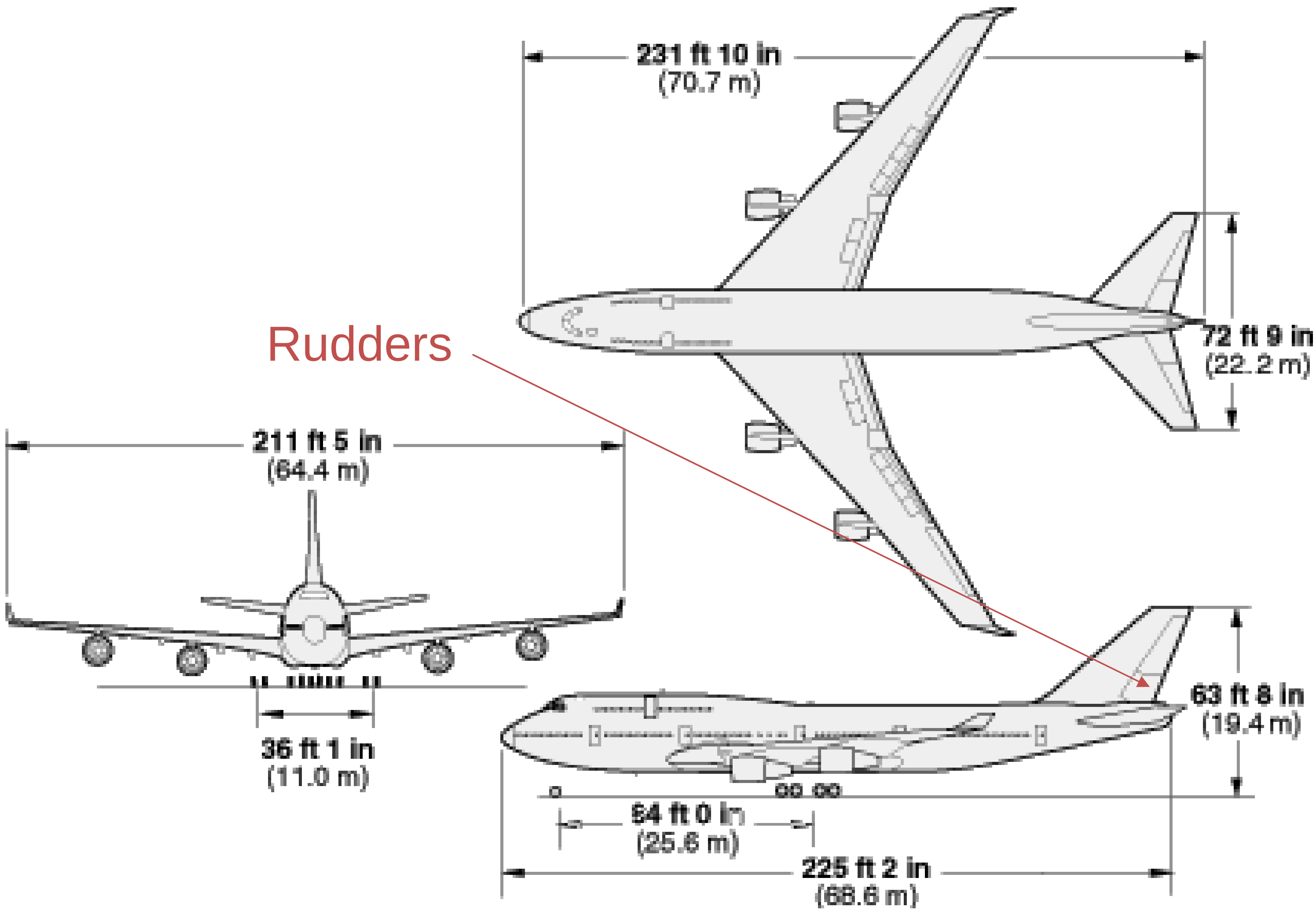
The vertical tail behaves like a wing at an angle of attack, producing a side force, rotates the aircraft to its original direction

All of this occurs without pilot action or intervention

Enough Vertical Fin for Lightly Damped Directional Oscillations "Dutch Roll"

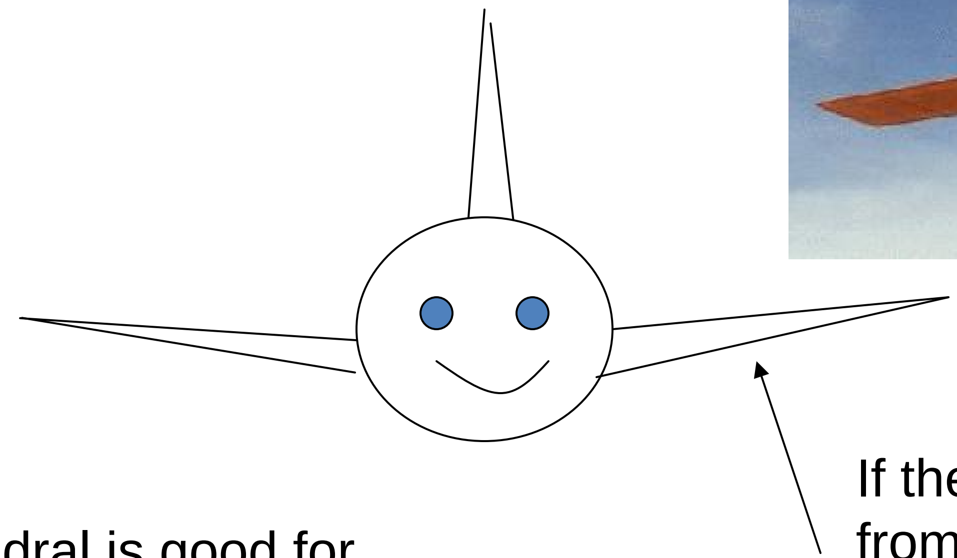


Rudders: B747



Lateral Stability

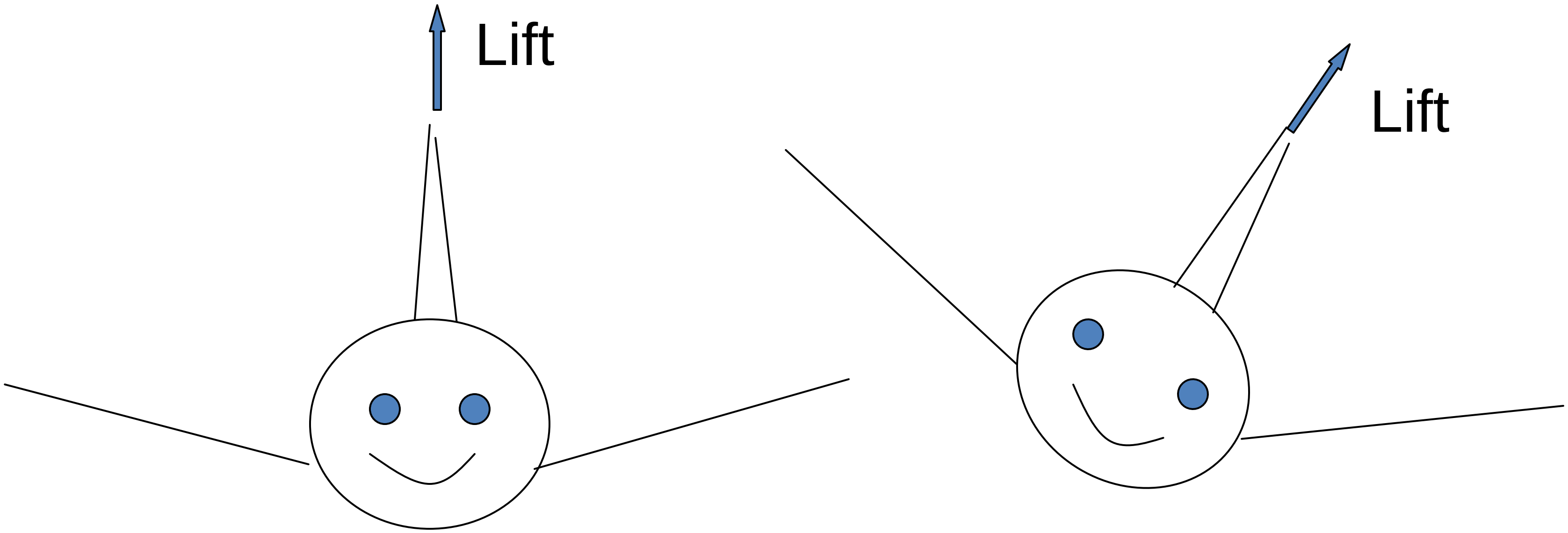
- It is the ability of the aircraft to recover from a roll disturbance without pilot intervention



Dihedral is good for lateral stability

If the wing is tilted upwards from root to tip, it has a dihedral

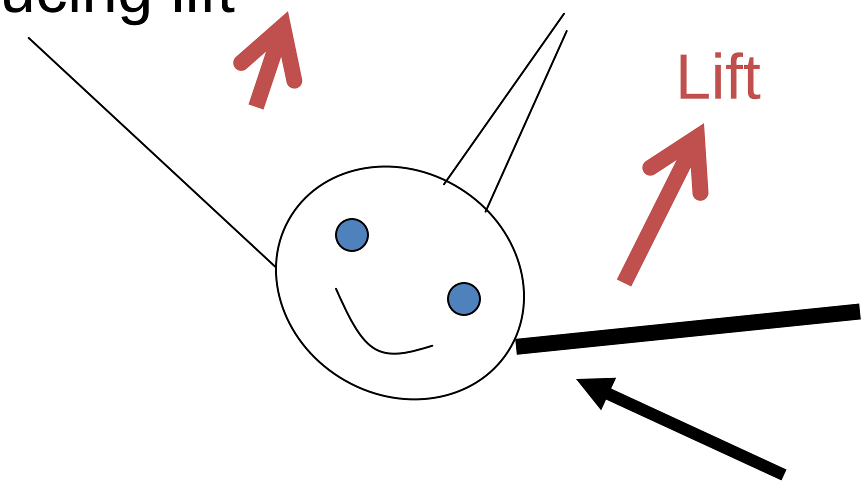
What happens when the aircraft undergoes a roll?

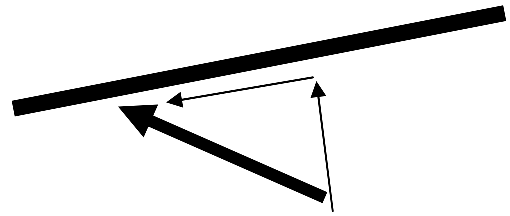


A portion of the lift is pointed sideways
The vehicle moves laterally -
This is called sideslip

During sideslip, a relative wind flows from right to left: Lateral Static Stability

A similar downwash occurs
on the left wing,
reducing lift





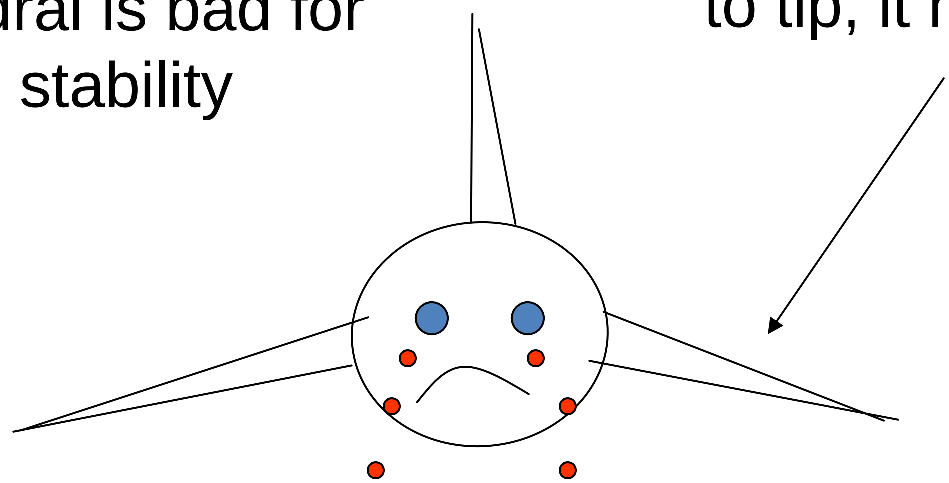
This wind has
a component normal
to the wing on
the right, viewing
from the front
This is an upwash.
The upwash increases
lift on the right wing

As a result, the aircraft rights itself,
and recovers from the roll!

Anhedral

If the wing dips down from root to tip, it has an anhedral

Anhedral is bad for lateral stability



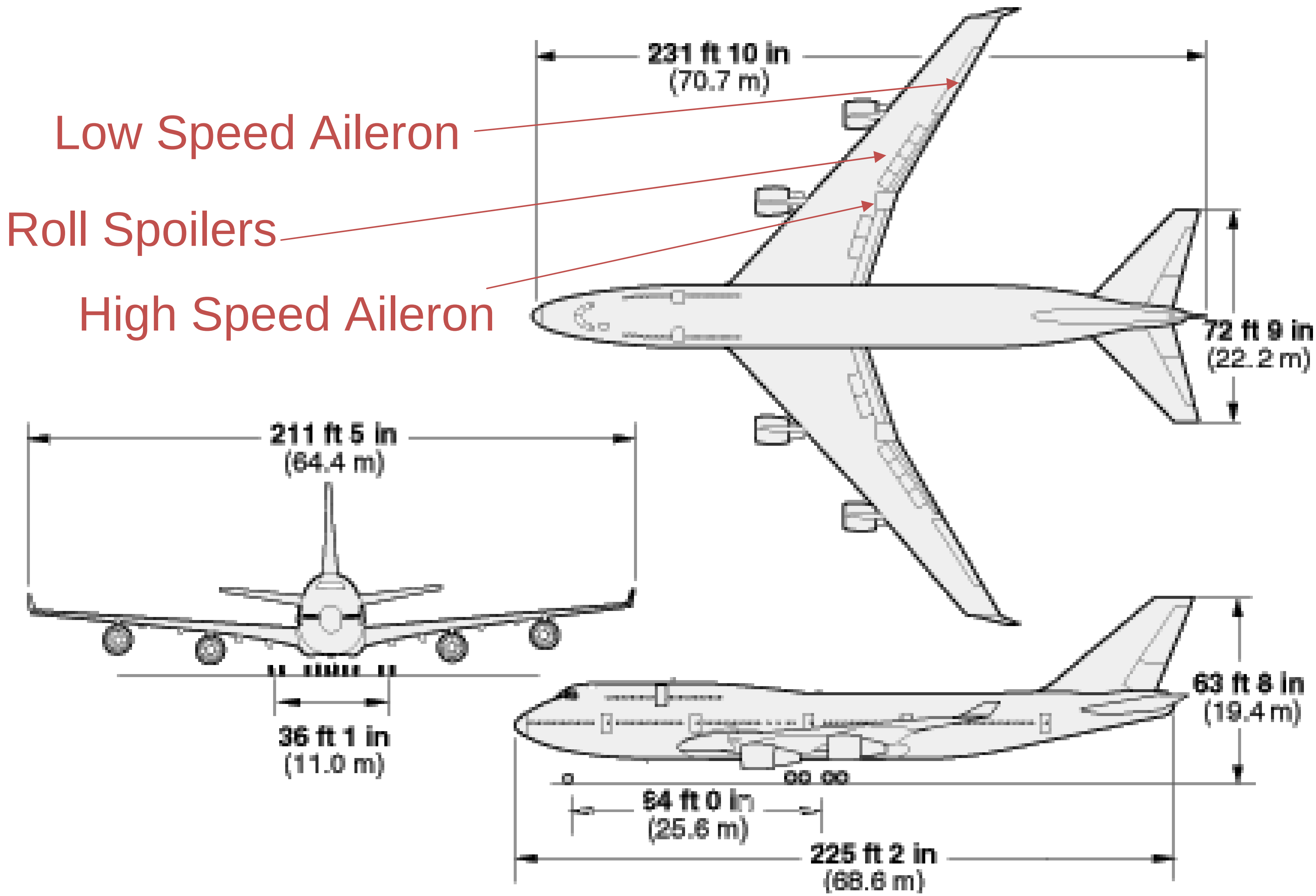
Dihedral Effect

- Dihedral effect can come from
  - From wing dihedral, high wing, or wing sweep
  - From vertical tail
- Anhedral can be used to get desired level of dihedral effect

F-104

AV-8B

High/Low Speed Ailerons: B747



The Wrights

- Conventional Wisdom: Airplane should hold course, and the pilot should deflect the rudder to turn, the “Boat Model”
- Wrights invented wing warping, first lateral control
- Early Wright airplanes were unstable, difficult to fly, and maneuverable