AERO 374 Aircraft Performance
2014/2015

This course provides an introduction to the performance analysis of aircraft. Aircraft performance in gliding, climbing, level and turning flight are analyzed. Calculation of vehicle take off and landing distance, range and endurance are done to check the performance of aircrafts. Credits (3).

<u>Prerequisites by topic</u>: Differential and Integral Calculus, Computer usage: Spreadsheets.
<u>Textbook</u>: Airplane Performance and Design by John Anderson Jr.; McGraw-Hill, 1999.
<u>References</u>:
Introduction to Flight 4th Edition by John Anderson, McGraw-Hill, 2000
Dynamics of Flight by B. Etkin, John Wiley & Sons, 1982.
Aerodynamic for Navel Aviators Naval Air Systems
FAR
Commercial Pilots Manual
Operators Manual: Piper Warrior

Course Objectives:

By the end of this course the student will be able to identify and communicate

- **basic knowledge of Airplane Performance and the design parameter impacting the performance.**
- **Describe and apply Aeronautical Fundamentals that are used in**
  design,
  performance parameters and
  problem solving process/ techniques used in predicting airplane performance.
- **Also the student will have working knowledge and understanding of FAR's**

Topics to be Covered (Subject to change):

- **Introduction to flight dynamics and Environment**
- **General equation of motion in three dimensions**
- **Aircraft Weight and Balance fundamentals**
- **Airplane performance, including takeoff, rate of climb, ceilings, power required, range, maximum endurance, descent, landing, operating limitations.**
- **Static stability and control**
- **Introduction to Federal Aviation Regulations (FAR)**

Course Activities

1) Demonstrate an understanding of Airplane Performance Parameters:
    - Forces Acting on the Airplane in Flight
    - Load Factors
    - Weight and Balance on Airplane Performance
    - Airplane Nomenclature

2) Understand the Importance of Atmospheric factors

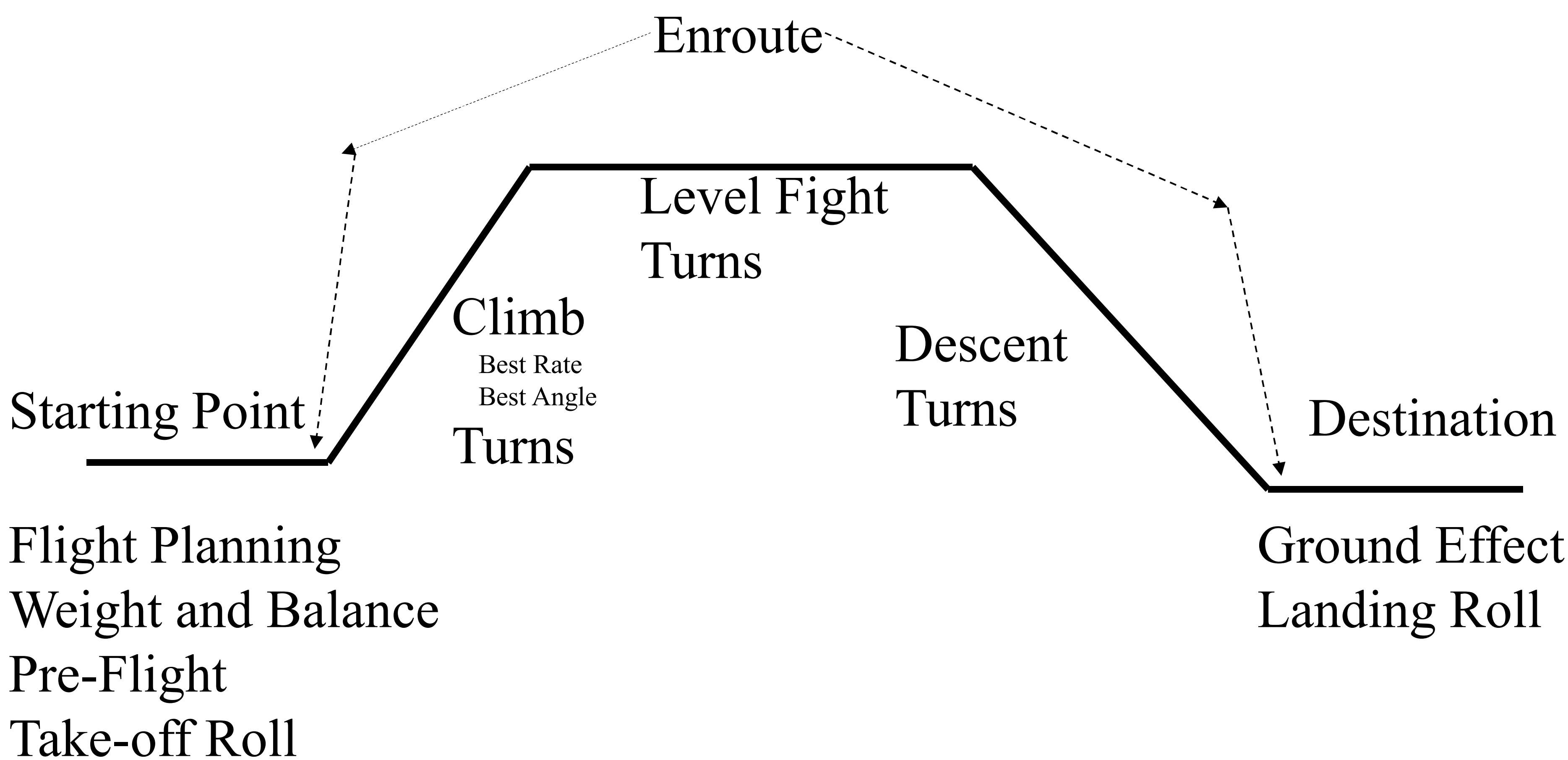
3) Solve simple Airplane performance problems
    - Takeoff Distances
    - Best Rate of Climb
    - Best Angle of Climb
    - Endurance

4) Have a basic concept and understanding of Flight Instruments.

5) Use Spreadsheets to present graphical solution to performance problems

6) To present Engineering Analysis and Projects in the form of an oral presentation and written reports.

Course Progression

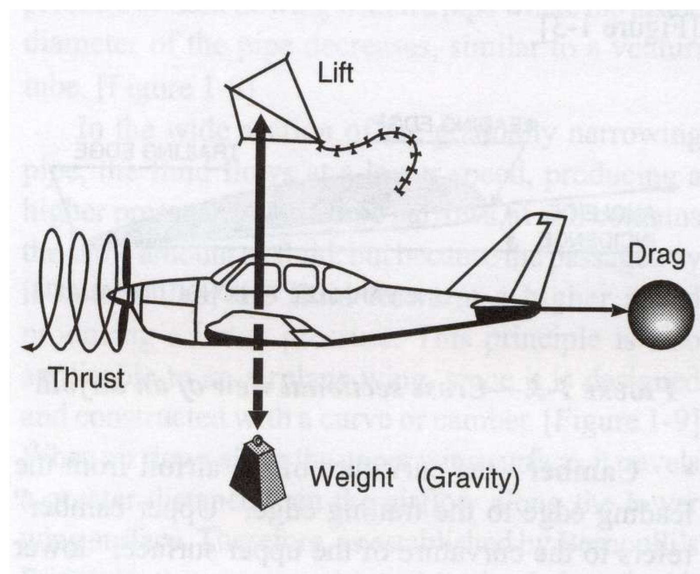


Airplane Performance

Is concerned with the movement of the airplane through the atmosphere.

An airplane comprises several aerodynamic systems and sub-systems that responds to the four forces of flight. The four forces are:

Lift
Drag
Weight
Thrust

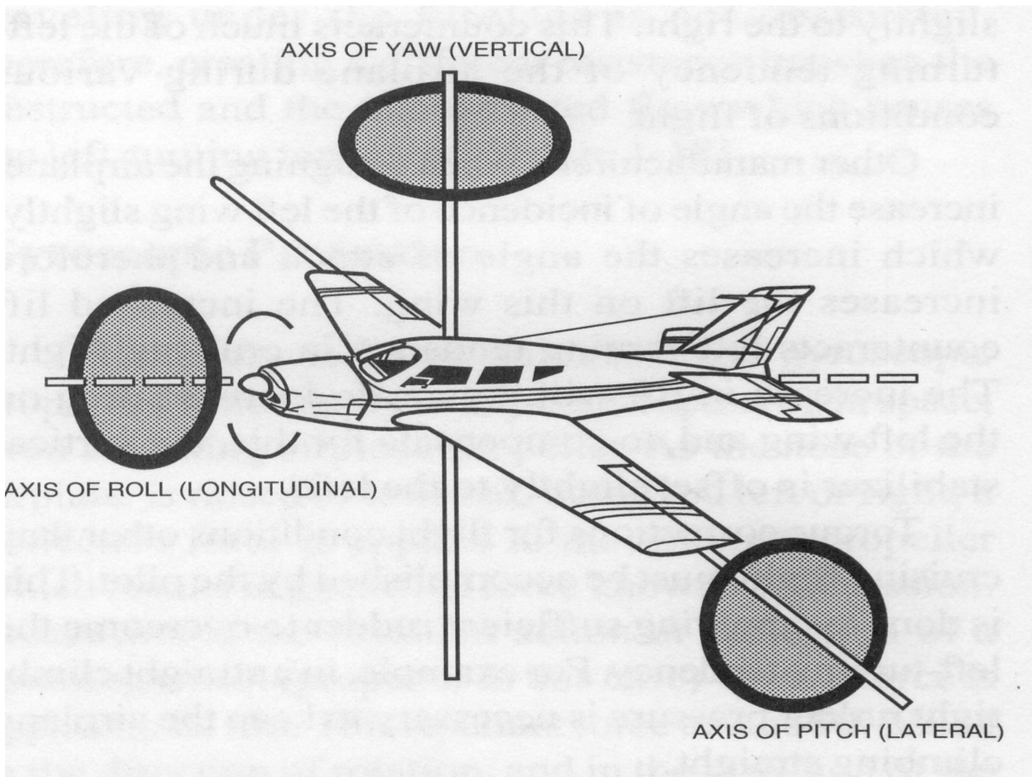


Three Axis of Rotation

Pitch - Elevator – Push or Pull

Roll – Ailerons – Turn Left or Right

Yaw – Rudder – Step Left or Right



Aircraft Types per FAA

1) Fix wing Aircraft — Airplanes

   Single Engine

   Multi Engine

2) Rotary Wing – Helicopters

3) Non-powered airplanes – Gliders

4) Lighter-than-Air – Balloons

5) Power Lift Aircraft – Harrier and V-22 Osprey






Forces Acting on the Airplane in Flight

Relationship Between Angle of Attack and Lift

Relationship of Thrust and Drag in Straight and Level Flight

Relationship Between Lift and Weight in Straight and Level Flight

Factors Affecting Lift and Drag

- Effect of Wing Area on Lift and Drag
- Effect of Airfoil Shape on Lift and Drag
- Effect of Wing Design on Stall
- Effect of Airspeed on Lift and Drag
- Effect of Air Density on Lift and Drag

Loads and Load Factors

Load Factors and Airplane Design
Effect of Turns on Load Factors
Effect of Load Factors on Stalling Speed
Effect of Speed on Load Factors
Effect of Flight Maneuvers on Load Factors
Effect of Turbulence on Load Factors
Determining Load Factors in Flight
Forces Acting on the Airplane when at Airspeed Slower than Cruise
Forces in a Climb
Forces in a Glide
Turns During Flight

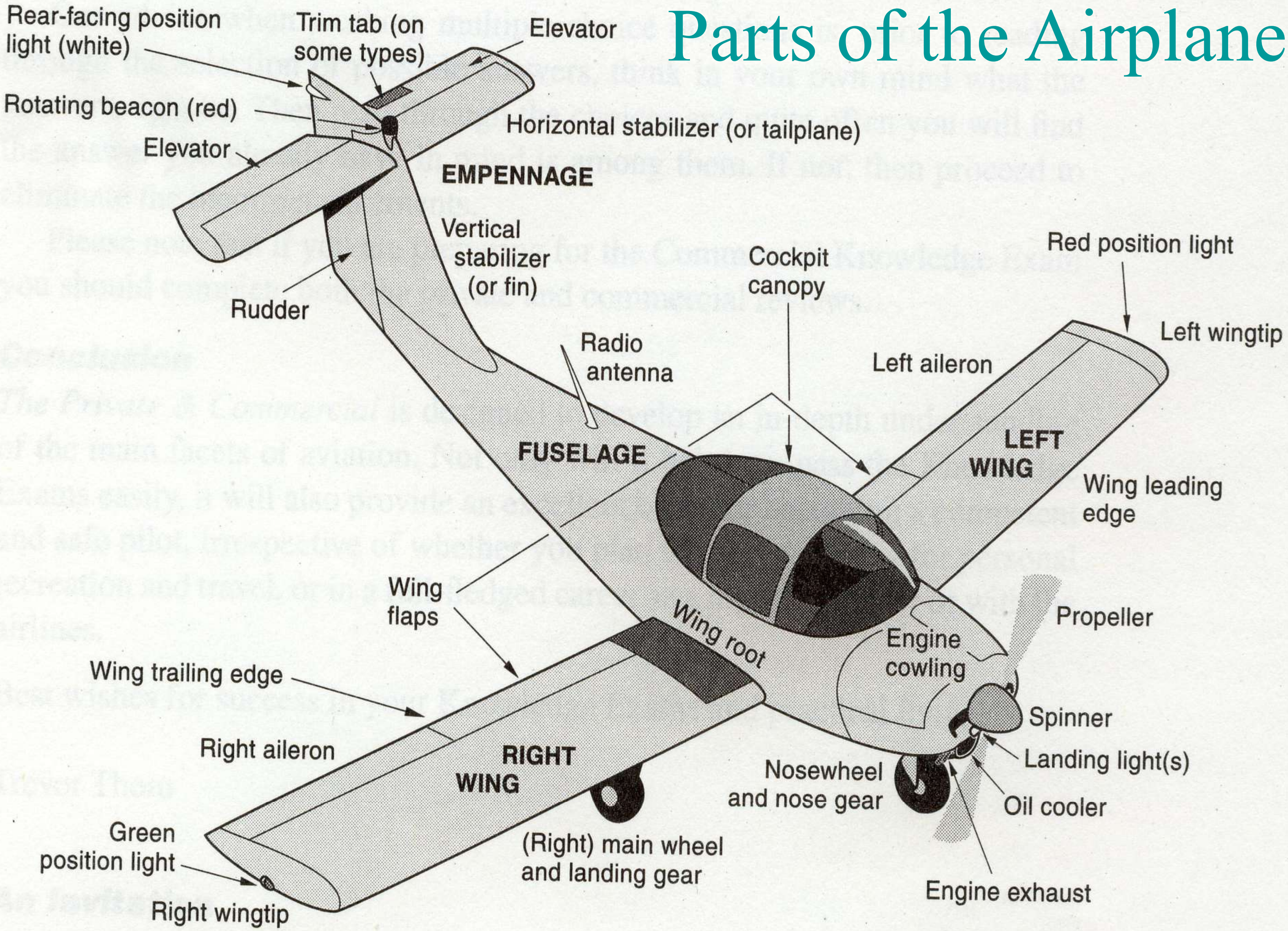
<u>Weight and Balance on Airplane Performance</u>

- Weight Control
  - Effects of Weight
  - Weight Changes

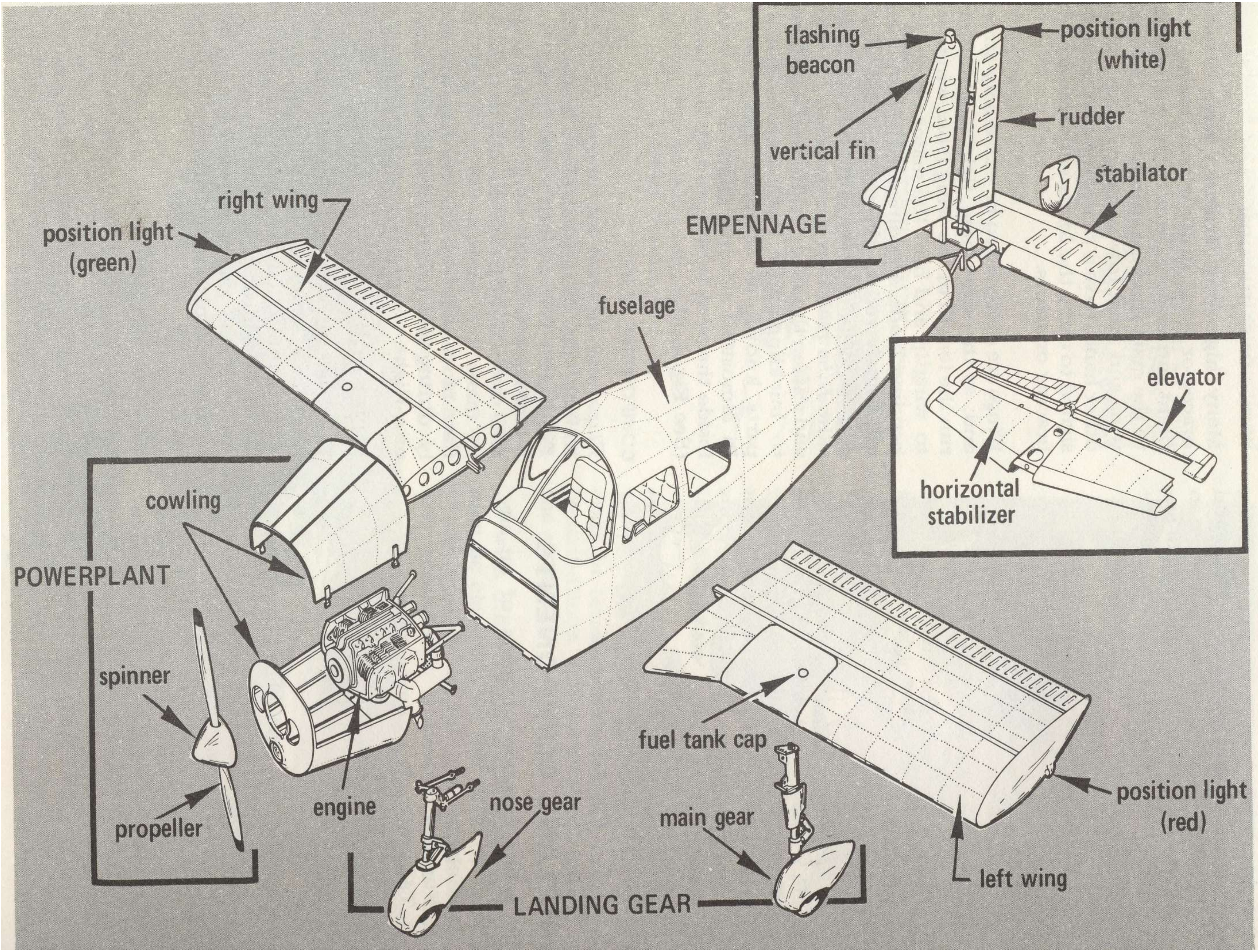
- Balance, Stability, and Center of Gravity
  - Effect of Adverse Balance
  - Management of Weight and Balance Control
  - Weight and Balance Computation
  - Weight and Balance Restrictions

- Determining Loaded Weight and Center of Gravity

Parts of the Airplane



Features of a modern training airplane


flashing beacon
position light (white)
rudder
vertical fin
stabilator
EMPENNAGE
right wing
position light (green)
fuselage
elevator
horizontal stabilizer
cowling
POWERPLANT
spinner
propeller
engine
nose gear
main gear
fuel tank cap
position light (red)
left wing
LANDING GEAR

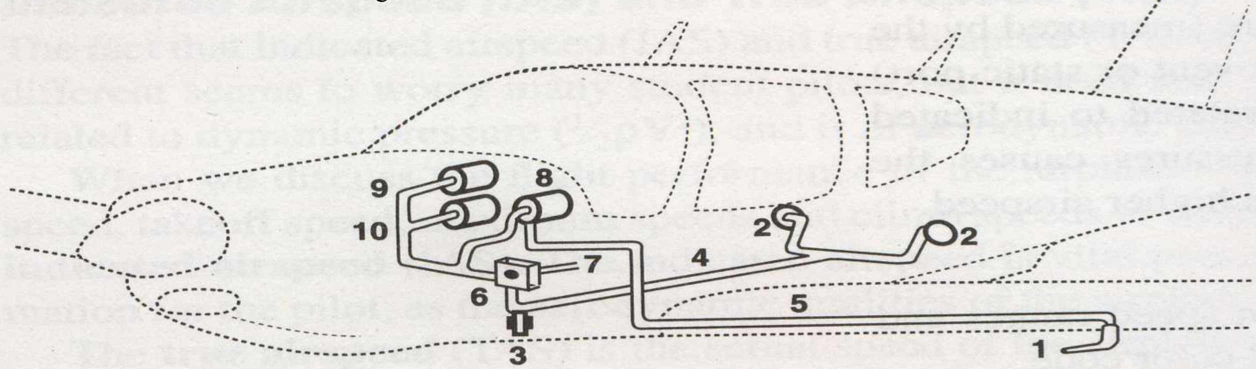
Review of Airplane Nomenclature

Wing
Ailerons
Flaps
Winglets
Spoilers
Leading Edge
Trailing Edge
Pitot Tube
Fuselage

Elevator
Rudder
Trim Tabs

Introduction to Airplane Flight Instrumentation

Moving from Wind Tunnel instruments to real world



1. Pitot tube
2. Static vents
3. Static drain
4. Static line
5. Pitot line
6. Alternate static selector
7. Alternate static pressure
8. Airspeed indicator
9. Altimeter
10. Vertical speed indicator

Figure 8-4. Typical pitot-static installation

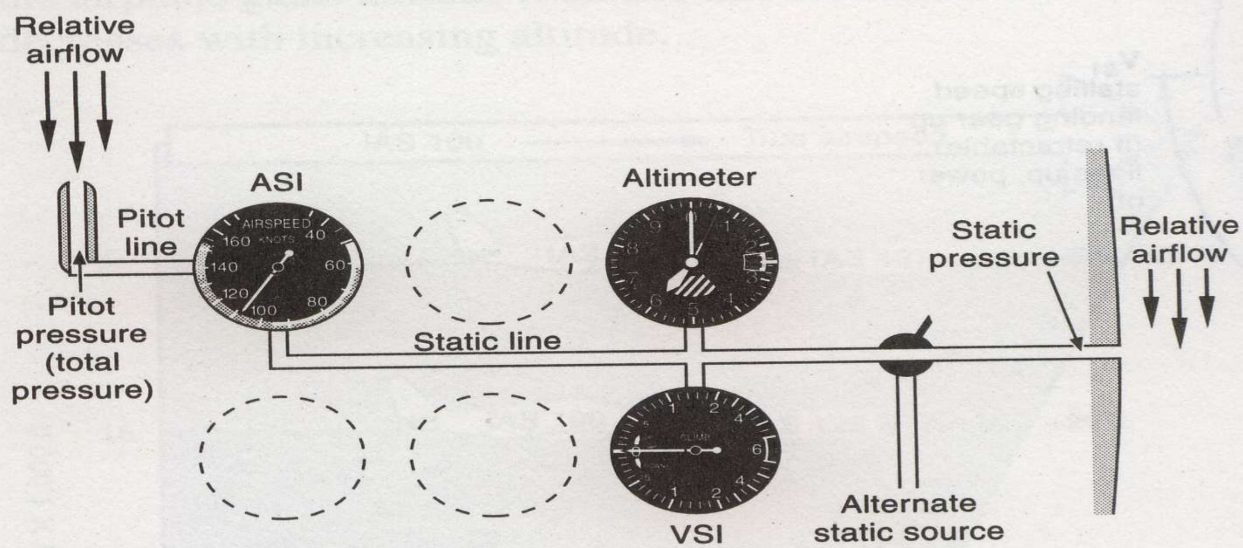


Figure 8-5. The pitot-static system

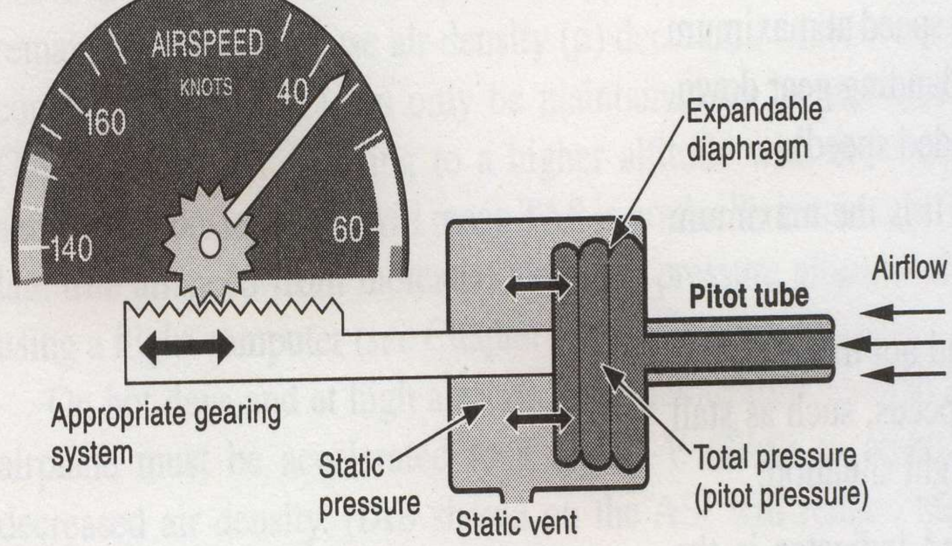


Figure 8-6. The airspeed indicator measures dynamic pressure

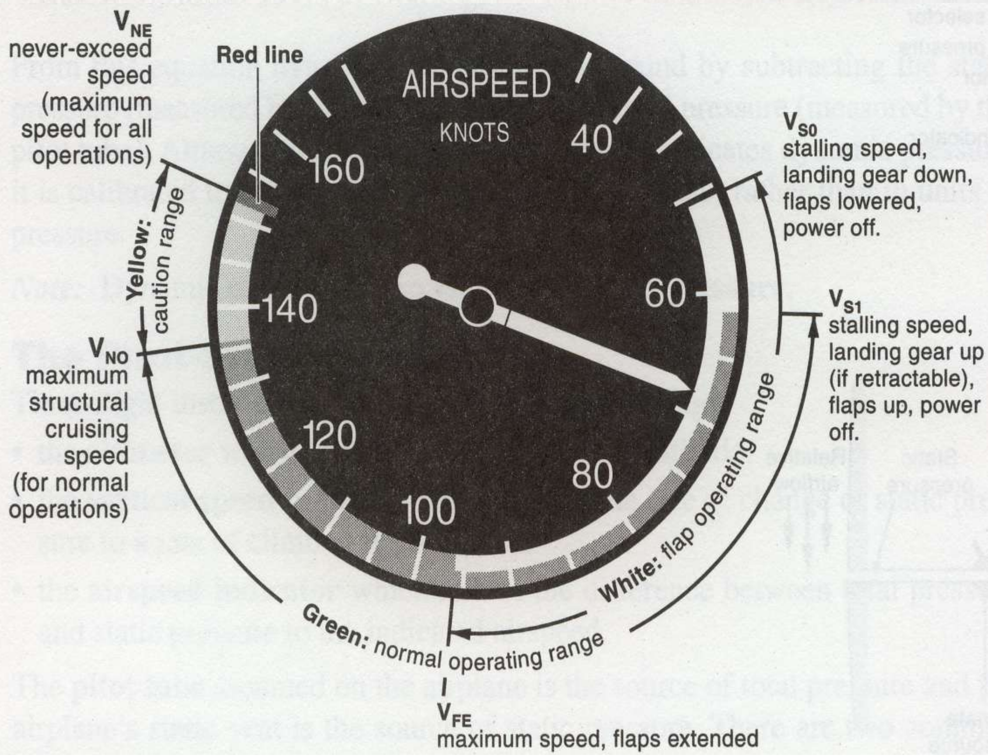


FIGURE 3-4.—Airspeed indicator.

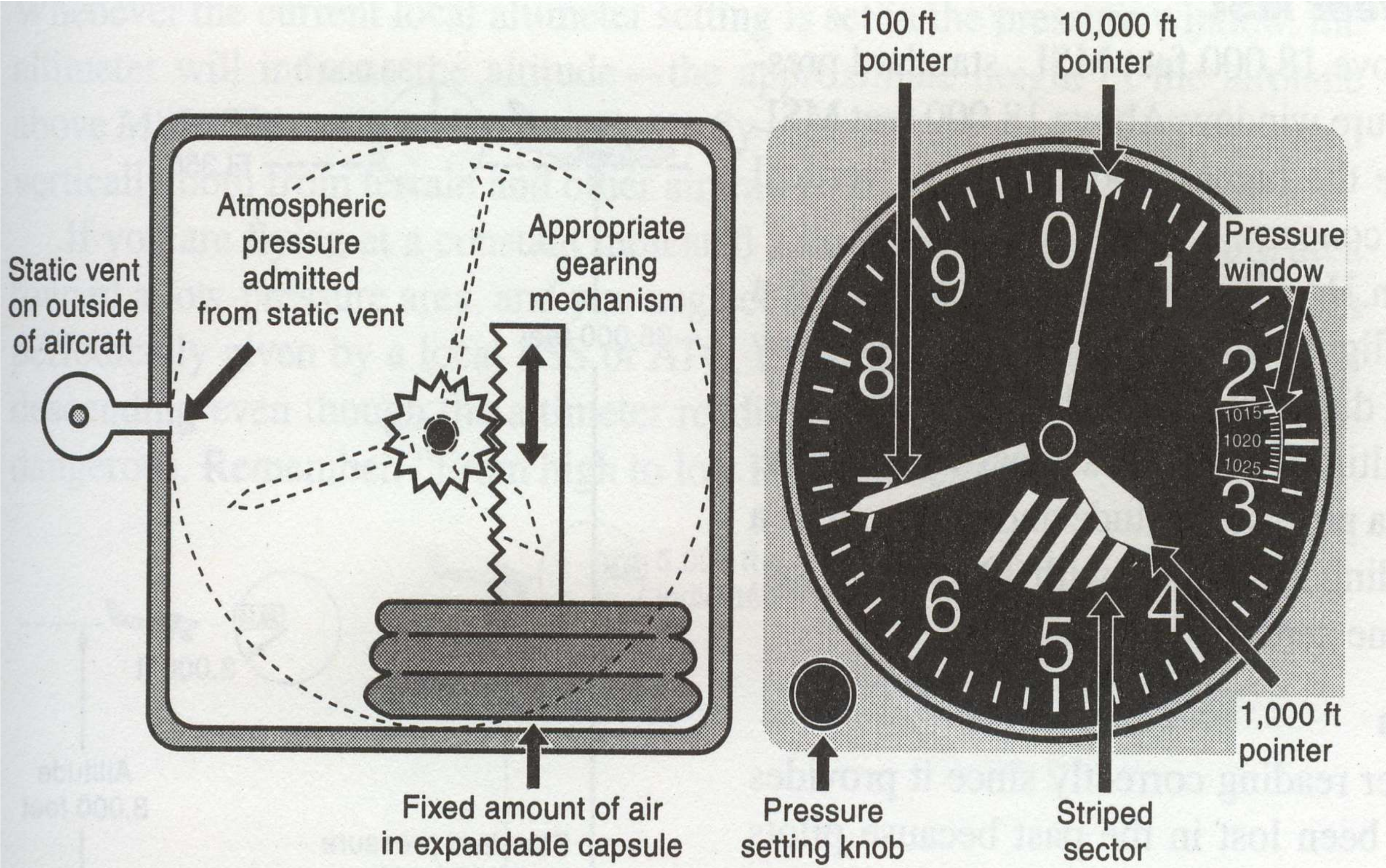
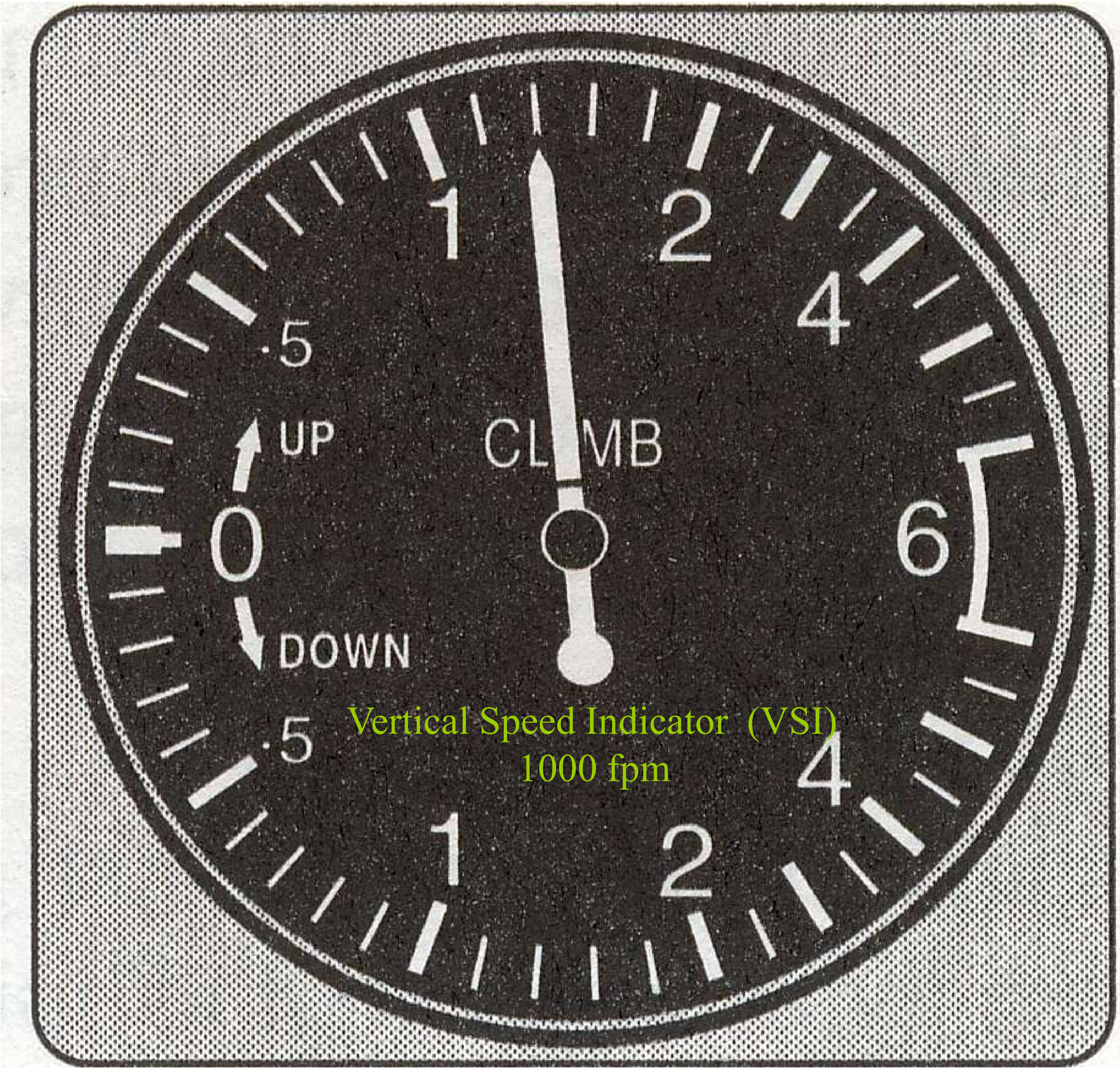


Figure 8-9. The altimeter is a pressure-sensitive instrument

Reading of the Altimeter

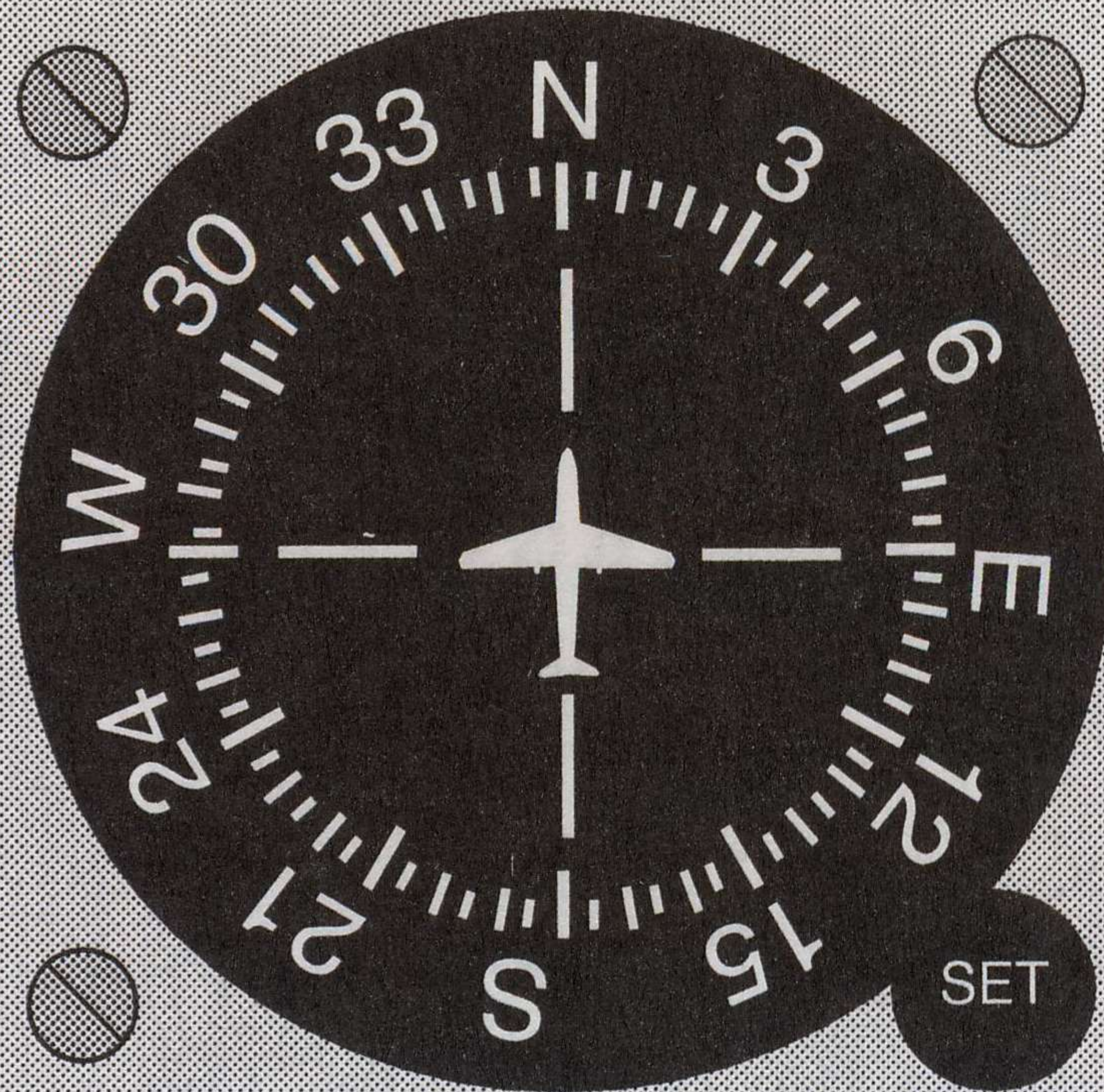
10,000	Pointer	Reads 0
1,000	Pointer	Reads 3
100	Pointer	Reads 7

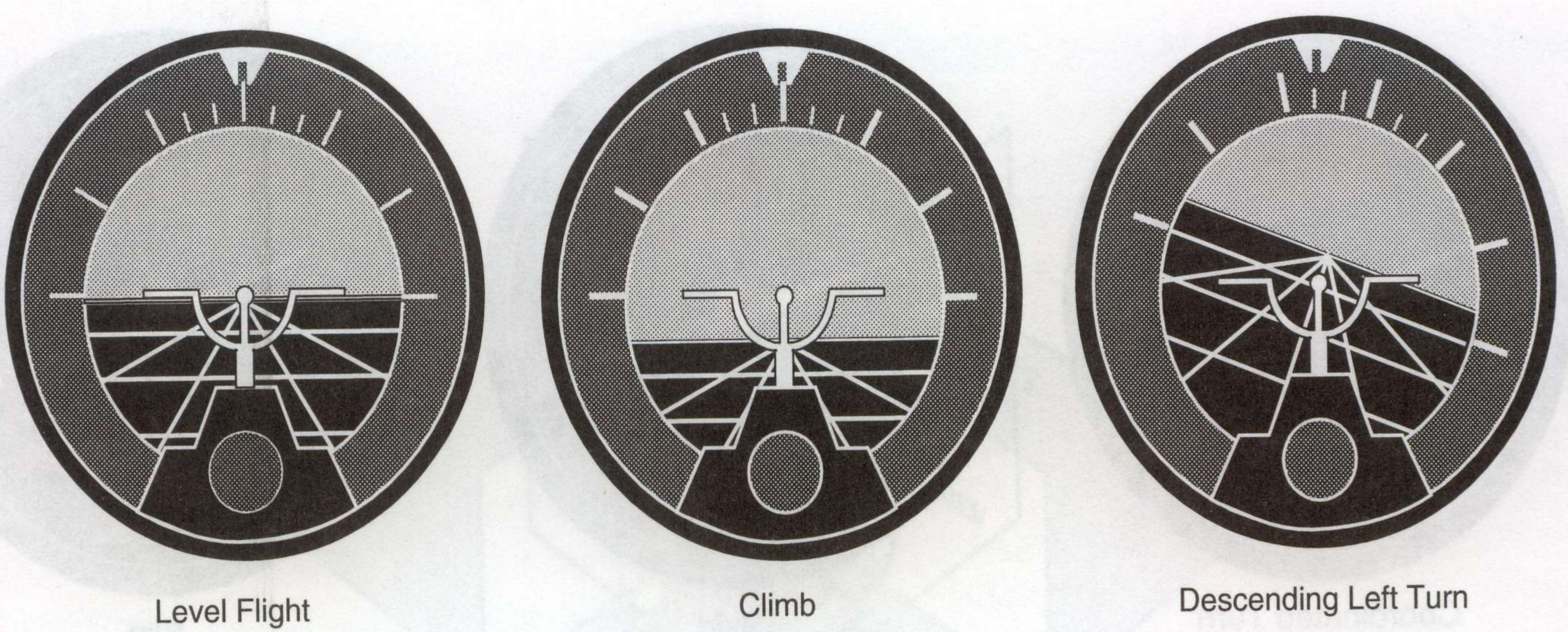
(10000 x 0) + (1000 x 3) + (100 x 7) = 3700 ft



Vertical Speed Indicator (VSI)
1000 fpm

Heading Indicator





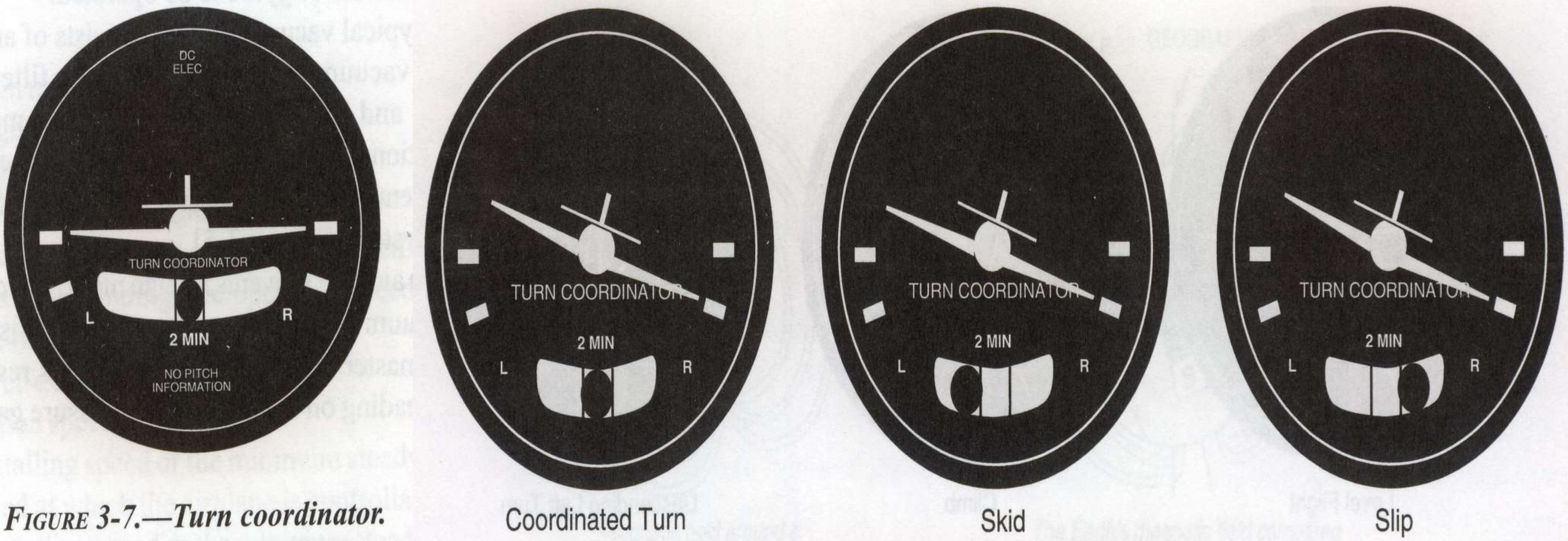


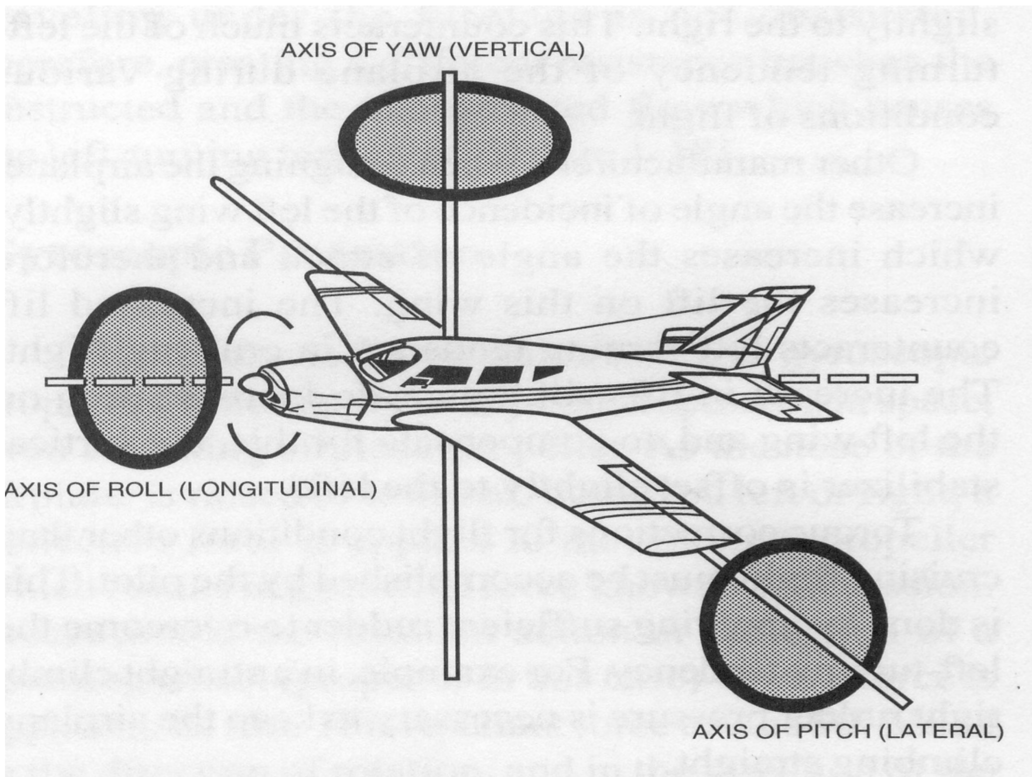
FIGURE 3-7.—Turn coordinator.

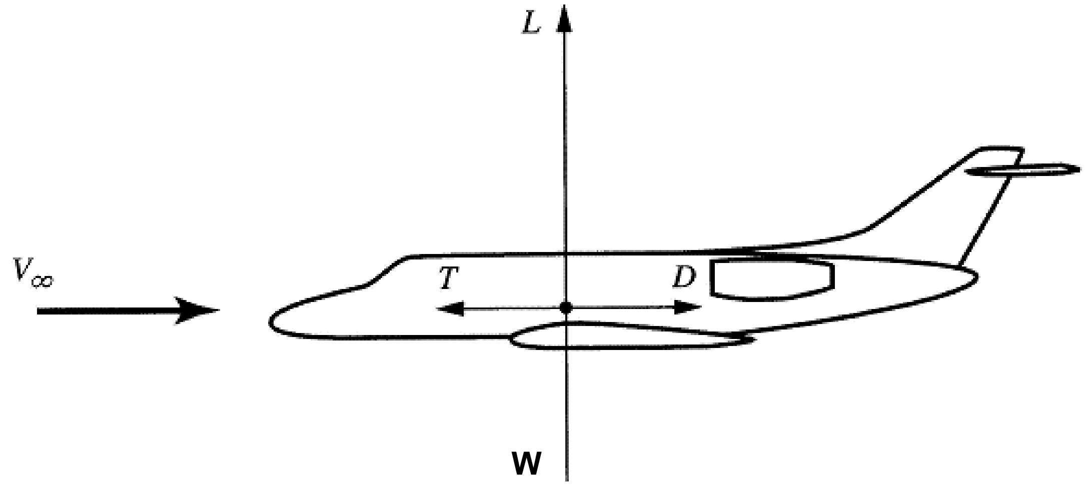
Three Axis of Rotation

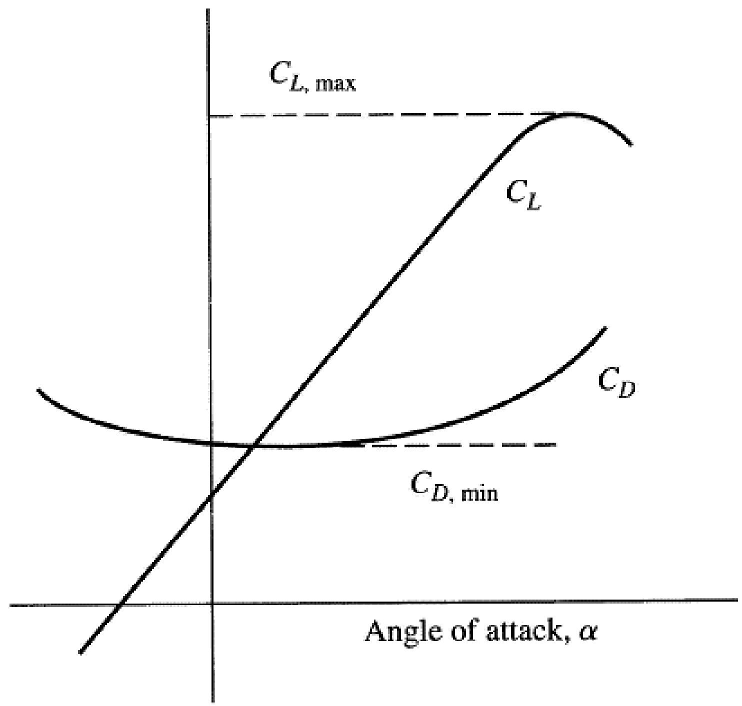
Pitch - Elevator – Push or Pull

Roll – Ailerons – Turn Left or Right

Yaw – Rudder – Step Left or Right







Schematic of lift and drag coefficients versus angle of attack; illustration of maximum lift coefficient and minimum drag coefficient.

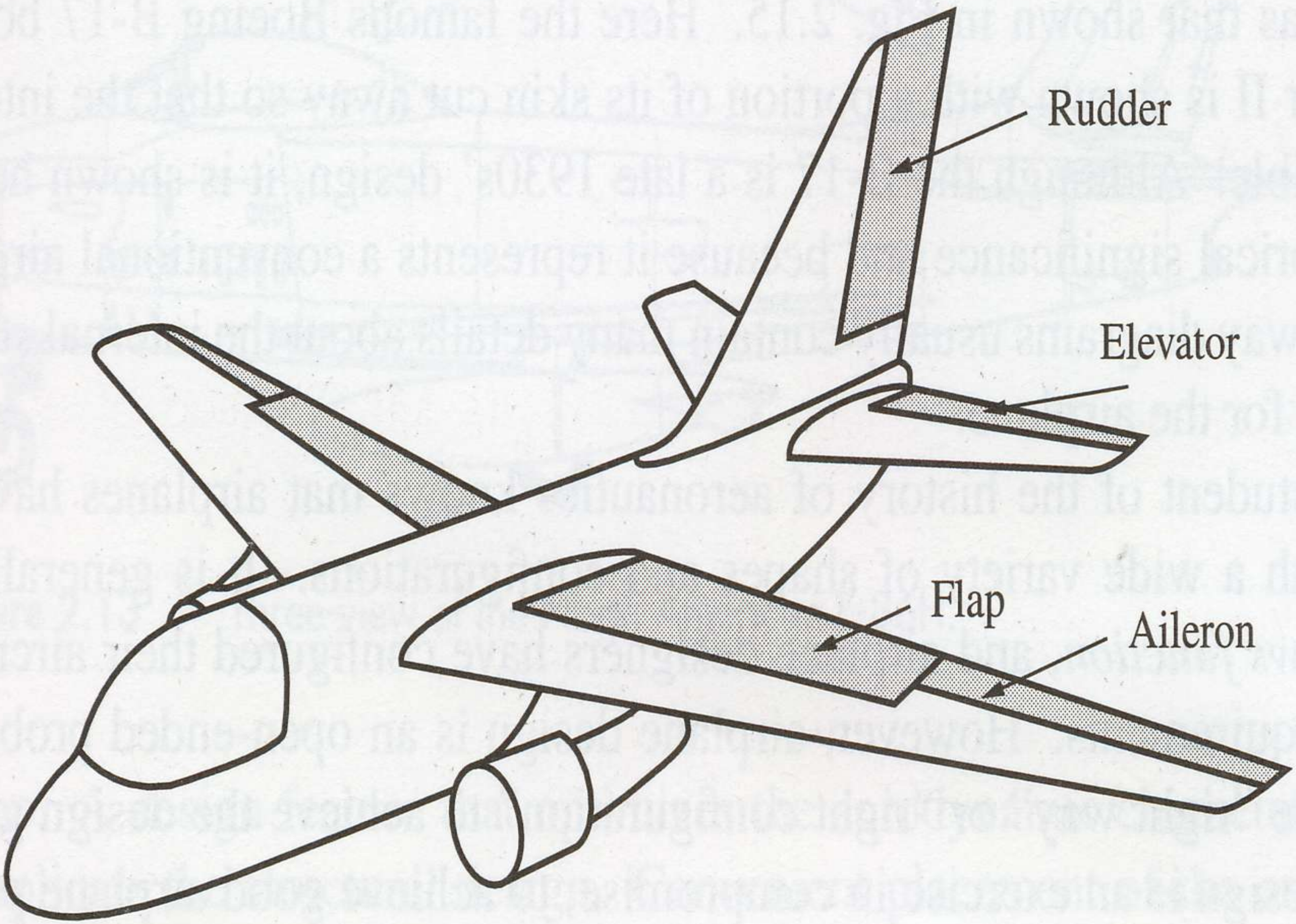
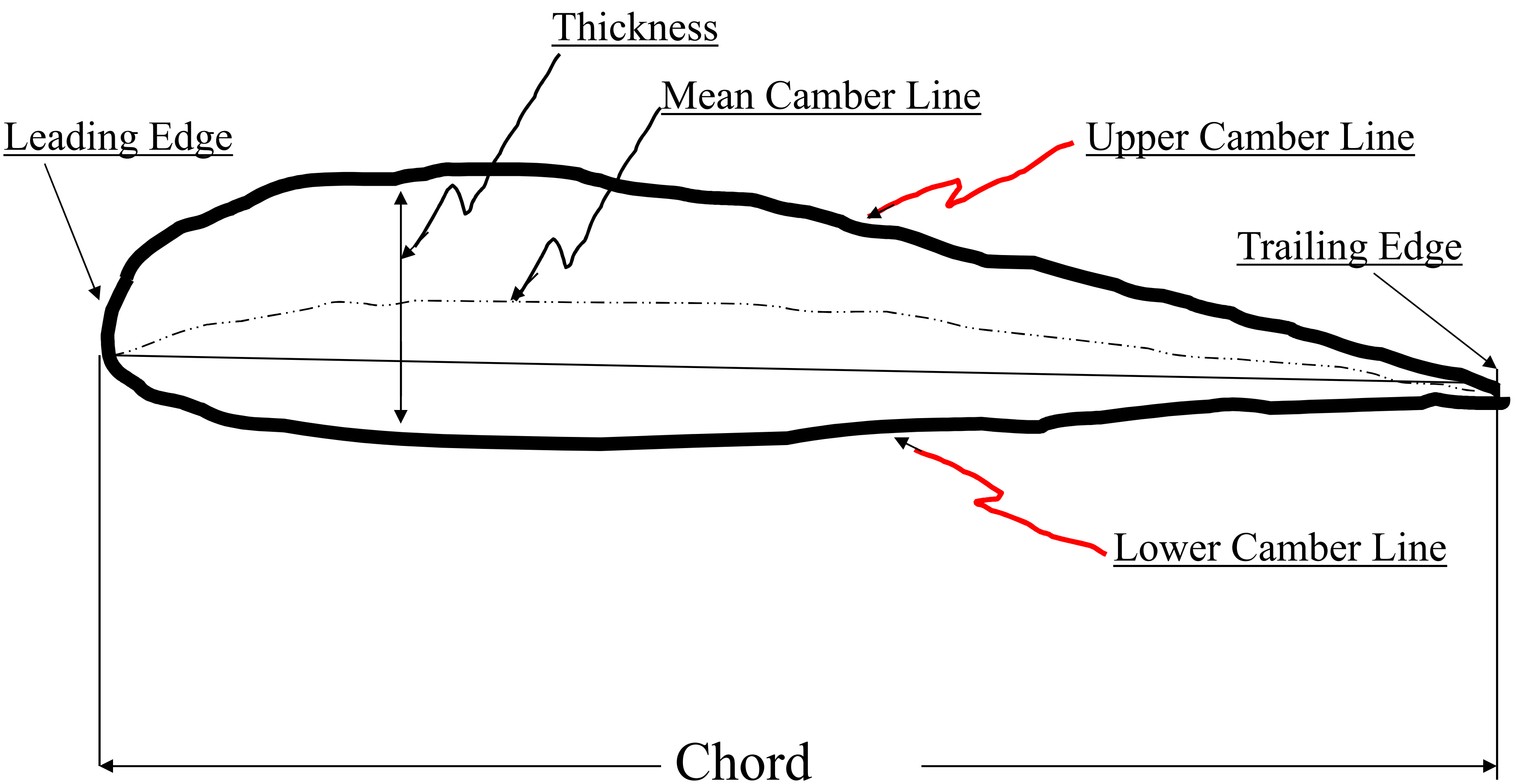


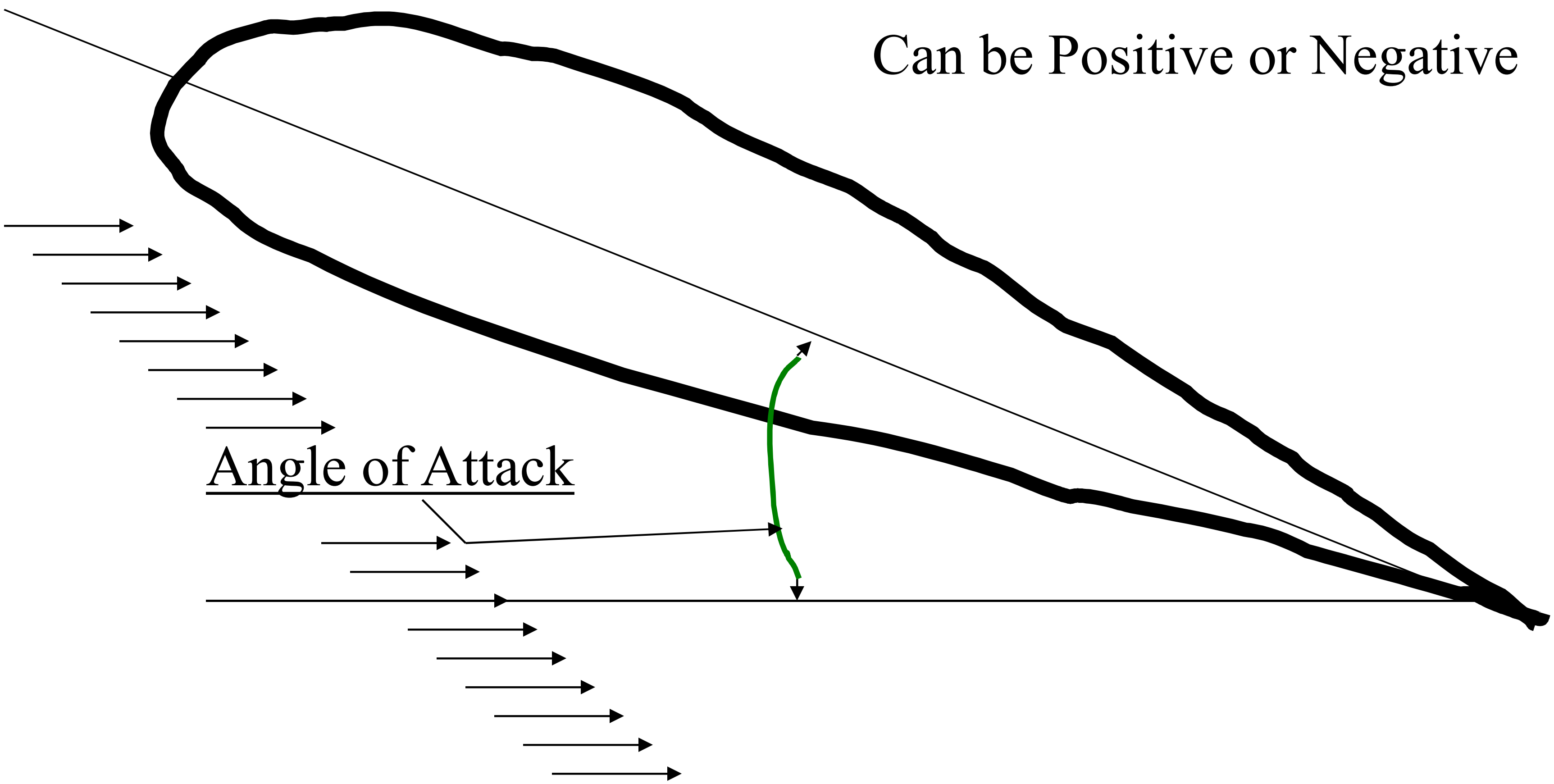
Figure 2.12 Control surfaces and flaps.

NACA Airfoil Nomenclature



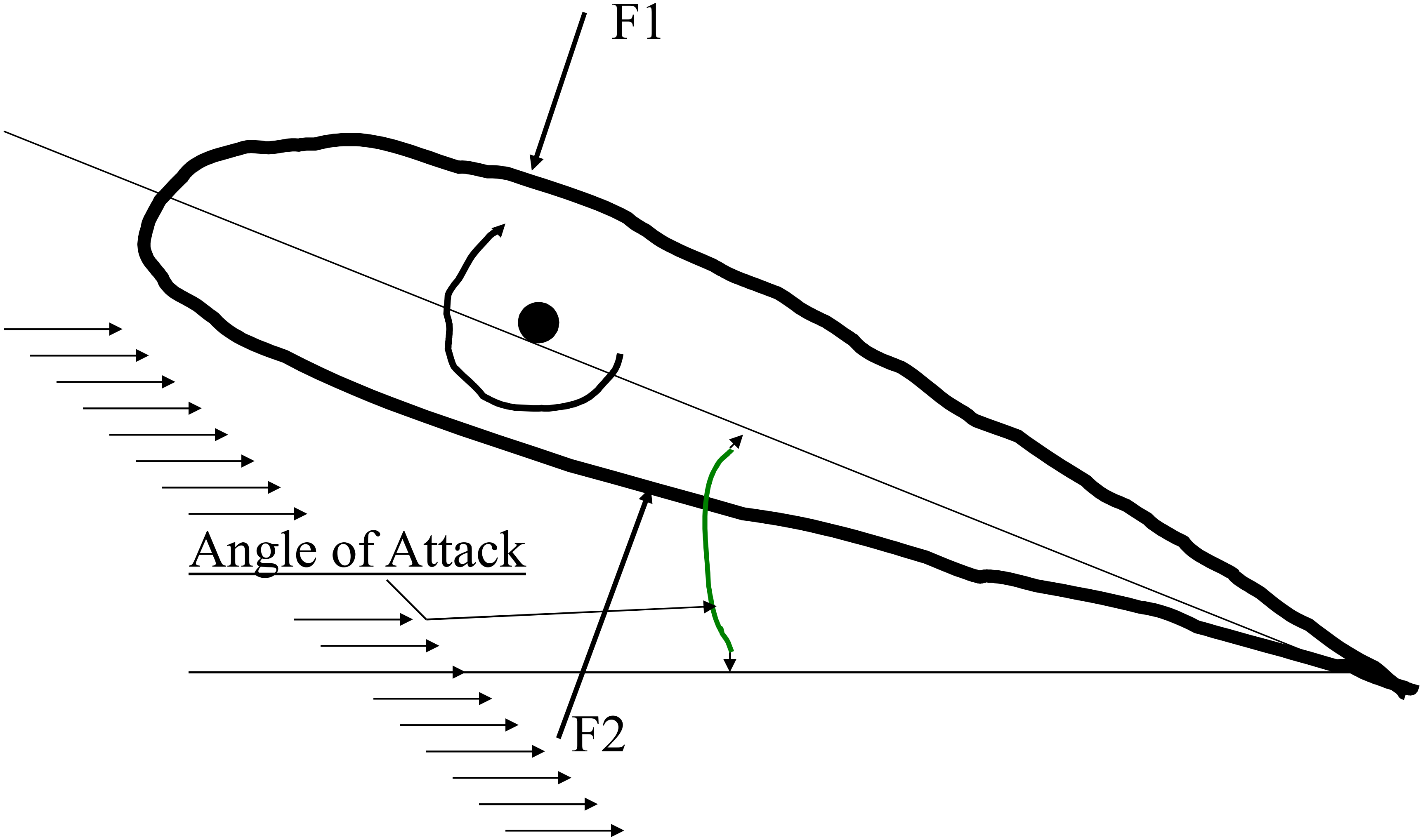
National Advisory Committee for Aeronautics (NACA)

Change in Attitude



National Advisory Committee for Aeronautics (NACA)

Turning Moment of an Airfoil



National Advisory Committee for Aeronautics (NACA)

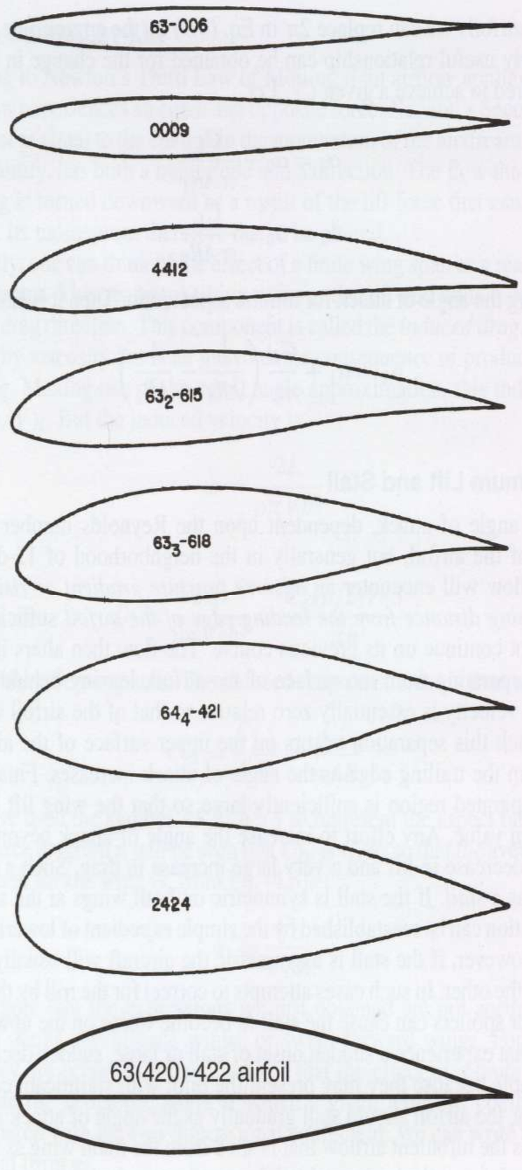
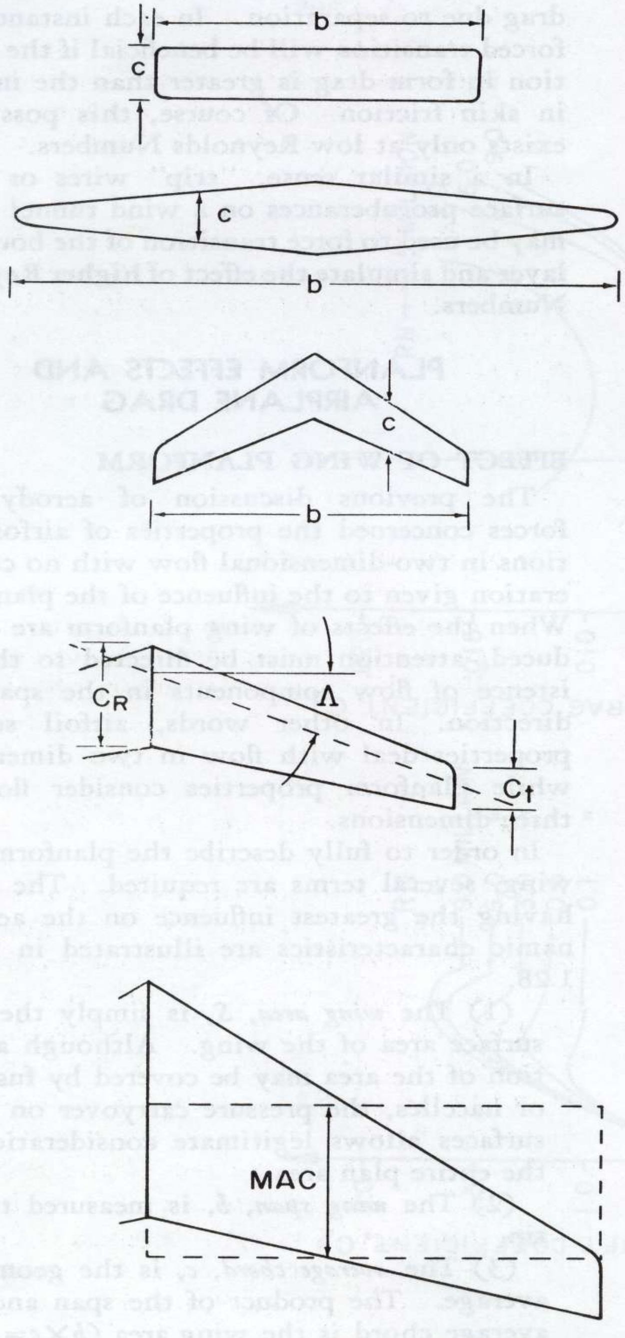


Fig. 4.1 Tested airfoils.



S = WING AREA, SQ. FT.

b = SPAN, FT

c = AVERAGE CHORD, FT

AR = ASPECT RATIO

$AR = b/c$

$AR = b^2/S$

C_R = ROOT CHORD, FT

C_t = TIP CHORD, FT

λ = TAPER RATIO

$\lambda = C_t/C_R$

Λ = SWEEP ANGLE, DEGREES

MAC = MEAN AERODYNAMIC CHO

Figure 1.28. Description of Wing Planform

(DATA FROM NACA REPORT NO. 824)

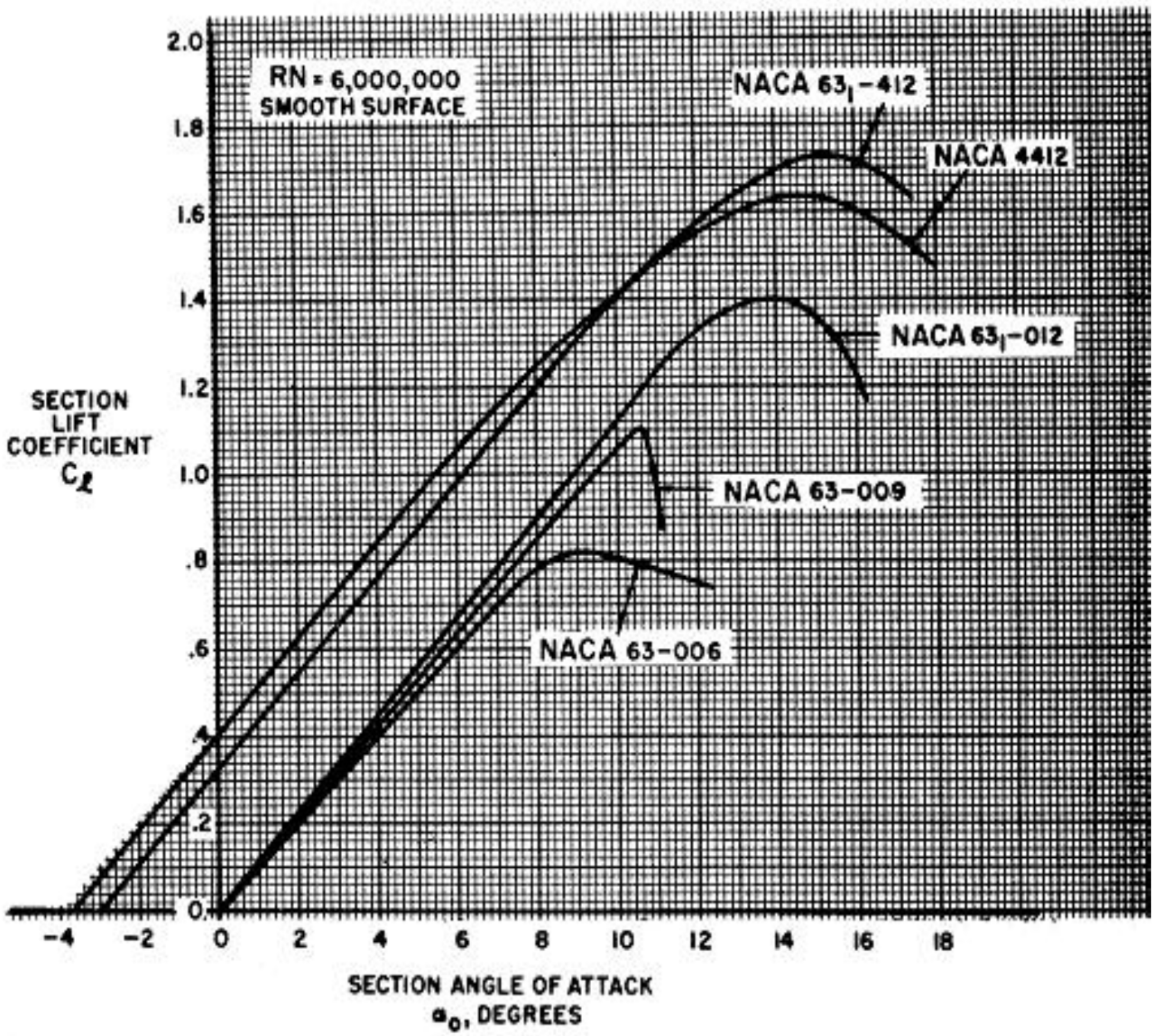


Figure 1.12. Lift Characteristics of Typical Airfoil Sections

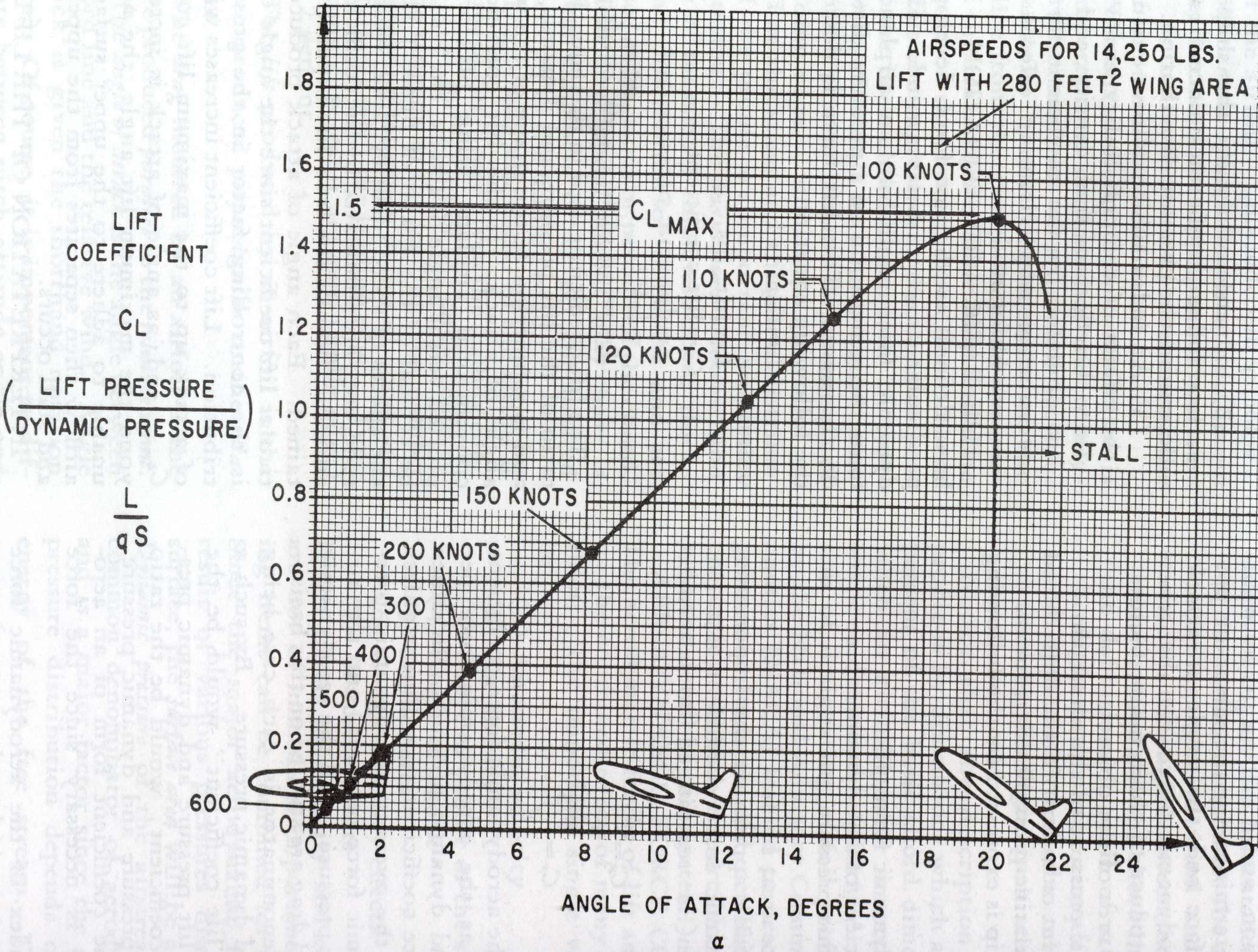


Figure 1.11. Typical Lift Characteristics

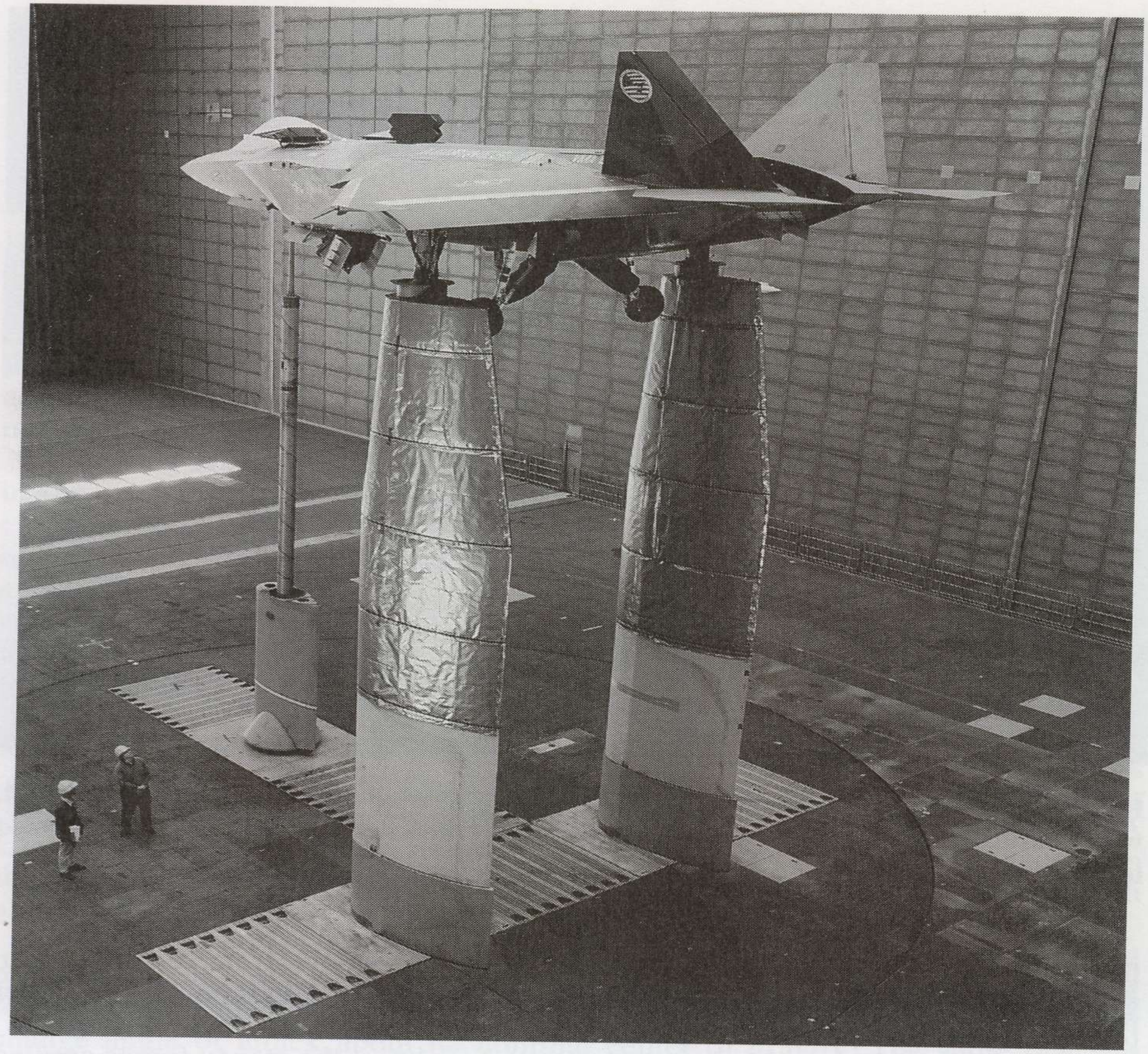


Fig. 6.2 Large-scale model in the 40 × 80 ft full-scale wind tunnel at NASA Ames Research Center. The use of the three-point support allows the model's angle of attack to be varied. The entire rig appears to be mounted on a turntable, which can be rotated to vary the aircraft's angle of sideslip.

FACTORS THAT IMPACT LIFT, DRAG, TURNING MOMENT

- V   Air Velocity
- ρ *Air Density*
- μ *Air Viscosity*
- *S*   *Airfoil Surface Area*
- *a*   *Speed of Sound in fluid*
- *α*   *Angle of Attack*

Types of Drag

Skin-friction Drag- Drag due to frictional shear stress integrated over the surface i.e. all surfaces in the flow stream. (wind tunnel)

Parasite Drag – Drag due to items that are in the flow stream yet do not provide any lift i.e. pitot tubes, antennas, position light, Ordnance etc. (complete airplane)

Induced Drag – Drag due to the downwash associated with the vortices created at the tips of the finite wing. (page 79) (wind tunnel and complete airplane)

Interference Drag – Drag due to mutual interaction of the flow fields Around each component of the airplane. (complete airplane)

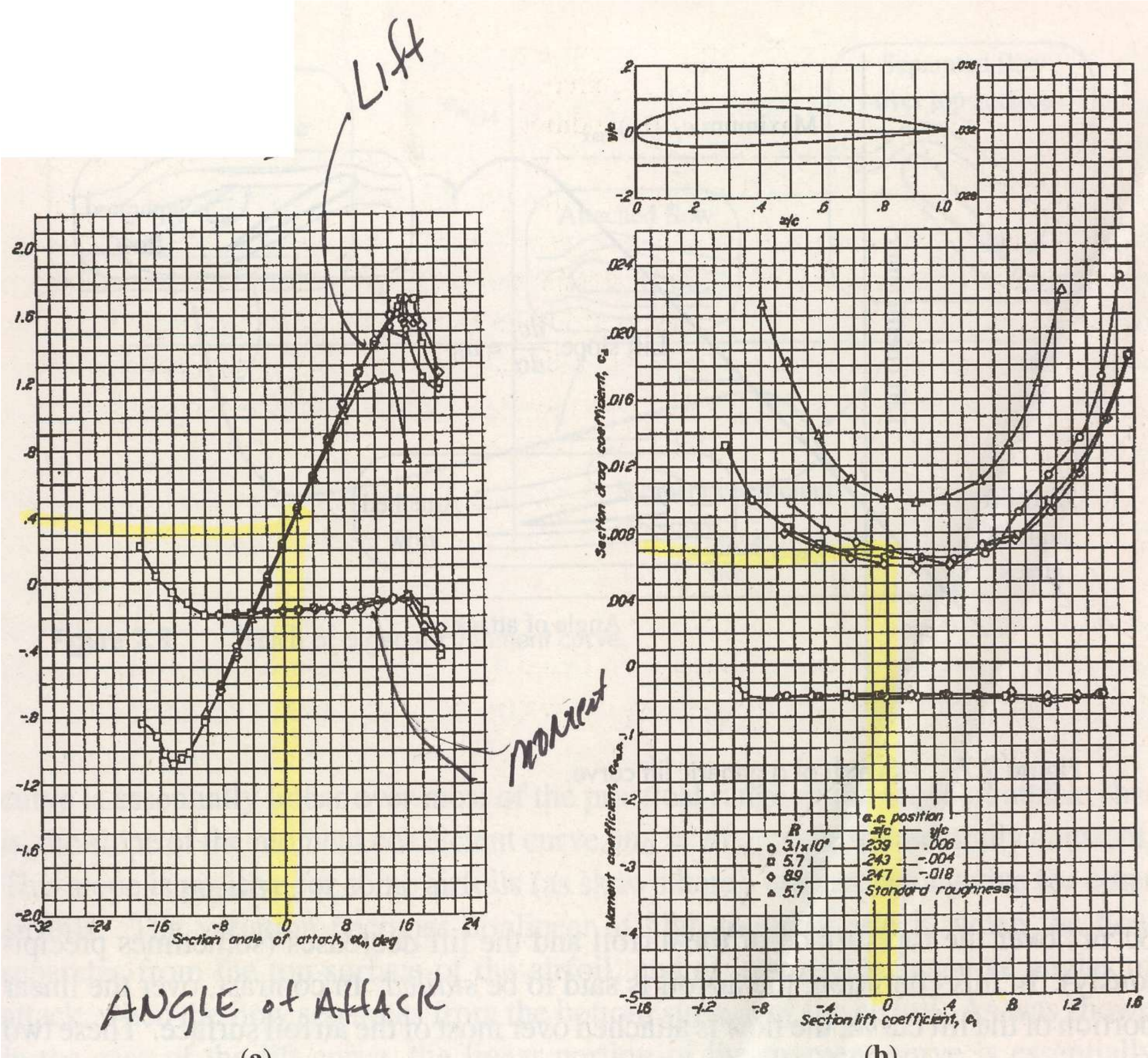
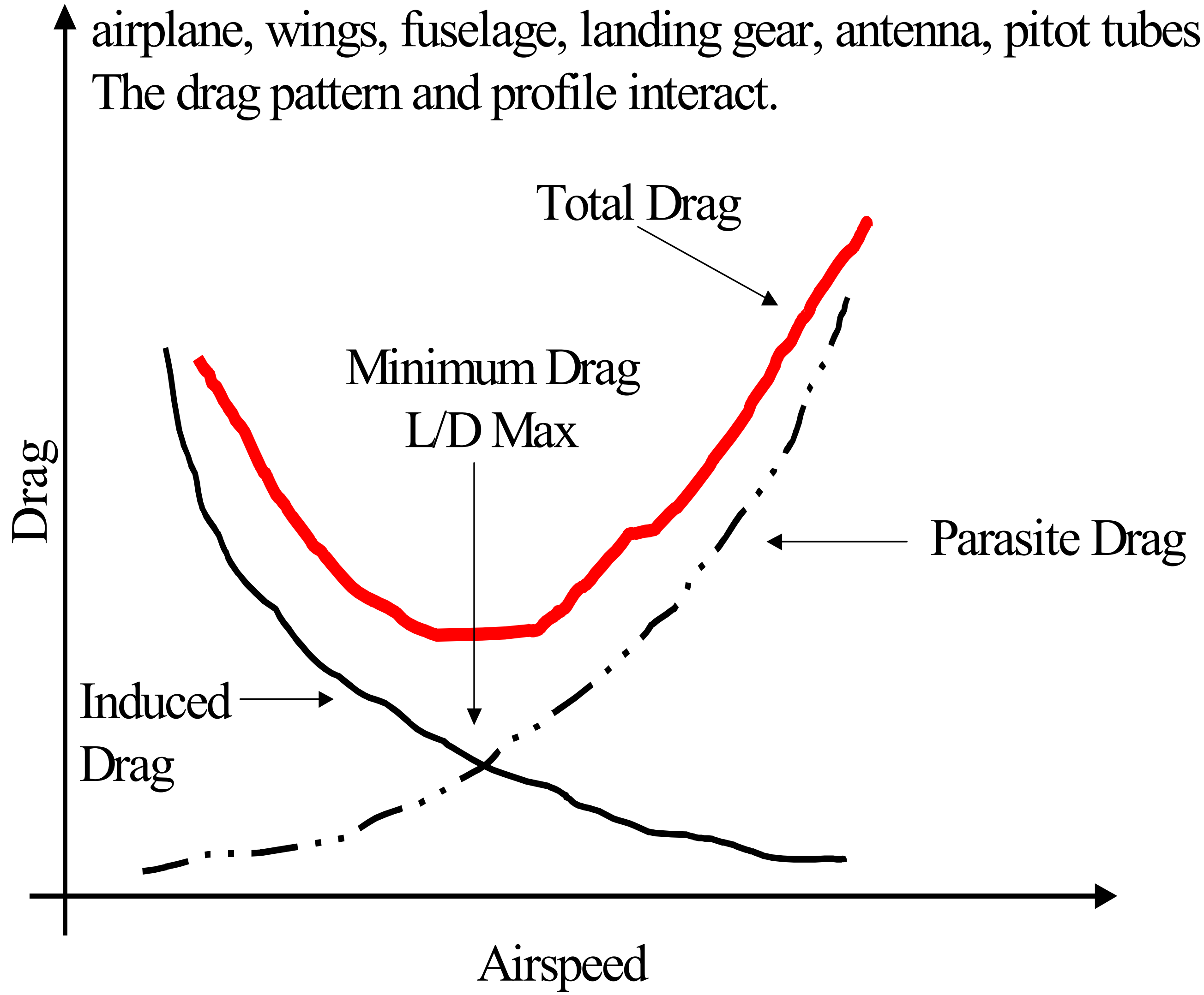
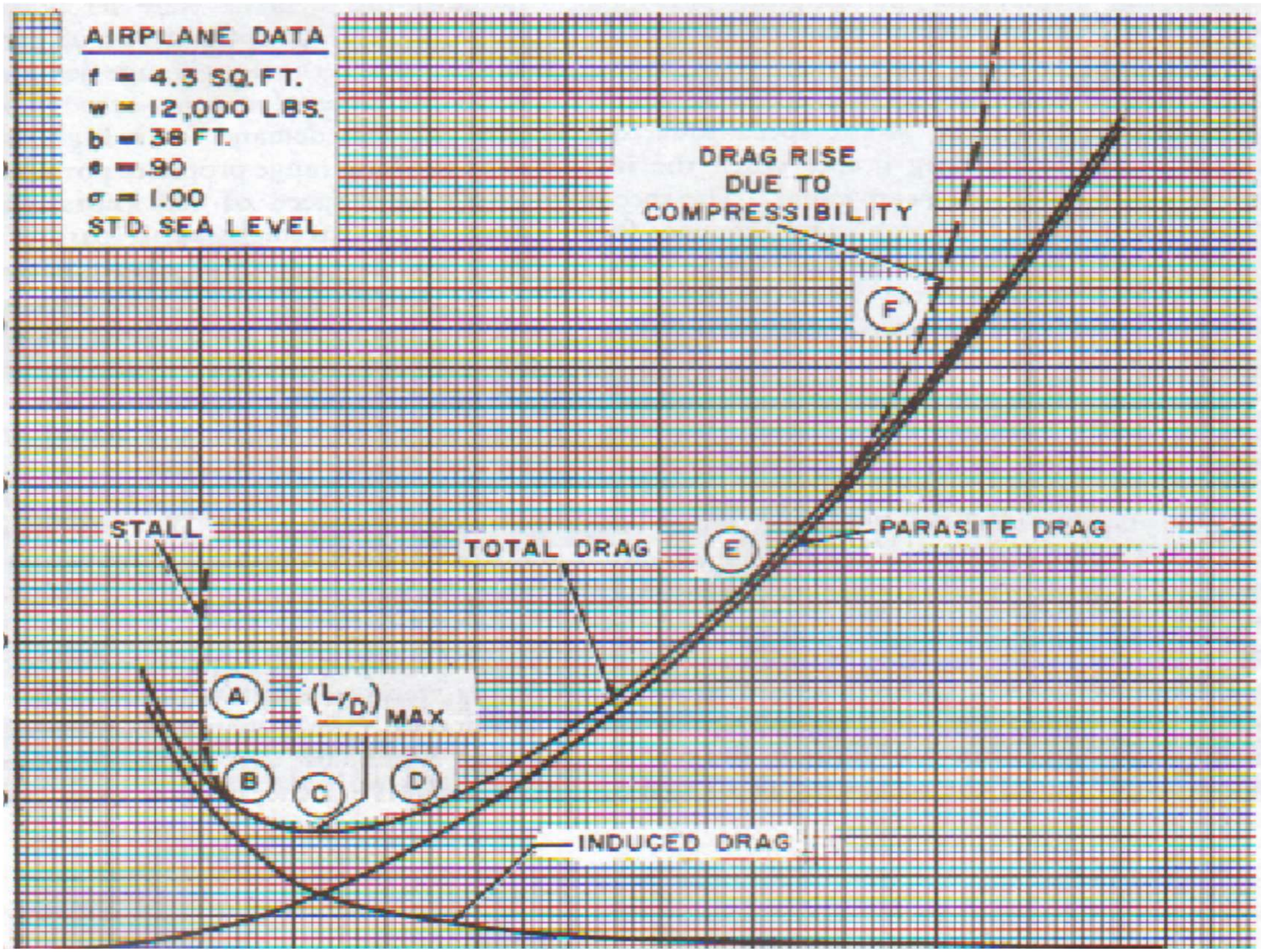


Figure 2.6 Data for the NACA 2412 airfoil. (**a**) Lift coefficient and moment coefficient about the quarter-chord versus angle of attack. (**b**) Drag coefficient and moment coefficient about the aerodynamic center as a function of the lift coefficient. (From Abbott and von Doenhoff, Ref. 19.)

Drag is a systems issue it involves everything external on the airplane, wings, fuselage, landing gear, antenna, pitot tubes etc. The drag pattern and profile interact.




AIRPLANE DATA
f = 4.3 SQ.FT.
w = 12,000 LBS.
b = 38 FT.
e = .90
σ = 1.00
STD. SEA LEVEL
DRAG RISE DUE TO COMPRESSIBILITY
F
STALL
TOTAL DRAG
E
PARASITE DRAG
A
(L/D) MAX
B
C
D
INDUCED DRAG

Aerodynamic Coefficients

$$L = L(\rho_\infty, V_\infty, S, \alpha, \mu_\infty, a_\infty) \quad [2.2a]$$

$$D = D(\rho_\infty, V_\infty, S, \alpha, \mu_\infty, a_\infty) \quad [2.2b]$$

$$q_\infty = \frac{1}{2}\rho V_\infty^2$$

Dynamic pressure

$$M = M(\rho_\infty, V_\infty, S, \alpha, \mu_\infty, a_\infty) \quad [2.2c]$$

$$C_L = \frac{L}{q_\infty S} \quad [2.3]$$

Reynolds number (based on chord length): $\mathrm{Re} = \dfrac{\rho_\infty V_\infty c}{\mu_\infty}$

$$C_D = \frac{D}{q_\infty S} \quad [2.4]$$

Mach number: $M_\infty = \dfrac{V_\infty}{a_\infty}$

$$C_M = \frac{M}{q_\infty S c} \quad [2.5]$$

$$C_L = f_1(\alpha, \mathrm{Re}, M_\infty)$$

$$C_D = f_2(\alpha, \mathrm{Re}, M_\infty)$$

$$C_M = f_3(\alpha, \mathrm{Re}, M_\infty)$$

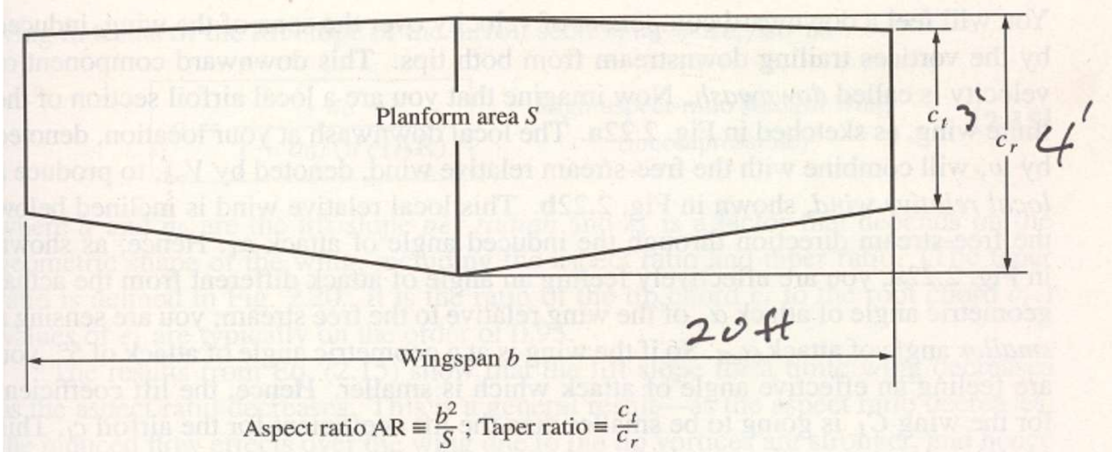


Figure 2.20 Finite-wing geometry.

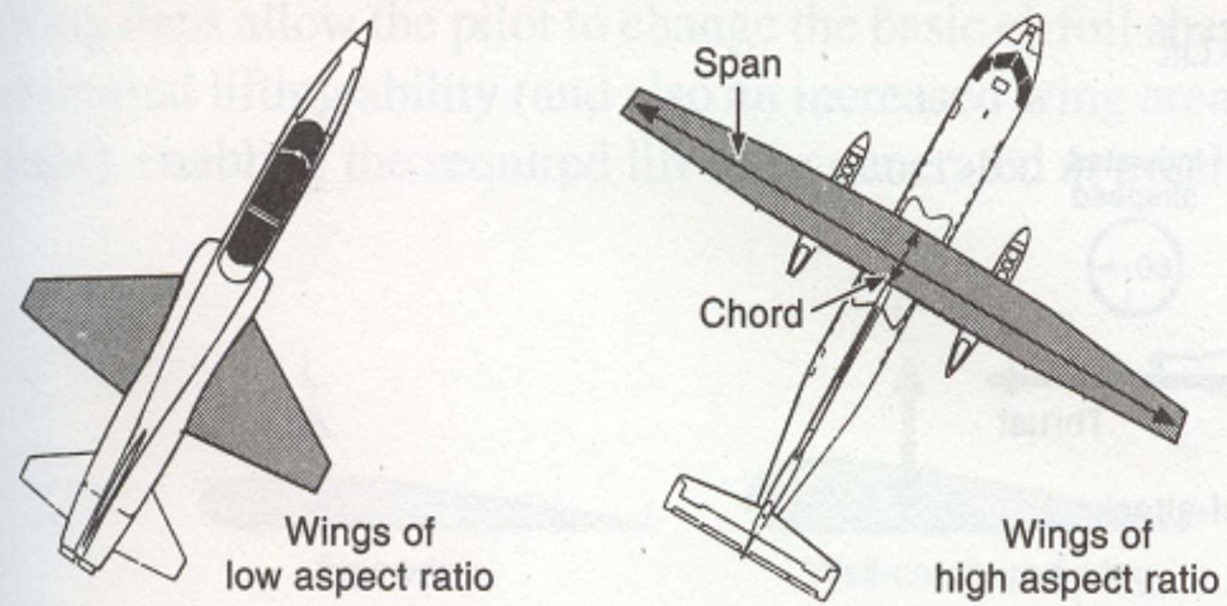
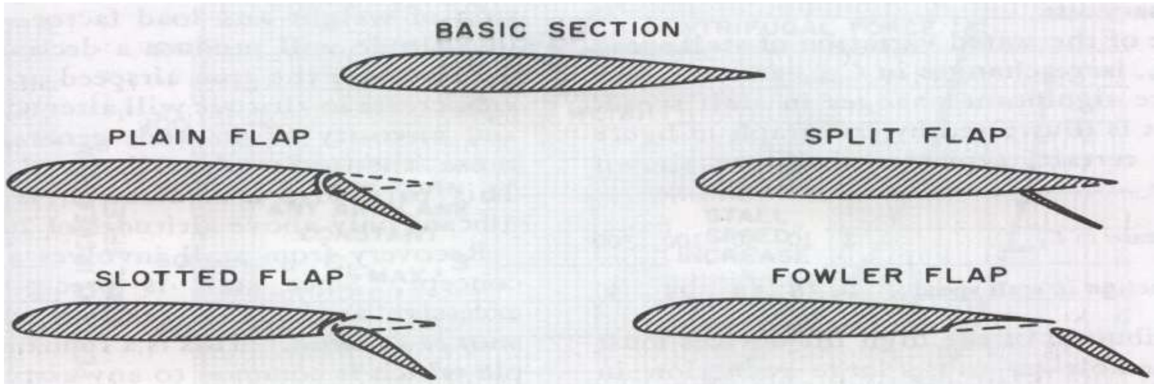
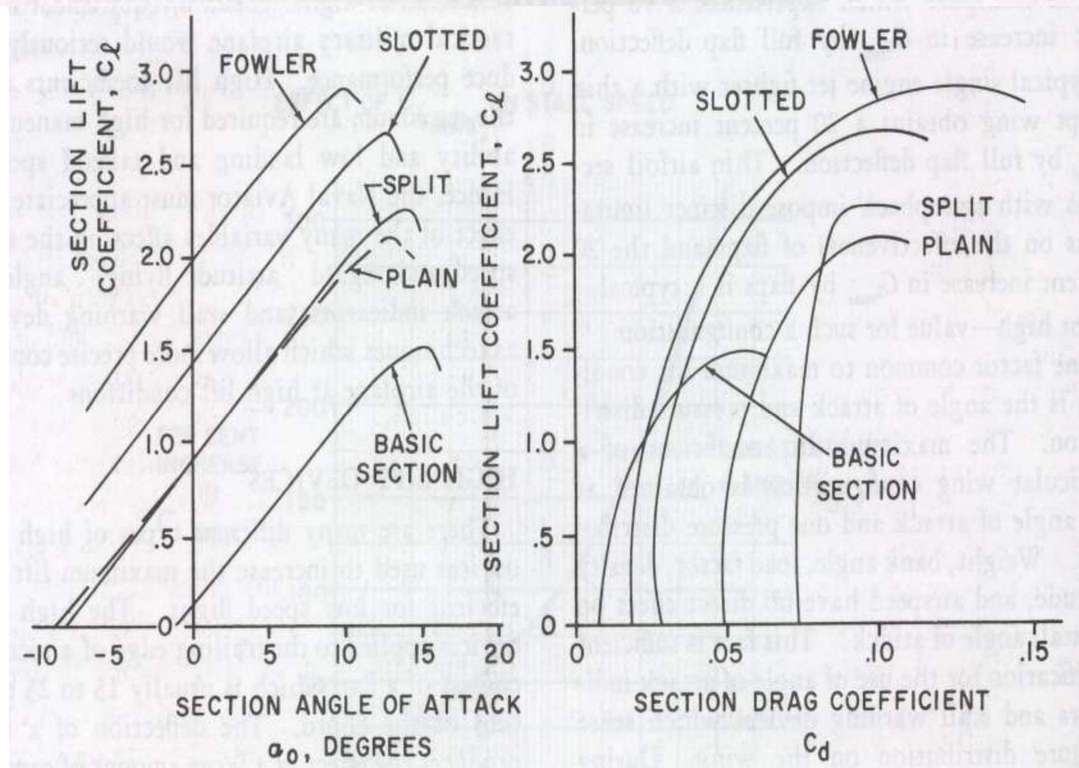


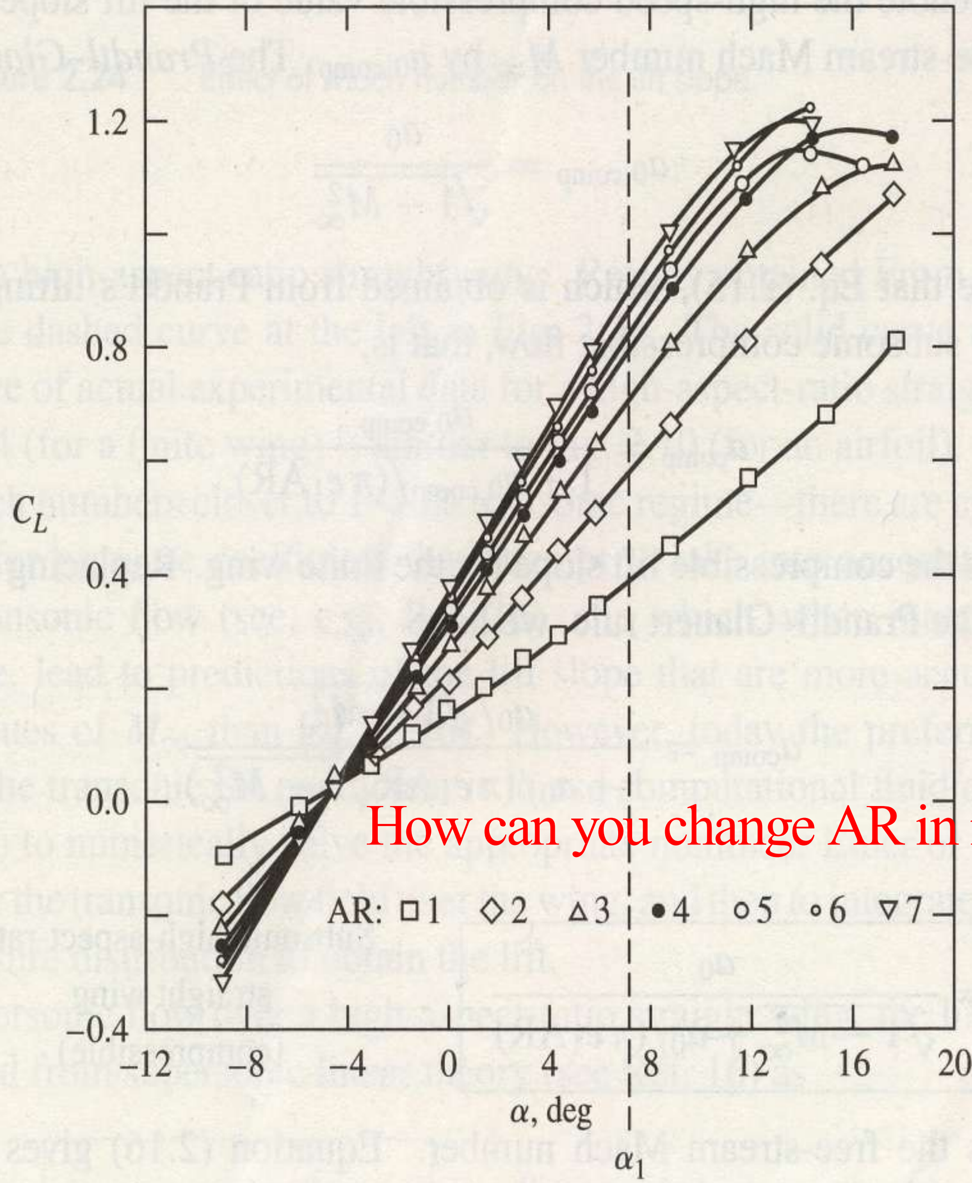
Figure 1-38. Aspect ratio



Flaps also improve Boundary Layer Performance

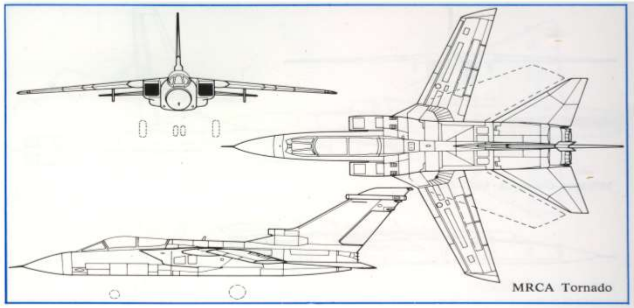
EFFECT ON SECTION LIFT AND DRAG CHARACTERISTICS OF A 25% CHORD FLAP DEFLECTED 30°



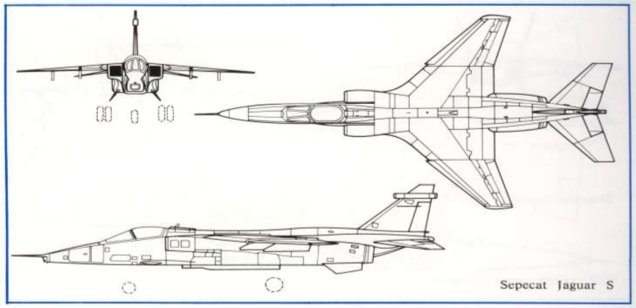


How can you change AR in mid flight?

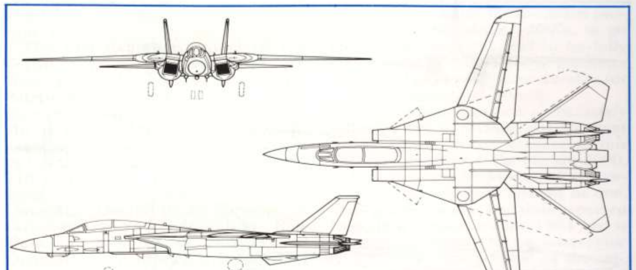
Figure 2.23 Effect of aspect ratio on the lift curve.



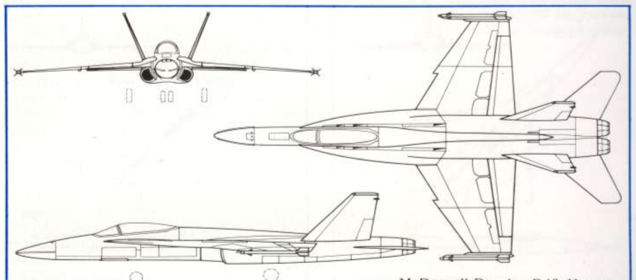
MRCA Tornado



Sepecat Jaguar S



Grumman F-14A Tomcat



McDonnell-Douglas F-18 Hornet

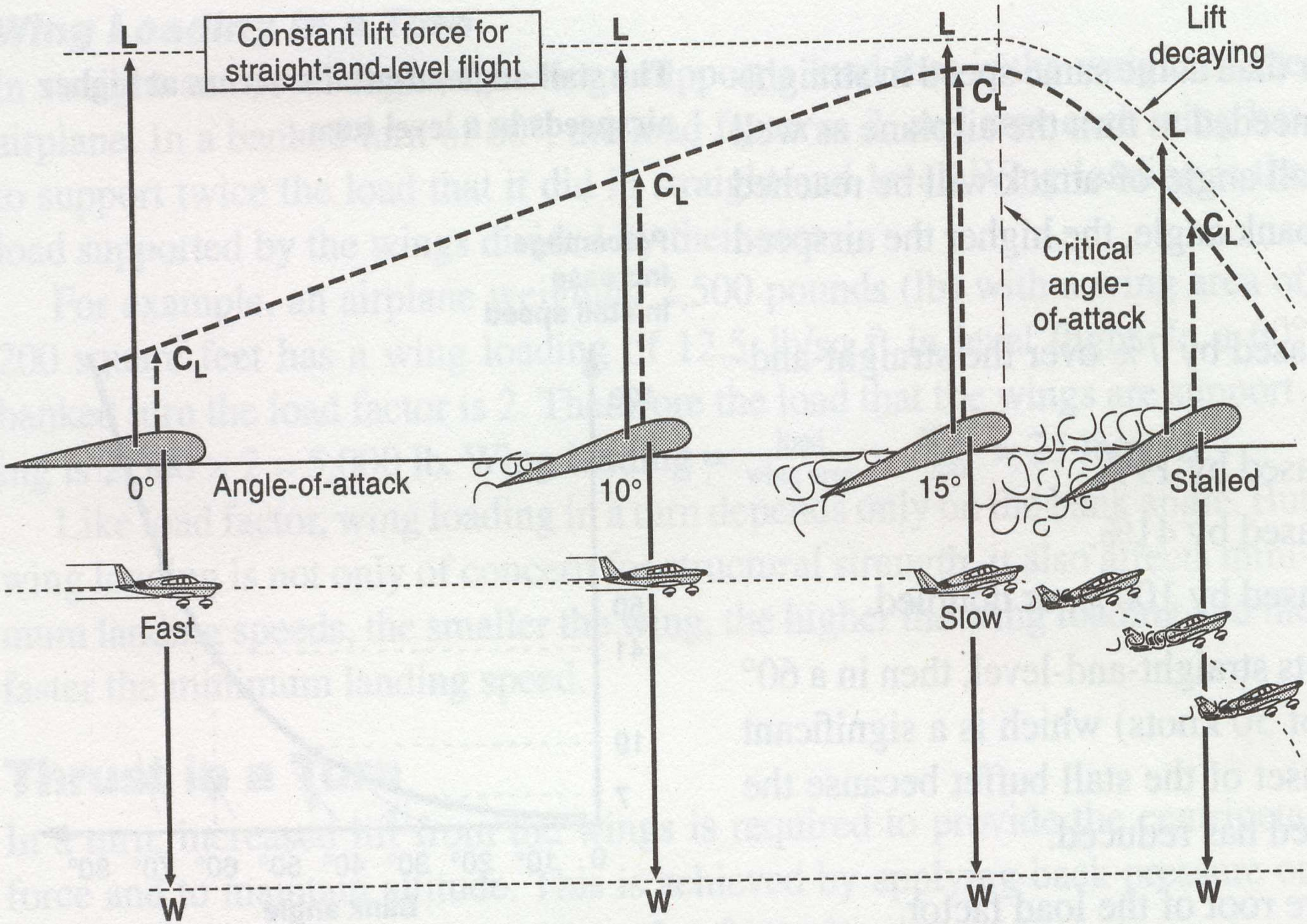


Figure 3-28. An airfoil reaches its maximum lifting ability at the critical angle-of-attack

In class quiz:
How would you re-design this aircraft to reduce or avoid
The impact of stall turbulence on the horizontal stabilizer or
elevator?

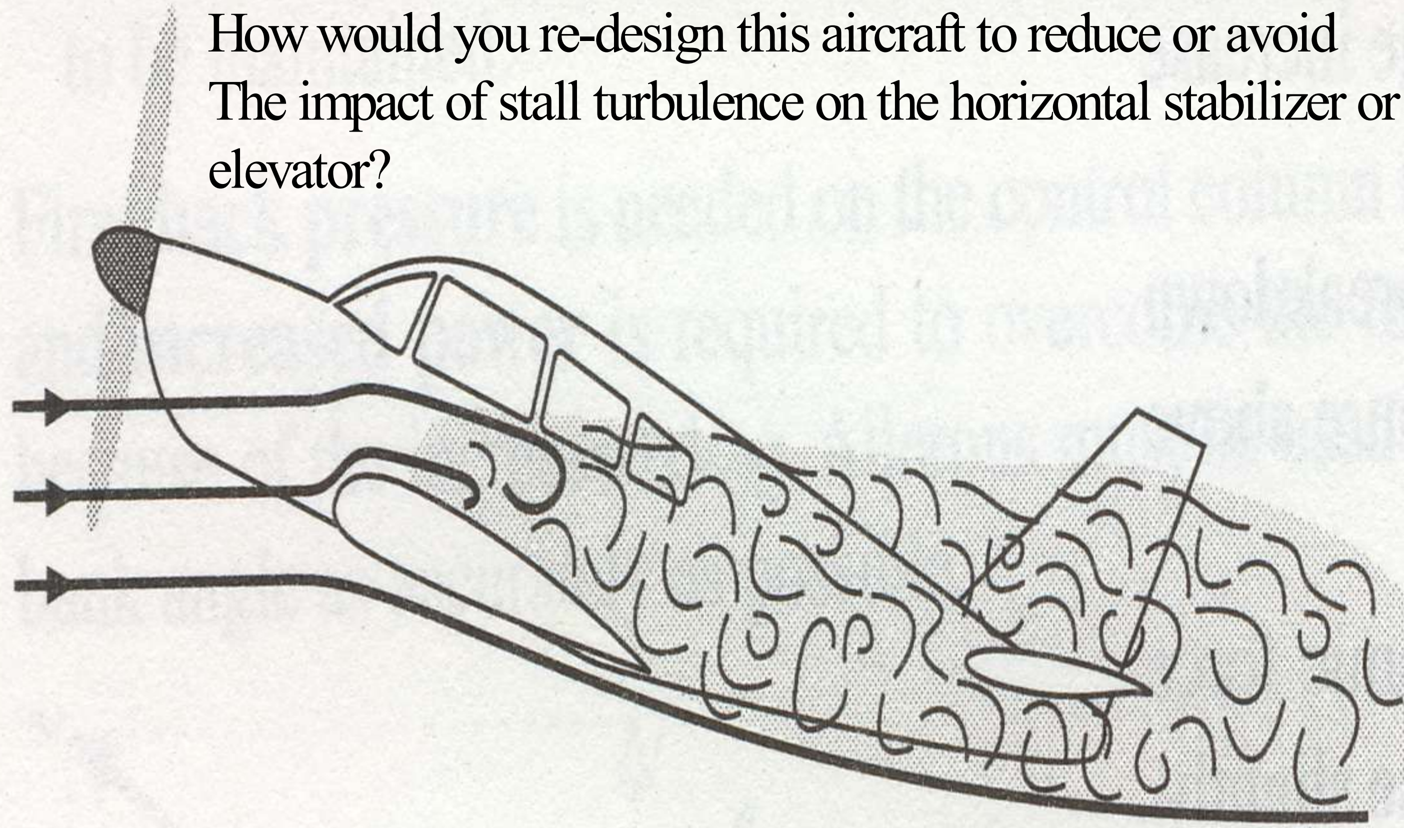


Figure 3-30. Turbulent flow over the horizontal stabilizer


N37000

Boundary Layer