The University of Texas at Austin
Aerospace Engineering
and Engineering Mechanics
Cockrell School of Engineering

27 AUGUST 2024

ASE 367K: FLIGHT DYNAMICS

TTH 09:30-11:00
CMA 2.306

JOHN-PAUL CLARKE
Ernest Cockrell, Jr. Memorial Chair in Engineering, The University of Texas at Austin

Instructor and Teaching Assistant

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TUTORIALS:

W 15:00-17:00

ASE 3.204

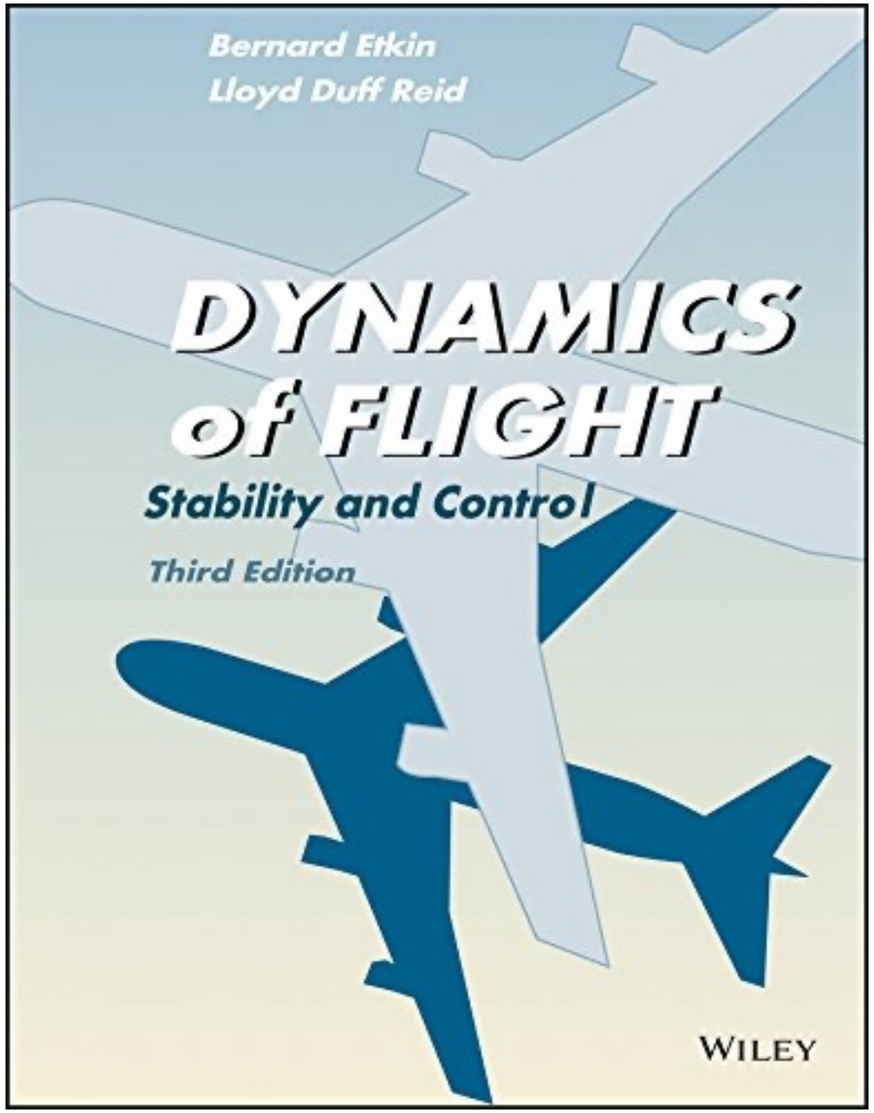
Learning Objectives

- Understand aircraft configuration aerodynamics, performance, stability, and control
- Estimate an aircraft's aerodynamic characteristics from geometric and inertial properties
- Analyze linear and nonlinear dynamic systems
- Recognize airplane modes of motion and their significance
- Compute aircraft motions
- Appreciate historical development of aviation

Course Topics

- Aerodynamics
- Statics & Dynamics
- Cruise Flight Performance
- Accelerated Flight Performance
- Differential Eçquations & Linear Algebra
- Non-Linear 6-Degree of Freedom Equations of Motion
- Airplane Control
- Linearized Equations of Motion
- Longitudinal & Lateral Dynamics
- Stability & Analysis of Linear Systems

Textbook



Title:	Dynamics of Flight Stability and Control 3rd Edition
Authors:	Bernard Etkin and Lloyd Duff Reid
Publisher:	Wiley
Year:	2010

Deliverables and Grade Contributions

HW 1	FRI	06-SEP	23:59	7.5%
HW 2	FRI	13-SEP	23:59	7.5%
HW 3	FRI	20-SEP	23:59	7.5%
HW 4	FRI	27-SEP	23:59	7.5%
Exam 1	TUE	01-OCT	09:30	10.0%
HW 5	FRI	18-OCT	23:59	7.5%
HW 6	FRI	25-OCT	23:59	7.5%
HW 7	FRI	01-NOV	23:59	7.5%
HW 8	FRI	08-NOV	23:59	7.5%
Exam 2	TUE	12-NOV	09:30	10.0%
Term Project	FRI	06-DEC	23:59	20.0%

Homework and Exams

Homework:

- Homework due electronically at 23:59 on due dates.
- Working together on assignments is permitted; however, every student must turn in their own original work.
- Late assignments will ONLY be accepted if an extension is requested a priori due to the observance of a religious holy day.

Exams:

- The exams during the term (01-OCT and 12-NOV) will take approximately one hour and 15 minutes and occur during the lecture period on the respective days.
- There will be NO final exam.

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AIRCRAFT BASICS

From Various Sources

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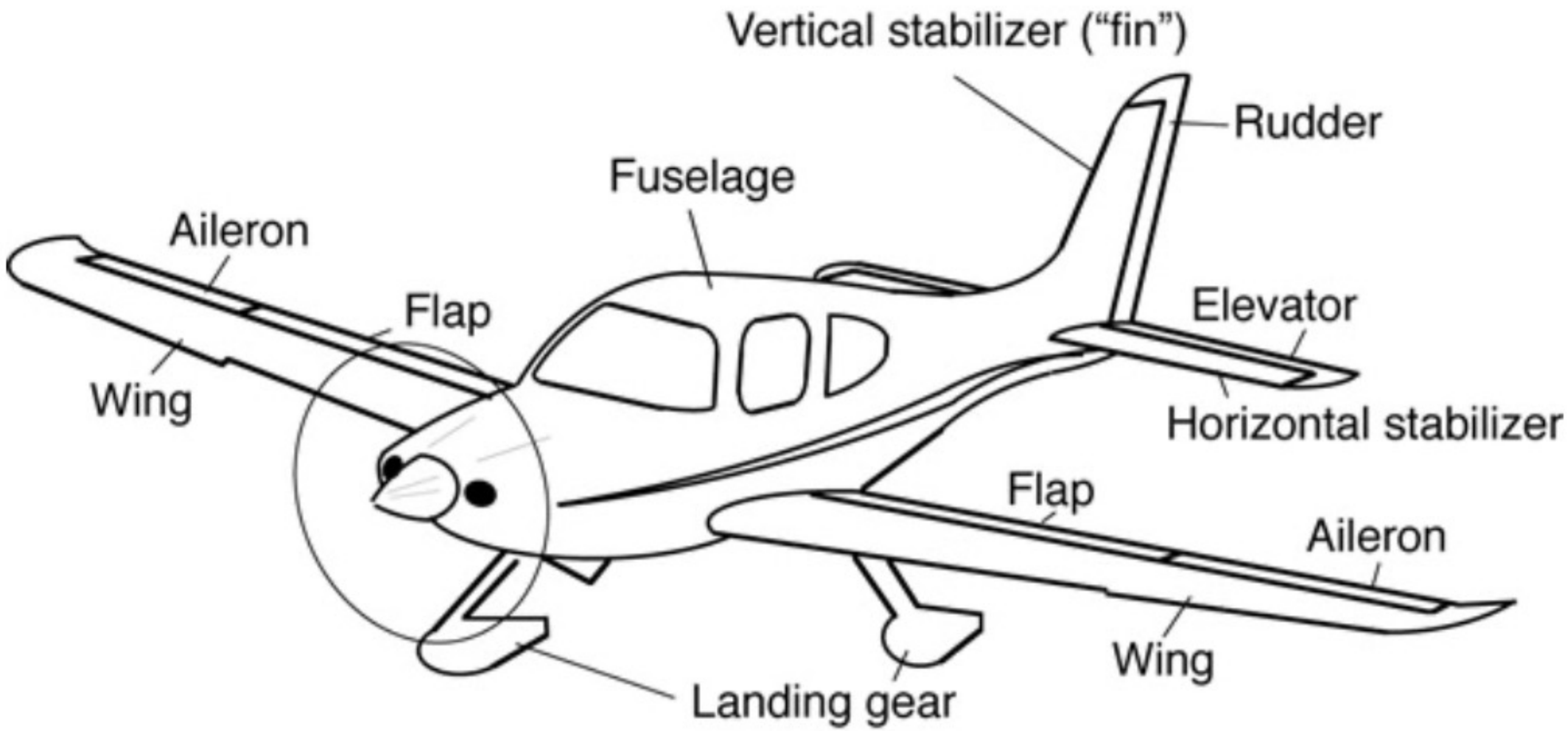
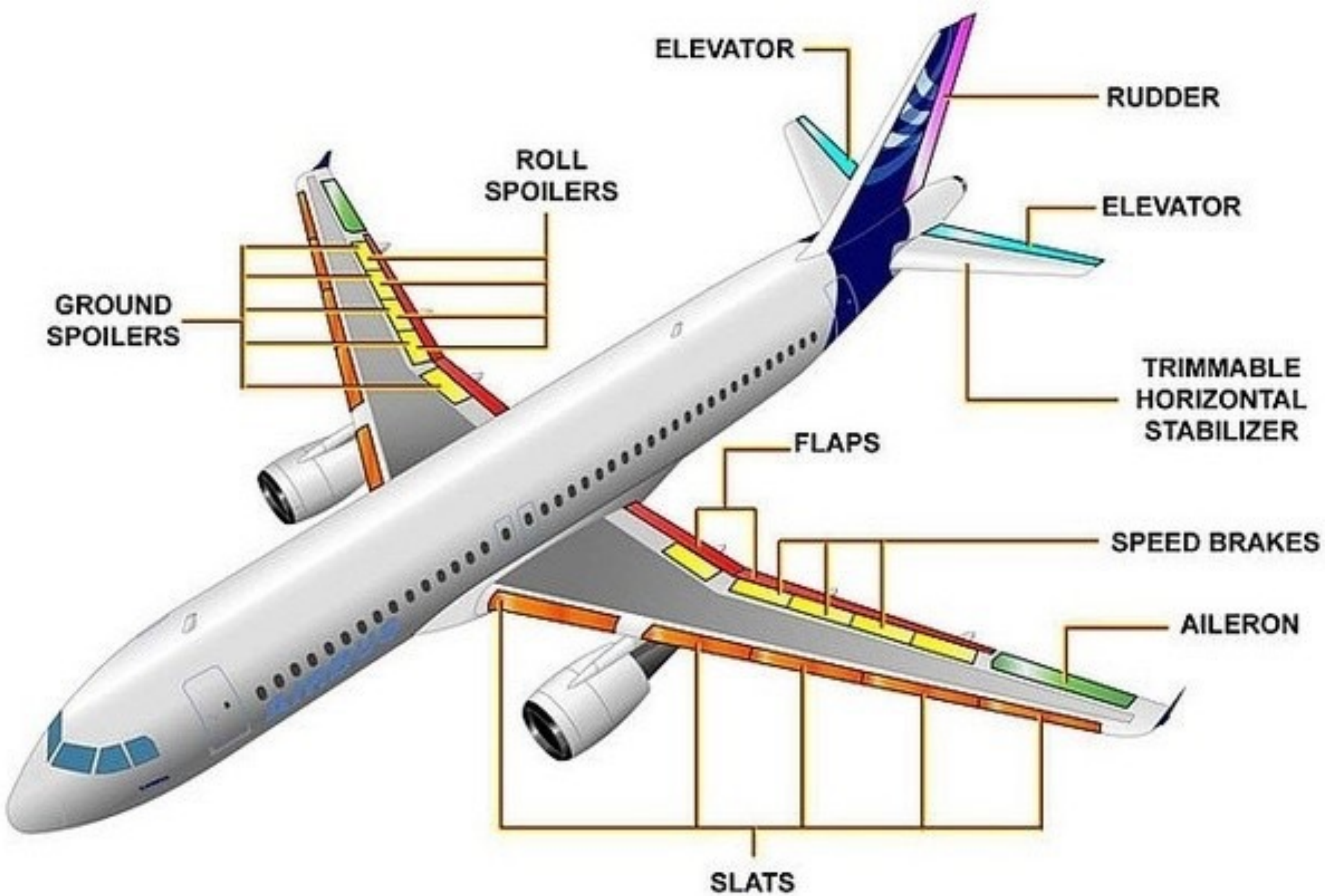
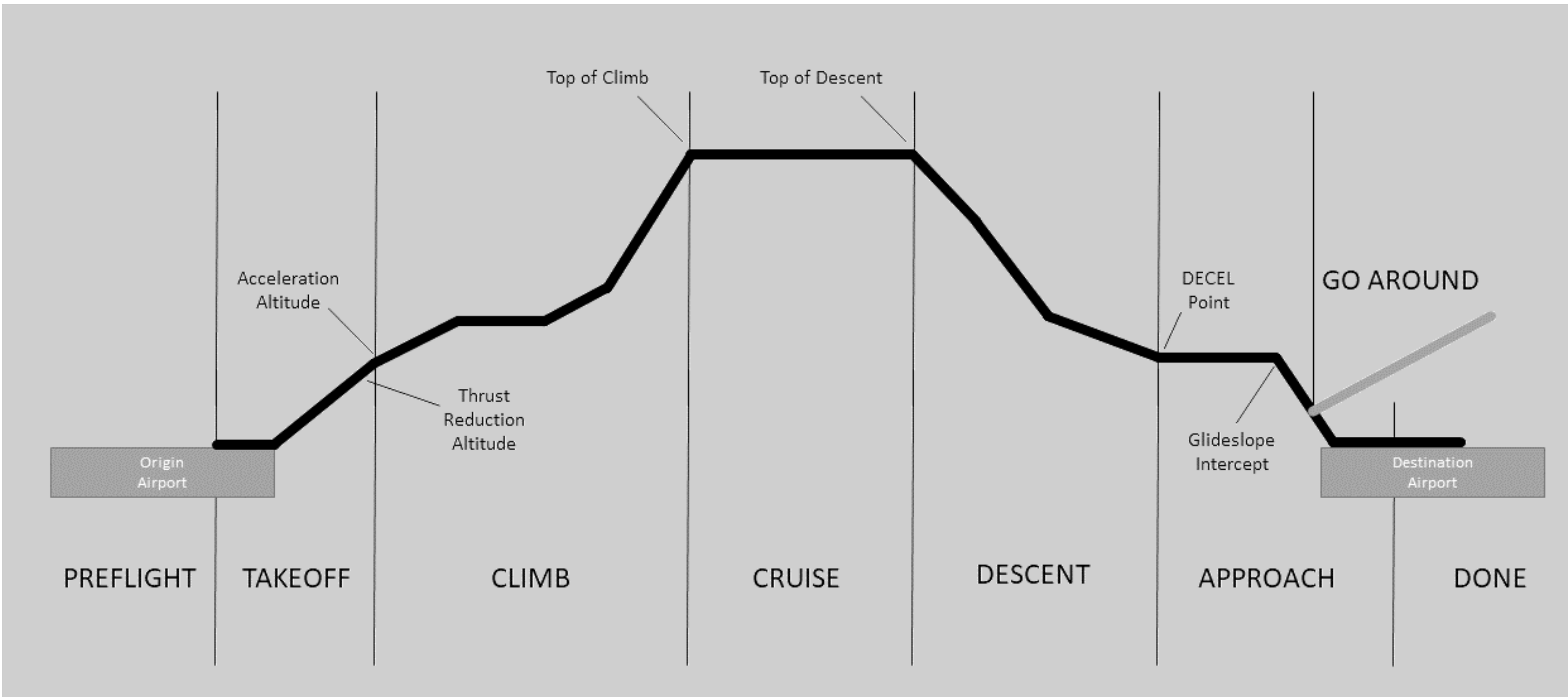
Airplane Components



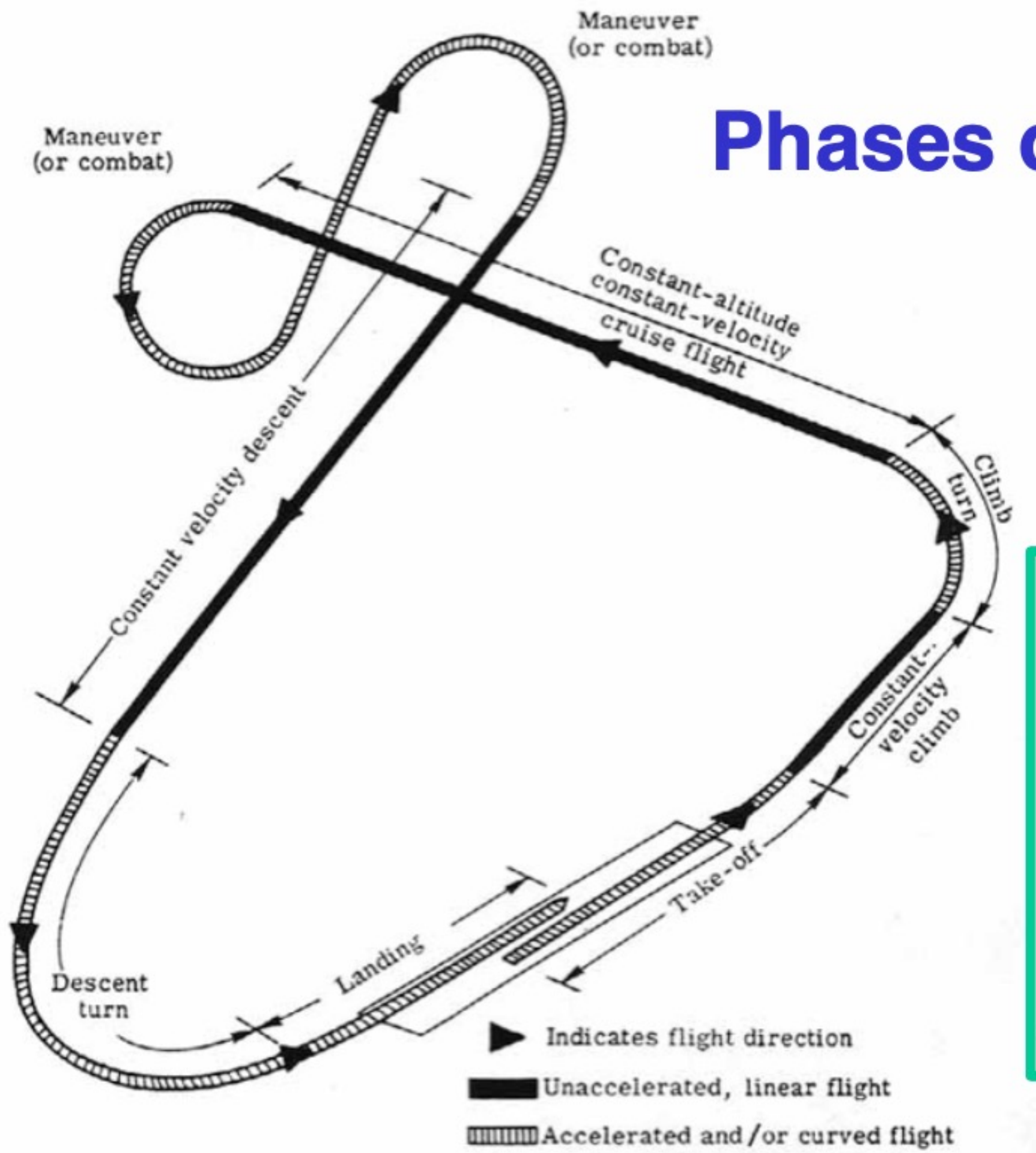
Aircraft Control Surfaces

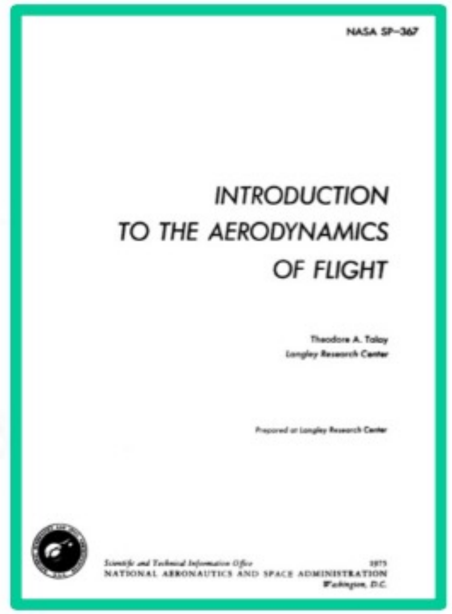


Phases of Flight (Commercial)



Phases of Flight (Military)





NASA SP-367

INTRODUCTION
TO THE AERODYNAMICS
OF FLIGHT

Theodore A. Talay
Langley Research Center

Prepared at Langley Research Center

Scientific and Technical Information Office 1975
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

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BASICS OF AERODYNAMICS

From Clarke + Stengel

JOHN-PAUL CLARKE
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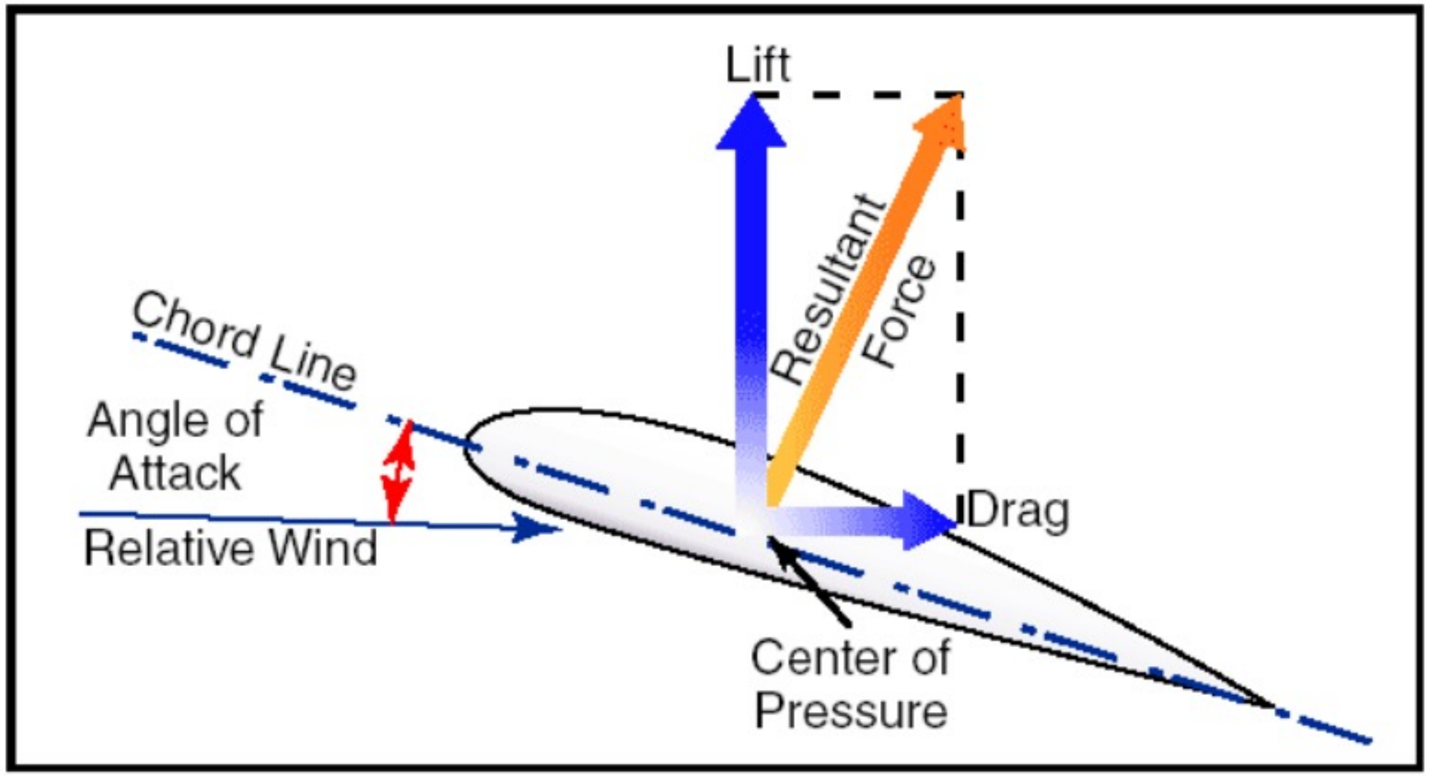
Wing Lift and Drag

- **Lift:** **<u>Perpendicular</u> to free-stream airflow**
- **Drag:** **<u>Parallel</u> to the free-stream airflow**



What is drag?

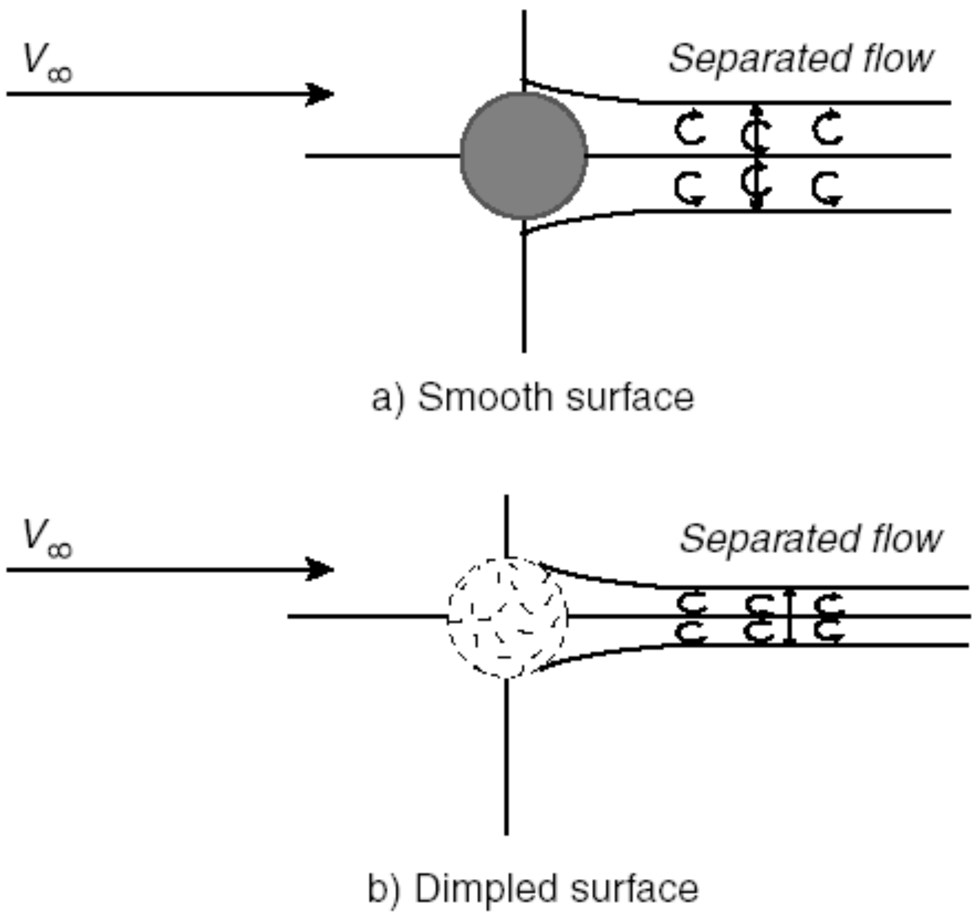
- Aerodynamic force that opposes an aircraft's motion through the air
  - Caused by interaction of a solid body with a fluid
  - Aerodynamic "friction" or resistance to motion
- Depends on:
  - Wing shape
  - Angle of attack
  - Air viscosity
  - Compressibility
- Two components
  - Profile drag
  - Induced drag

Profile drag

- Also called “form drag” because the separation of the boundary layer around an object is a function of its form
  - Related to viscous effects of flow over lifting surface
- Question:
  - What happens to yourbody when you are running and just happen to brush against a stationary object?

Profile drag (cont.)

- Dimples = greater skin friction drag = greater distance to separation of flow = lower profile drag
- Vortices “take away” energy from the airflow
- Question: Why is this important for drag?

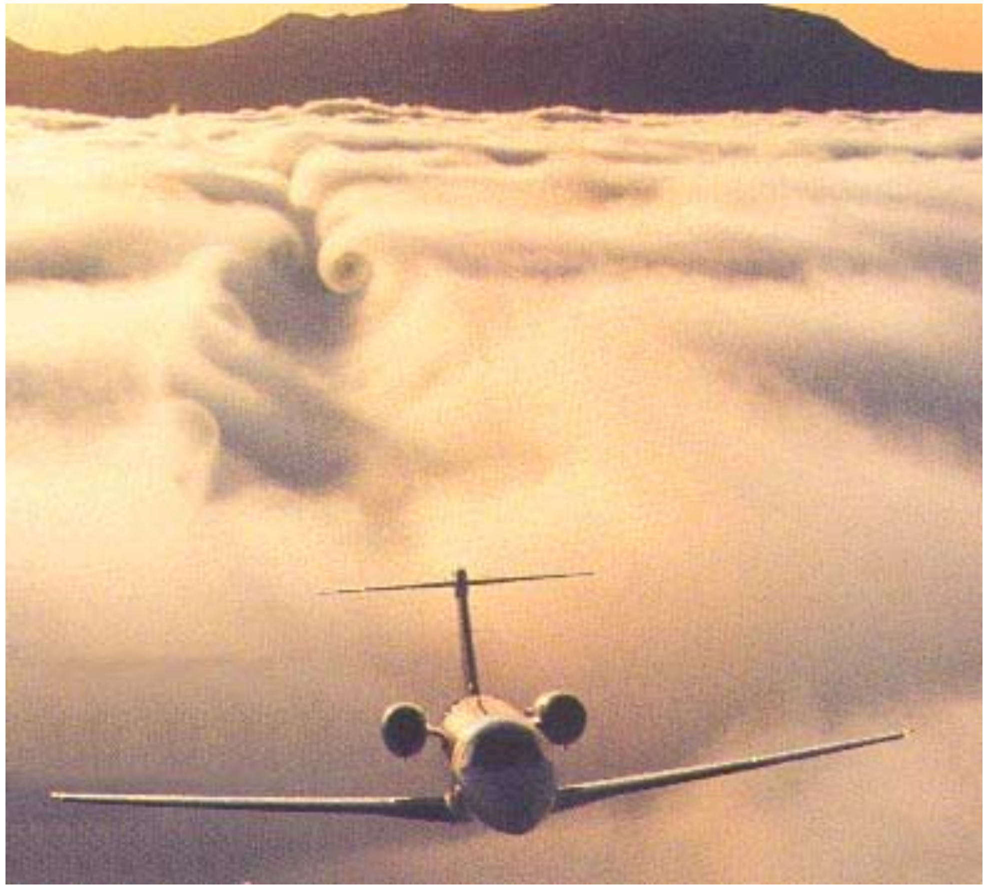


Source: Newman, Dava J., *Interactive Aerospace Engineering and Design*

Induced drag

- Arises from 3-dimensional effects of a wing caused by downwash velocity near wing tip
- Vortices create a downward velocity component at the wing
- Non-dimensional coefficient of induced drag:
  - $C_{D_I} = C_L^{\,2} / \pi e \mathrm{AR}$

Induced drag



Source: Newman, Dava J., *Interactive Aerospace Engineering and Design*

Total drag

- Total drag = profile drag + induced drag

- Coefficient of total drag
  - $C_{D_{TOTAL}} = C_{D_0} + C_L^{\,2} / \pi e \mathrm{AR}$

What is lift?

- Lift is the force that holds an aircraft in the air
  - $L = W$ in straight and level flight!!!
- Coefficient of lift: empirical non-dimensional parameter for easier evaluation of lift
  - $C_L = L / (0.5 \rho v^2 S)$
  - q = dynamic pressure = $0.5 \rho v^2$
  - Substituting in q, $L = qSC_L$

How does a wing generate lift?

- To really answer this question you need to understand:
  - Kinetic Theory
  - Bernoulli's Equation
- So… that's what we will cover next!

Kinetic Theory

- The change in momentum in the x-direction for each individual molecule and each collision is:

$$\Delta Mom_x = 2 \cdot m \cdot v_x$$

- In a time interval Δt the number of collisions for a given molecule on a box of length L in the x-direction is:

$$\Delta t \cdot v_x / (2 \cdot L)$$

- Thus, the momentum change for an individual molecule over a time interval Δt is:

$$\Delta Mom_x = \Delta t / L \cdot v_x^2$$

Kinetic Theory

- Generalizing to N molecules we get:

$$\Delta Mom_x = N \bullet \Delta t / L \bullet \overline{v^2}_x$$

- Then, when we consider the Y and Z directions, we get:

$$\Delta Mom_x = N \bullet \Delta t / L \bullet 1/3 \bullet \overline{v^2}$$

- Finally, we use the definition of force and the definition of pressure to get:

$$\mathrm{P} = (\Delta Mom_x / \Delta t) / \mathrm{A} = 2/3 \bullet \mathrm{N} / \mathrm{V} \bullet (0.5\ \mathrm{m}\ \overline{v^2})$$

Bernoulli's Equation

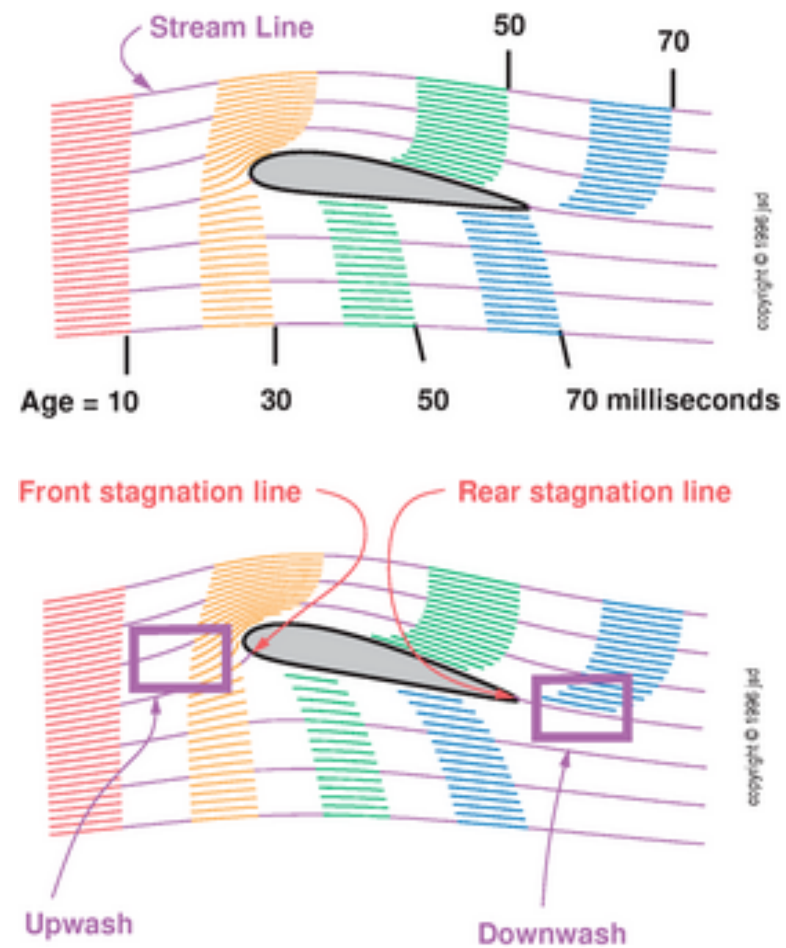
- Simple form of Bernoulli's equation is:

$$P + 0.5\,\rho\,v^2 = P_0$$

- This is a simple form of the law of conservation of energy for an incompressible fluid
  – Energy that is not used to move the fluid is used to generate pressure
  – Therefore, a moving fluid will have lower static pressure!!!

How does the airflow over a wing look?

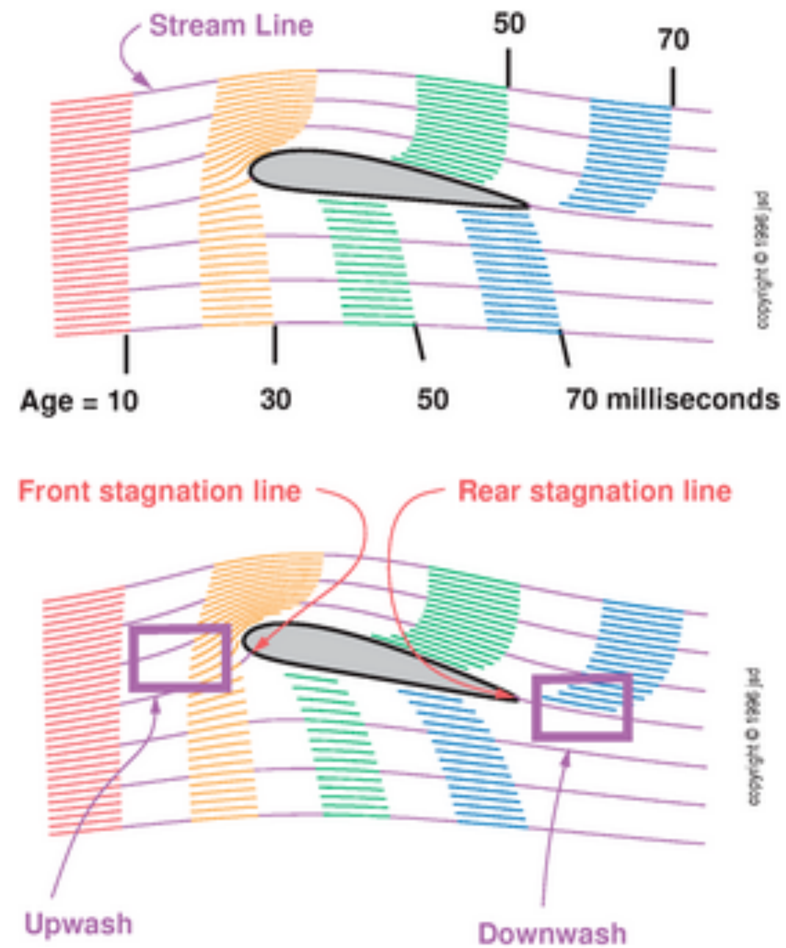
- Air above is speeded up relative to the corresponding air below.
  - The different colored areas above and below the wind represent time slices through the flow



Source: http://www.av8n.com/how/

How does the airflow over a wing look?

- Each air parcel gets a temporary change in speed and a permanent offset in position.
  - The change in speed results in a change in pressure because the energy that is nominally used to create pressure is being used to move the flow.



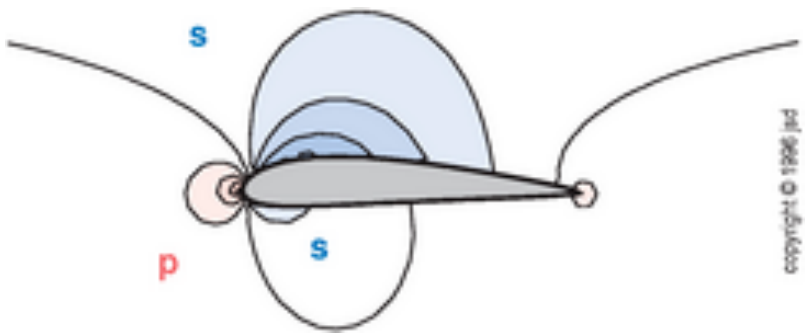
Source: http://www.av8n.com/how/

What is the net effect of this airflow?

- Bernoulli’s Principle states that faster air has lower pressure.

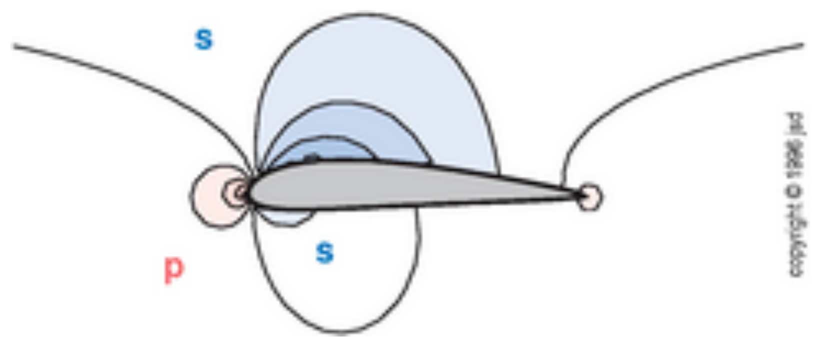
$$P + \frac{1}{2}\rho V^2 = k$$

- Strong suction (relative to ambient pressure) above the wing.
- Much less suction (or higher pressure) below the wing.
- Net force is lift!



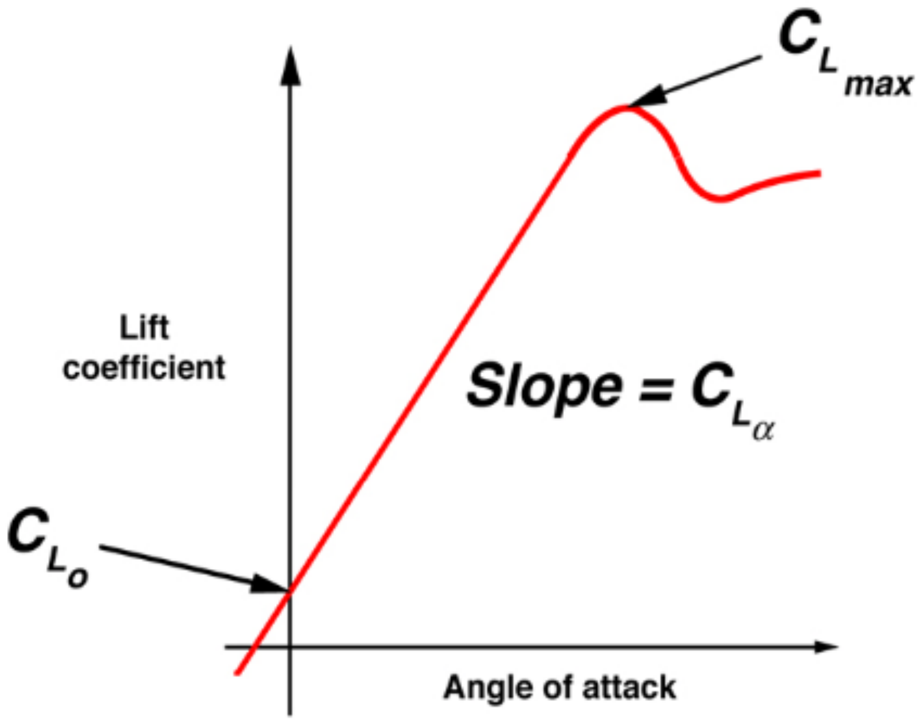
What are the key points to remember?

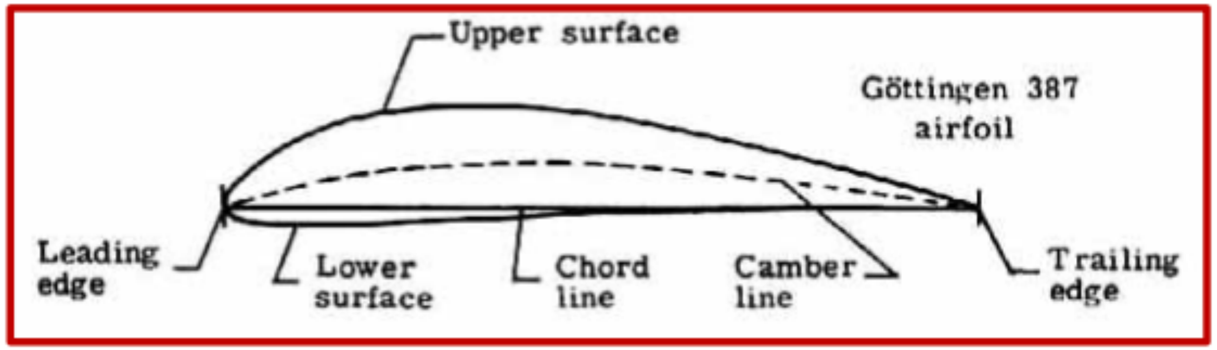
- Suction on the top of the wing is more important than pressure acting on the bottom of the wing.
  – Almost no high pressure on the bottom of the wing at low angles of attack.
  – Suction above the wing does more than 100% of the job of lifting.
- The front quarter or so of the wing does half of the lifting.



Lift vs. Angle of Attack

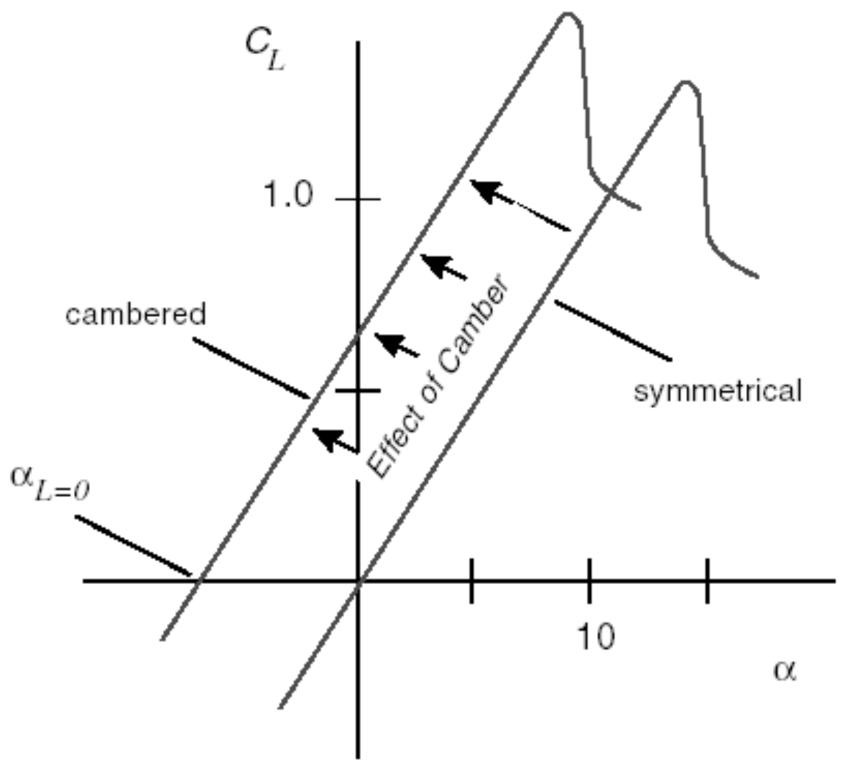
2-D Lift (inviscid, incompressible flow)



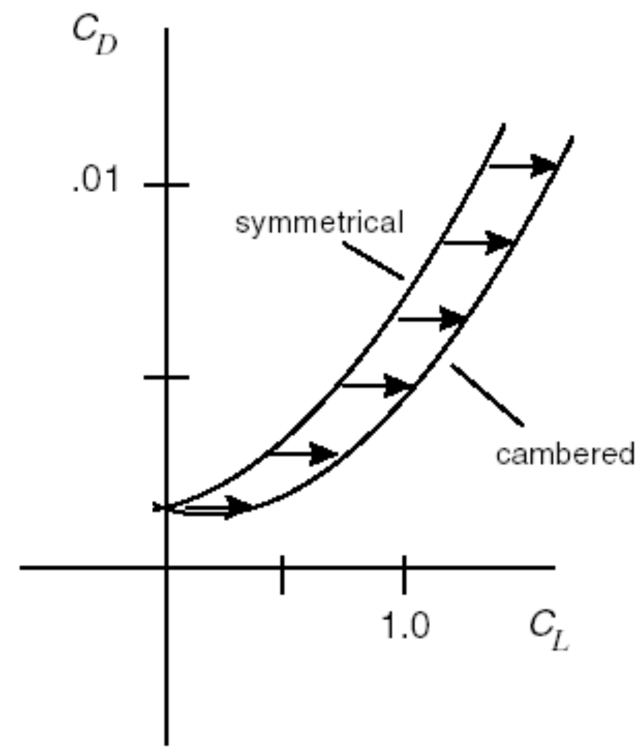


Effects of camber

Lift Curve



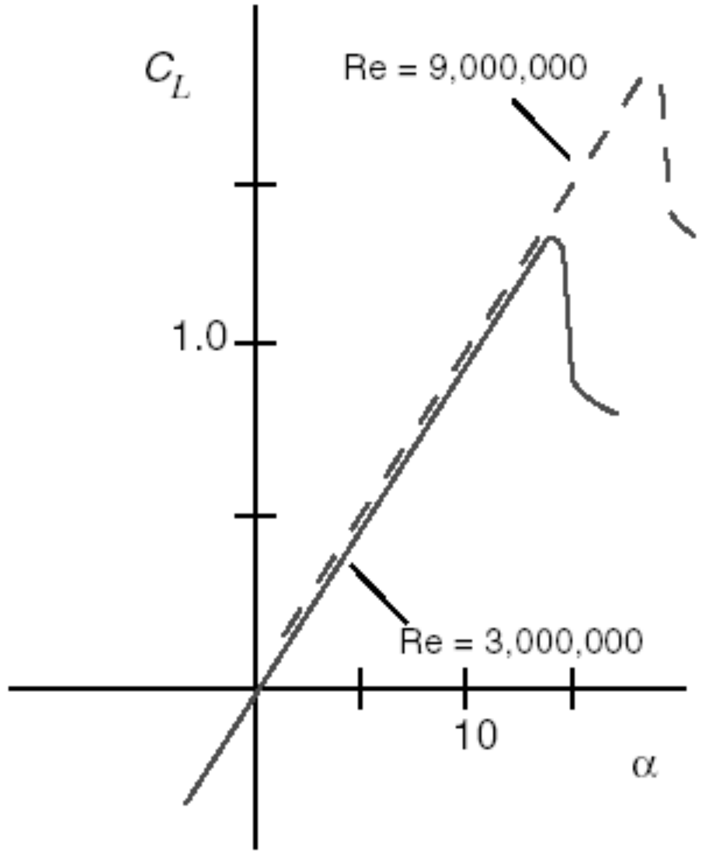
Drag Polar Curve



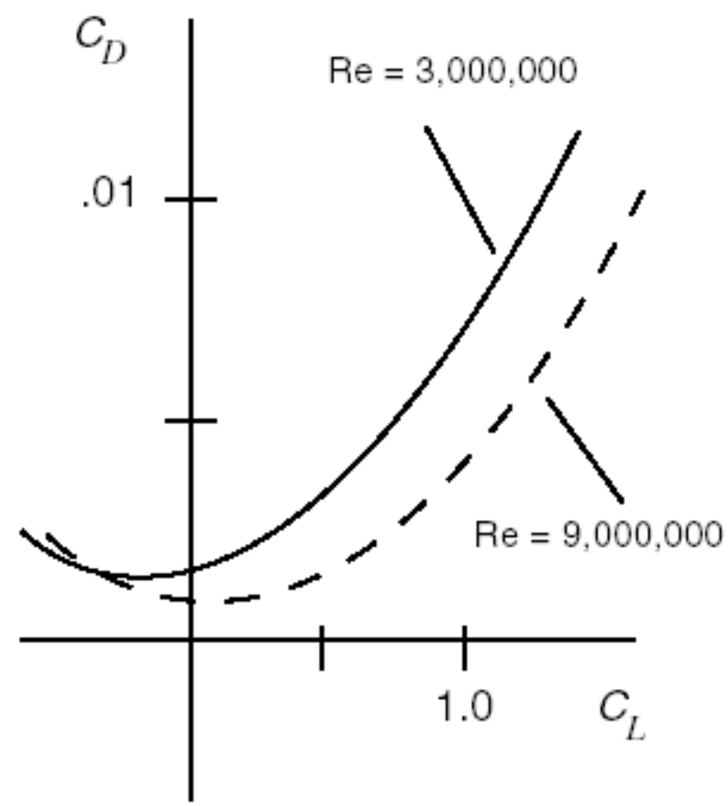
Source: Newman, Dava J., *Interactive Aerospace Engineering and Design*

Effect of skin friction drag

Lift Curve



Drag Curve

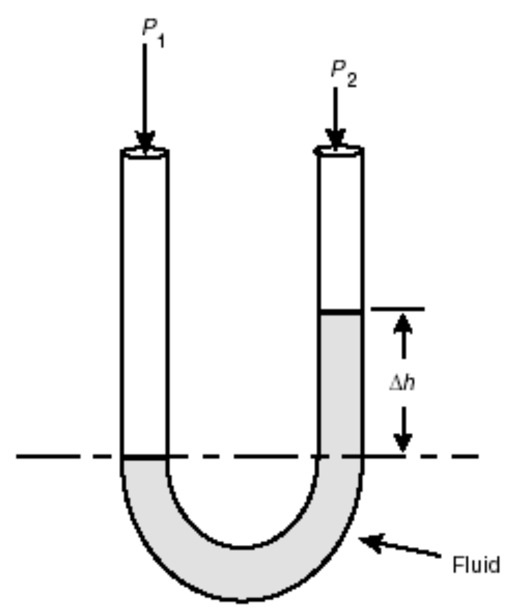


Source: Newman, Dava J., *Interactive Aerospace Engineering and Design*

Bernoulli and Pitot tubes

- Bernoulli's equation is also very important for measuring the speed of an aircraft
- Basis of Pitot tube a.k.a. a glorified manometer!

$v = \sqrt{2((P_0 - P)/\rho)}$



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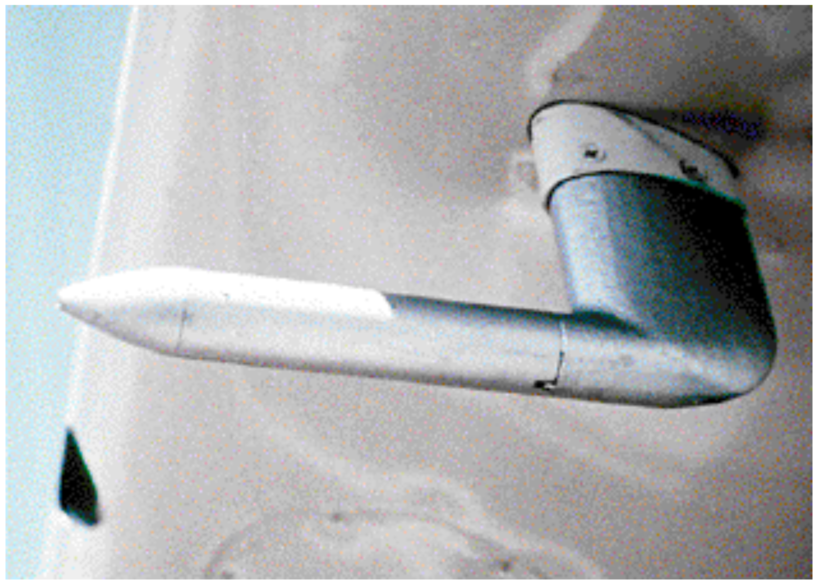
What do Pitot tubes look like?



Basic relationships of lift and drag (1)

- Lift and drag are functions of air density, airspeed, wing area, wing shape and angle of attack:

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

$$D = \tfrac{1}{2}\rho V^2 S C_D$$

- In "steady flight" all the forces must balance, thus:

$$-L\sin(\gamma) - D\cos(\gamma) + T\cos(\gamma + \alpha) = 0$$

$$L\cos(\gamma) - D\sin(\gamma) + T\sin(\gamma + \alpha) = W$$

Longitudinal Aerodynamic Forces

Non-dimensional force coefficients, C_L and C_D, are

dimensionalized by

dynamic pressure, $\bar{q}$, N/m^2 or $lb/sq\ ft$

reference area, S, m^2 of ft^2

$$\boxed{\begin{aligned} Lift &= C_L \bar{q} S = C_L \left(\frac{1}{2} \rho V^2 \right) S \\ Drag &= C_D \bar{q} S = C_D \left(\frac{1}{2} \rho V^2 \right) S \end{aligned}}$$

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