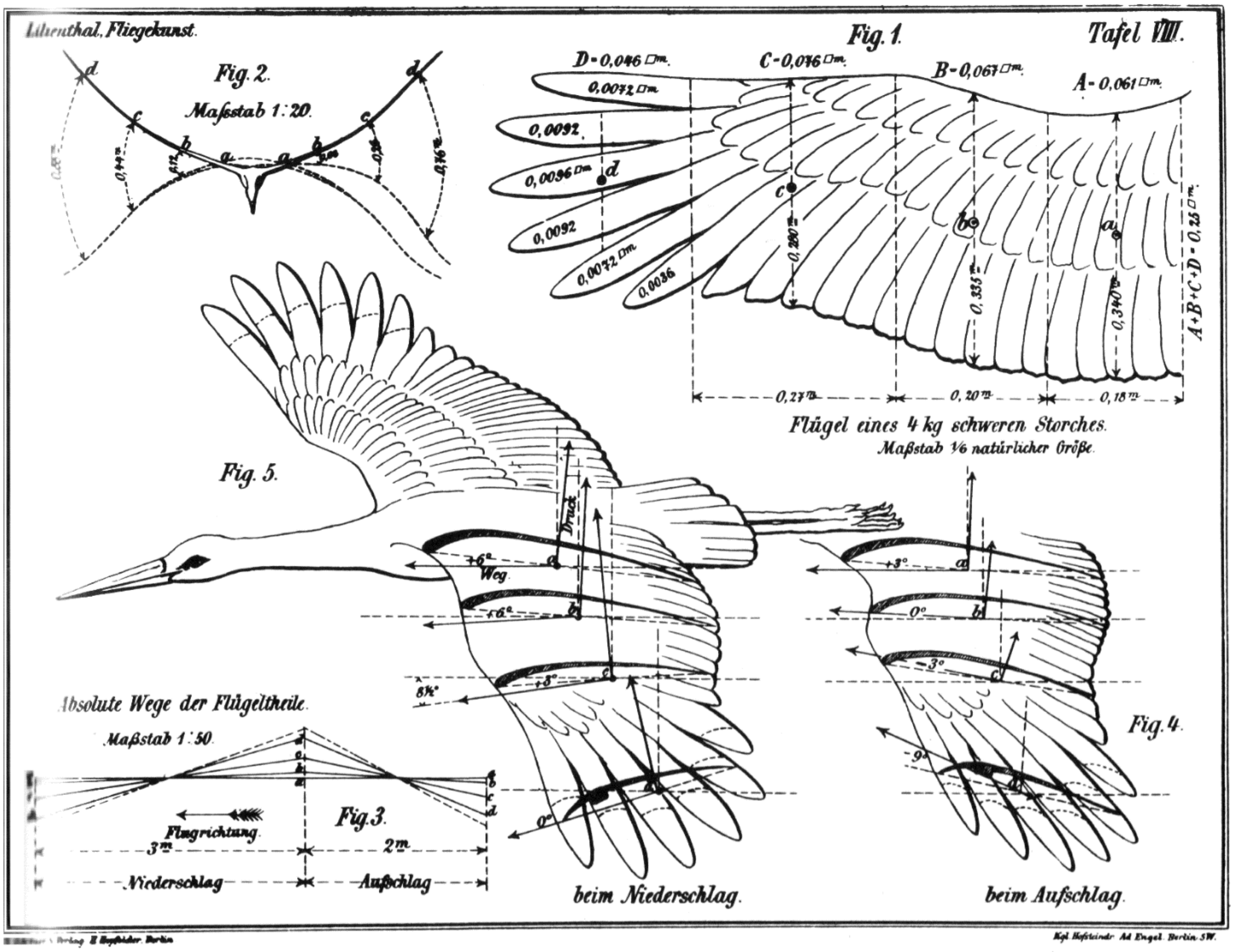
Section 1



Fundamental Principles

(Chap A1)

Fundamental Principles of Aerodynamics

(Anderson Fundamental of Aerodynamics Chapter 1)

Aerodynamics: Objectives & Terminology (A1.2)

Course Objectives:

1) **Learn to compute the forces (normal and shear) on a flying vehicle**

2) **Understand the trade-offs between vehicle external shape and resultant forces on it, leading to insights about optimum shapes for the mission**

Aircraft Wisdom: If it looks good, it flies good?

https://techxplore.com/news/2020-09-rolls-royce-plane-technology-electric.html


NASA
Goleta Air & Space Museum
www.Air-and-Space.com
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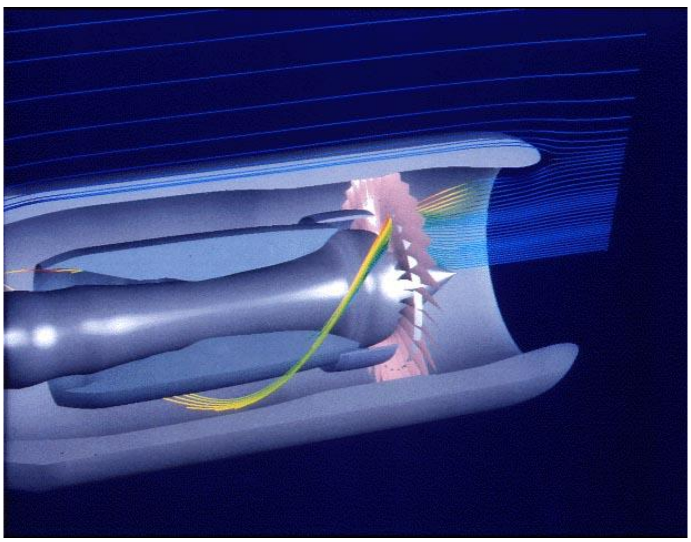
U.S. AIR FORCE

Ideal (?):

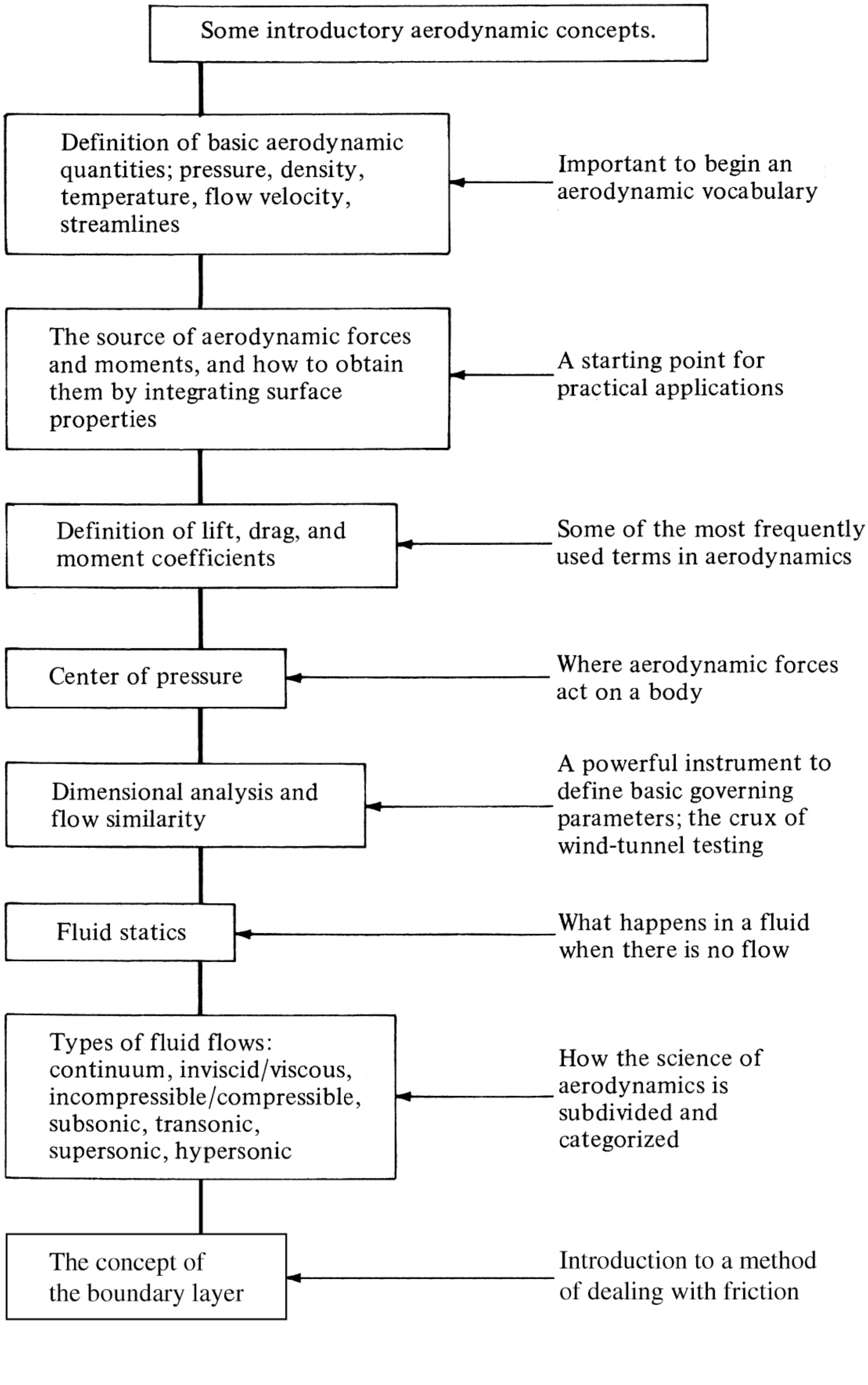
Terminology:

- **Fluid: liquid or gas**
- **Hydrodynamics: flow of liquids**
- **Gas Dynamics: flow of gases**
- **Aerodynamics: flow of air**

Internal vs External Aerodynamics



Roadmap (A1.3):


Some introductory aerodynamic concepts.
Definition of basic aerodynamic quantities; pressure, density, temperature, flow velocity, streamlines
Important to begin an aerodynamic vocabulary
The source of aerodynamic forces and moments, and how to obtain them by integrating surface properties
A starting point for practical applications
Definition of lift, drag, and moment coefficients
Some of the most frequently used terms in aerodynamics
Center of pressure
Where aerodynamic forces act on a body
Dimensional analysis and flow similarity
A powerful instrument to define basic governing parameters; the crux of wind-tunnel testing
Fluid statics
What happens in a fluid when there is no flow
Types of fluid flows: continuum, inviscid/viscous, incompressible/compressible, subsonic, transonic, supersonic, hypersonic
How the science of aerodynamics is subdivided and categorized
The concept of the boundary layer
Introduction to a method of dealing with friction

<u>Aerodynamic Variables (A1.4)</u> – The Language of Aerodynamics

- **Density**
  - **Mass/unit volume**
  - **Scalar**
- **Temperature**
  - **Scalar**
- **Flow Velocity**
  - **Vector**
  - **Always measured relative to something, so reference frame is essential to state or to assume correctly**

FORCES: Normal and Shear

- **Pressure**
  - **Normal force/unit area due to time rate of change of momentum of gas molecules impacting surface**
  - **Vector or scalar?**

- **Shear stress (internal to fluid)**
  - **Tangential force between adjacent fluid elements**

Airplane Nomenclature (F2.6)

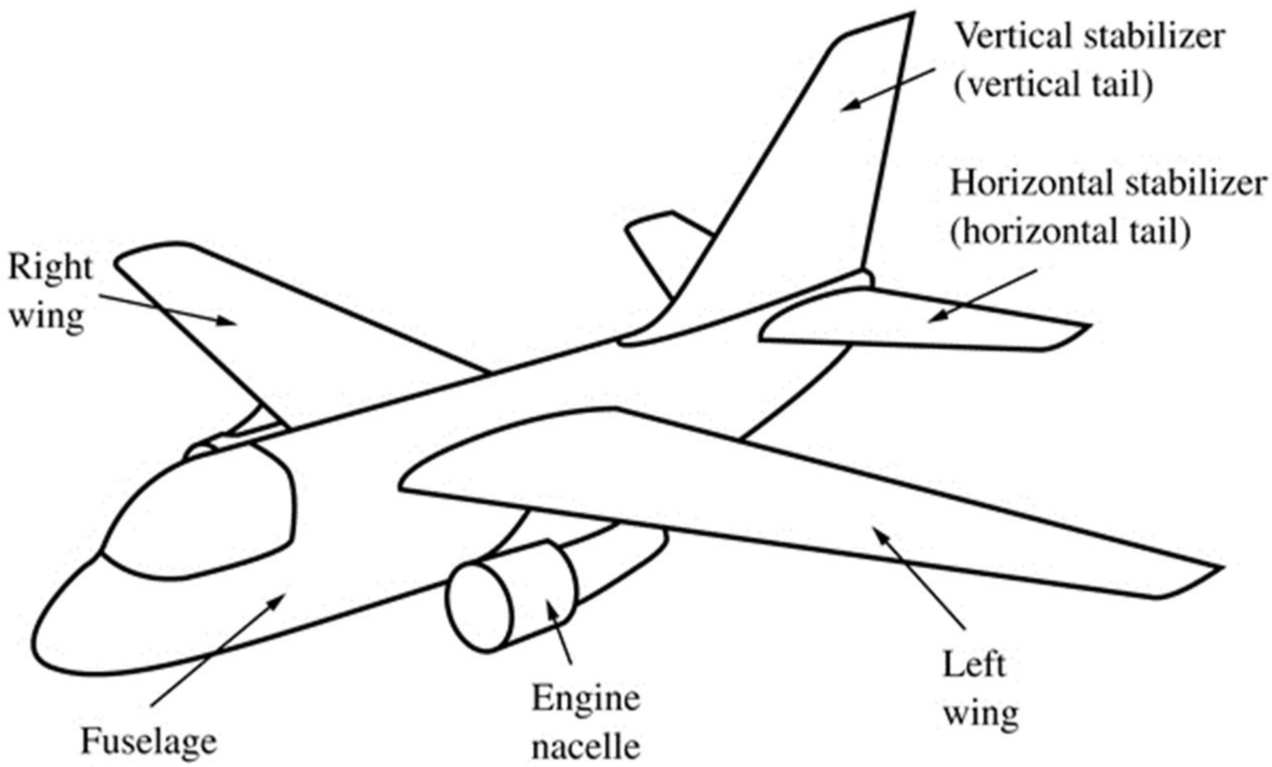


Figure 2.13 Basic components of an airplane.

Airplane Nomenclature (F2.6)

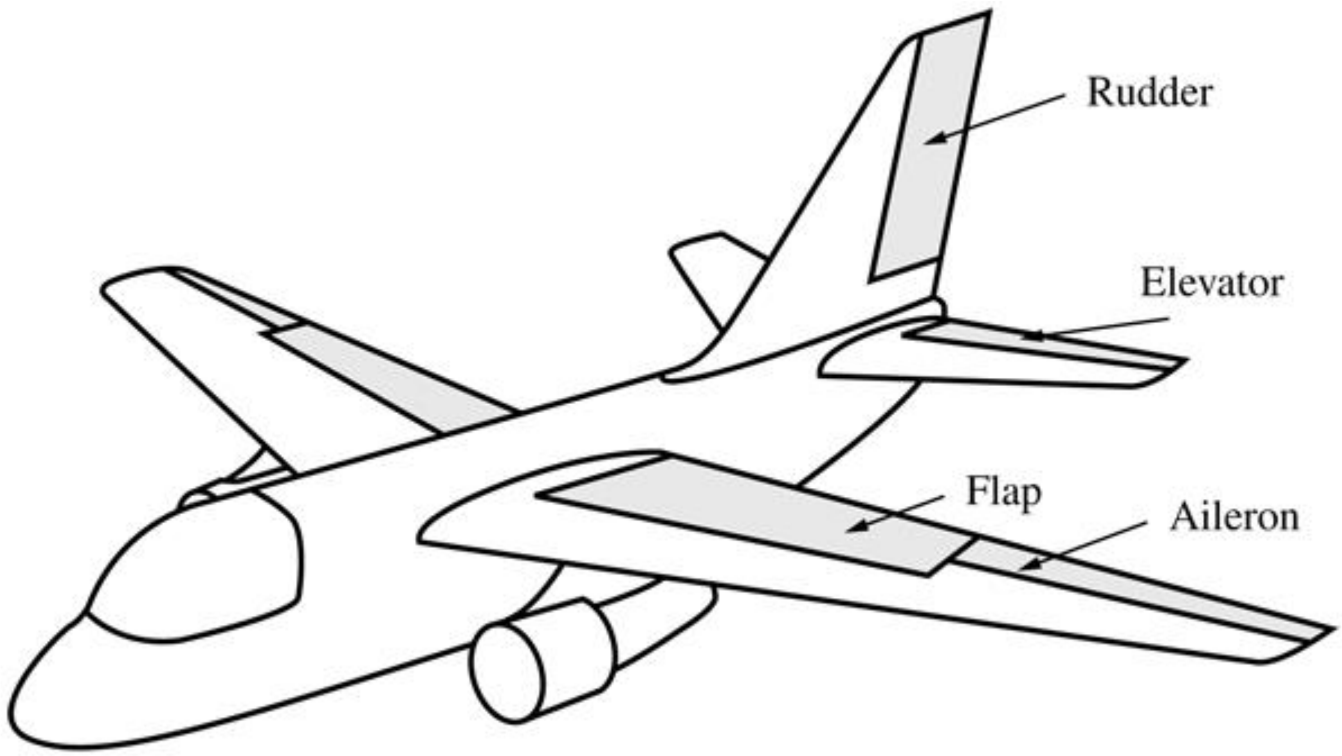


Figure 2.14 Control surfaces and flaps.

Airfoil Nomenclature (F5.2)

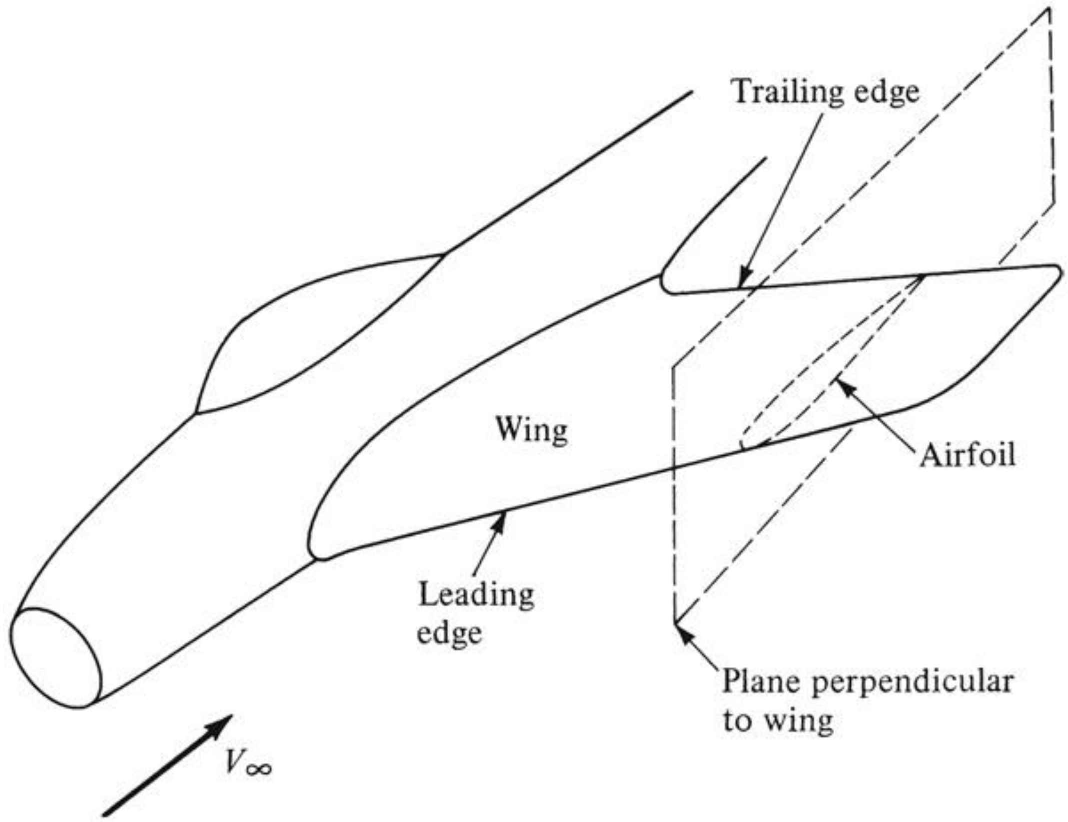


Figure 5.2 Sketch of a wing and airfoil.

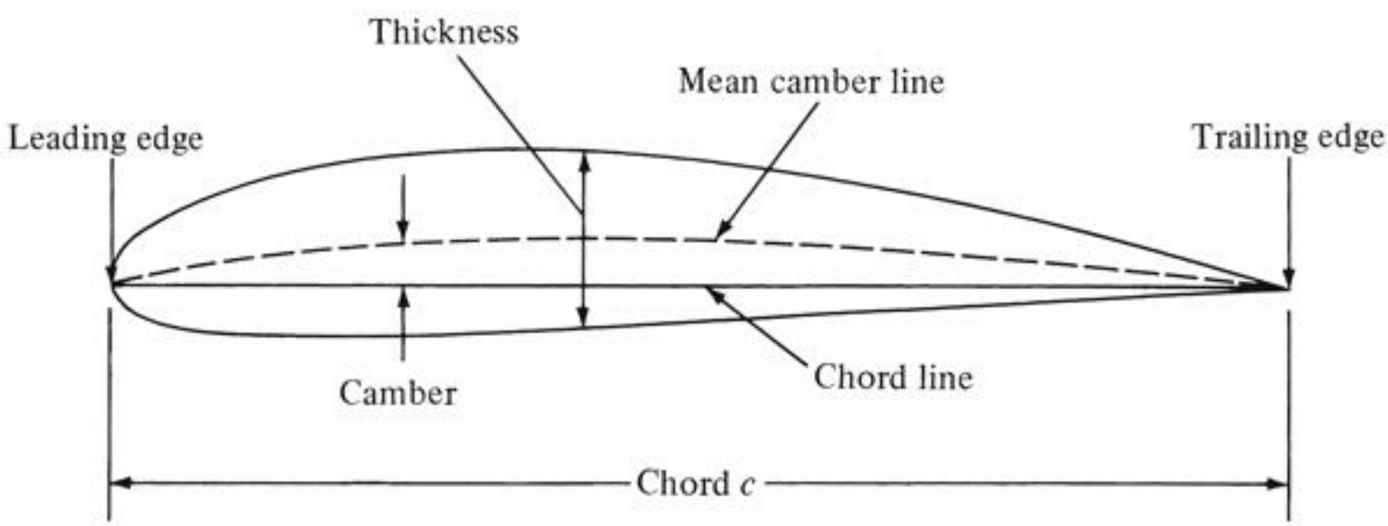


Figure 5.3 Airfoil nomenclature. The shape shown here is a NACA 4415 airfoil.

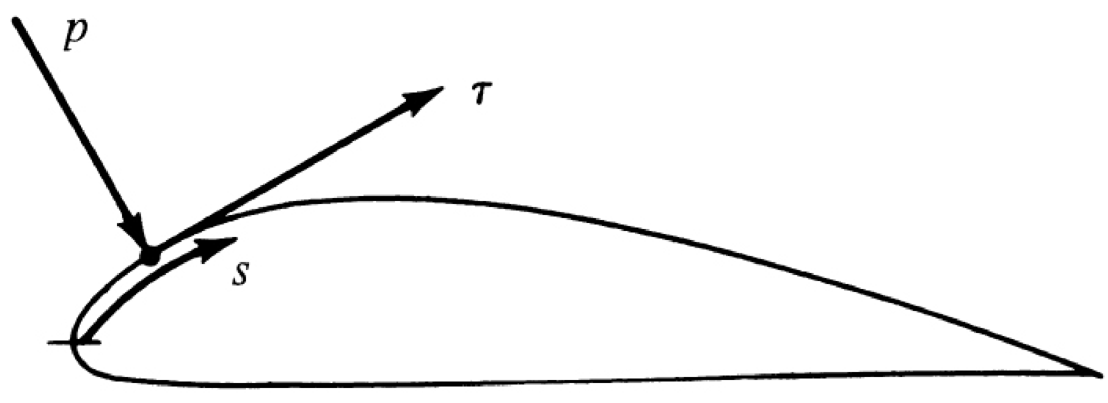
Airfoil Nomenclature (F5.2)

What do we want to be able to predict?

- **Lift forces**
- **Drag forces**
- **Moments**

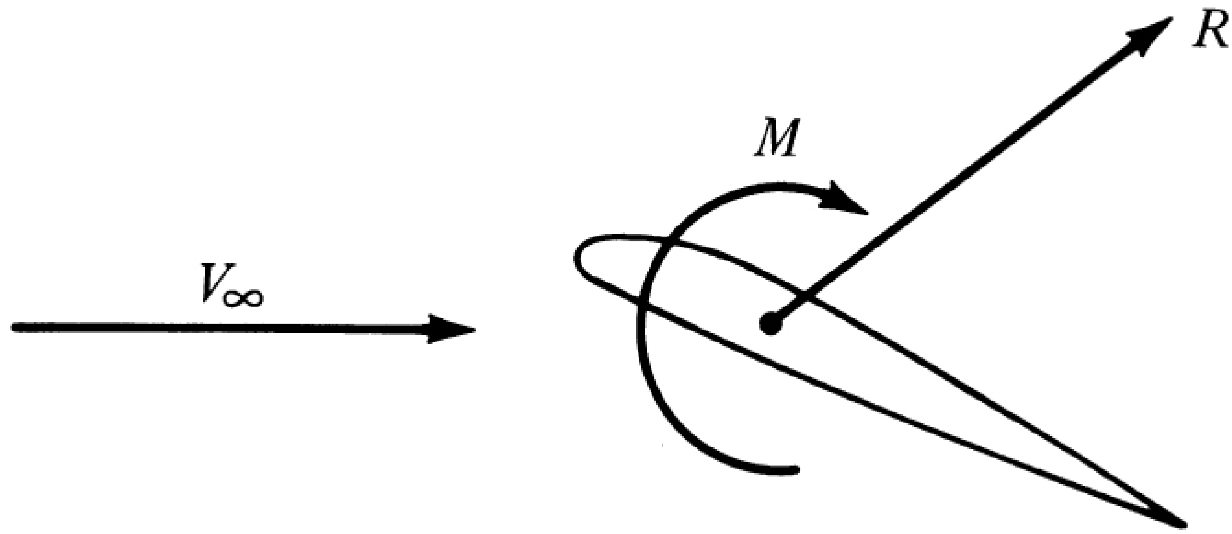
<u>Aerodynamic Forces and Moments (A1.5)</u>

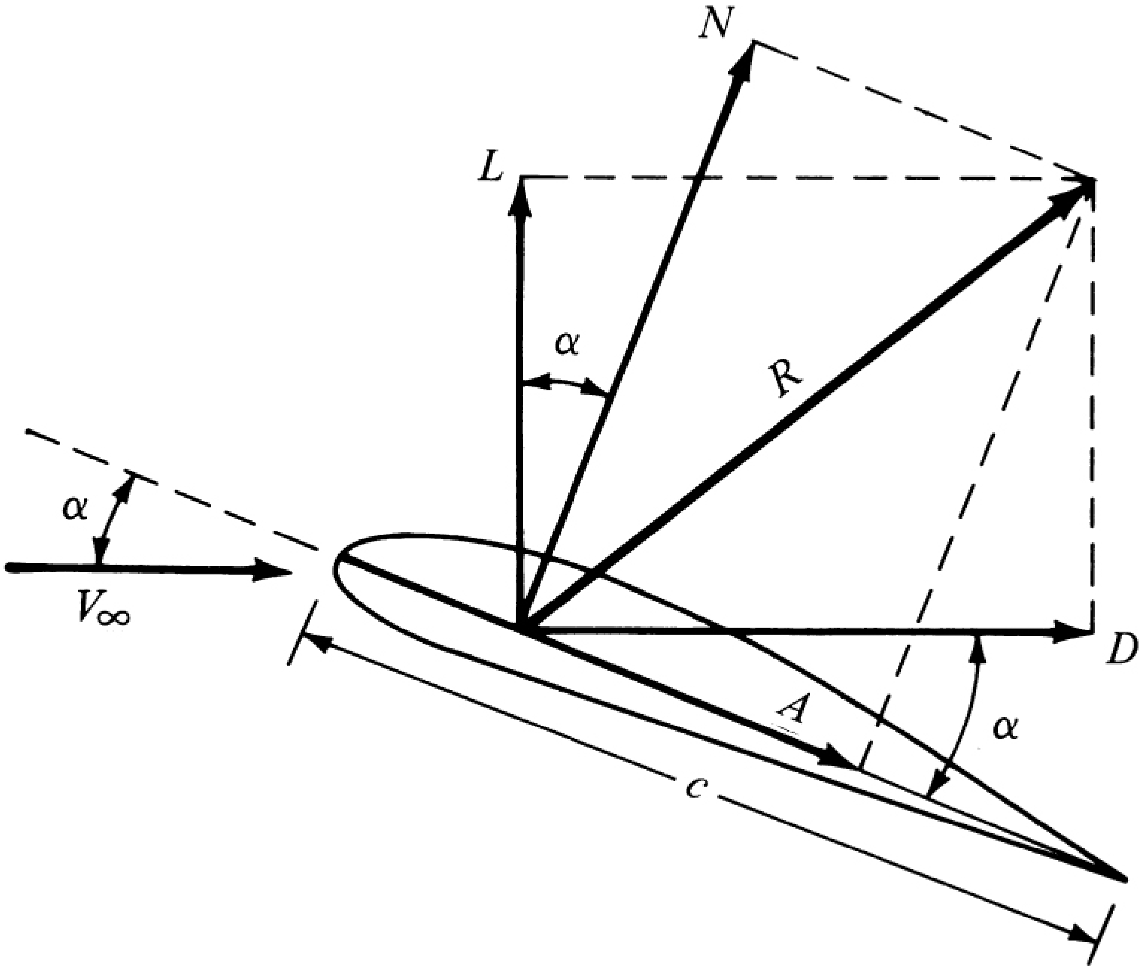
- **Why study aerodynamics? What's the point?**
- **Generally, to estimate the forces on the vehicle, to quantify performance**
- **How many kinds of airflow-induced forces act on the surface of a vehicle? Just TWO!**

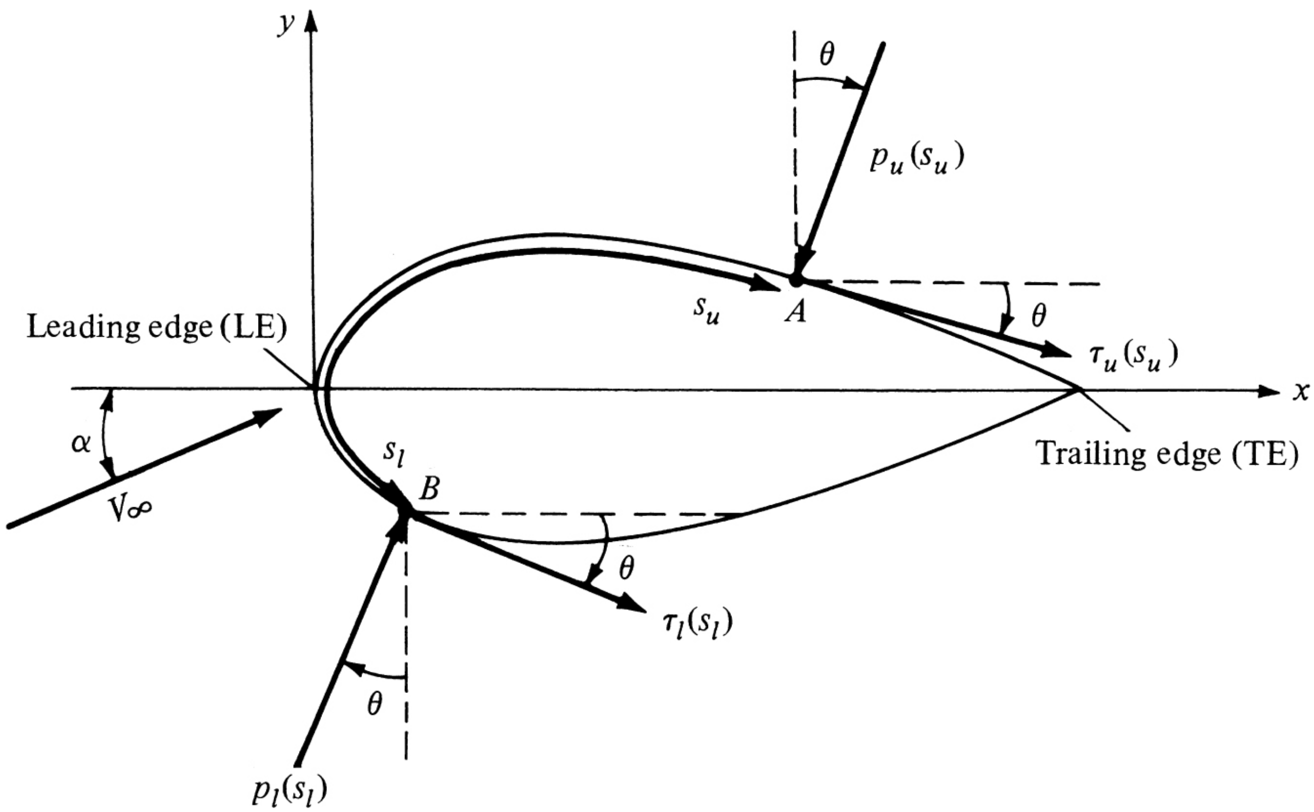


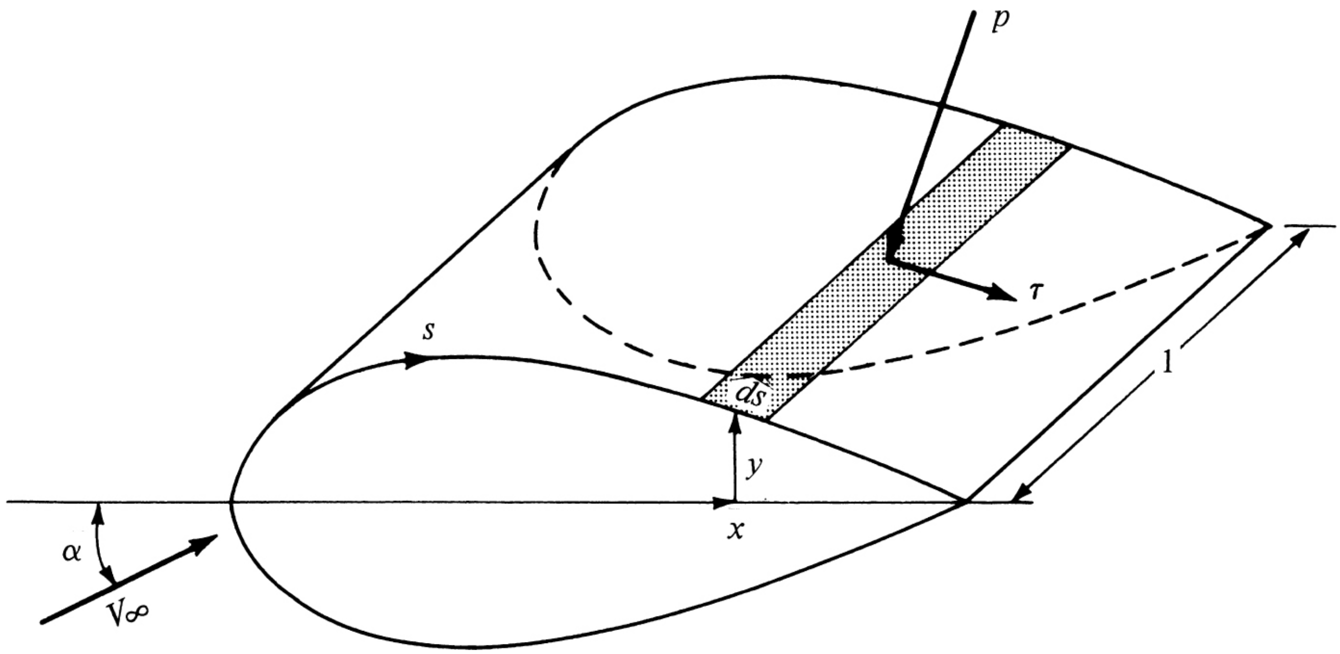
$p = p(s)$ = surface pressure distribution
$\tau = \tau(s)$ = surface shear stress distribution

- **Normal force (pressure distribution over surface)**
- **Tangential force (shear stress distribution over surface)**
- **Dimensions of both are of *stress* (force/unit area)**

- **For net effect of stress distributions, integrate over surface to form resultant aerodynamic force and moment, acting at a chosen point (more on choosing that point later!):**
- 


N
L
α
R
α
V∞
D
A
α
c


y
θ
$p_u(s_u)$
s_u
A
θ
$\tau_u(s_u)$
Leading edge (LE)
x
α
Trailing edge (TE)
s_l
B
V∞
θ
$\tau_l(s_l)$
θ
$p_l(s_l)$


p
τ
s
l
ds
y
x
α
V∞

- **So, if we know the surface stresses (normal and tangential, or pressure and shear), p(s) and τ(s) over an aerodynamic body, we can integrate to compute the resultant aerodynamic**

<u>Lift, Drag, and Moment</u>

- **Therefore the trick is to learn enough about fluid flow to be able to predict the imposed stresses on a given body shape…**

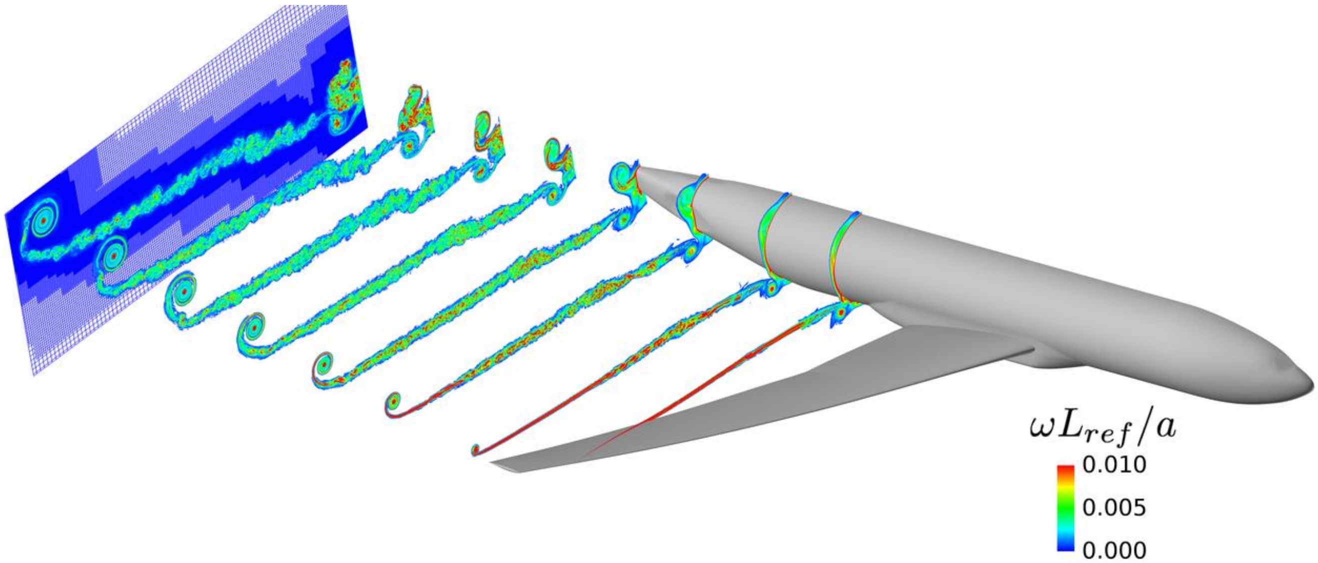
<u>This is the field of Aerodynamics</u>

A Preliminary Note About DRAG

Drag due to pressure differences:

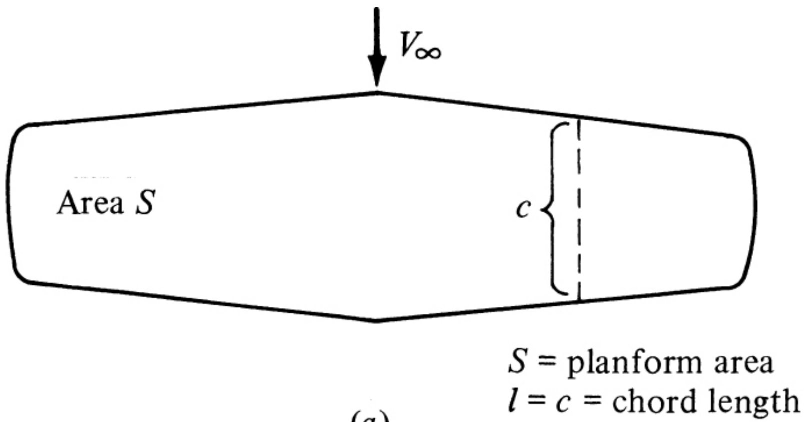
Drag due to friction:

Drag due to lift:

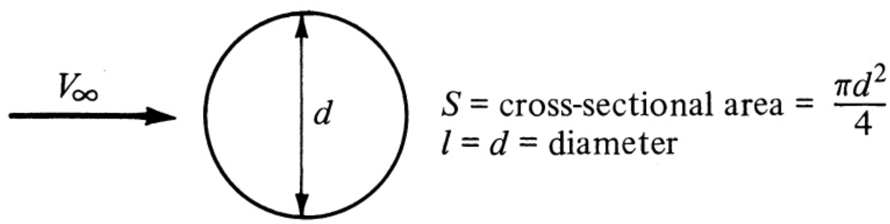


Guy Schauerhamer, PhD (2018)

Dimensionless Force and Moment Coefficients

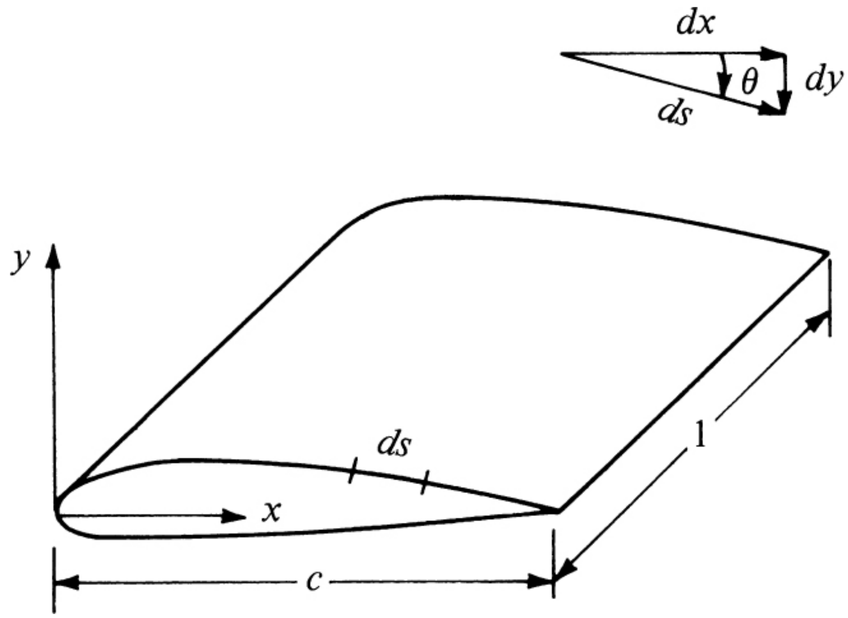


(*a*)



(*b*)

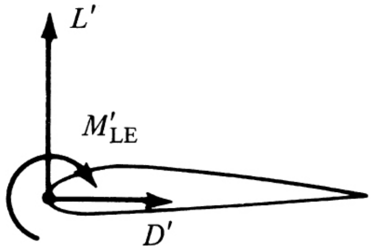
Force & Moment Integrals in Coefficient Form:



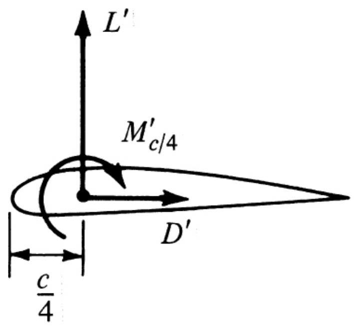
Center of Pressure (A1.6):

- **Engineering: Replace P and τ surface distributions with a resultant force and moment, applied anywhere you choose, as long as the moment is adjusted so that the combined force/moment effect is the same as that of the distributed stresses.**

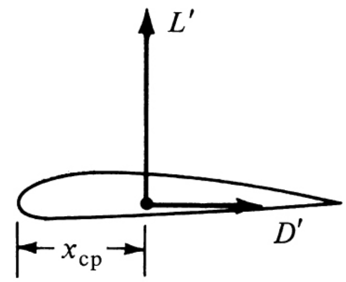
- **But there is one point of resultant application on the airfoil where there is no moment required: *"Center of Pressure"***



Resultant force at leading edge



Resultant force at quarter-chord point



Resultant force at center of pressure

Dimensional Analysis (A1.7):

For a given aerodynamic body at a given angle of attack, α, what does the resultant force on the body depend on?

Simplify by Dimensional Analysis to get grouped variables.

Results:

Generalize our findings as:

Flow Similarity (A1.8):

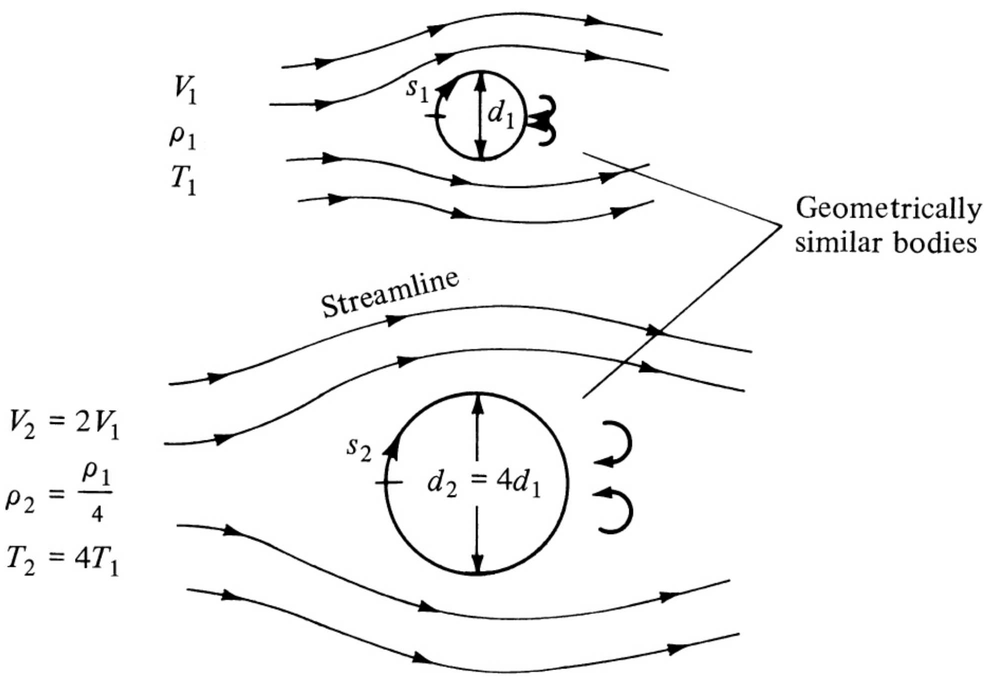
Two flows are dynamically similar if:

1) **Boundaries and bodies in flow are geometrically similar (same shape, not necessarily same size)**

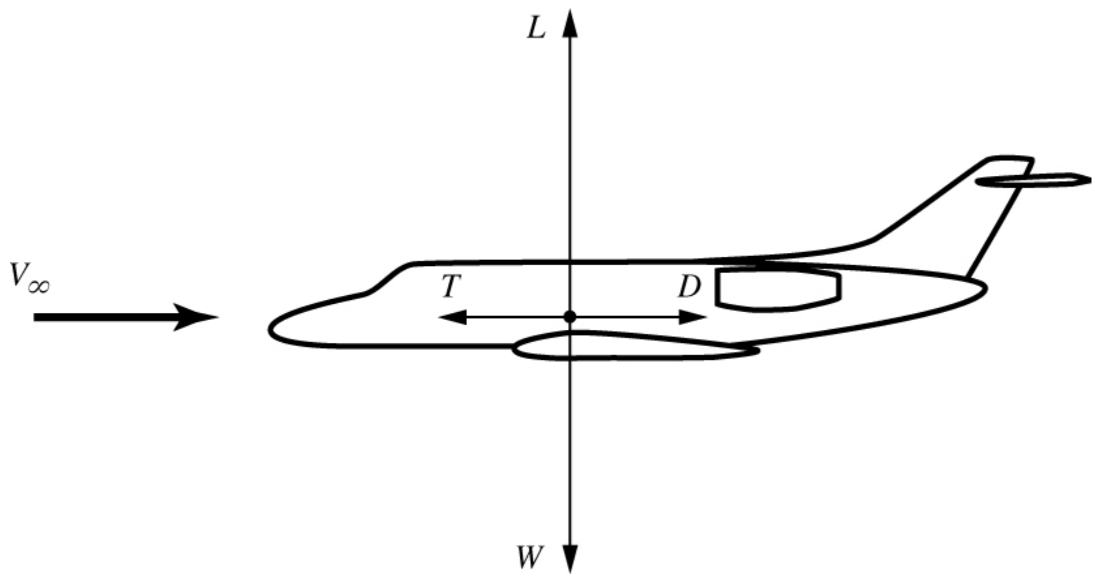
2) **Similiarity parameters are the same**

Wind tunnel testing example:

Example 1.5:


V_1
ρ_1
T_1
s_1
d_1
Geometrically similar bodies
Streamline
$V_2 = 2V_1$
$\rho_2 = \frac{\rho_1}{4}$
$T_2 = 4T_1$
s_2
$d_2 = 4d_1$

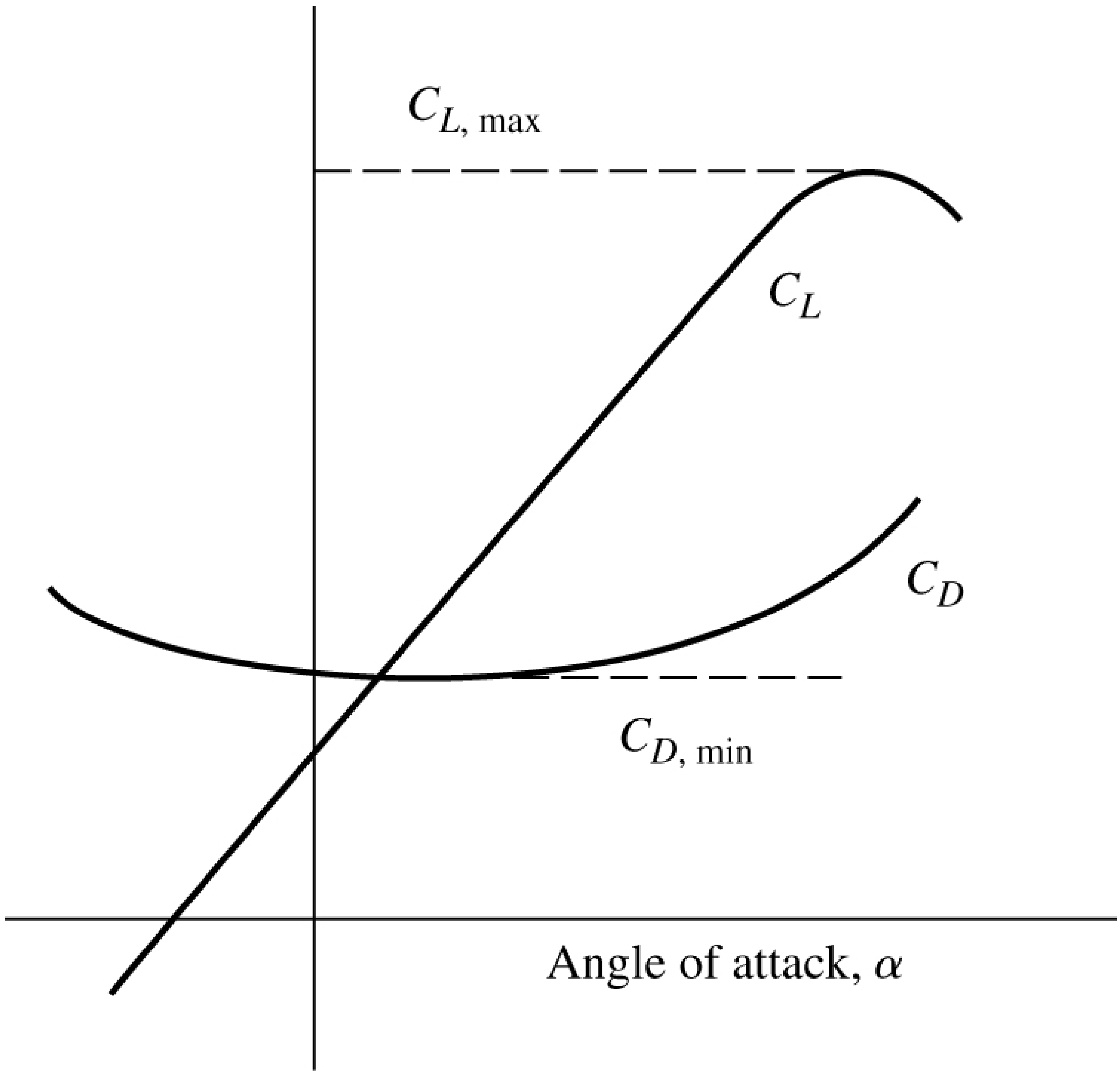
Design Box (A pg 46): Importance of C_L and C_D



High-Lift Aircraft: McDonnell Douglas C-17

Low-Drag Airplane: Northrup B2

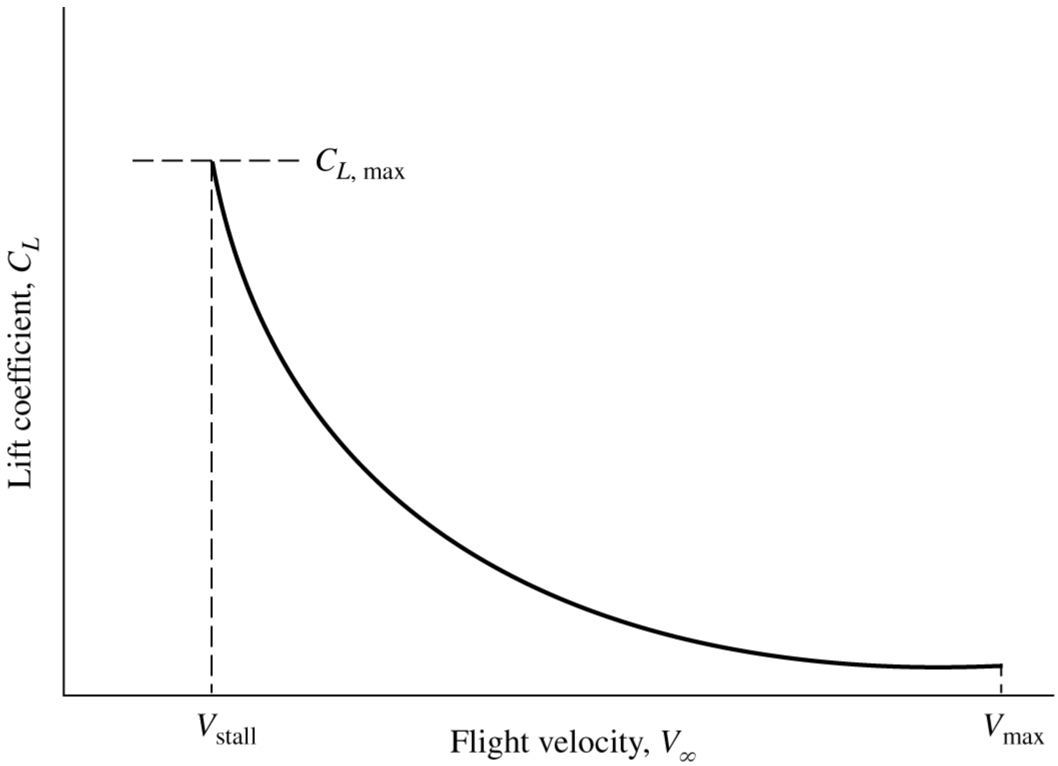
Stall

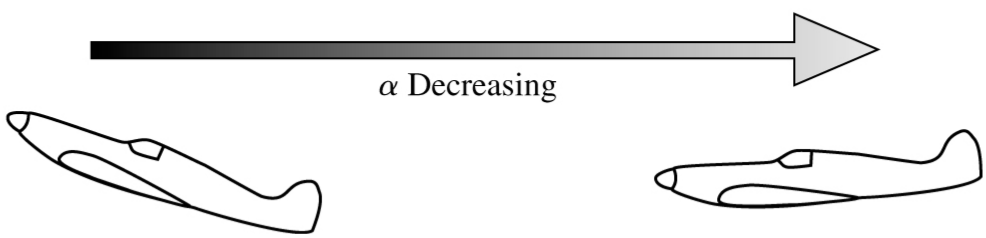


How <u>fast</u> can you fly?

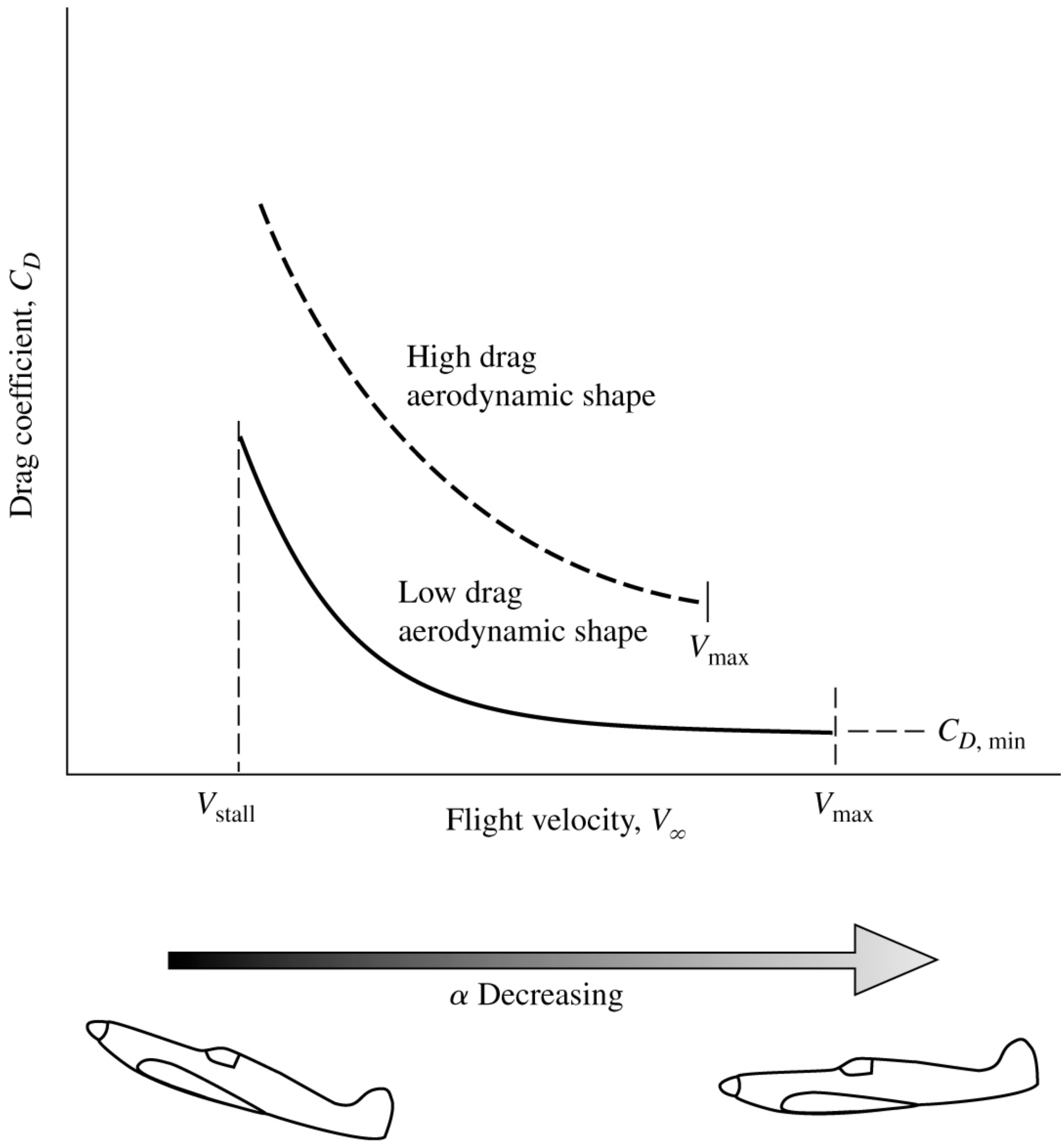
How <u>fast</u> can you fly?

Relationship between aircraft speed and C_L





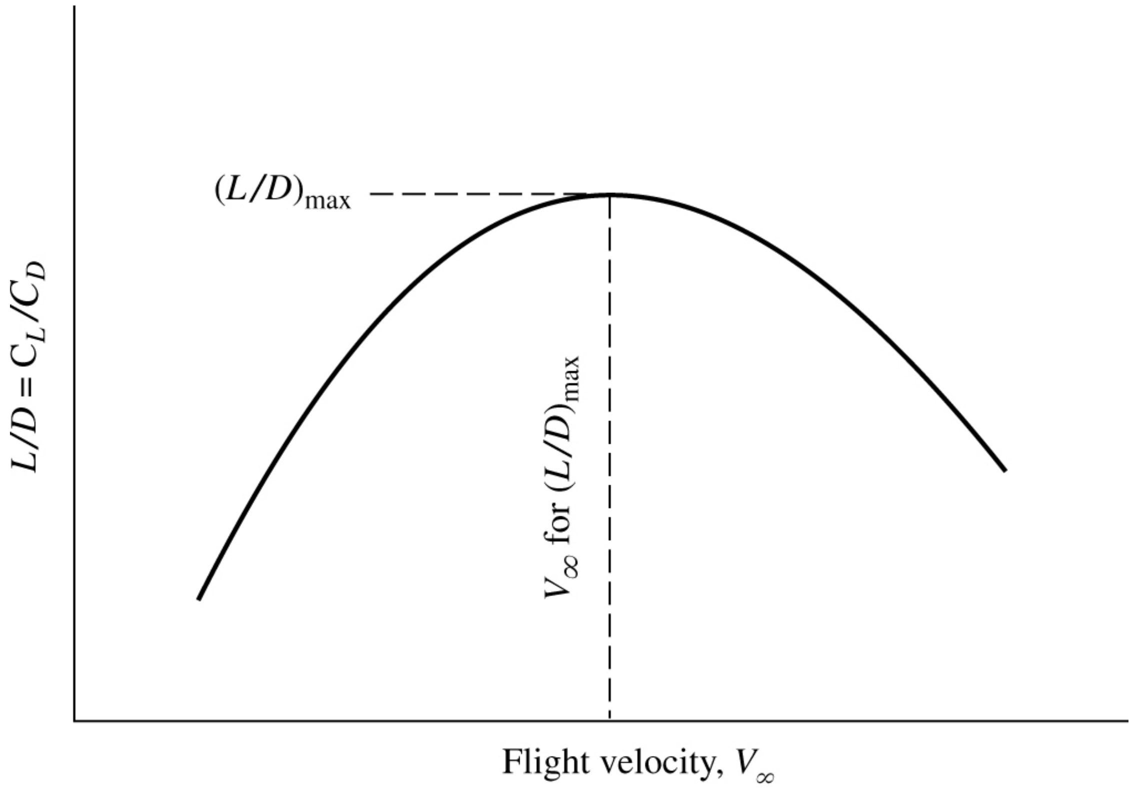
Relationship between aircraft speed and C_D

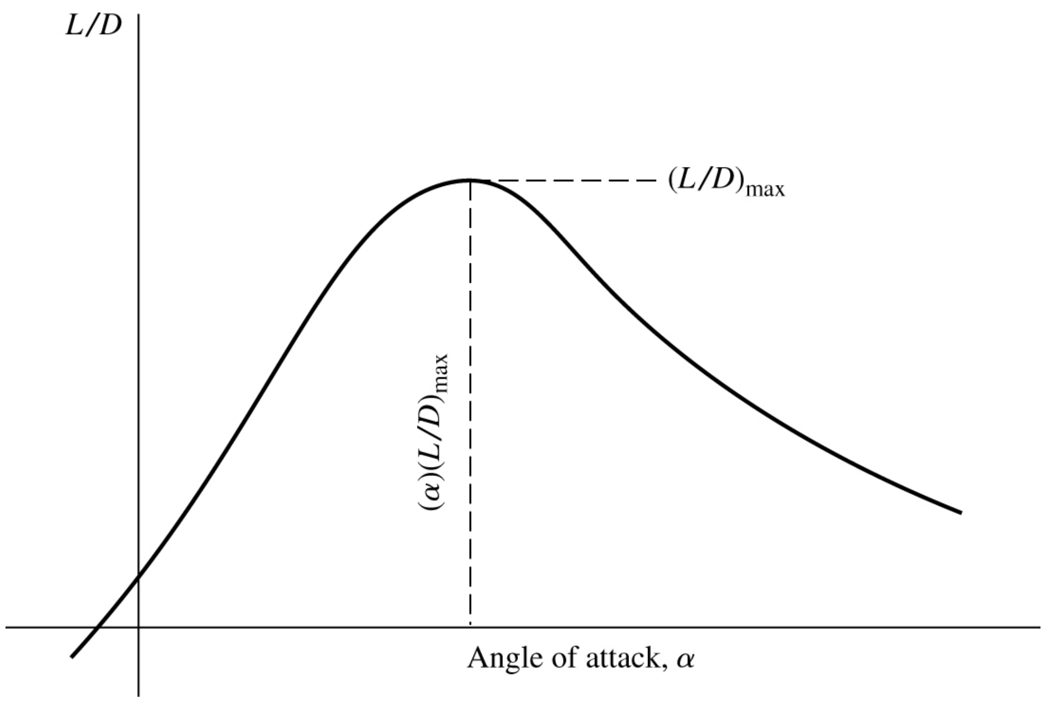


How Do Planes Take Off?

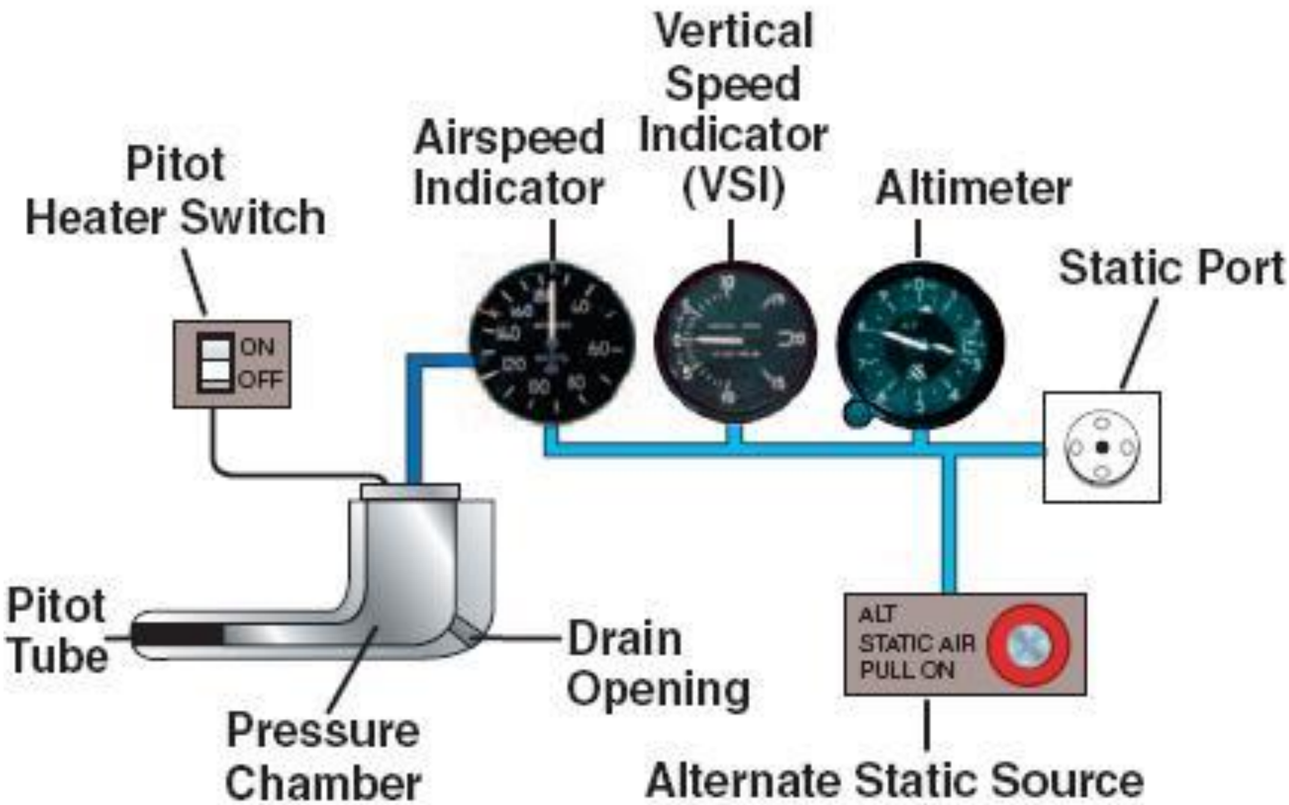
Aerodynamic Efficiency of Aircraft: Lift/Drag Ratio

Aerodynamic Efficiency of Aircraft: Lift/Drag Ratio


$(L/D)_{max}$
$L/D = C_L/C_D$
V_∞ for $(L/D)_{max}$
Flight velocity, V_∞

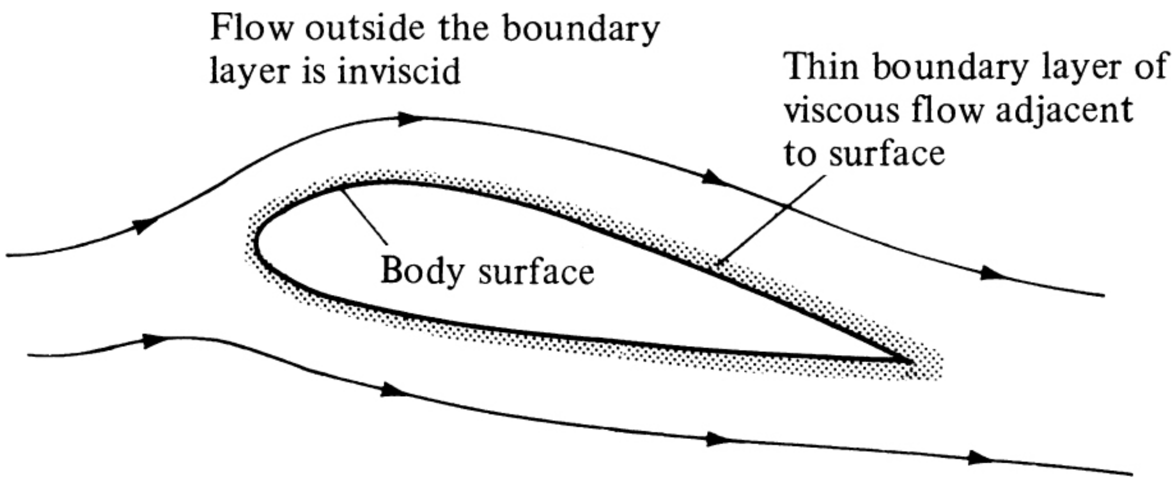

L/D
$(L/D)_{max}$
$(\alpha)(L/D)_{max}$
Angle of attack, α

Fluid Statics: Manometry (A1.9):

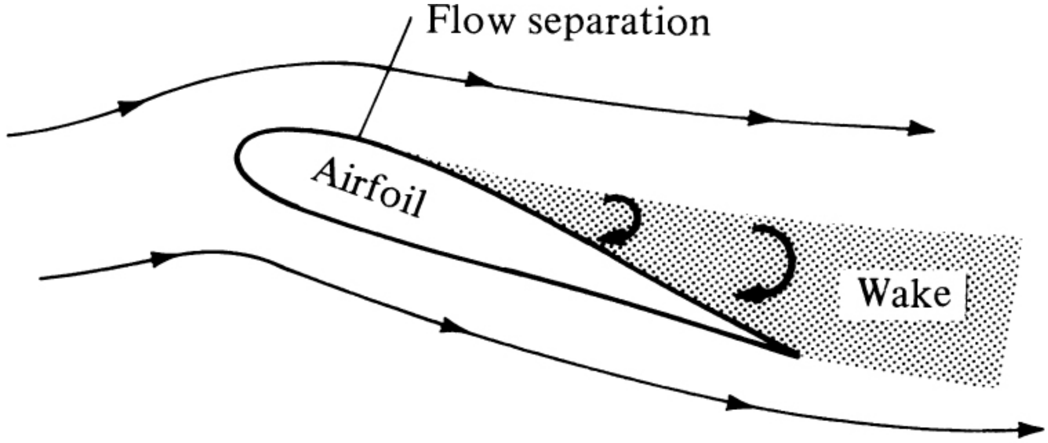


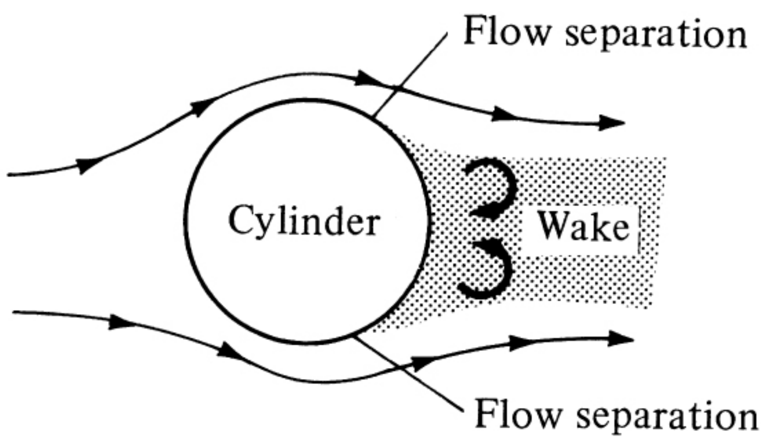
<u>Types of Flow (A1.10):</u>

Inviscid vs Viscous Flow:



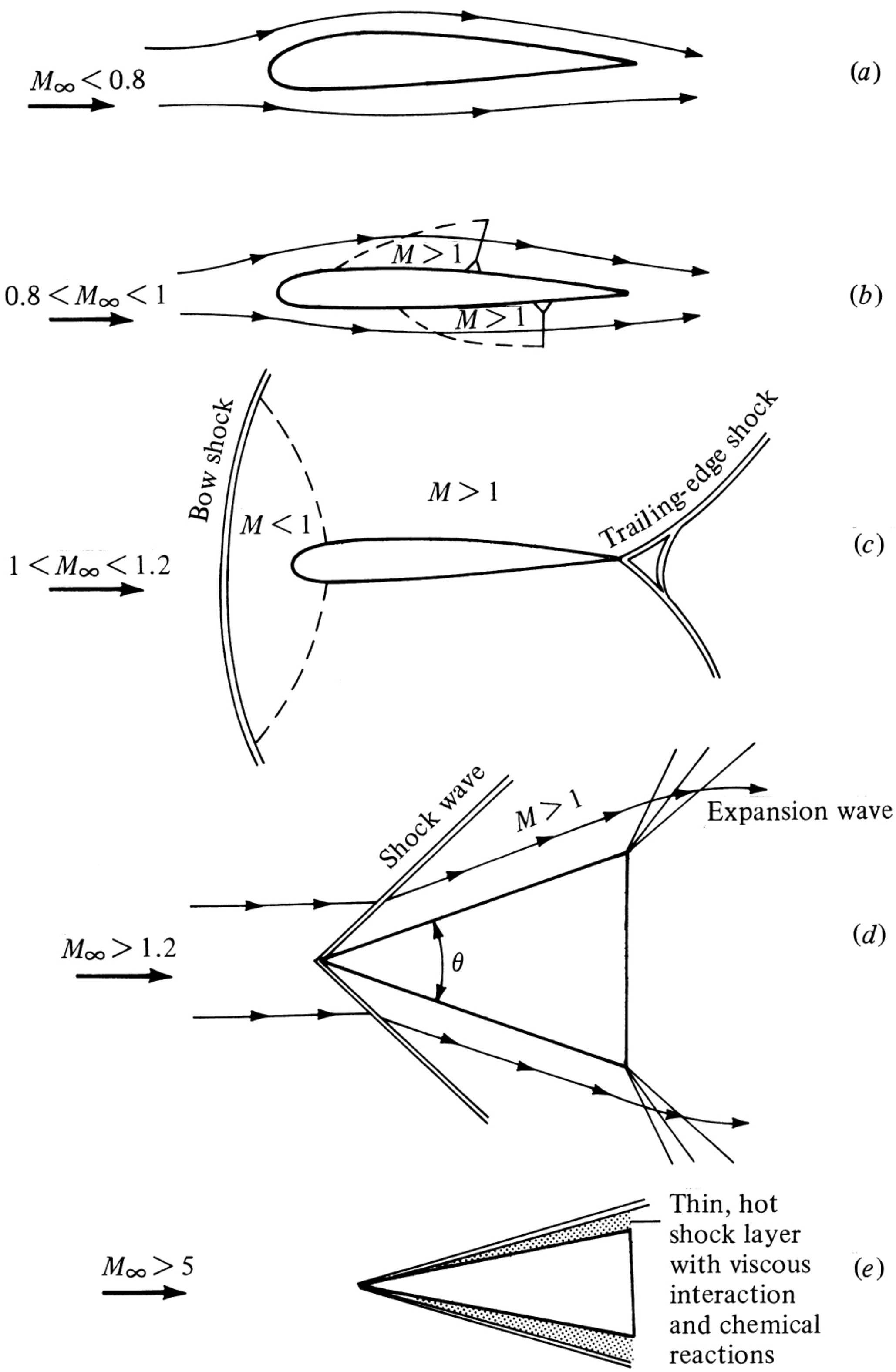
Inviscid vs Viscous Flow:





Incompressible vs Compressible Flow:

Mach Number Regimes:



(a) Subsonic flow

(b) Transonic flow with $M_\infty < 1$

(c) Transonic flow with $M_\infty > 1$

(d) Supersonic flow

(e) Hypersonic flow