Aerodynamics

  

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Basic Information

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Textbook：

Fundamentals of Aerodynamics
John D. Anderson
Fourth Edition
McGraw Hill

Grading：

Homework: 20%

Report: 20%

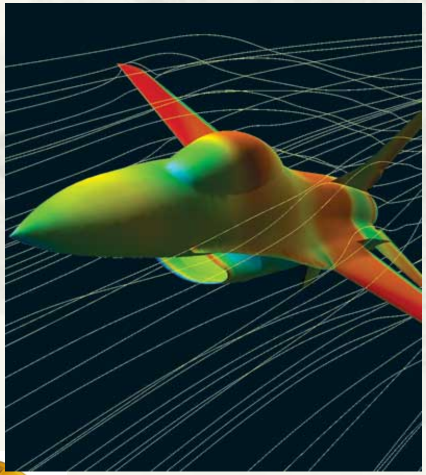
Final： 60%

Chapter 1 Introduction to Aerodynamics

Aerodynamics

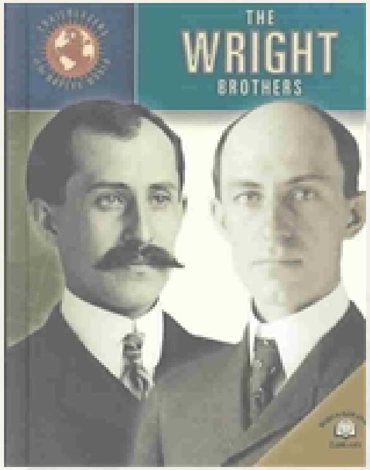
Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with *a moving object*.

Aerodynamics is a subfield of fluid dynamics and gas dynamics, with much theory shared between them.

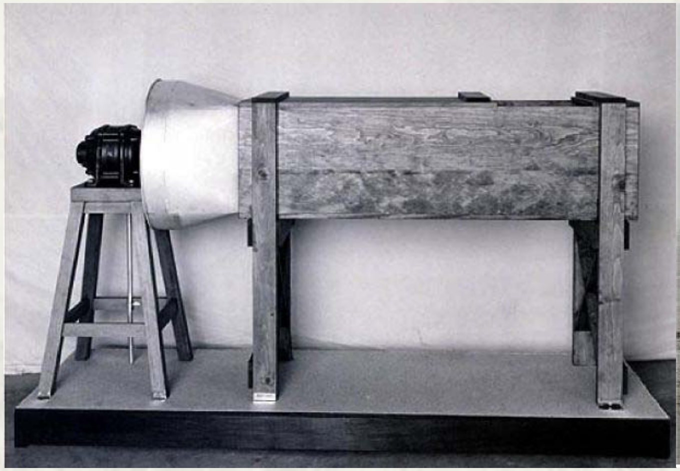


Chapter 1 Introduction to Aerodynamics

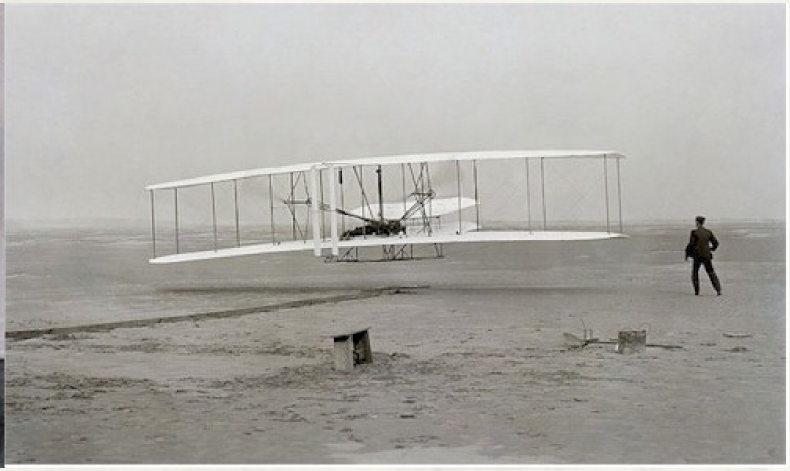
1.1 Importance of Aerodynamics



Wright Brothers



Replica of Wright Brothers' Wind Tunnel



First Flight, 1903

In any case, as famous as we became for our "Flyer" and its system of control, it all would never have happened if we had not developed our own wind tunnel and derived our own correct aerodynamic data. - Wilbur Wright

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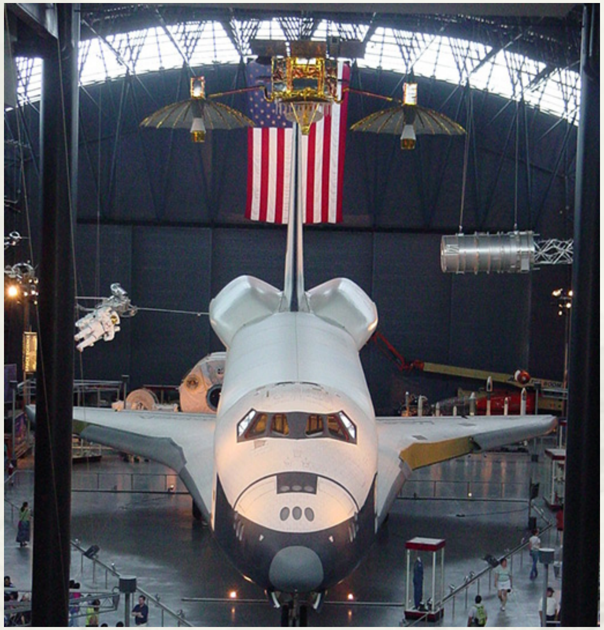
1.1 Importance of Aerodynamics



Why don’t they use sharp-pointed, slender reentry body shapes to reduce the drag of supersonic vehicles?

—— To minimize aerodynamic heating

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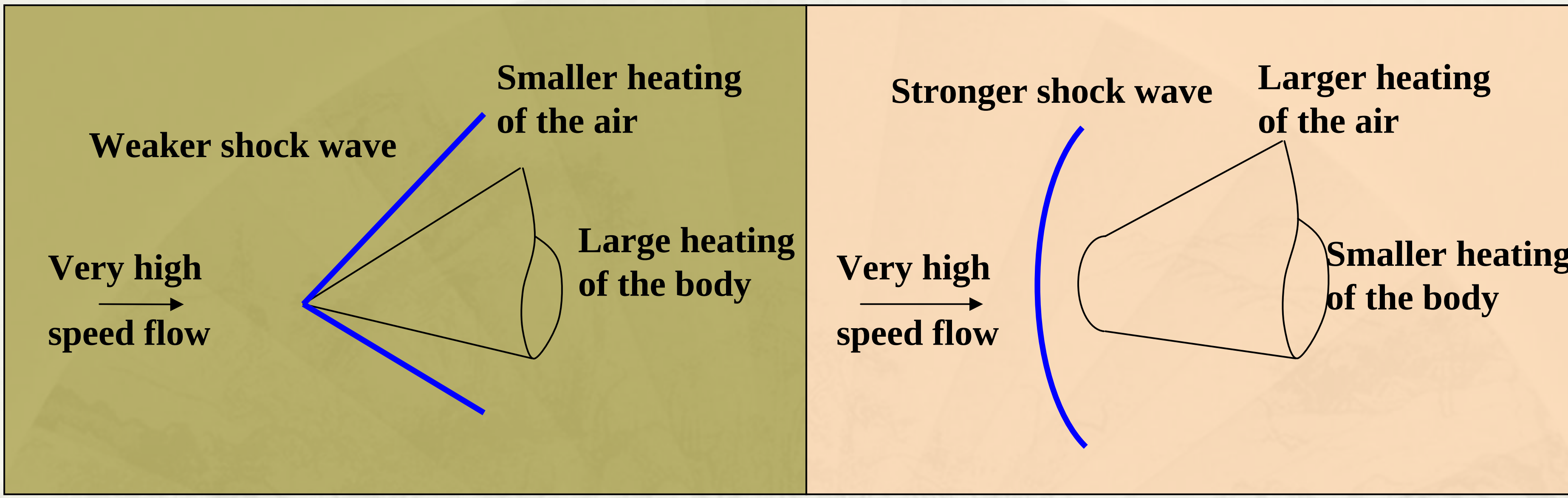
1.1 Importance of Aerodynamics



Slender reentry body

Blunt reentry body

(H. Julian Allen)

Kinetic energy, Potential energy → Heating the body, Heating the airflow around the body

Chapter 1 Introduction to Aerodynamics

1.2 Some Fundamental Aerodynamic Variables

Fluid is used to denote either a liquid or a gas.

Fluid Dynamics →
- Hydrodynamics – flow of liquids
- Gas Dynamics – flow of gases
- Aerodynamics – flow of air

The objectives of Aerodynamics →
- The prediction of forces and moments on, and heat transfer to, bodies moving through a fluid (usually air).
- Determination of flows moving internally through ducts.

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1.2 Some Fundamental Aerodynamic Variables

Pressure: The normal force per unit area exerted on a surface due to the time rate of change of momentum of the gas molecules impacting on that surface.

Density: Mass per unit volume.

Temperature: The temperature of a gas is directly proportional to the average kinetic energy of the molecules of the fluid. In fact, if KE is the mean molecular kinetic energy, then temperature is given by KE=3kT/2, where k is the Boltzmann constant.

Velocity: velocity is the rate of change of position. It is a vector physical quantity; both speed and direction are required to define it.

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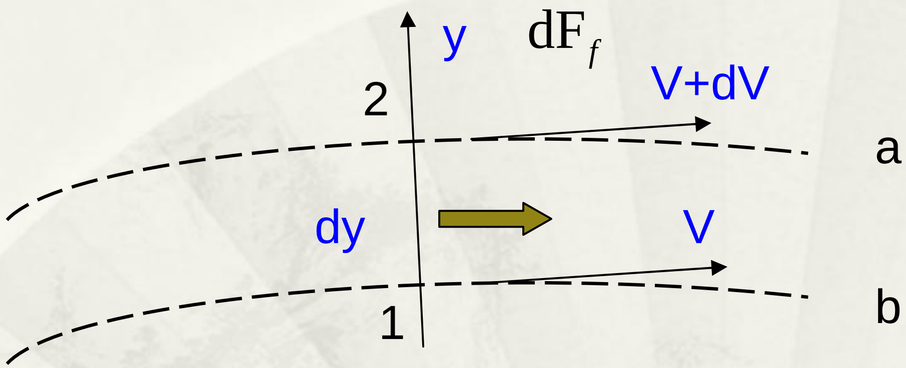
1.2 Some Fundamental Aerodynamic Variables



$$\tau = \lim\left(\frac{dF_f}{dA}\right)$$

Shear Stress: The limiting form of the magnitude of the frictional force per unit area, where the area of interest is perpendicular to the y axis and has shrunk to nearly zero at point 1.

$$\tau = \mu \frac{dV}{dy}$$

μ ,viscosity coefficient

dV/dy, velocity gradient

In reality, μ is a function of the temperature of the fluid.

Chapter 1 Introduction to Aerodynamics

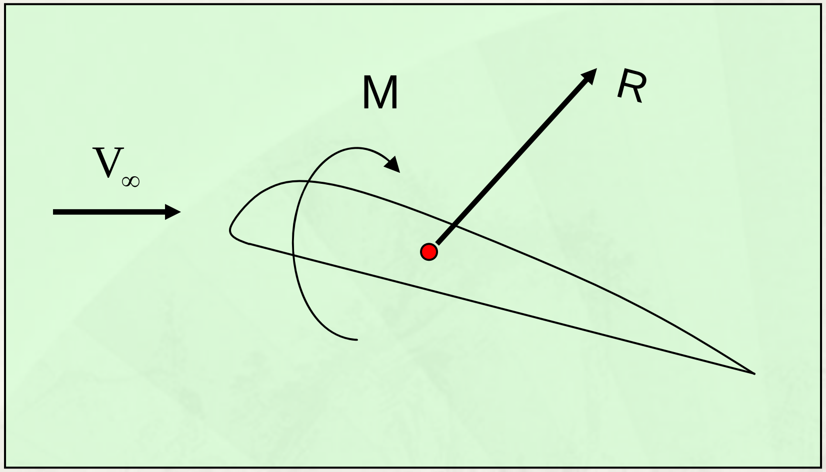
1.3 Aerodynamic Forces and Moments

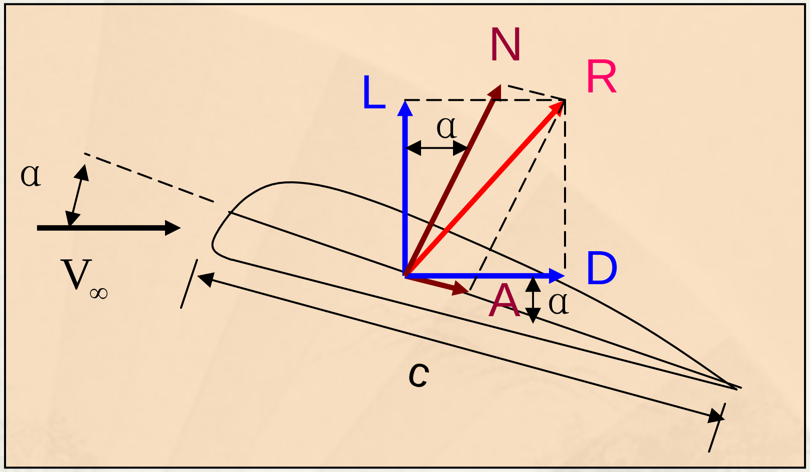
Two sources:	Pressure distribution over the body surface. Shear stress distribution over the body surface.

Illustration of pressure and shear stress on an aerodynamic surface

Chapter 1 Introduction to Aerodynamics

1.3 Aerodynamic Forces and Moments





L ≡ lift ≡ component of R perpendicular to V_∞

D ≡ drag ≡ component of R parallel to V_∞

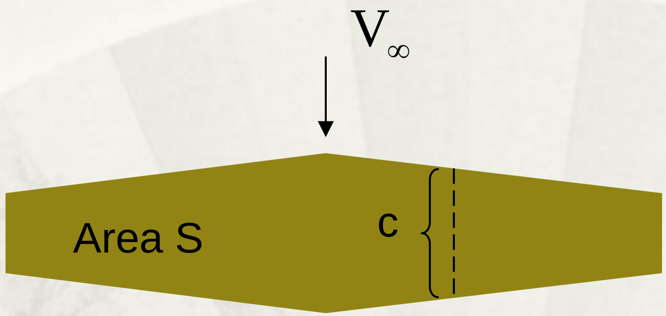
N ≡ normal force ≡ component of R perpendicular to c

A ≡ axial force ≡ component of R parallel to c

$$L = N\cos\alpha - A\sin\alpha$$

$$D = N\sin\alpha + A\cos\alpha$$

1.3 Aerodynamic Forces and Moments



S= planform area

l = c = chord length

Dynamic pressure: $$q_\infty \equiv \frac{1}{2}\rho_\infty V_\infty^2$$

The dimensionless force and moment coefficients:

$$C_L \equiv \frac{L}{q_\infty S} \quad C_D \equiv \frac{D}{q_\infty S} \quad C_N \equiv \frac{N}{q_\infty S} \quad C_A \equiv \frac{A}{q_\infty S} \quad C_M \equiv \frac{M}{q_\infty S l}$$

Pressure coefficient: $$C_p = \frac{p - p_\infty}{q_\infty}$$

Skin friction coefficient: $$C_f = \frac{\tau}{q_\infty}$$

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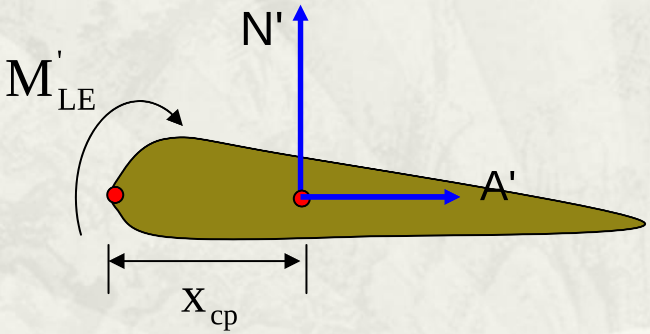
1.4 Center of Pressure

Questions: If the aerodynamic force on a body is specified in terms of a resultant single force R, or its components such as N and A, where on the body should this resultant be placed?

Answer: The resultant force should be located on the body such that it produces the same effect as the distributed loads.



The moment about the leading edge:

$$M'_{LE} = -(x_{cp})N'$$

$$x_{cp} = -\frac{M'_{LE}}{N'}$$

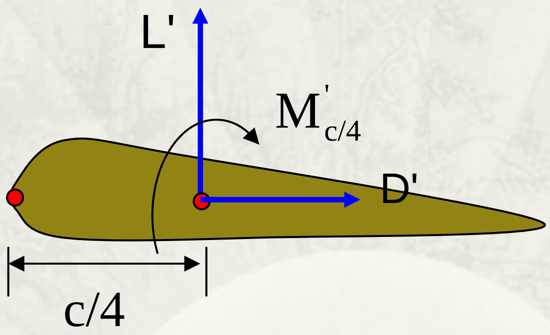
x_{cp} is defined as the center of pressure

1.4 Center of Pressure

When α is small: $\sin\alpha \approx 0 \quad \cos\alpha \approx 1 \quad L' \approx N'$

$$x_{cp} \approx -\frac{M'_{LE}}{L'}$$

As N' and L' decrease, x_{cp} increases. As the forces approach zero, the center of pressure moves to infinity.



Moment at the quarter-chord point: $M'_{LE} = -\frac{c}{4}L' + M'_{c/4}$

1.5 Dimensional Analysis: The Buckingham Pi Theorem

Questions: What physical quantities determine the variation of these forces and moments?

Answer: Dimensional analysis.

Dimensional analysis is based on the obvious fact that in an equation dealing with the real physical world, each term must have the same dimensions.

For example, if $\phi + \varphi + \psi = \beta$

Is a physical relation, then β, ϕ, ψ and Φ must have the same dimensions.

The above equation can be made dimensionless by dividing any one of the terms, say, β.

$$\frac{\phi}{\beta} + \frac{\varphi}{\beta} + \frac{\psi}{\beta} = 1$$

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1.5 Dimensional Analysis: The Buckingham Pi Theorem

Buckingham Pi Theorem:

Let K equal the number of fundamental dimensions required to describe the physical variables.(In mechanics, all physical variables can be expressed in terms of the dimensions of mass, length, and time; hence, K=3.) Let P_1, P_2, …., P_N represent N physical variables in the physical relation

$$f_1(P_1, P_2, \cdots, P_N) = 0$$

Then, the physical relation equation may be reexpressed as a relation of (N-K) dimensionless products (called π products),

$$f_2(\Pi_1, \Pi_2, \cdots, \Pi_{N-K}) = 0$$

Where each π product is a dimensionless product of a set of K physical variables plus one other physical variable.

1.5 Dimensional Analysis: The Buckingham Pi Theorem

Buckingham Pi Theorem:

Let P_1, P_2, …., P_K be the selected set of K physical variables. Then

$$\Pi_1 = f_3(P_1, P_2, \cdots, P_K, P_{K+1})$$
$$\Pi_2 = f_4(P_1, P_2, \cdots, P_K, P_{K+2})$$
$$\cdots\cdots\cdots\cdots\cdots\cdots$$
$$\Pi_{N-K} = f_{N\text{-}K}(P_1, P_2, \cdots, P_K, P_N)$$

The choice of the repeating variables, P1, P2,…,PK should be such that they include all the K dimensions used in the problem. Also, the dependent variable should appear in only one of the products.

Homework：read textbook from page 36 to page 38

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1.5 Dimensional Analysis: The Buckingham Pi Theorem

Similarity Parameters:

Reynolds Number: $$\mathrm{Re} = \frac{\rho_\infty V_\infty c}{\mu_\infty}$$

The ratio of inertia forces to viscous forces in a flow.

Mach Number: $$\mathrm{M} = V_\infty / a_\infty$$

The ratio of flow velocity to the speed of sound.

Prandtl Number: $$\mathrm{Pr} = \mu_\infty \mathrm{c}_p / k_\infty$$

The ratio of momentum diffusivity to thermal diffusivity.

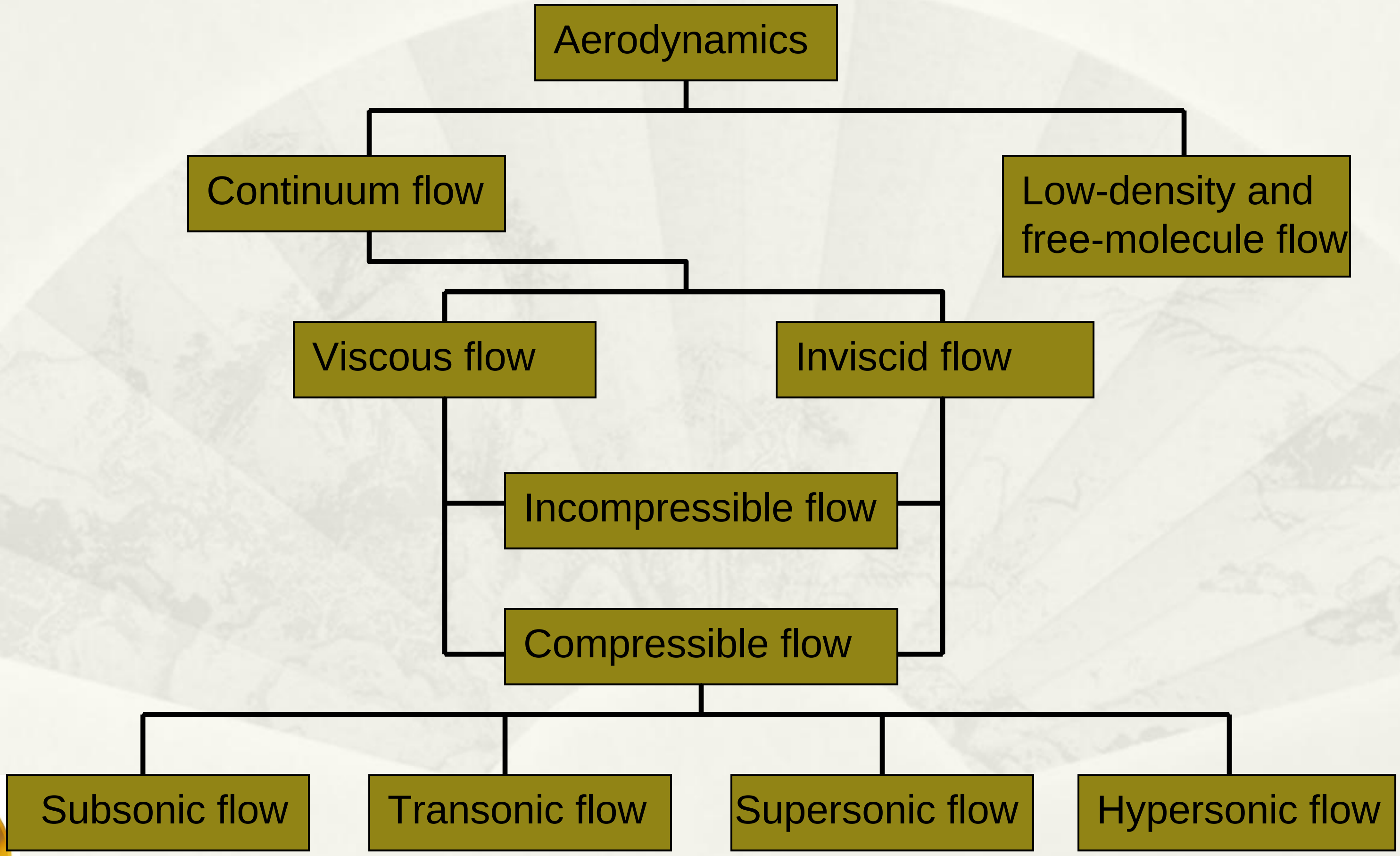
1.6 Flow Similarity

Two flows will be dynamically similar if:

1. The bodies and any other solid boundaries are geometrically similar for both flows.

2. The similarity parameters are the same for both flows.

1.7 Types of Flow



1.7 Types of Flow

Continuum Versus Free Molecule Flow:

The mean distance that a molecule travels between collisions with neighboring molecules is defined as the **mean-free path** λ.

1. Continuum Flow: If λ is orders of magnitude smaller than the scale of the body measured by *d*, the molecules impact the body surface so frequently that the body can not distinguish the individual molecular collisions.

2. Free Molecule Flow: If λ is on the same order as the body scale; here the gas molecules are spaced so far apart that collisions with the body surface occur only infrequently, and the body surface can feel distinctly each molecular impact.

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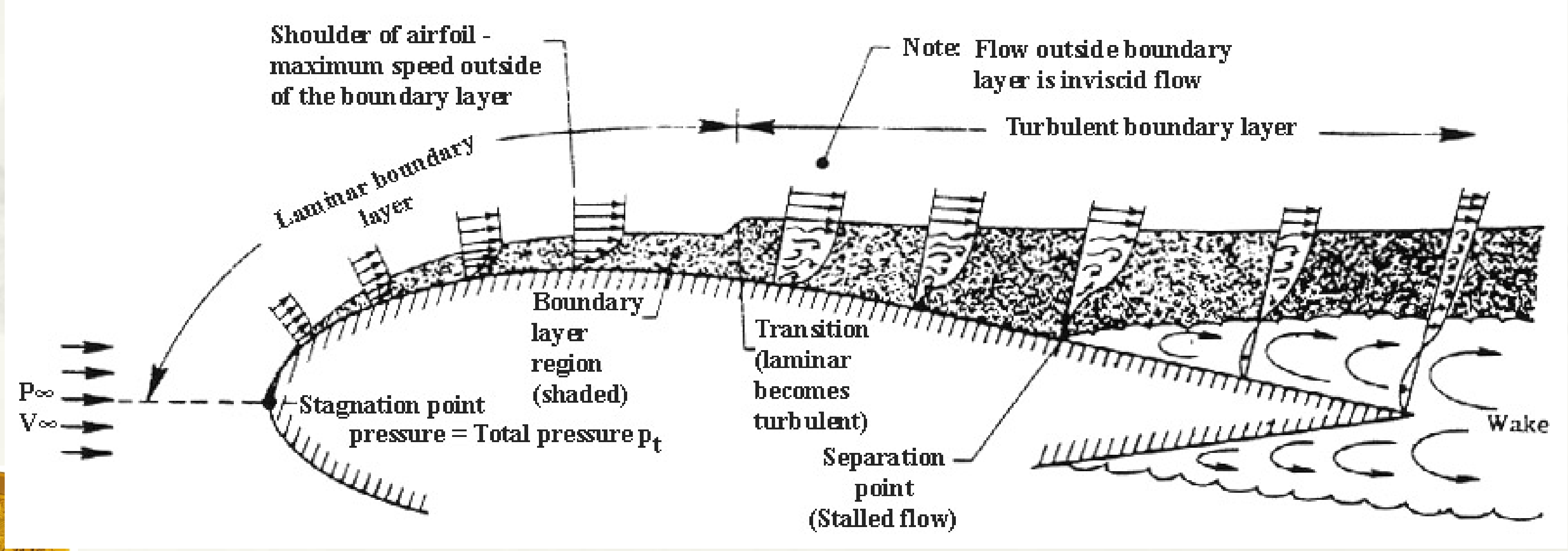
1.7 Types of Flow

Inviscid Versus Viscous Flow:

1. **Inviscid Flow**: does not involve friction, thermal conduction, or diffusion.

2. **Viscous Flow**: involve friction, thermal conduction and diffusion.



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1.7 Types of Flow

Incompressible Versus compressible Flow:

1. **Incompressible Flow**: Mach number is smaller than 0.3.
2. **Compressible Flow**: Mach number is lager than 0.3.

Mach Number Regimes:

1. **Subsonic**: M<1
2. **Sonic**: M=1
3. **Supersonic**: M>1

When M becomes large enough such that viscous interaction and/or chemically reacting effects begin to dominate the flow, the flow field is called hypersonic.

Chapter 1 Introduction to Aerodynamics

Report

Research Progress on a Specific Topic of Aerodynamics

1. Fixed-wing Airplane
2. Rocket
3. Helicopter
4. Automobile
5. Birds
6. Insects
7. Sports
8. Civil Engineering
9. Trains
10. Turbines
11. Anything else?

Thank you!!!