1.Introduction
Some Basic Concepts

1.What is a fluid?

A SUBSTANCE THAT CANNOT REMAIN STATIONARY IN THE PRESENCE OF SHEAR FORCE

2. What Properties Do Fluids Have?

- Density , ρ , kg/m^3
- Pressure , p , N/m^2 , Pa
- Temperature , T , K
- Viscosity μ (dynamic) kg/ms ; ν (kinematic) m^2/s $(\nu = \mu/\rho)$
- Velocity m/s , $\vec{V}$, $\mathbf{V}$, u, v, w, v_θ ......
- Compressibility

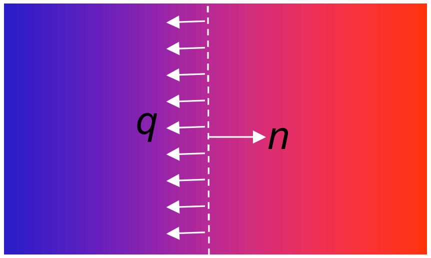
- CONTINUUM : (FLUID MATTER IS INFINITELY DIVISIBLE)

Fourier's Law of Heat Conduction

THERMAL CONDUCTIVITY

$$q = -k \frac{\partial T}{\partial n}$$

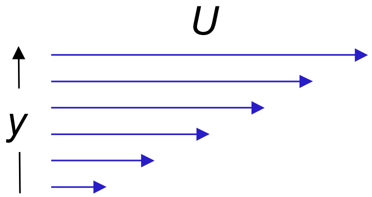
HEAT FLUX
PER AREA



Newton's Law of Viscosity

$$\tau = \mu \frac{\partial u}{\partial y}$$

Shear
STRESS



3. What Constrains Fluid Motion?

Vanguard Class Submarine

> CONSTITUTIVE RELATIONS

> BOUNDARY CONDITIONS

> CONSERVATION LAWS

- CONS. OF MASS
- CONS. OF MOMENTUM
- CONS OF ENERGY

Two Important Parameters

Rate of change of momentum (inertial force)	=	Sum of pressure forces, viscous forces and body forces

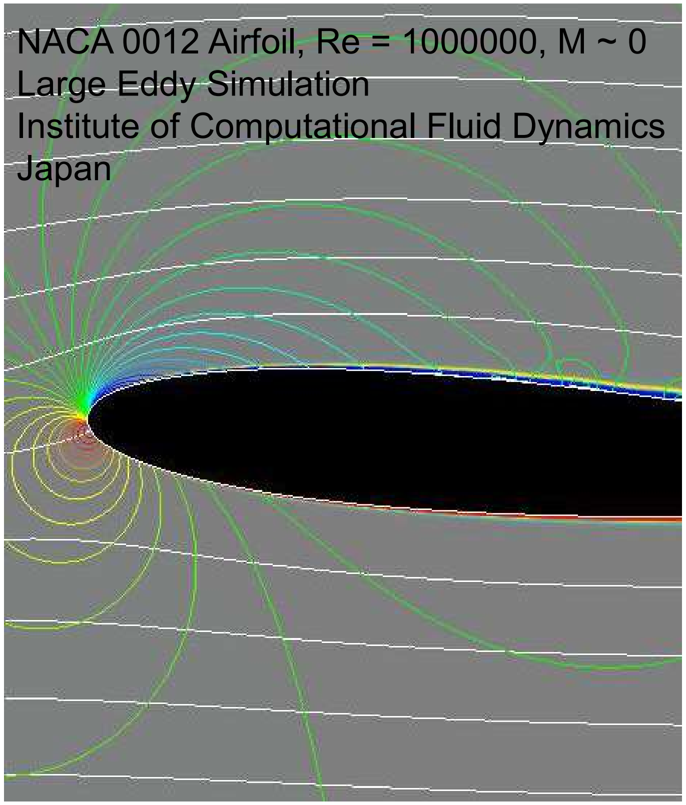
$$\text{MACH NO.} = \sqrt{\frac{\text{INERTIAL FORCES}}{\text{FORCES RESISTING COMPRESSION}}}$$

$$= V/a$$

a ← SPEED OF SOUND

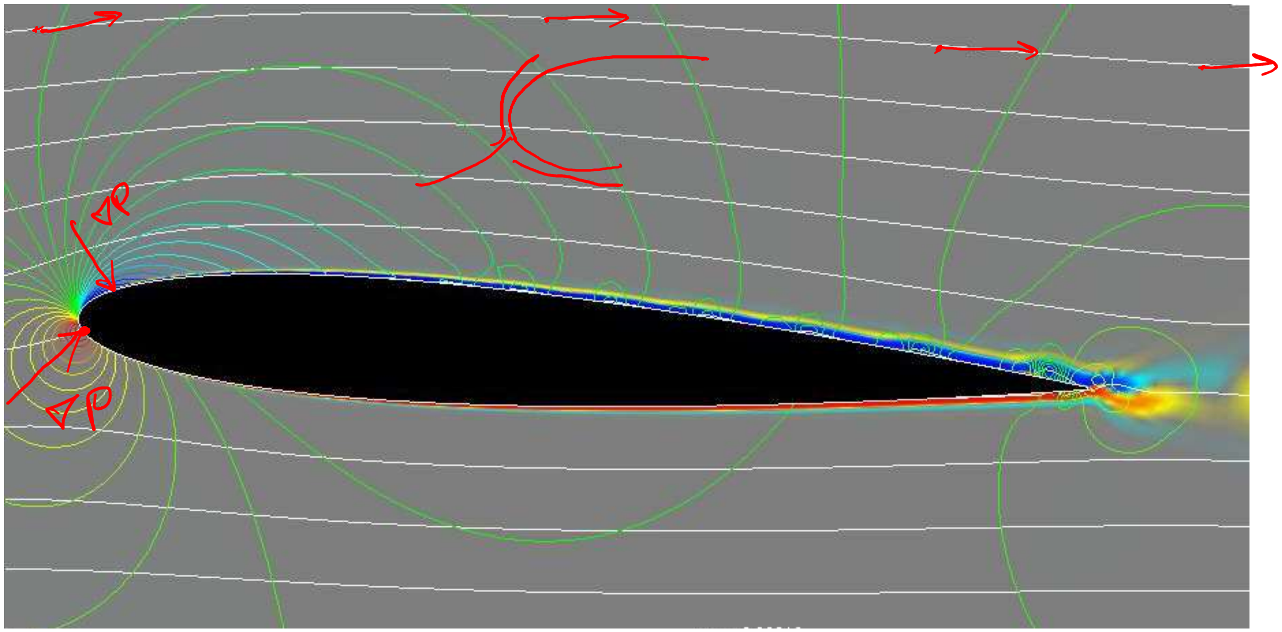
$$\text{REYNOLDS NUMBER} = \frac{\text{INERTIAL FORCES}}{\text{VISCOUS FORCES}}$$

$$\left(\text{FROUDE No} = \frac{\text{INERTIAL FORCES}}{\text{BODY FORCES}}\right)$$



3a. Ideal Flow

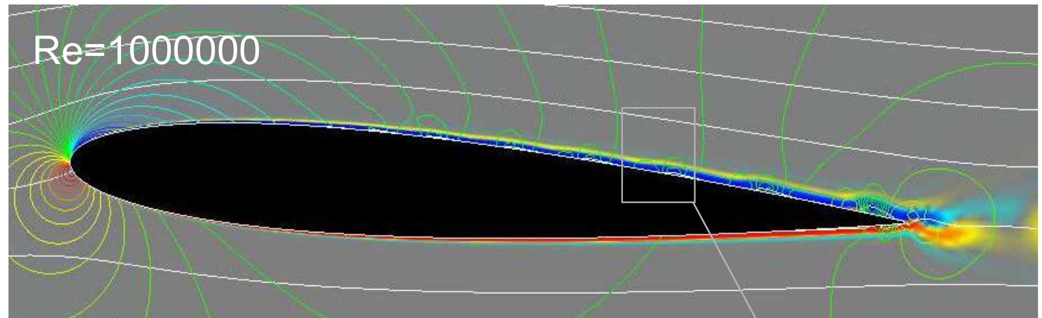
Viscous and compressible effects small (large Re, low M). *Flow is a balance between inertia and pressure forces, i.e. acceleration vector balances the pressure gradient vector*



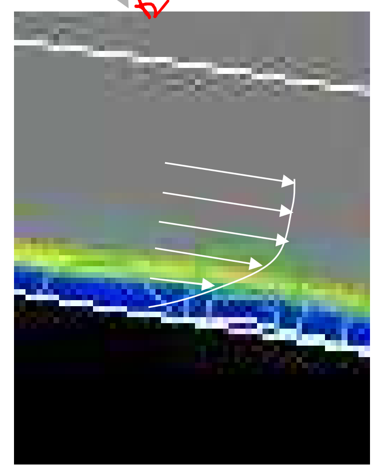
Streamline: A LINE EVERYWHERE TANGENT TO THE VELOCITY

3b. Viscous Flow

Importance of viscous effects governed by $\mathrm{Re} = \frac{VL}{\nu}$



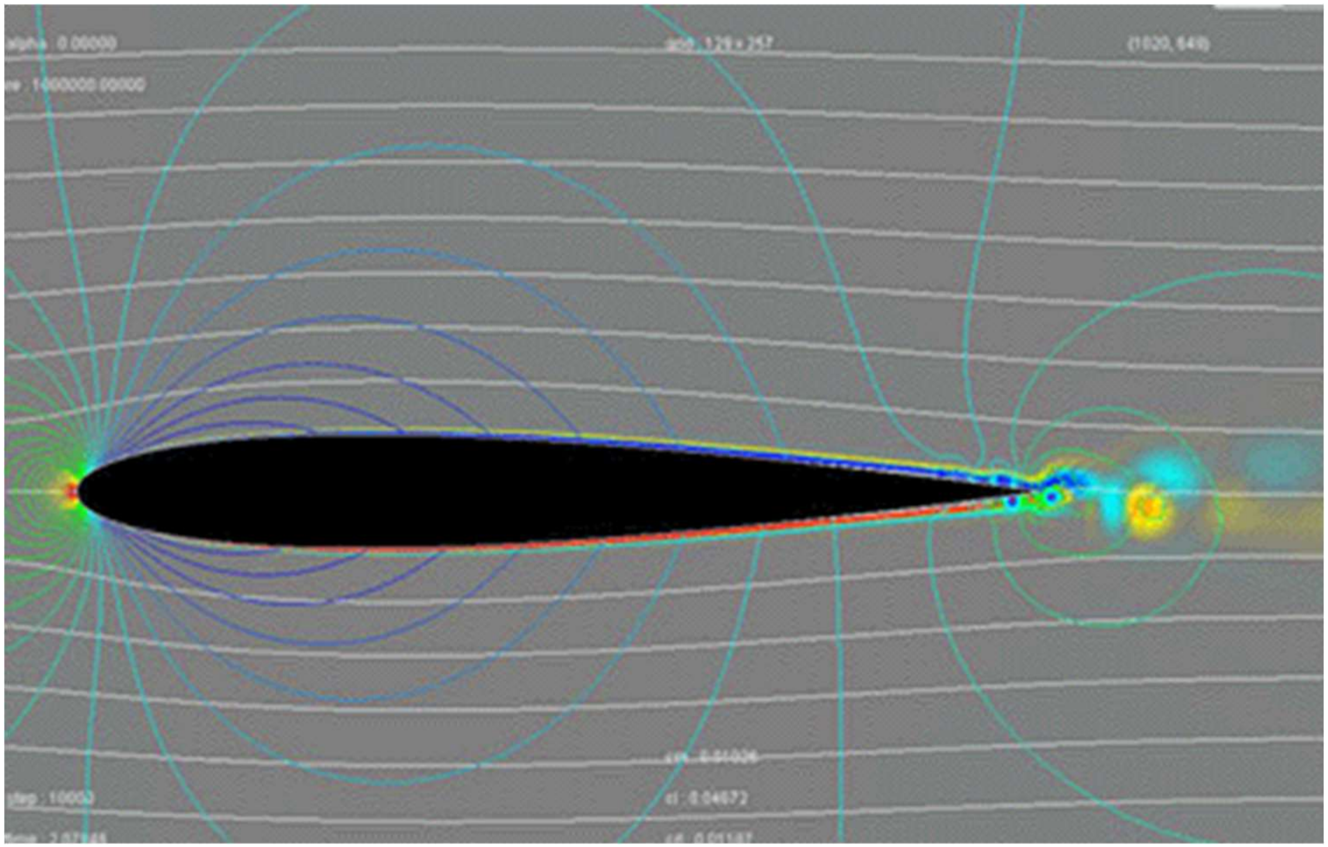
Boundary layer: THIN REGION ADJACENT TO A SOLID SURFACE WHERE FRICTION SLOWS THE FLOW



What is the pressure gradient across a boundary layer?

No-slip condition: FLUID ADJACENT TO A SURFACE DOESNOT MOVE RELATIVE TO IT

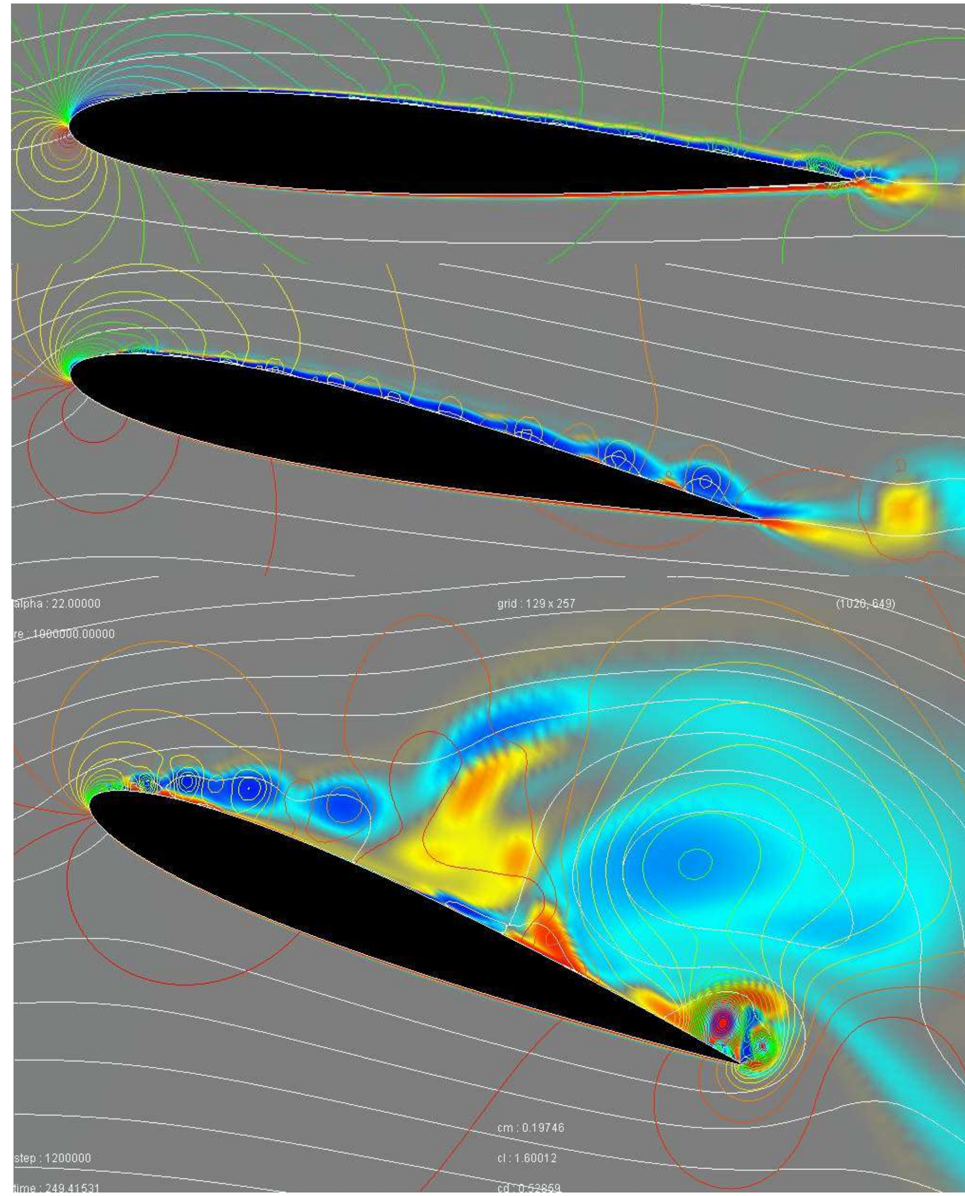
Varying angle of attack



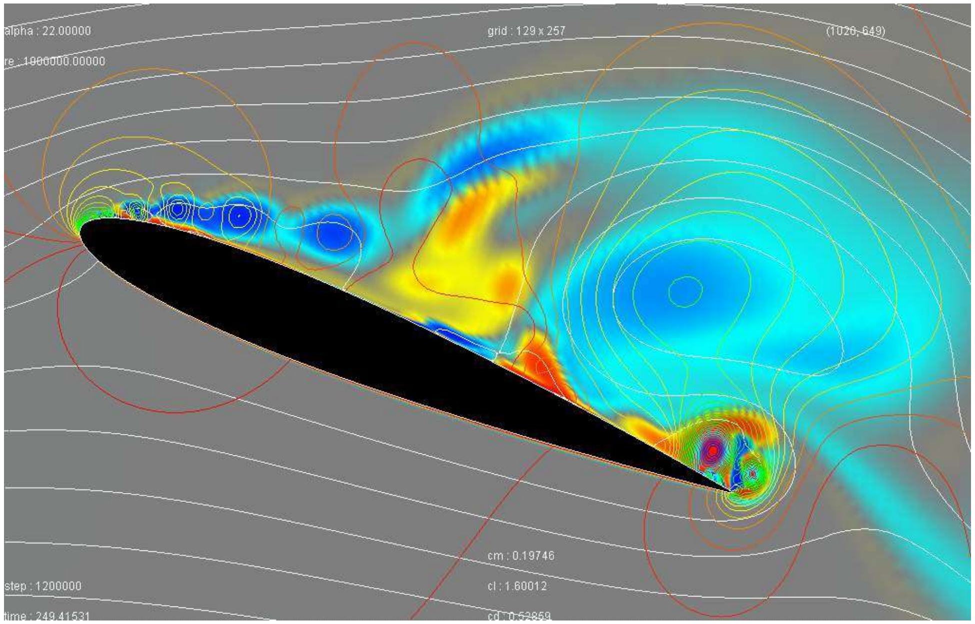
3b Viscous Flow

Viscous region not always confined to a thin layer

Separation: Large region of viscous flow produced when the boundary layer leaves a surface because of an adverse pressure gradient, or a sharp corner



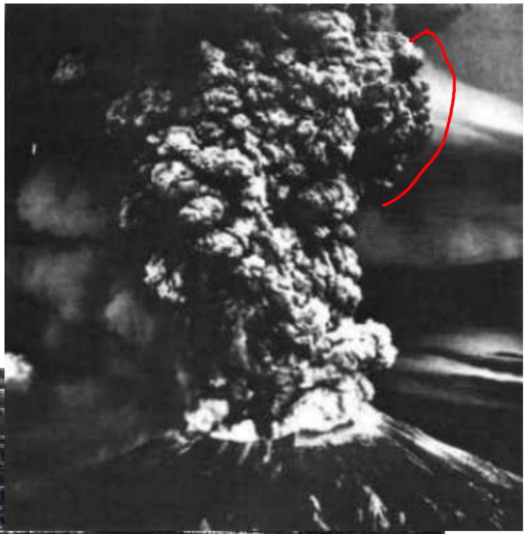
3b Viscous Flow

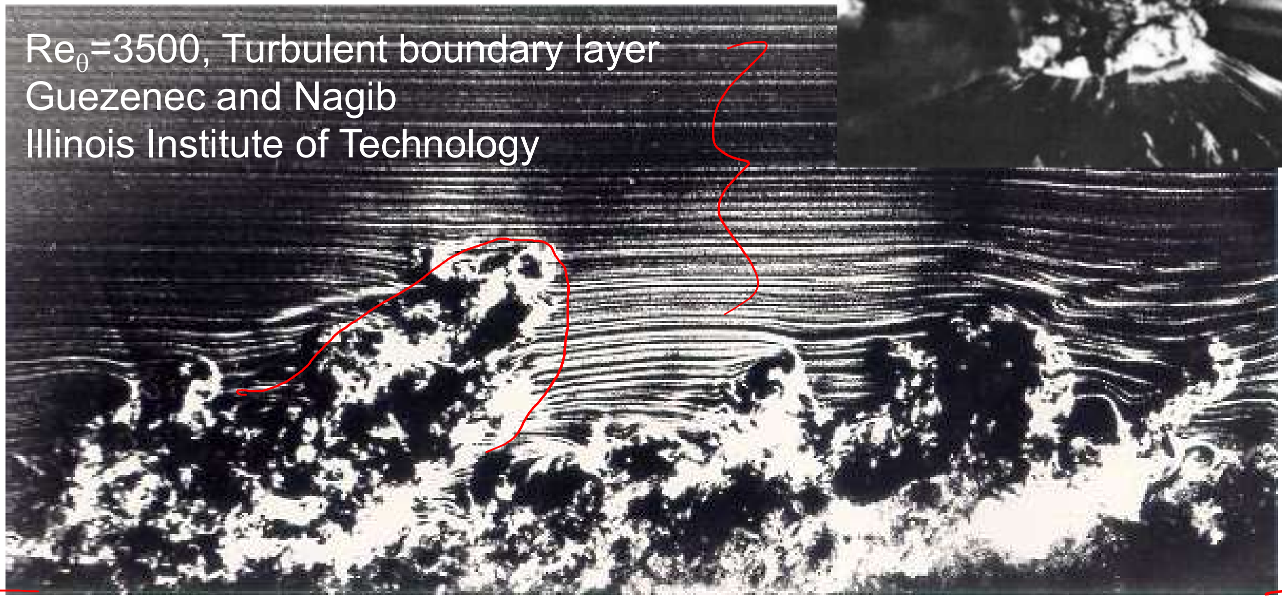


Turbulence: Chaotic motion and mixing on many scales initiated by viscous instability

Laminar Flow: Flow moves in ordered layers mixing only on a molecular scale

Turbulence

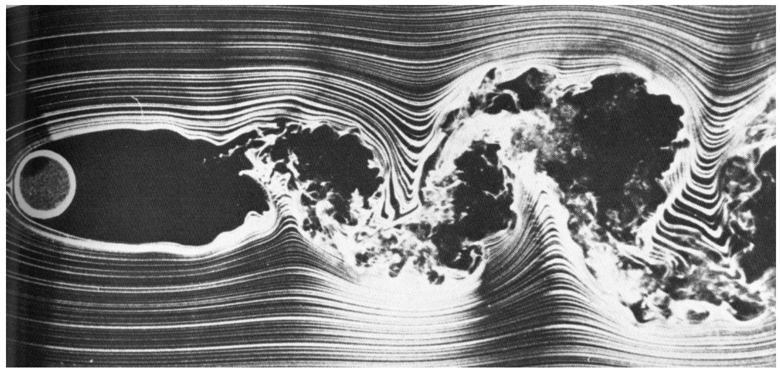



Re$_\theta$=3500, Turbulent boundary layer
Guezenec and Nagib
Illinois Institute of Technology

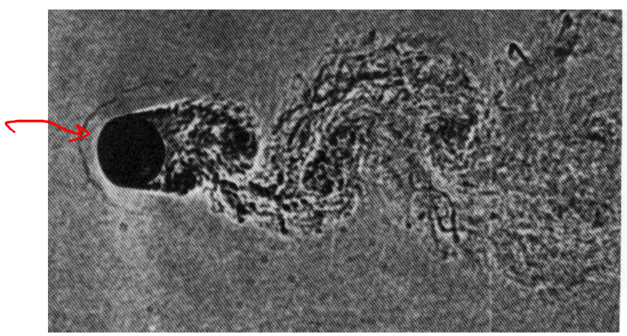
3c. Compressibility

Importance of compressibility effects governed by $M = \dfrac{V}{c}$ (speed of sound)

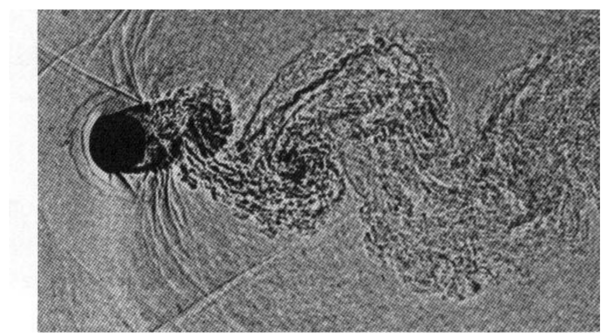
Flow Past a Circular Cylinder



Re = 10,000 and Mach approximately zero



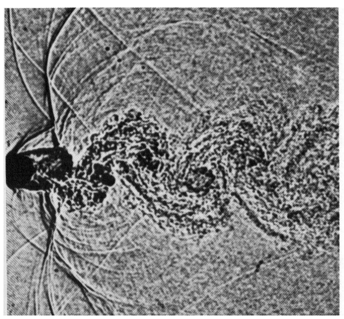
Re = 110,000 and Mach = 0.45



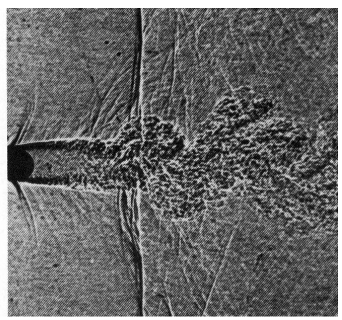
Re = 1.35 M and Mach = 0.64

Pictures are from *“An Album of Fluid Motion”* by Van Dyke

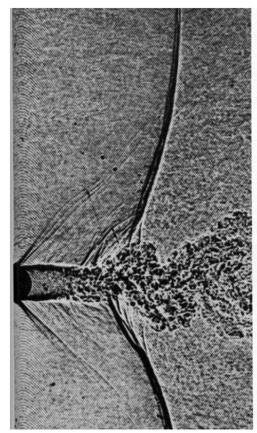
Flow Past a Circular Cylinder



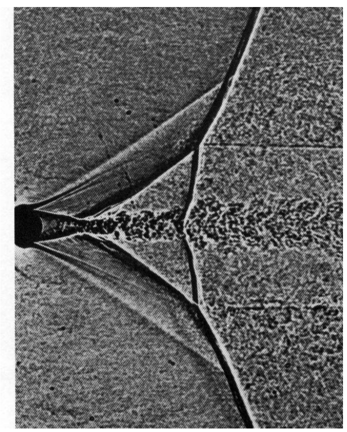
Mach = 0.80



Mach = 0.90



Mach = 0.95



Mach = 0.98

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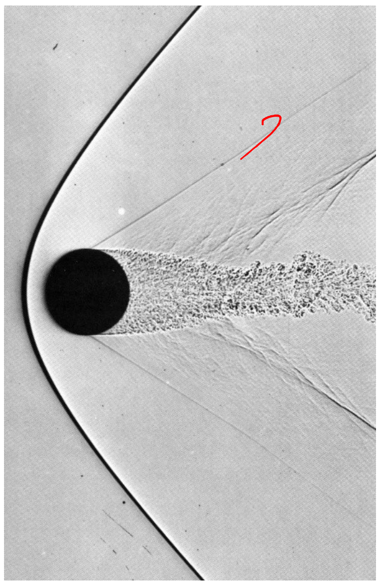
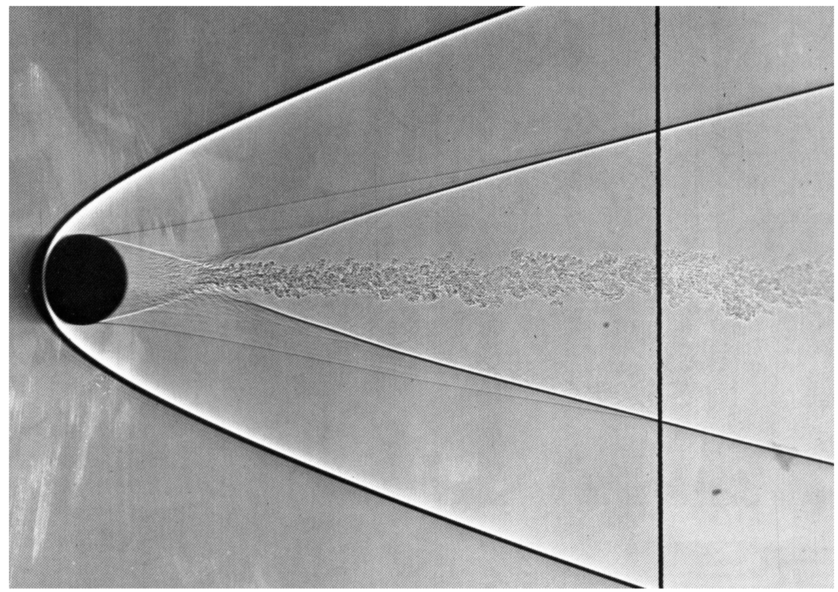
Flow Past a Sphere



Mach = 1.53



Mach = 4.01

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3c. Compressibility

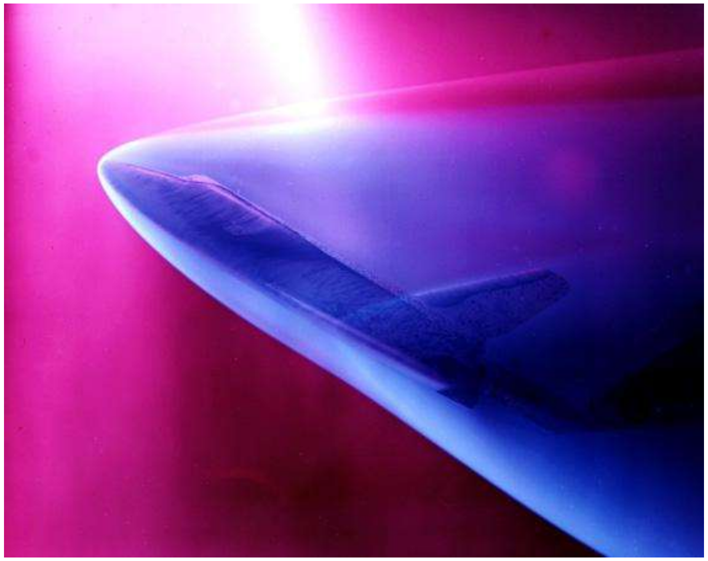
Importance of compressibility effects governed by $M = \dfrac{V}{c}$

- Incompressible Regime $M<0.3$
  - Negligible compressibility effects
- Subsonic Regime $0.3<M<0.7$
  - Quantitative effects, no qualitative effects
- Transonic Regime $0.7<M<1.3$
  - Large regions of subsonic and supersonic flow. Large qualitative effects.
- Supersonic Regime $M>1.3$
  - Almost entirely supersonic flow. Large qualitative effects

3c. Compressibility

Some Qualitative Effects

Shock wave: Very strong, thin wave, propagating supersonically, producing almost instantaneous compression of the flow, and increase in pressure and temperature.

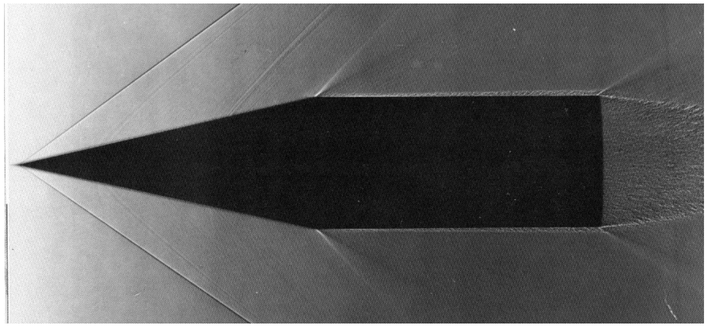


Hypersonic vehicle re-entry
NASA Image Library

3c. Compressibility

Some Qualitative Effects

- Expansion or isentropic compression wave: Finite wave (often focused on a corner), moving at the sound speed, producing gradual compression or expansion of a flow (and raising or lowering of the temperature and pressure).



Cone-cylinder in supersonic free flight, Mach = 1.84.
Picture from *"An Album of Fluid Motion"* by Van Dyke.