Fall 2022, undergraduate course

Fluid Mechanics

Hyungmin Park

Multiphase Flow and Flow Visualization Lab.

서울대학교 기계공학부
DEPARTMENT OF MECHANICAL ENGINEERING
SEOUL NATIONAL UNIVERSITY

Multiphase Flow and
Flow Visualization Lab.

Course Introduction

- Fluid Mechanics 001 (M2794.001300, 001)
- Prof. Hyungmin Park(박형민)
  - Office: 301동 1405호 (Tel: 880-4159)
  - Email: hminpark@snu.ac.kr
  - Office hour: with appointment

- Goals
  - In this course,
    - we study the basic theories and concepts of fluid dynamics and derive the governing equations to describe the relevant phenomena
    - to possess the capability of understanding and analyzing the fluid mechanics phenomena occurring in the diverse industrial and natural environments.

Course Introduction

- Textbook
  - Main
    - Fluid Mechanics (F. M. White), McGraw-Hill Higher Education
    - Lecture Notes (to be uploaded after each class)
    - Supplementary materials – **please check "eTL" frequently**
  - References
    - Viscous Fluid Flow (F. White)
    - Boundary Layer Theory (H. Schlichting)
    - ETC.

- Evaluation
  - Attendance (10%), Homework (15%), Midterm1 (20%), Midterm2 (20%), Final (35%)

Course Introduction

- Scope (Schedule) – to be operated flexibly
  - Ch.1
    - Concept of fluid, Continuum, Properties of fluid flow, Dimensions and units, Basic flow analysis techniques, Flow patterns
  - Ch.2
    - Pressure and pressure gradient, Hydrostatic pressure
  - Ch.3
    - Basic physical laws of fluid mechanics, Reynolds transport theorem, Control volume analysis
  - Ch.4
    - Equations for mass and linear momentum conservation - continuity and Navier-Stokes equation

Course Introduction

❑ Scope (Schedule) – to be operated flexibly

- Ch.5
  - Principle of dimensional homogeneity, Non-dimensional parameters, Pi-theorem
- Ch.6
  - Internal viscous flows, laminar vs. turbulent flows, skin-friction drag
- Boundary-layer theory

TA info

- 여지은(yeojieun@snu.ac.kr), 김대일(rlaeodlf7598@snu.ac.kr)
- Lab. Location: 313동 222호 (Tel: 880-9161)

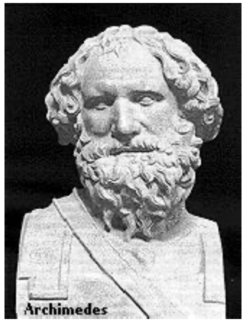
- TA Hour
  - Flipped learning (online) – TA video will be uploaded in eTL biweekly
  - Q&A
  - To solve example problems
  - To derive theory/equation, not covered in the lecture
  - Some stuffs covered in TA hour will be reflected in the exams.

Fluid Mechanics

- Fluids essential to life
  - Human body 65% water
  - Earth' s surface is 2/3 water
  - Atmosphere extends 17 km above the earth' s surface
- History shaped by fluid mechanics
  - Geomorphology
  - Human migration and civilization
  - Modern scientific and mathematical theories and methods
  - Warfare
- Affects every part of our lives

History

Faces of Fluid Mechanics



Archimedes
(C. 287-212 BC)

Newton
(1642-1727)

Leibniz
(1646-1716)

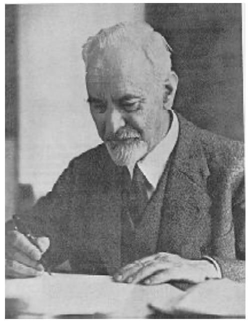
Bernoulli
(1667-1748)

Euler
(1707-1783)

Navier
(1785-1836)

Stokes
(1819-1903)

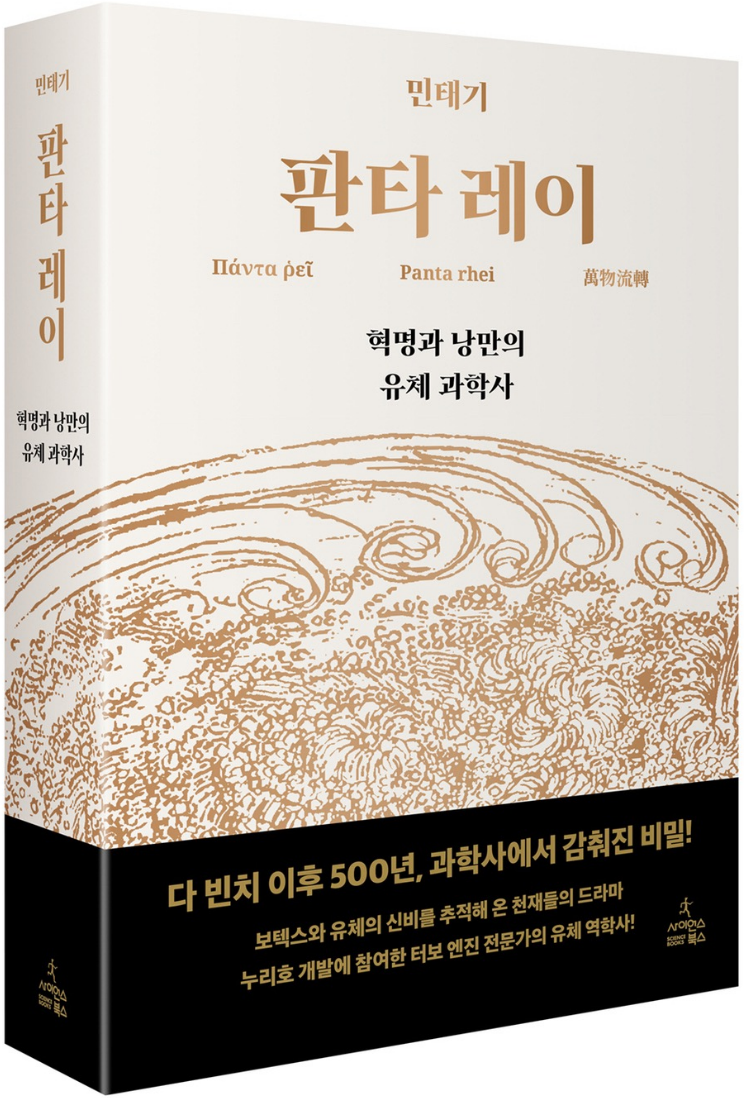
Reynolds
(1842-1912)



Prandtl
(1875-1953)

Taylor
(1886-1975)

History



민태기 박사 강연
기계산업경영2

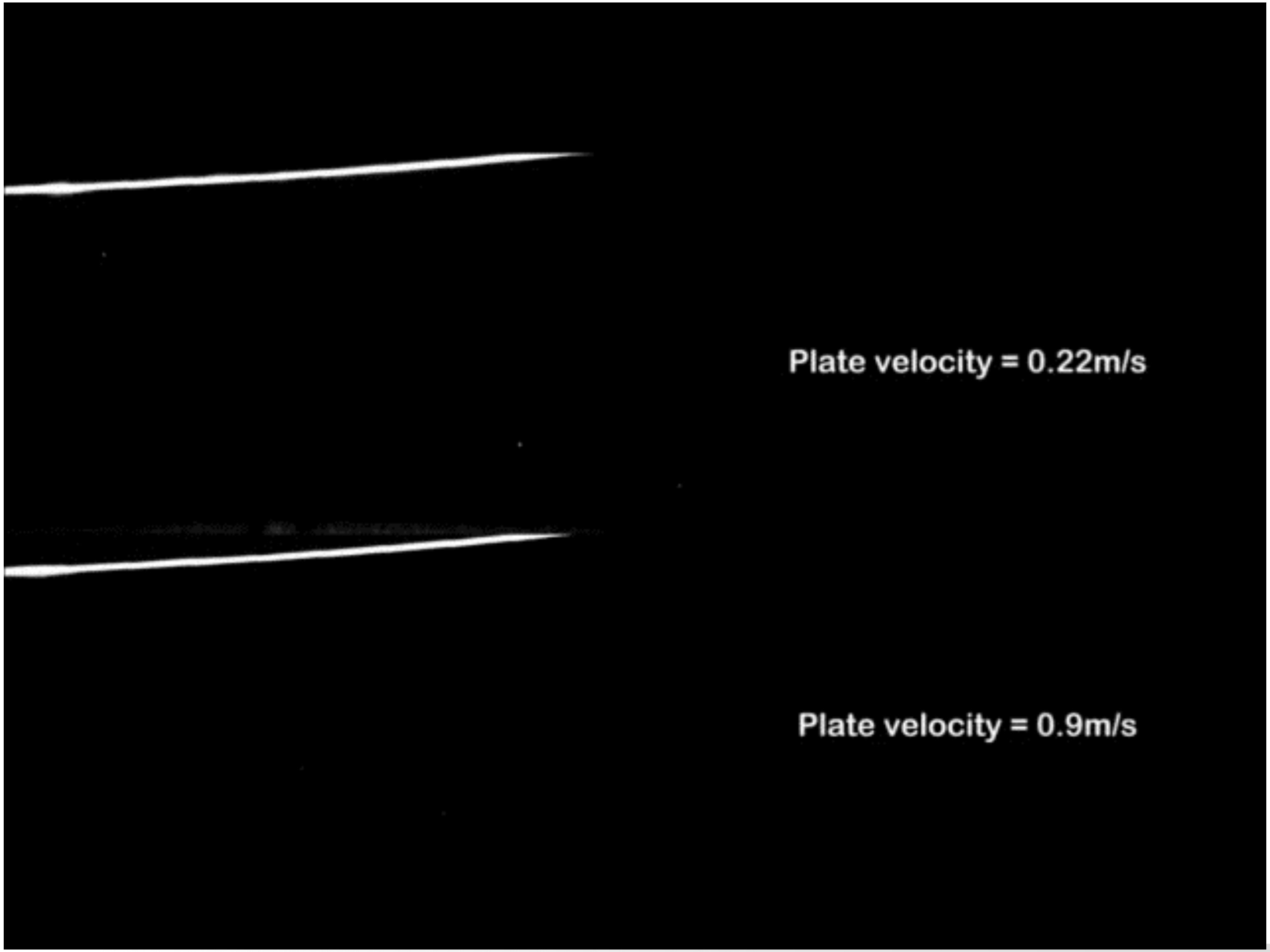
"경계를 뛰어넘은 과학자들"

9월 14일 16:00 301동 118호

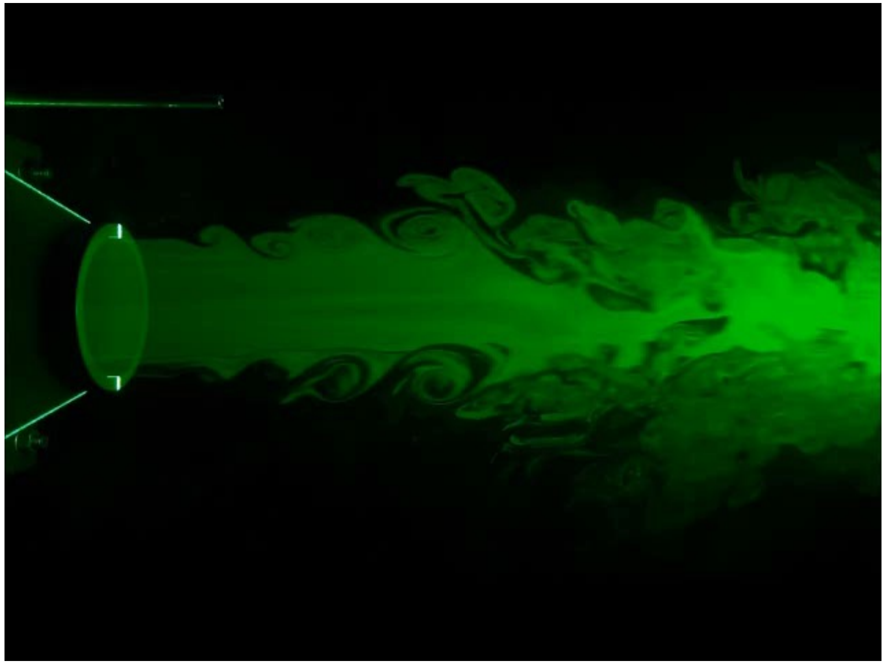
Significance

- Fluids omnipresent
    - Weather & climate
    - Vehicles: automobiles, trains, ships, and planes, etc.
    - Environment
    - Energy
    - Biology
    - Semiconductor industry
    - Physiology, medicine, and virus
    - Sports & recreation
    - Many other examples!

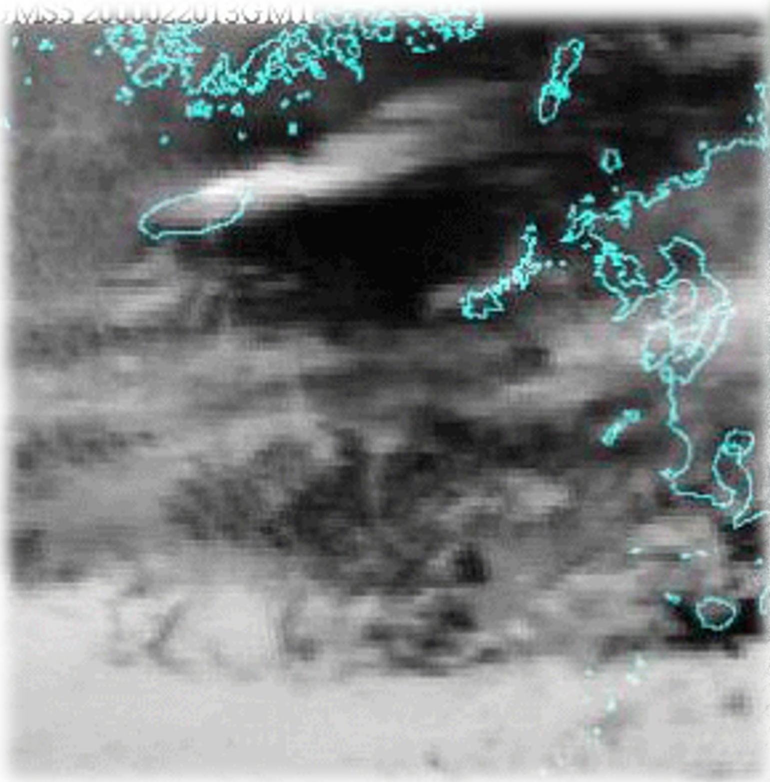
Boundary-layer flow (경계층 유동)

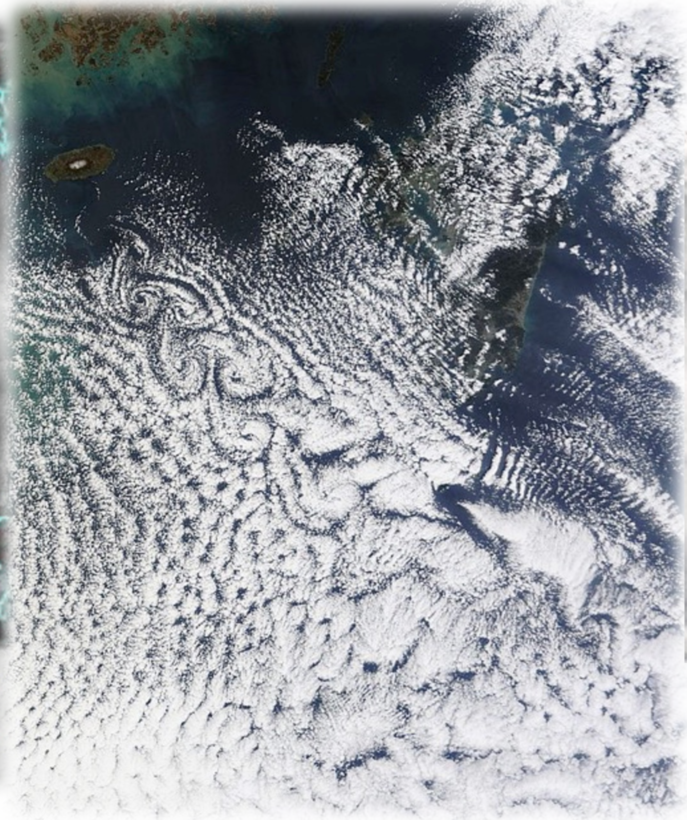


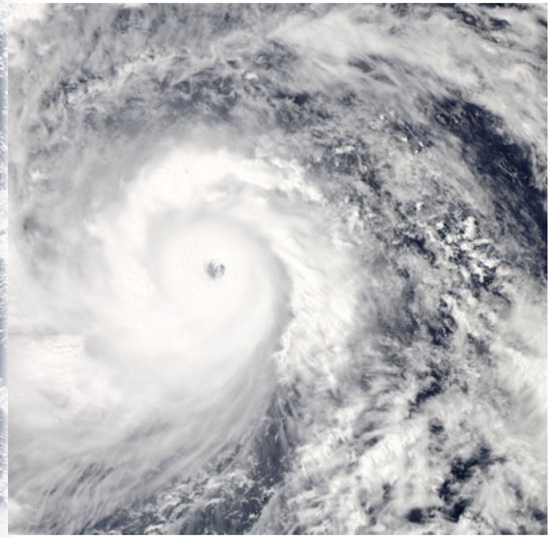
Kelvin-Helmholtz instability (Karman vortex street)



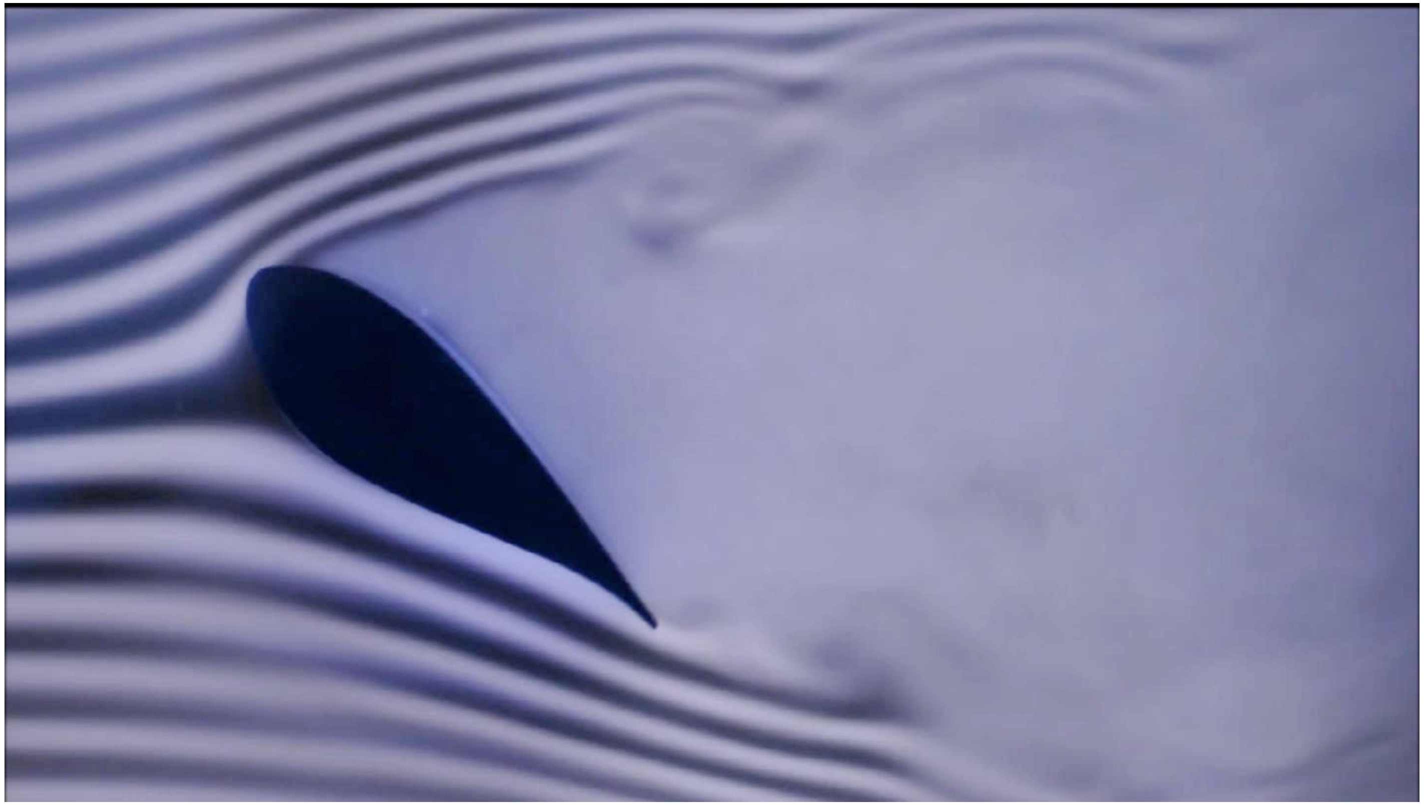
Kelvin-Helmholtz instability (Karman vortex street)



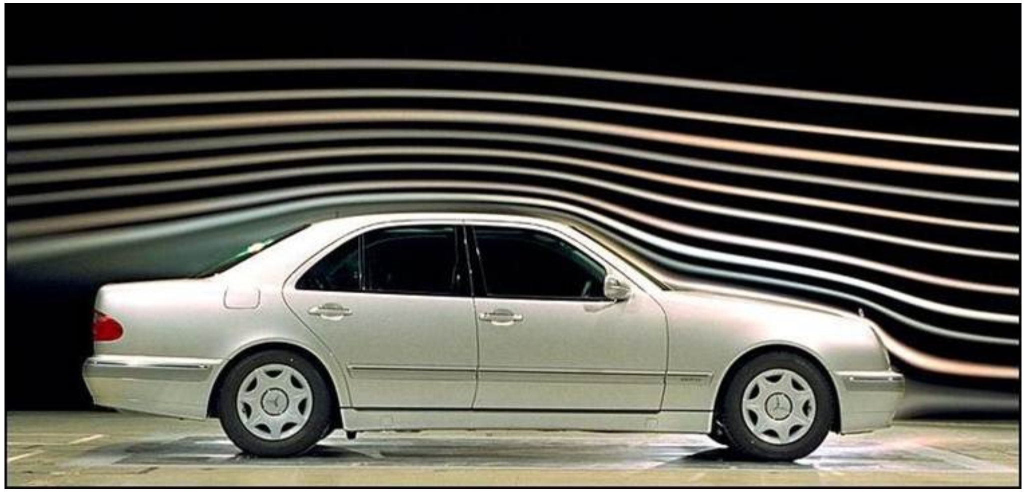


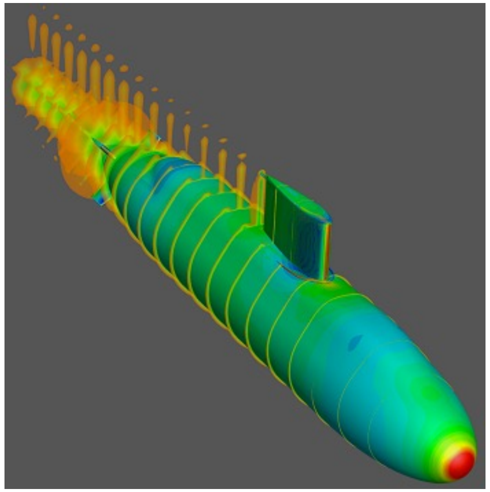


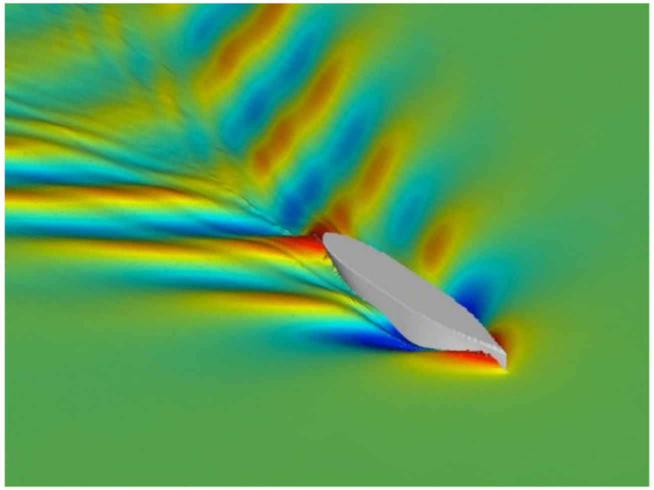
Flow around a streamlined body

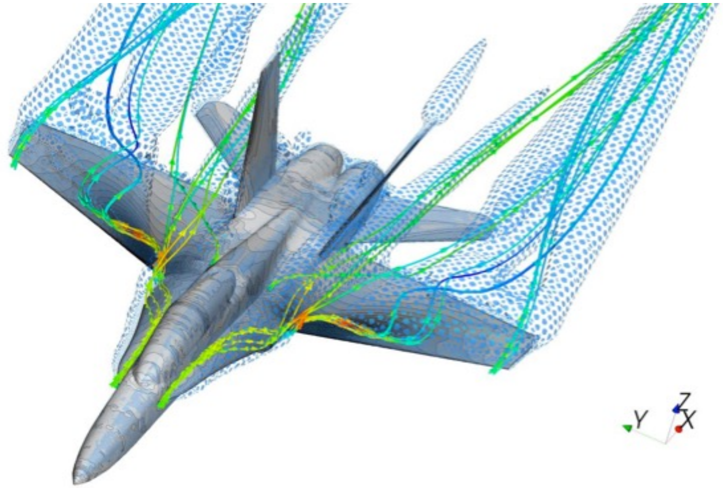


Diverse flows in industry…









Vehicles

Vehicles

MK 뉴스 인쇄하기 취 소

4000만원대 `포르쉐 킬러`, 대박났다…`역대급` 아이오닉6, 계약 신기록 [왜 몰랐을카]

올해 목표보다 `3배` 이상 많아
당초 공개가격보다 300만원↓
보조금 100% 가격 `화룡점정`
타이칸보다 공간·전비 한수 위

최기성 기자 입력 : 2022.08.23 15:48:31 수정 : 2022.08.23 2


공기역학 성능, 타이칸·모델S보다 우수

https://www.mk.co.kr/news/print/2022/744910 5페이지/8페이

MK 뉴스 기사 인쇄하기 2022. 8. 29. 오후 12:1

△포르쉐 타이칸 [사진출처=포르쉐]

아이오닉6을 고성능 전기차 시장을 주도하는 포르쉐 타이칸, 테슬라 모델S와 비교하면 성능의 우수성을 파악할 수 있다.

아이오닉6는 전장x전폭x전고가 4855x1880x1495mm다. 현대차 쏘나타는 4900x1860x1445mm다. 쏘나타보다 짧지만 넓고 높다.

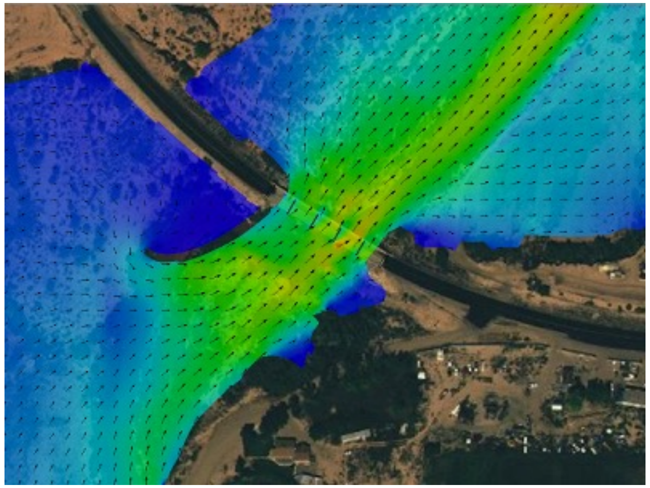
포르쉐 타이칸(4965x1965x1380mm)과 테슬라 모델S(4979x1964x1435mm)보다는 짧고 좁지만 높다.

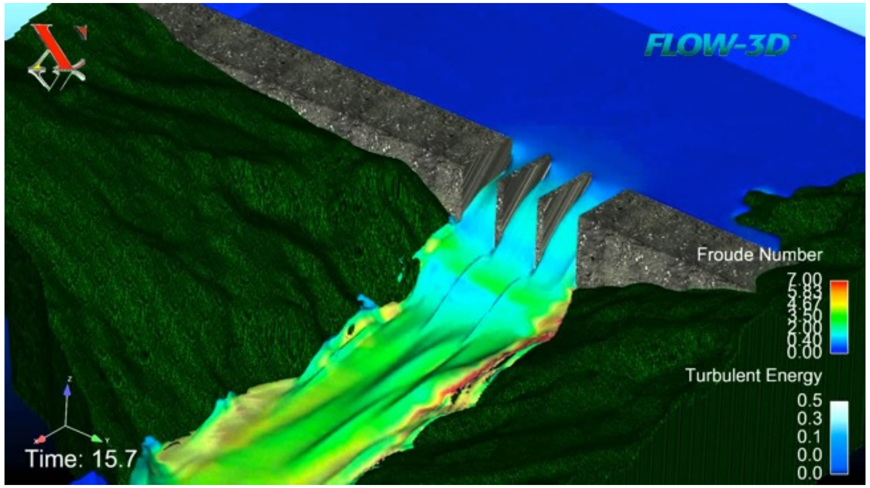
휠베이스는 2950mm에 달한다. 쏘나타(2840mm), 타이칸(2900mm)보다 길다. 현대차 아이오닉5(3000mm)보다는 짧지만 대형 SUV인 팰리세이드(2900mm)보다 길다.

그만큼 실내공간이 넉넉하다. '공간 마술사'라 부르는 현대차의 노하우와 전기차 전용 플랫폼이 결합한 효과다.

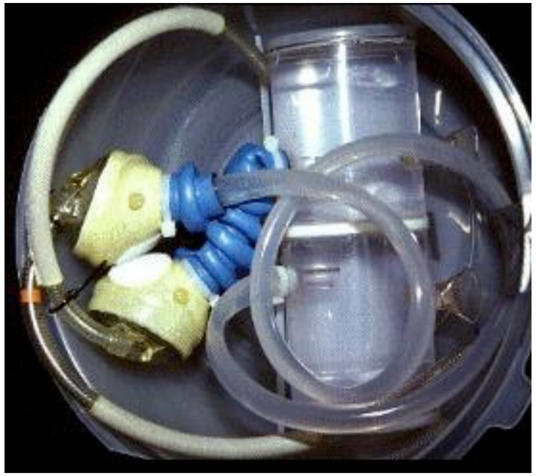
공기저항계수는 0.21에 불과할 정도로 우수하다. 아이오닉5(0.28)보다 대폭 개선했다.

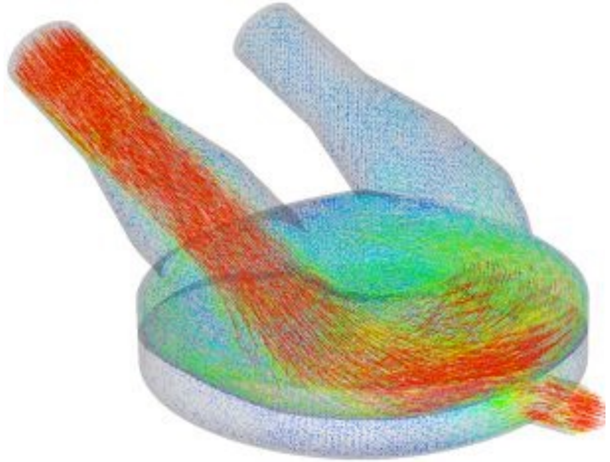
Environment



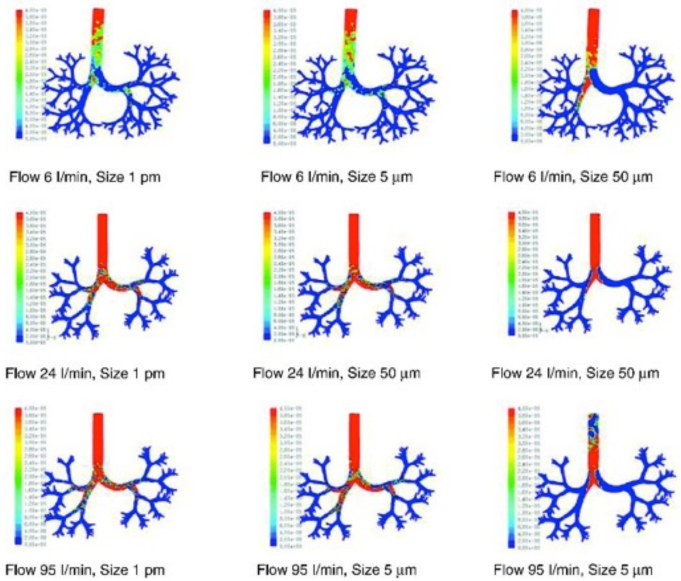


Physiology and Medicine

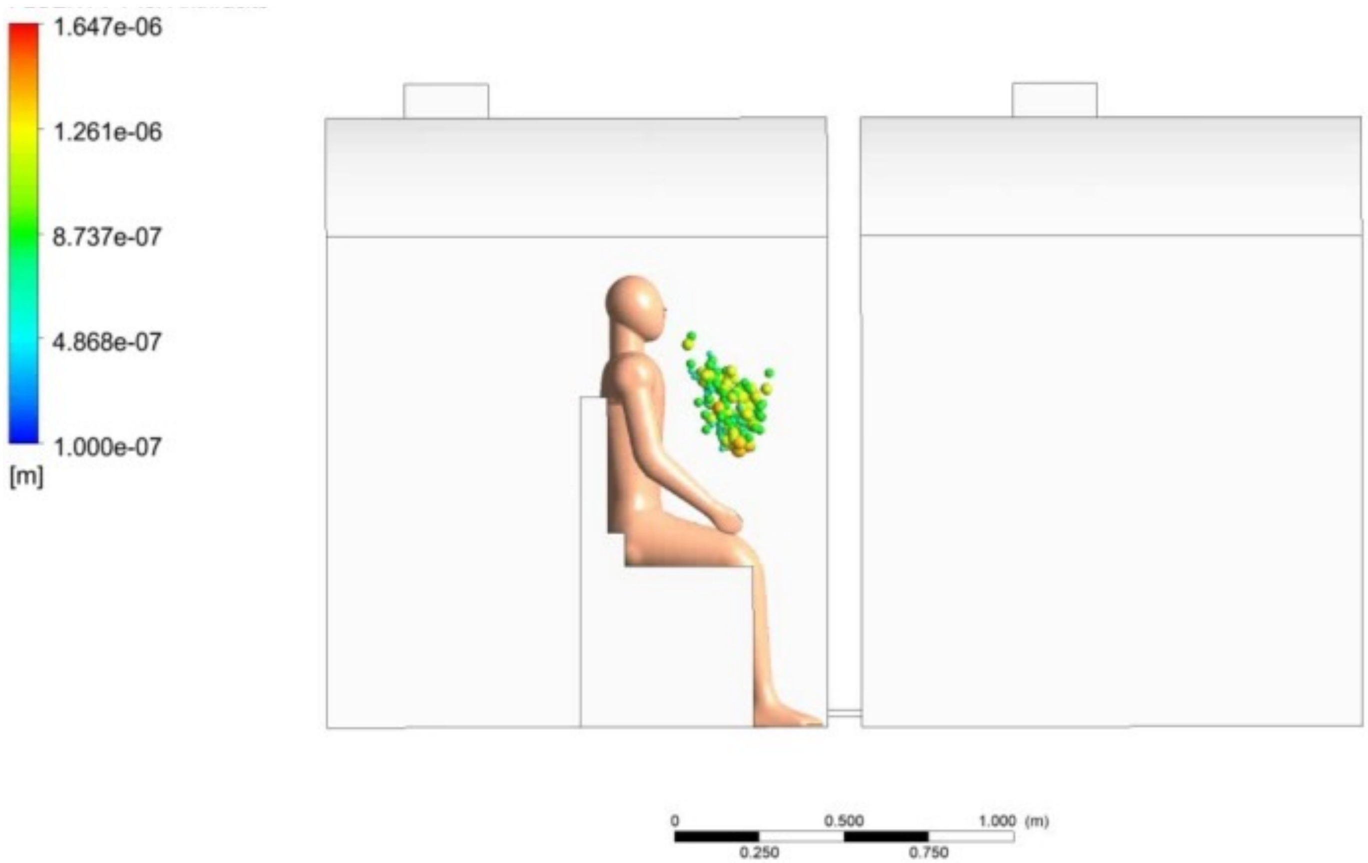




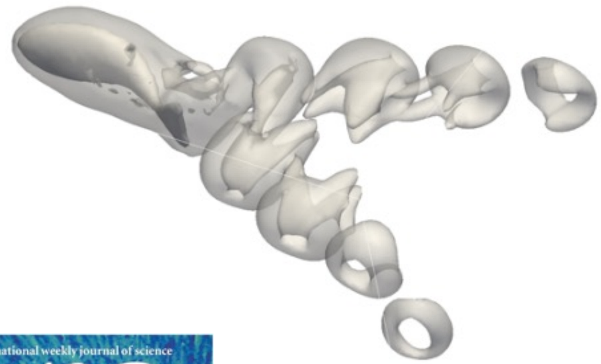
Ventricular assist device

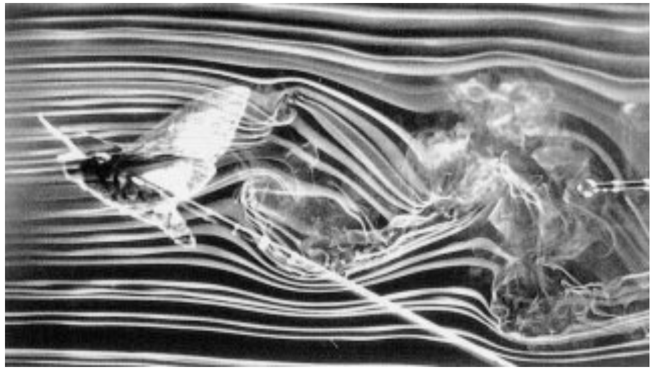


Physiology and Medicine

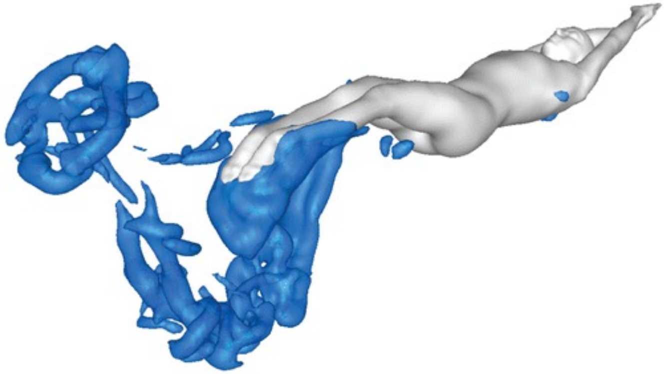


Flows in Nature

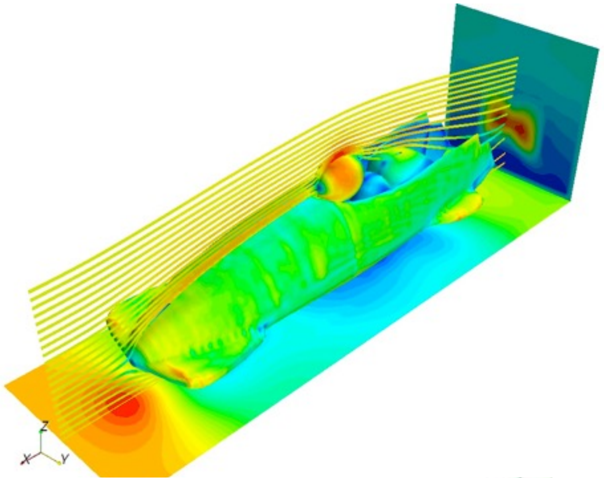


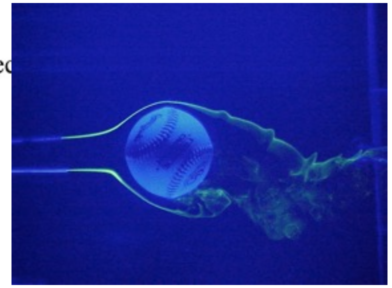


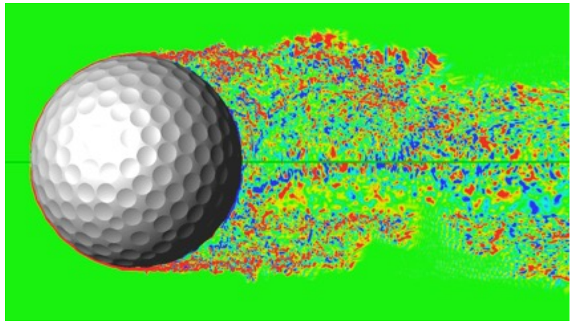
Sports & Recreation

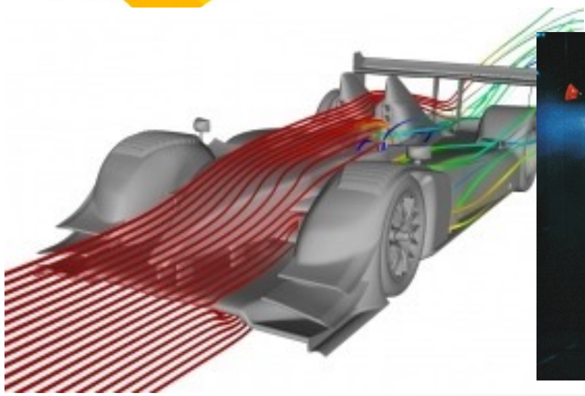


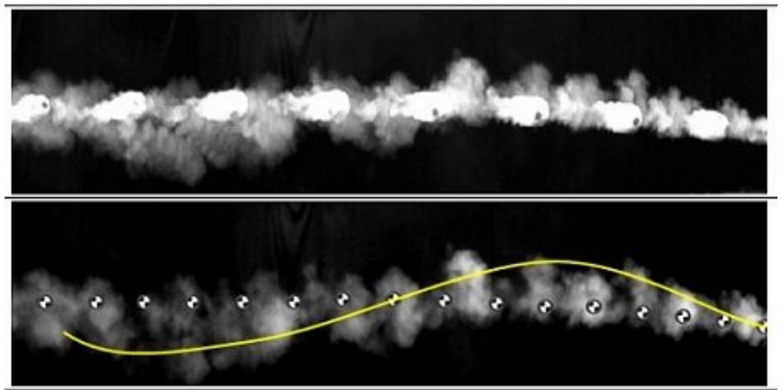
Wei T, et al. 2014.
Annu. Rev. Fluid Mec



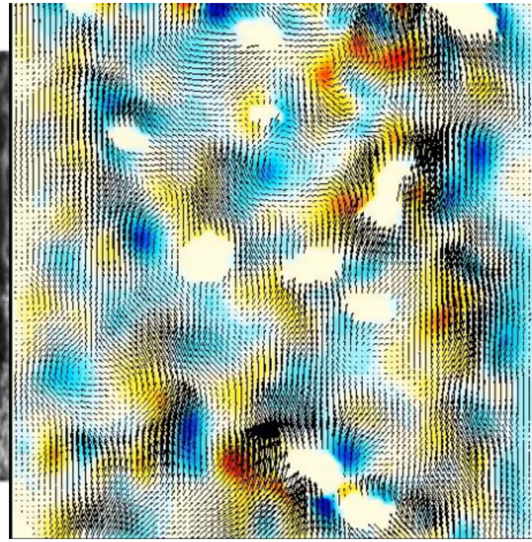


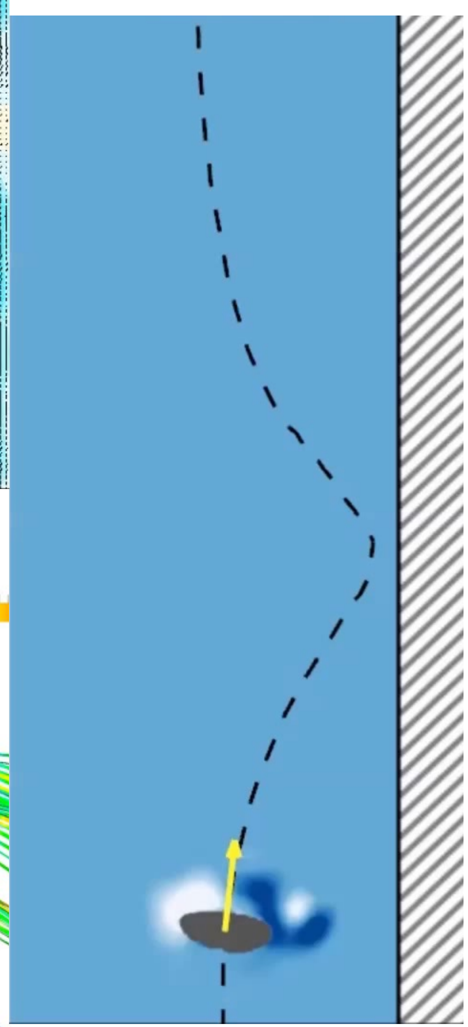


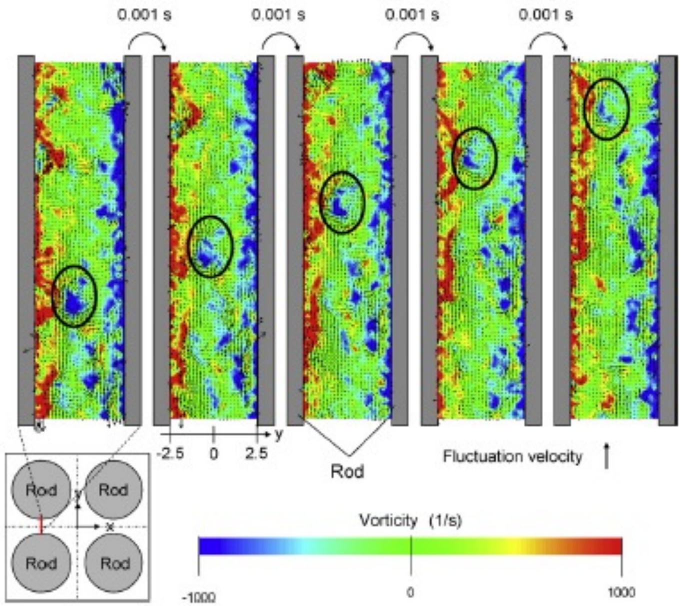


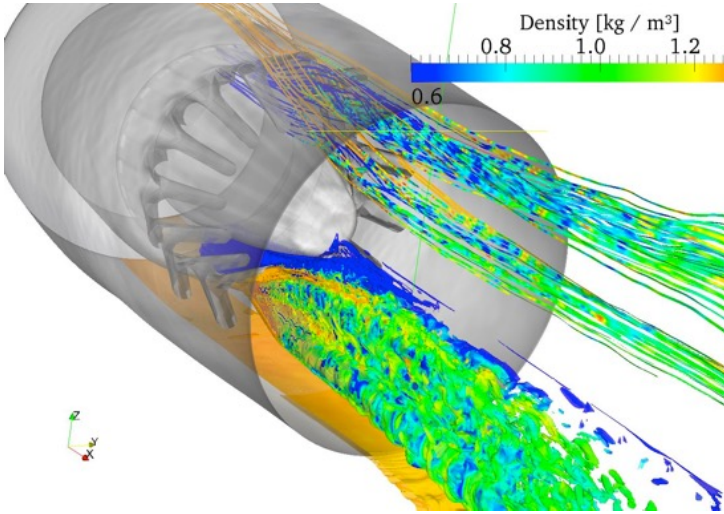


Energy & Power conversion









Ch. 1 INTRODUCTION

1.1 Preliminary Remarks

Fluid mechanics is the study of fluids (gas and liquids) either in motion or at rest, especially the interactive effects between ① fluids – fluids and ② fluids – solids.

↳ Approaches : experiments , CFD (Computational Fluid Dynamics)

modeling (theory)

backup

1.2. History and Scope of F.M

· Archimedes (285–212 BC) : Law of buoyancy.

- Leonardo da Vinci (1452-1519)
  : equation of mass conservation in 1D steady flow. ($\partial/\partial t = 0$)
  ↔ unsteady.
  : first flow visualization.
  (sketches for many complex flow phenomena)
- Edme Mariotte (1620-1684)
  : first built a wind tunnel (풍동) and tested.
- Issac Newton (1642-1727) : Law of motion (momentum)
  ↳ Law of viscosity (Newtonian fluid)

- Frictionless fluid (theory / assumption)
  - 18C mathematicians, Euler, d'Alembert, Lagrange, ...

    developed both differential and integral equations. (Bernoulli eq.)

    d'Alembert Paradox : a body immersed in a frictionless fluid experiences a zero drag force.

unrealistic.

- Hyraulics (수리학. 수력학) — relying on the experiments.

  application oriented.

↓ : Pitot, Hagen, Poiseuille, Darcy, ...

produced data on various flows, but they were used in raw form without regard to the fundamental physics of flow.

· End of 19C : experimental hydraulics

+

theoretical hydrodynamics.

|

Froude, Rayleigh, Reynolds. ...

dimensional analysis (ch.5)

↳ Reynolds Number

$$Re \equiv \frac{\rho V L}{\mu}$$

$\sim \frac{\text{inertia}}{\text{viscosity}}$

- Meanwhile, viscous-flow theory is available,
  Navier (1785-1836), Stokes (1819-1903)
  ⇒ too-difficult to solve for
  arbitrary flows.

⇓

- Ludwig Prandtl. (1875-1953)
  (: published the most important paper (1904)
  ever written on F.M. "Boundary-layer theory".
  Von Karman, G.I. Taylor, ⋯.
- second half of 20C → CFD emerges.
  \+ sophisticated exp.
  techniques.

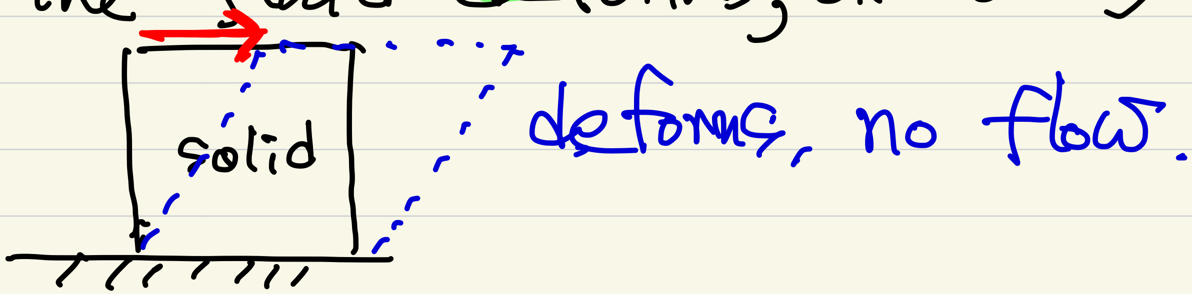
1.4 Concept of a fluid.

* matter { fluid / solid } ↕ reaction to an applied shear (or tangential) stress.

→ A solid can resist a shear stress by involving a static deformation (deflection)

But, a fluid can't!

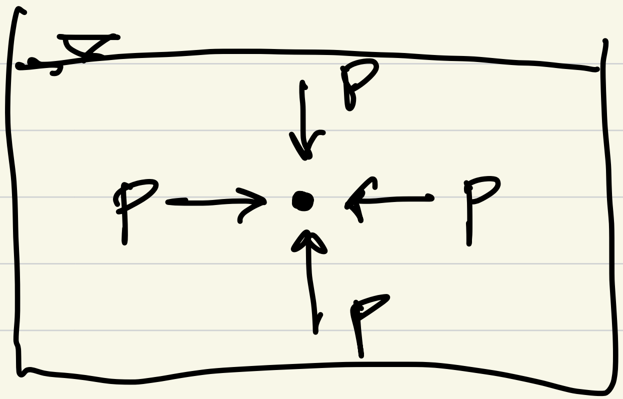
→ Any shear stress applied to a fluid will result in motion of that fluid.
(and the fluid deforms, as well)



· A fluid at rest is in a state of zero shear stress. (hydrostatic stress condition)
└ Ch. 2

* fluid [gas ↕ effect of cohesive force between molecules.
└ liquid
└→ under gravity, forms a free surface.

· for a hydrostatic condition (fluid at rest), the pressure at a point is equal to in all directions.



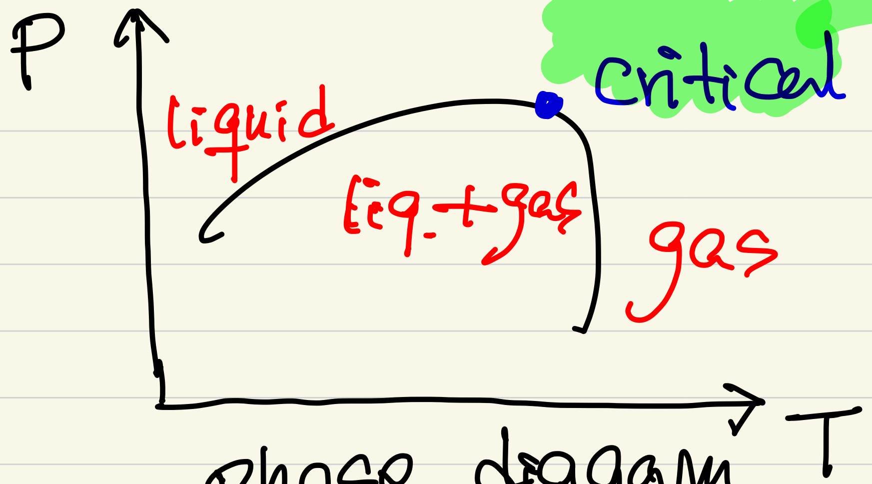
- **Rheology** (유변학): study of the flow of matter (liquid, in general), but also as "soft solids" that respond with plastic flow rather than deforming.

  (Rheo ← flow stream.)

  - · slurry mixture
  - asphalt, lead : resist shear stress for short time, → eventually deforms and show fluid behavior over long periods.

- Multiphase flow : two or more phases coexist.

- Supercritical fluid (초임계유체).



phase diagram.

- distinction between liq. and gas blurs.
- only single phase exists. (supercritical fluid).

1.5. The fluid as a continuum.

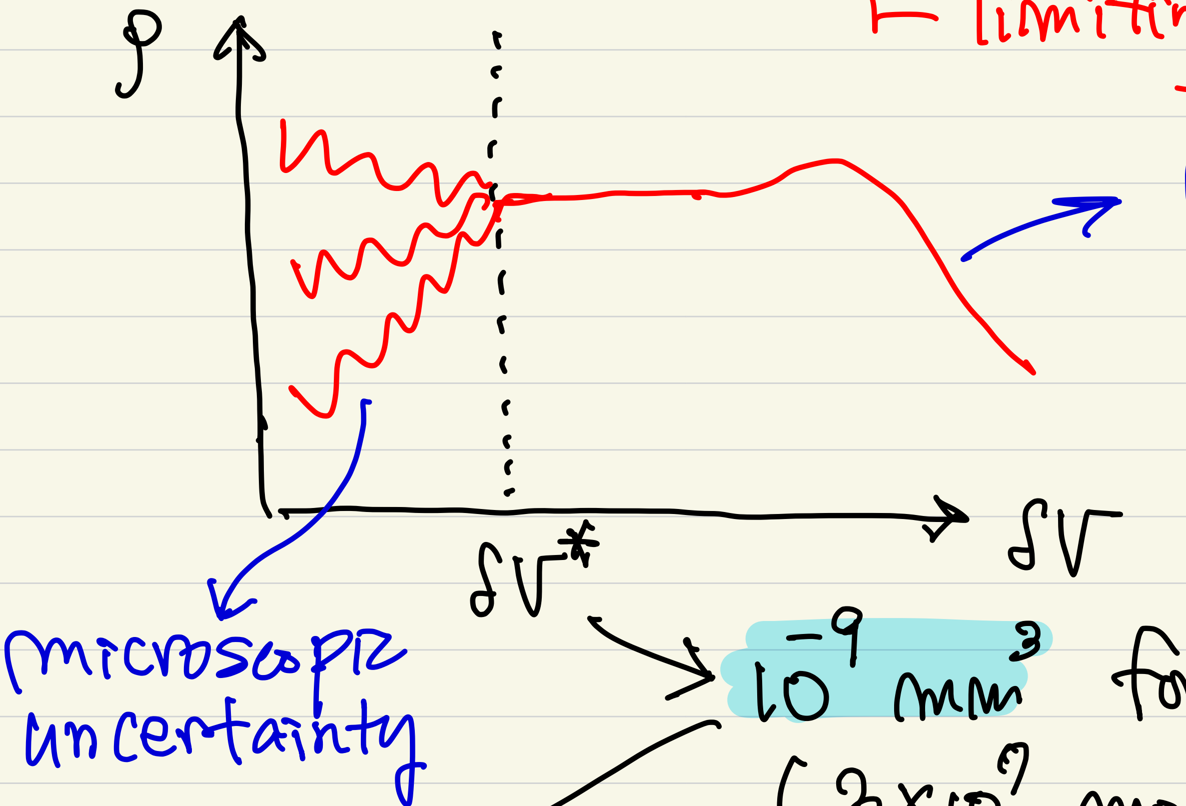
fluids : aggregation of molecules.
↓ freely moving to each other.

(gas : coarser
liq. : denser.

Q) How we define fluid property, e.g. density, viscosity ... ?

For example, $\rho = \lim_{\delta V \to \delta V^*} \frac{\delta m}{\delta V}$

← limiting volume.



δV^* → $10^{-9}\ mm^3$ for all liquids / gases.

(3×10^7 molecules in air)

Most engineering problems are concerned w/ physical dimensions much larger than δV^*.

|

↓
density is essentially a point function and fluid properties can be considered as varying continuously in space.
→ continuum.

1.6 Dimensions and Units.

- Dimension (차원) : a measure by which a physical variable is expressed quantitatively.
  (length, mass, time, ...)
- Units (단위) : a particular way of attaching a number to the quantitative dimension. (meter, gram, second, ...)

International system of Units (SI) : 1960

BG (British gravitational) units, ...

- Primary dimension.

mass M [kg]

length L [m]

time T [s]

temperature Θ [K].

secondary dimension.

- acceleration.

: LT^{-2}

- force. : MLT^{-2}.

- Principle of dimensional homogeneity.

(homogeneous

isotropic.

$\underline{A} + \underline{B} = \underline{C} + \underline{D}$

↳ should have the same dimension.

ex) Bernoulli eq.

$$p + \frac{1}{2}\rho V^2 + \rho g Z = \text{constant.}$$

pressure (p), density (ρ), velocity (V), grav. accel. (g), altitude (Z)

constant → should have the dimension of pressure → P_0 (stag. press.)

$\cdot\ P = F/A = [MLT^{-2}/L^2]$

$= [ML^{-1}T^{-2}]$

$\cdot\ \frac{1}{2} = [M^0L^0T^0]$, $\rho = m/\forall = [ML^{-3}]$

$V^2 = [LT^{-1}]^2 = [L^2T^{-2}]$

$\cdot\ g = [LT^{-2}]$, $Z = [L]$.