AerE310: Aerodynamics I: Incompressible Aerodynamics

Dr. Hui HU

Martin C. Jischke Professor and Director

Advanced Flow Diagnostics & Experimental Aerodynamic Laboratory

Aircraft Icing Physics and Anti-/De-icing Technology Laboratory

Department of Aerospace Engineering, Iowa State University

2251 Howe Hall, Ames, IA 50011-2271

Tel: 515-294-0094 / Email: huhui@iastate.edu

Lecture # 1: Course Polices & Syllabus

Dr. Hui HU
Department of Aerospace Engineering
Iowa State University, 2251 Howe Hall, Ames, IA 50011-2271
Tel: 515-294-0094 / Email: huhui@iastate.edu

❑ COURSE INSTRUCTIONS:

- ***Lecture time:*** *MWF: 3:20 ~ 4:10 pm*
- ***Office hours:*** *MWF: 4:10 ~ 5:10 pm.*
- ***Teaching Assistant:*** *Mr.* **Anvesh Dhulipalla**
  Office: Room 2242- Howe Hall
  Email: : adhulipa@iastate.edu
- ***Homework:*** ***Available at the course website***
- ***Class notes:*** ***Available at the course website***

- ***Textbook:***
  - ***1). John Anderson, "Fundamentals of Aerodynamics", McGraw-Hill***
  - ***2). John Bertin, "Aerodynamics for Engineers", Prentice Hall.***
  - ***Textbook is recommended, but not required.***

Course Policy

- *Homework:* 20%
  - *7 assignments throughout the semester*
- *5 minutes quizzes:* 10%
  - *Small quizzes/exercise during the lectures.*
- *1st mid-term exam (scheduled on Friday, Feb. 23, 2024):* 20%
- *2nd mid-term exam (scheduled on Friday, Apr. 05, 2024):* 20%
- *Final exam (scheduled on Monday,05/06/2024):* 30%

- *Important notes:*
  - *Homework is due at 5:00pm on Fridays.*
  - *25% score reduction if turned in after 5:00pm on the due date,*
  - *50% score reduction if turned in less than 2 days.*
  - *No credits if turned in more than 2 days after the due dates.*
  - *There is no make-up quizzes unless you have excusable reasons.*

- *Please review the course policies on Canvas*

Grading Policy

- ***Letter Grades defined:***

  - *100 –90 A*
  - *89 – 87 A-*
  - *86 – 83 B+*
  - *82 – 80 B*
  - *79 – 77 B-*
  - *76 – 73 C+*
  - *72 – 70 C*
  - *69 – 68 C-*
  - *67 – 64 D+*
  - *63- -64 D*
  - *62 – 60 D-*
  - *59 – 0 F*
  -

COURSE SYLLABUS

AerE 310, Spring 2024 Monday; Wednesday & Fridays; 3:20 pm ~ 4:10 pm In Hoover 1227

COURSE SYLLABUS

Date	Period		Topic/Text	Homework problems
Week 1				
15 Jan.	0	M	University Holiday (no class)	
17 Jan.	1	W	Course Syllabus and policies	
19 Jan	2	F	Review of calculus and vectors	
Week 2				
22 Jan.	3	M	Relations between different coordinate systems	
24 Jan.	4	W	Directional derivatives -1	
26 Jan.	5	F	Directional derivatives -2	
Week 3				
29 Jan.	6	M	Review of fluid mechanics	
31 Jan.	7	W	Relations between different coordinate systems	
02 Feb.	8	F	Reynolds transport theorem	Homework Set #1 Due.
Week 4				
05 Feb.	9	M	Conservation of Mass 1	
07 Feb.	10	W	Conservation of Mass 2	
09 Feb.	11	F	Conservation of Momentum 1	
Week 5				
12 Feb.	12	M	Conservation of Momentum 2	
14 Feb.	13	W	Conservation of Momentum 3	
16 Feb.	14	F	N-S equations in different systems	Homework Set #2 Due.
Week 6				
19 Feb.	15	M	Circulations and Stokes theorem	
21 Feb.	16	W	Bernoulli's equation	
23 Feb.	17	F	First hourly Exam #1	
Week 7				
26 Feb.	18	M	Streamlines and Stream functions	
28 Feb.	19	W	Potential flows and potential function	
01 Mar.	20	F	Basic Flows 1	Homework Set #3 Due.
Week 8				
04 Mar.	21	M	Basic Flows 2	
06 Mar.	22	W	Basic Flows 3	
08 Mar.	23	F	Basic Flows 4	
Week 9				
11 Mar.		M	SPRING BREAK	
13 Mar.		W	SPRING BREAK	
15 Mar.		F	SPRING BREAK	
Week 10				
18 Mar.	24	M	Basic Flows 5	
20 Mar.	25	W	Incompressible flow over an airfoil 1	
22 Mar.	26	F	Incompressible flow over an airfoil 2	Homework Set #4 Due.

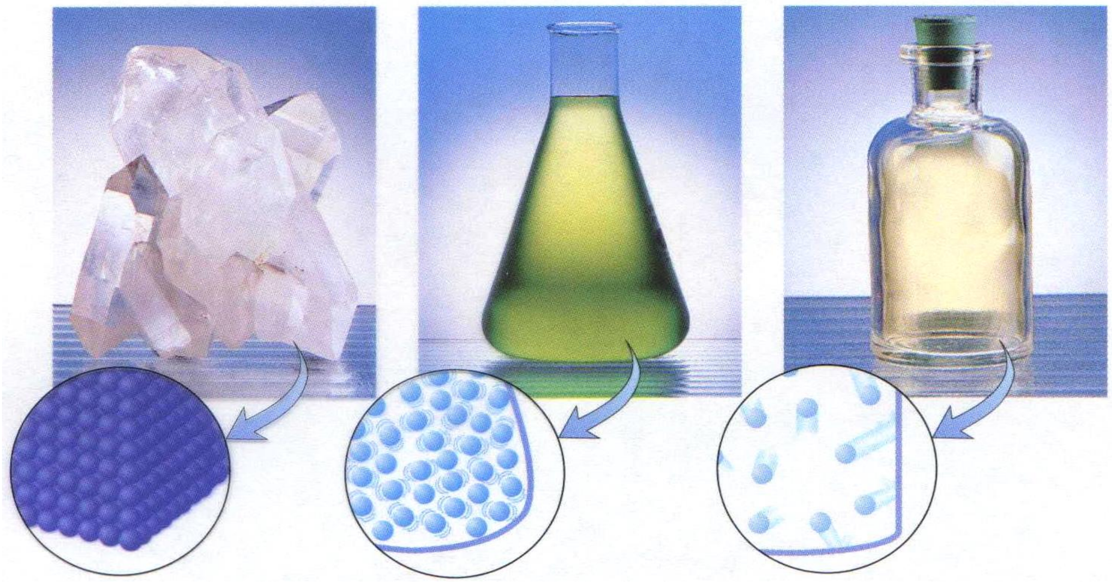
Date	Period		Topic/Text	Homework problems
Week 11				
25 Mar.	27	M	Incompressible flow over an airfoil 3	
27 Mar.	28	W	Incompressible flow over an airfoil 4	
29 Mar.	29	F	Incompressible flow over an airfoil 5	
Week 12				
01 Apr.	30	M	Incompressible flow over an airfoil 6	
03 Apr.	31	W	Incompressible flow over an airfoil 7	
05 Apr.	32	F	Second hourly Exam #2	Homework set #5 Due
Week 13				
08 Apr.	33	M	Introduction to Viscous Flows -1	
10 Apr.	34	W	Introduction to Viscous Flows -2	
12 Apr.	35	F	Introduction to Viscous Flows -3	
Week 14				
15 Apr.	36	M	Laminar and Turbulence Flows -1	
17 Apr.	37	W	Laminar and Turbulence Flows -2	
19 Apr.	38	F	Laminar and Turbulence Flows -3	Homework set #6 Due
Week 15				
22 Apr.	39	M	Boundary layer flow concept & theory -1	
24 Apr.	40	W	Boundary layer flow concept & theory -2	
26 Apr.	41	F	Boundary layer flow concept & theory -3	
Week 16				
29 Apr.	42	M	Boundary layer flow concept & theory -4	
01 May	43	W	Boundary layer flow concept & theory -5	
03 May	44	F	Class Review for Final Exam	Homework set #7 Due
Week 17				

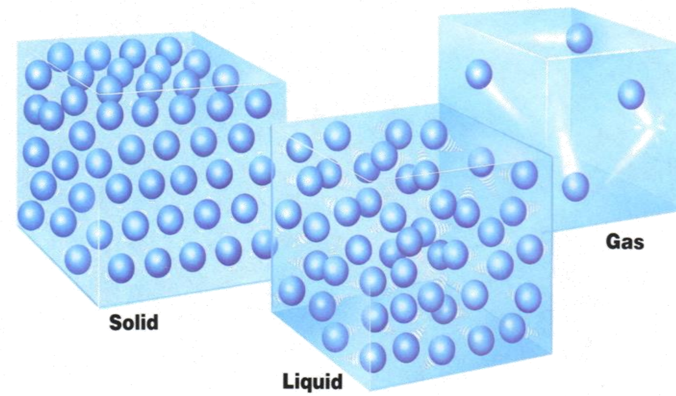
Final exam for AerE310

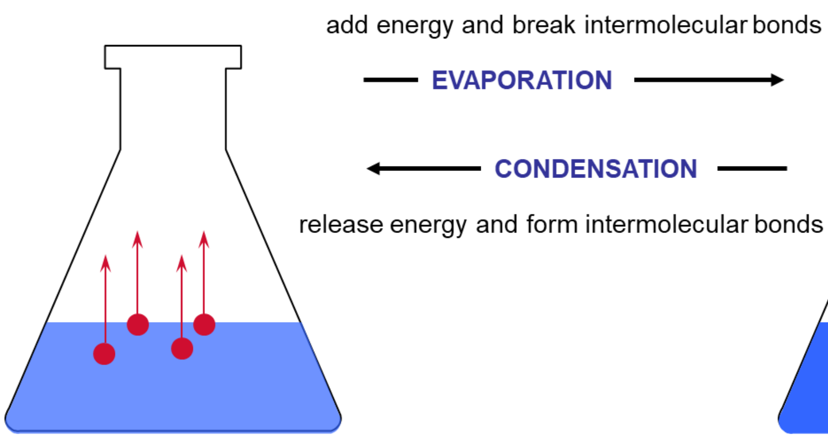
- According to https://www.registrar.iastate.edu/students/exams/fallexams, AerE310 final exam will be held at **2:15pm ~ 4:15pm on Monday, May 06, 2024**

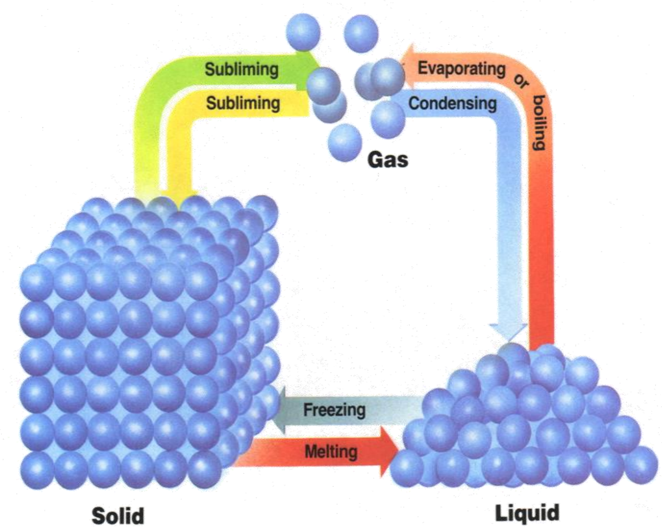
❑ Some Properties of Solids, Liquids, and Gases

(a) Particles in solid *(b) Particles in liquid* *(c) Particles in gas*

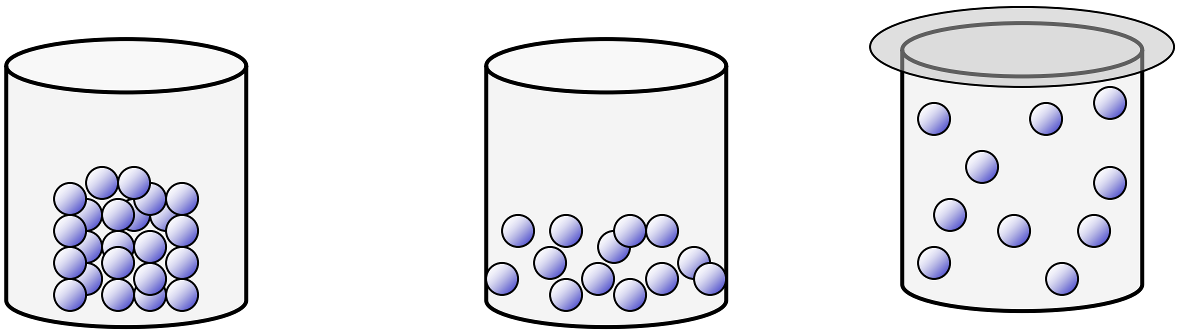








❑ Some Properties of Solids, Liquids, and Gases

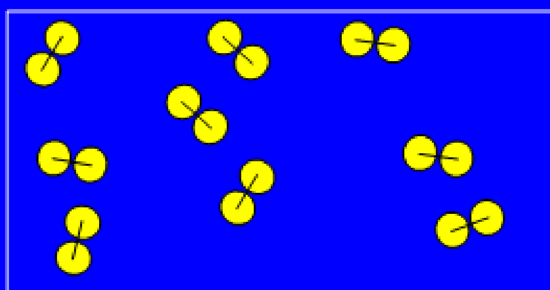
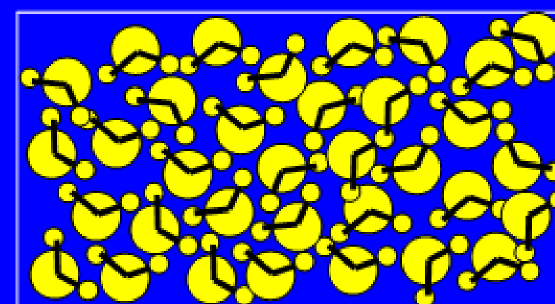


Property	Solid	Liquid	Gas
Shape	Has definite shape	Takes the shape of the container	Takes the shape of its container
Volume	Has a definite volume	Has a definite volume	Fills the volume of the container
Arrangement of Particles	Fixed, very close	Random, close	Random, far apart
Interactions between particles	Very strong	Strong	Essentially none

Liquid and Gas Fluids

The Smallest Length Scale of a Continuum

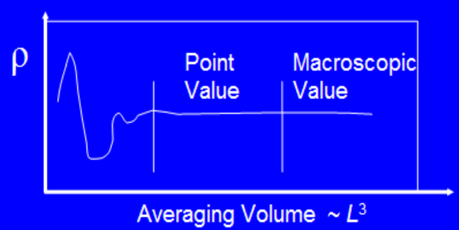
(Deen, Analysis of Transport Phenomena, 1998)

Gases (STP)		Liquids	
			
Molecular diameter	0.3 nm	Molecular diameter	0.3 nm
Number density (m^{-3})	3 E25	Number density (m^{-3})	2 E28
Intermolecular spacing	3 nm	Intermolecular spacing	0.4 nm
Displacement distance	100 nm	Displacement distance	1 pm
Molecular Velocity	500 m/s	Molecular Velocity	10^3 m/s

Liquid and Gas Fluids

The Smallest Length Scale of a Continuum
(Deen, Analysis of Transport Phenomena, 1998)

Average over sufficient number of molecules
- Point quantities, ρ, ***u***, *T*



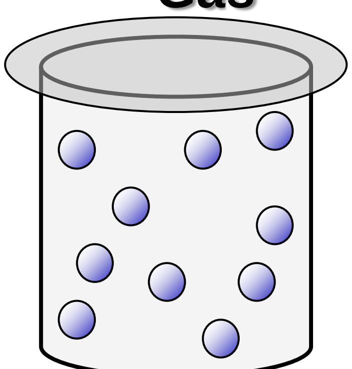
- Random process theory
  - $N \sim 10^4$ molecules $\sigma_\mu = \frac{\sigma_x}{N^{1/2}}$
- ***L* ~ 70 nm** (gases at STP)
- ***L* ~ 8 nm** (liquids)

The Smallest Length Scale of a Continuum
(Deen, Analysis of Transport Phenomena, 1998)

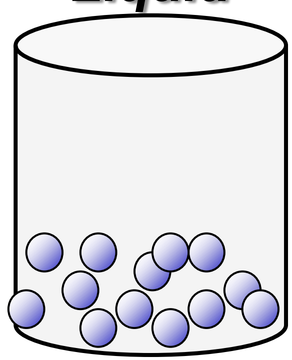
Length scale of molecular interactions (transport properties, μ, κ, *D*)
- Gases: mean free path ~ 100 nm
- Liquids: molecular diameter ~ 0.3 nm

Average over ~ 10^3 interaction length scales
- ***L* ~ 1 μm** (gases)
- ***L* ~ 3 nm** (liquids)

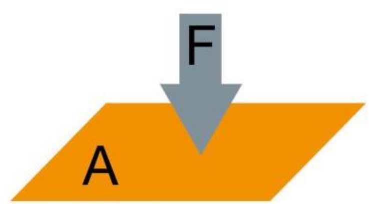
- ***Gas***

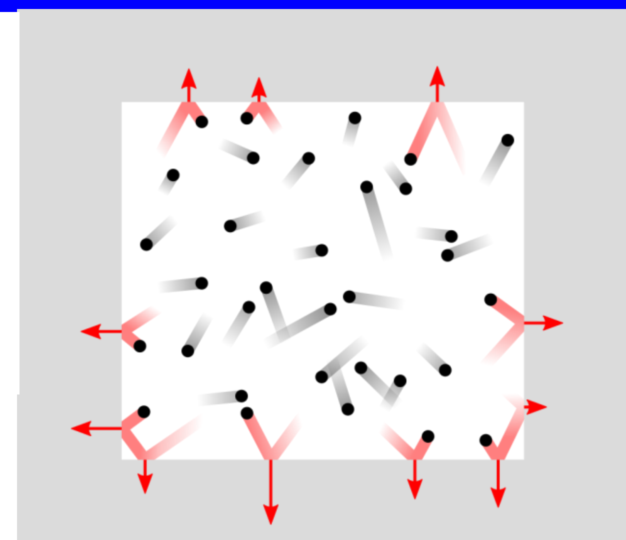


- ***Liquid***



$$Pressure\ (p) = \frac{Force\ (F_n)}{Area(A)}$$

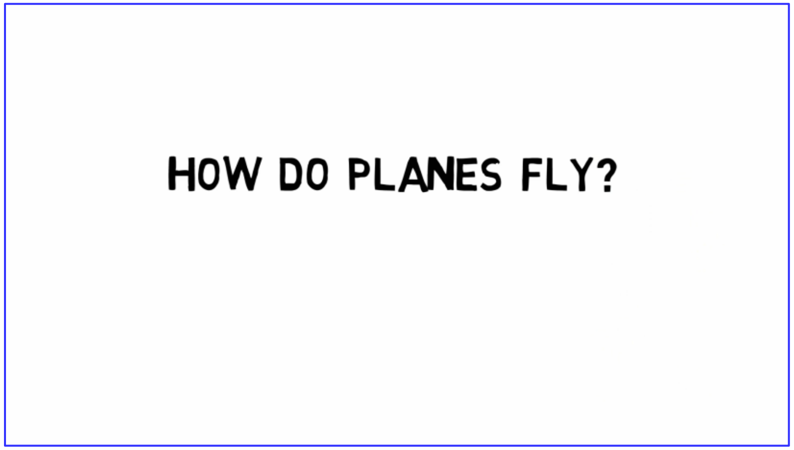


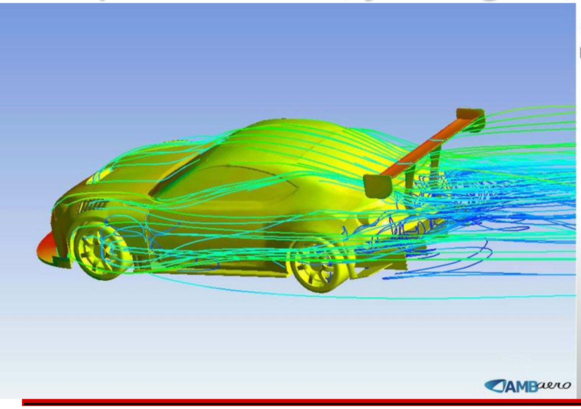


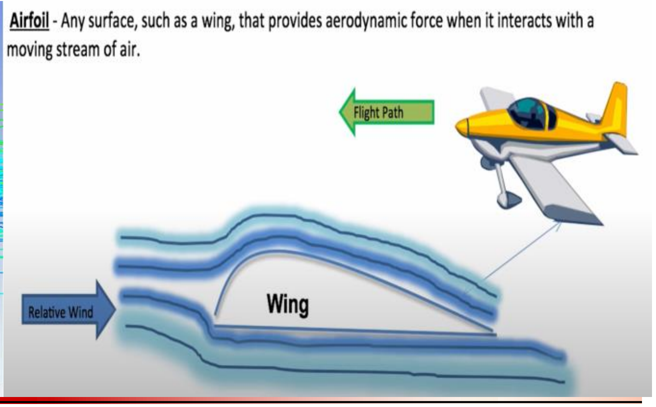
❑ What is aerodynamics?

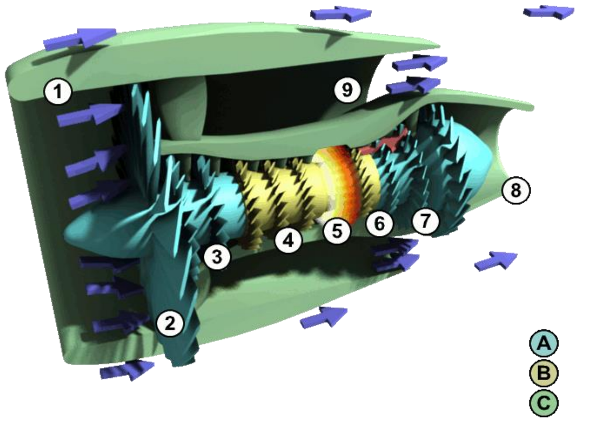
- ***From Greek word aerios (air) + dynamis (force)***
- ***The study of flow of air (and resulting forces) about a body (airplane, rocket, sails, baseball,…)***
- ***A subdivision of fluid dynamics***
  - ***Hydrodynamics : flow of liquids***
  - ***Gas dynamics: flow of gases***
  - ***Aerodynamics: flow of air***
- ***Often the goal is to predict forces and moments acting on a body due its relative motion in air : External flow.***
- ***Also includes study of air flow within "ducts" (wind tunnel, jet engine,…): Internal flow***

- https://www.youtube.com/watch?v=wFTHh-6jIT8





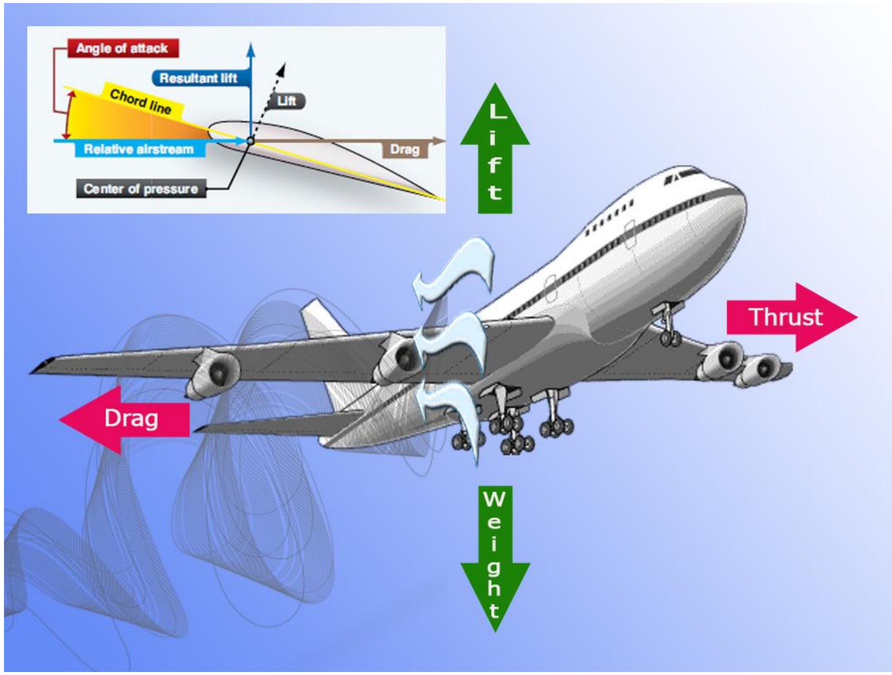




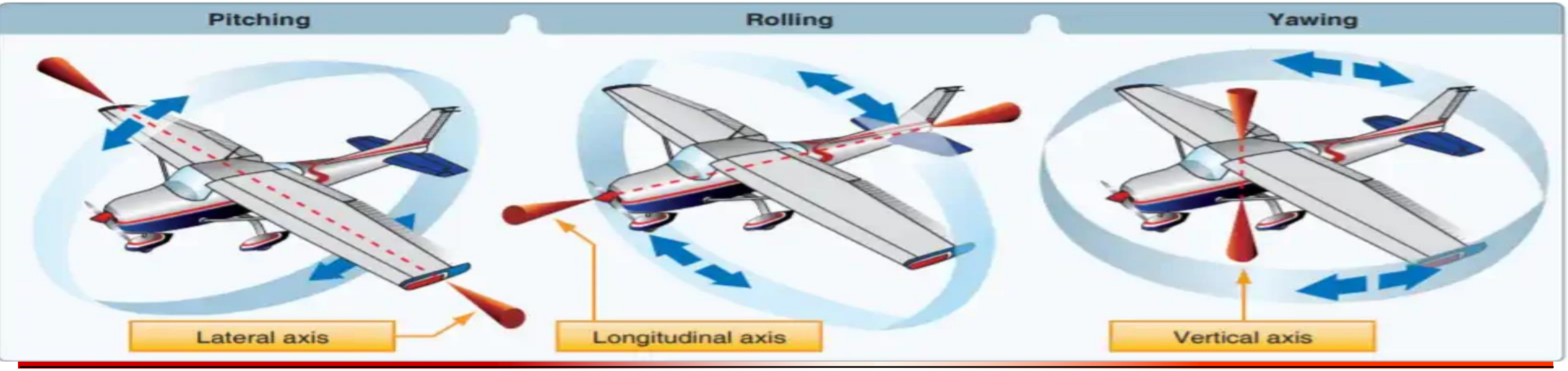
❑ Aerodynamic forces

- ***Lift:*** ***aerodynamic force opposing the weight of object***
- ***Drag:*** ***Air resistance to motion of the object***
- ***Aerodynamic forces do not necessarily act on center of gravity***

  →Aerodynamic moments
- ***The main goal in aerodynamics is to find these forces/moments.***



- https://www.youtube.com/watch?v=wFTHh-6jIT8

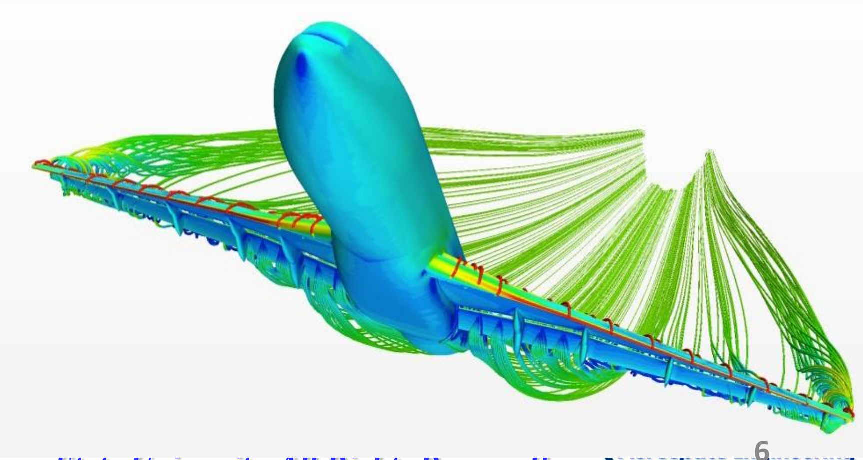


How do we obtain information about aerodynamic forces

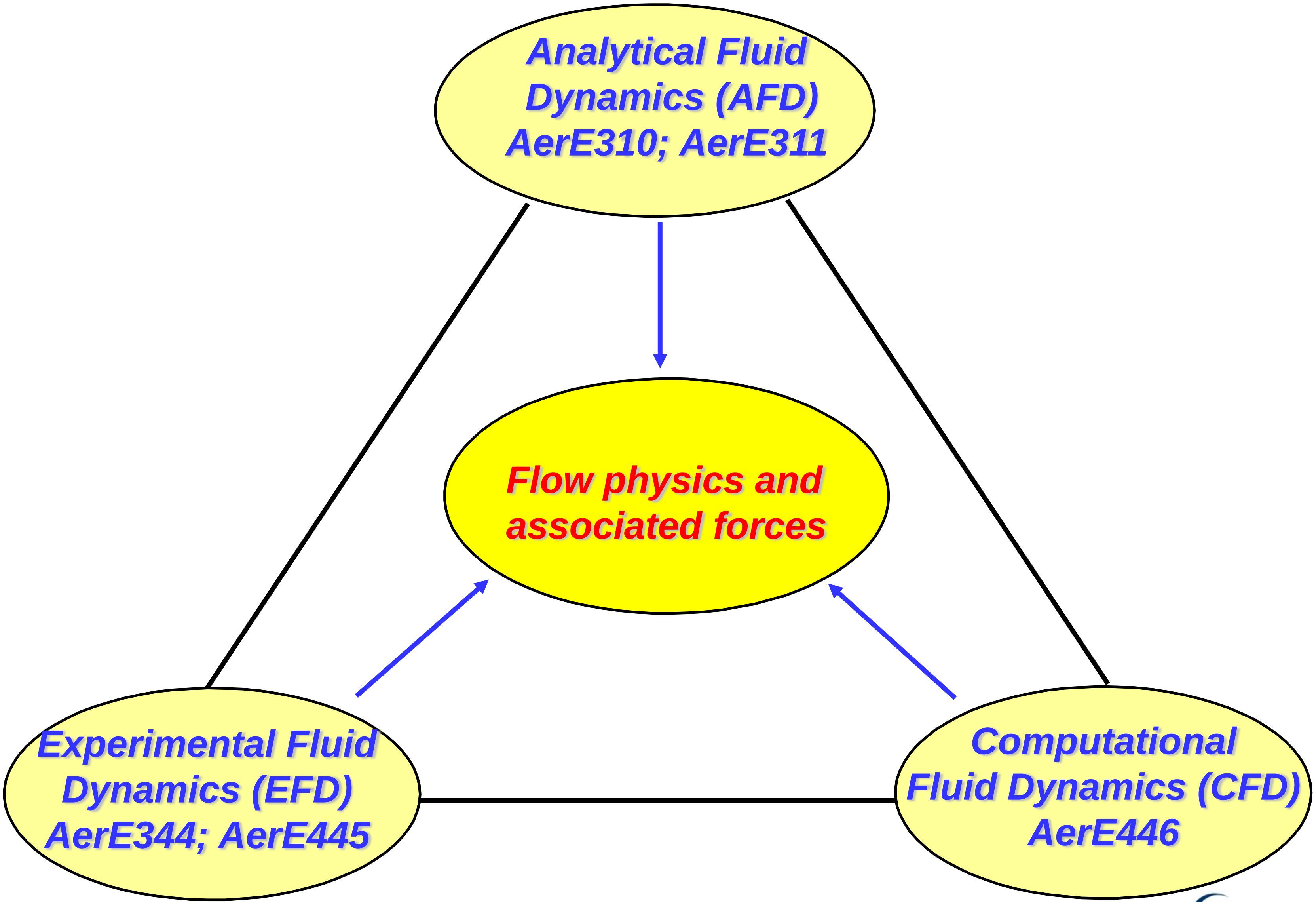
- *Experimental Fluid Dynamics (EFD)*
  - *Provides the exact answer under conditions of the experiment*
  - *Depicts the real physics of the flow*
  - *Measurement under realistic conditions can be very hard*
  - *Expensive!*

Source: boeingimages.com

- *Computational Fluid Dynamics (CFD)*
  - *Provides a wide range of data for one simulation*
  - *Easy to tweak parameters and obtain data under various conditions*
  - *cheaper to setup*
  - *Limited to the accuracy of the "model" and assumptions*
  - *Can provide non-physical result!*
  - *Complex simulation can become costly/impractical*

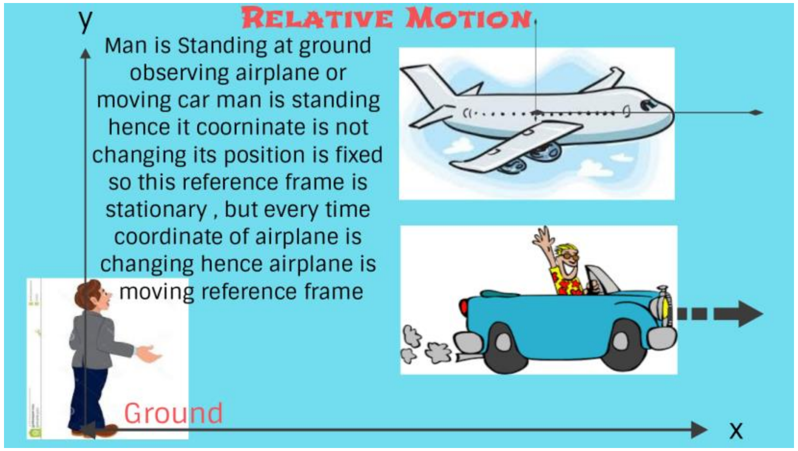


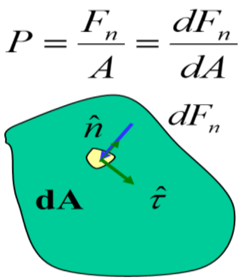
❑ AFD, CFD and EFD

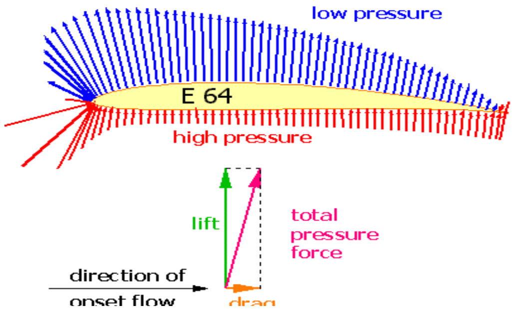


Aerodynamic variables

- Flow velocity : velocity of a fluid element as it passes through a fixed point in space
  - Fluid element: consider a very small mass of fluid within a region where continuum still applies
- Pressure $P = \lim \left(\frac{dF}{dA}\right) dA \to 0$
- density $\rho = \lim \left(\frac{dm}{dV}\right) dV \to 0$
- Temperature (Mean molecular Kinetic Energy=$\frac{3}{2}kT$)
- Viscosity
  - Shear stress $\tau = \lim \left(\frac{dF_f}{dA}\right) dA \to 0$
  - Newton's law $\tau = \mu \frac{dV}{dy}$







❑ AERODYNAMIC VARIABLES

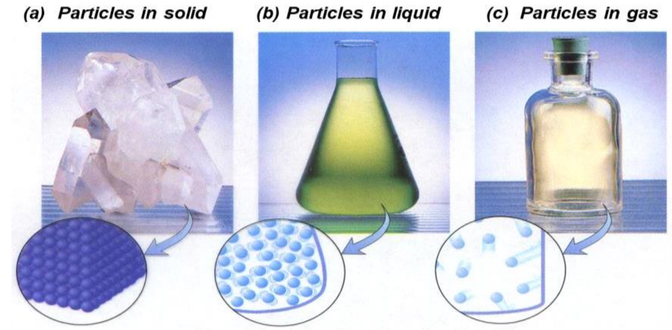
- Incompressible : fluid density (ρ) is constant (we will update this simple definition later!)

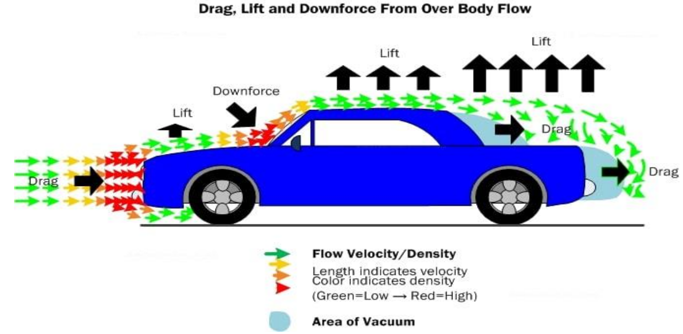
- Compressible: fluid density can change

- Viscous: there is friction between fluid elements

- Inviscid: There is no friction between fluid elements (viscosity is zero)
  - Reynolds number $Re = \frac{\rho V L}{\mu}$
  - Mach number $M = \frac{V}{a}$ a: speed of sound

- ***Speed of sound in air is about 760 mph (340 m/s)***

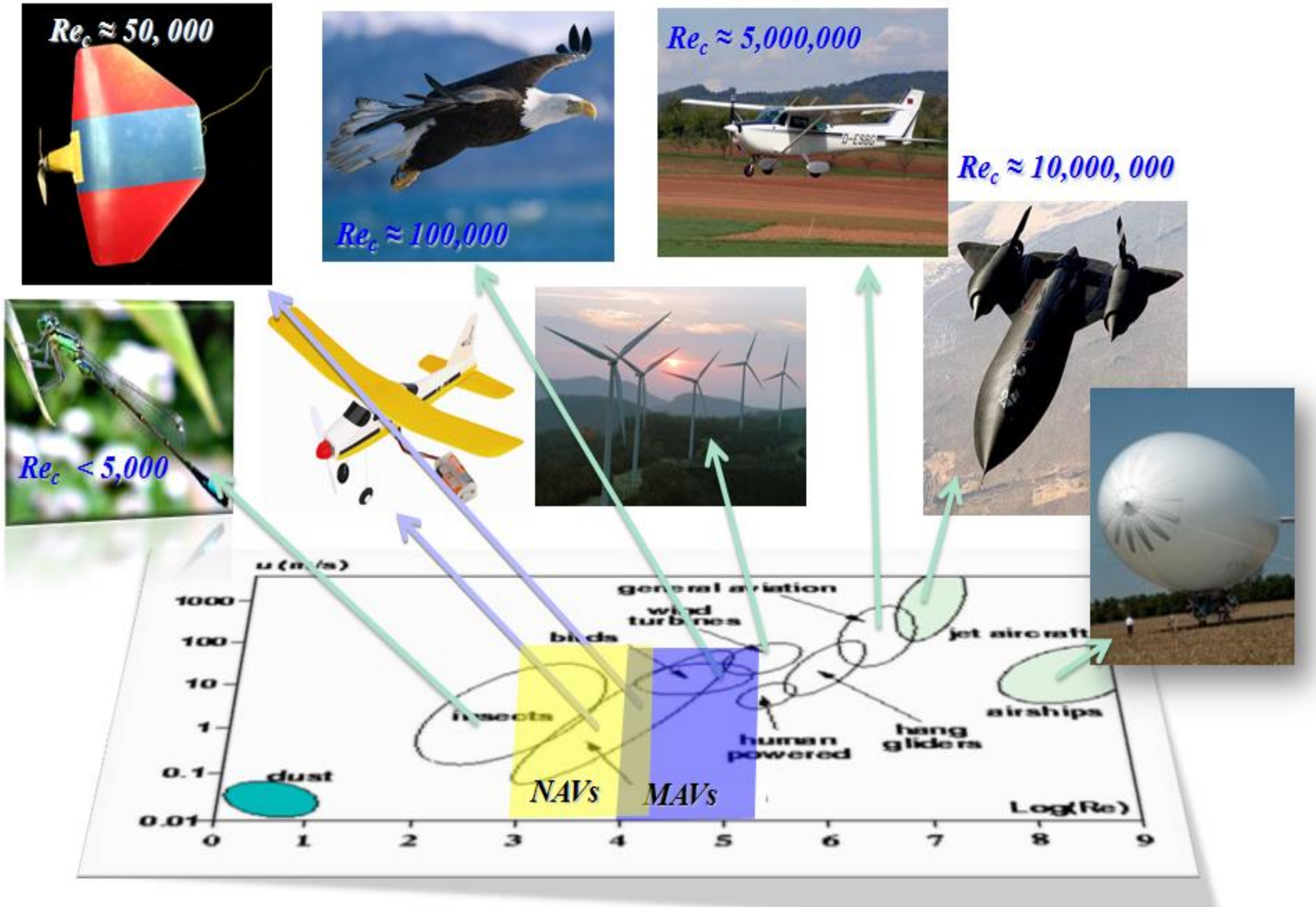




- ***Air can be considered as incompressible up to 220 mph (~100 m/s)***

- *Aircraft moving at 760 mph (340 m/s)*

❑ Flow with different Reynolds numbers

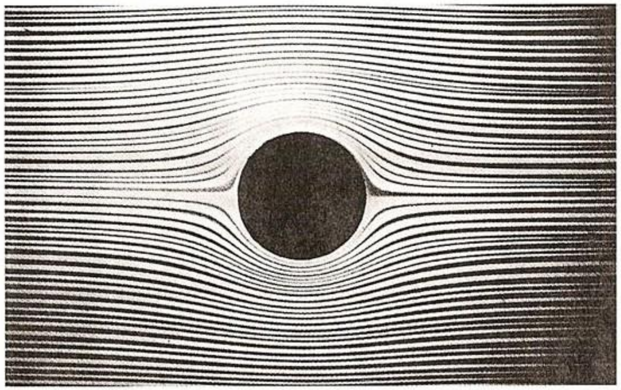


$$Re = \rho UL/\mu$$

- *Re number is higher for large/fast moving objects*
- *Viscosity can be neglected for high Reynolds number flows*

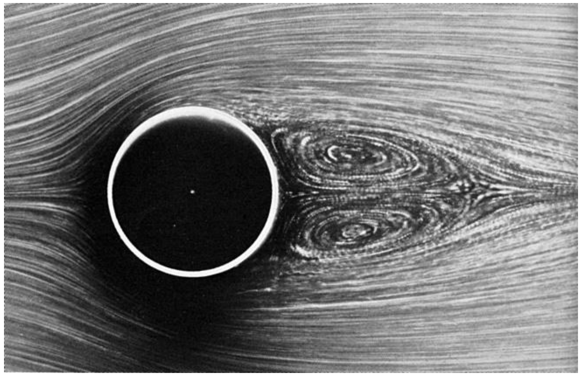
❑ Flows with different Reynolds numbers

Re << 1



Photograph by D. H. Peregrine

Re = 26

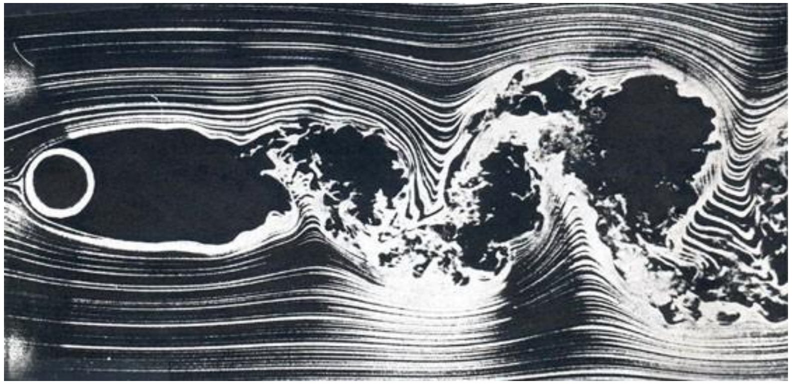


Photograph by S. Taneda

Re = 2000

Photograph by Werle and Gallon

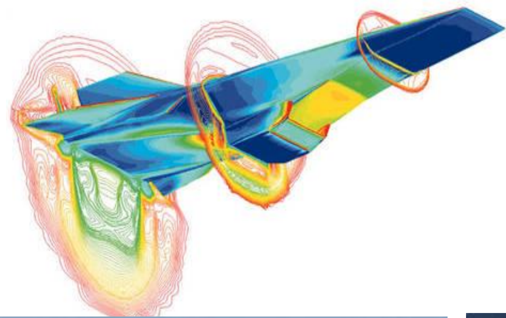
Re = 10000



Photograph by T. Corke and H. Naguib

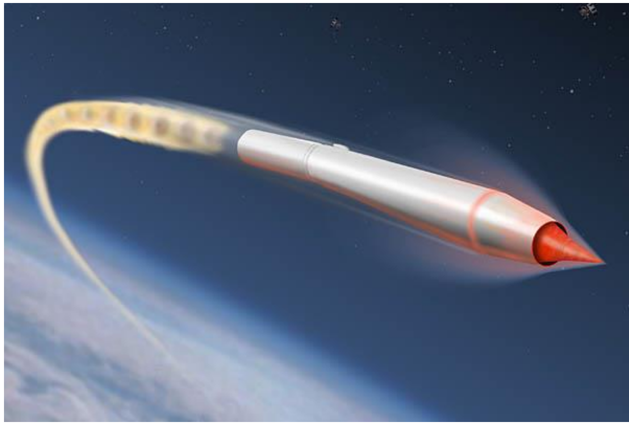
❑ Subsonic, Transonic, Supersonic and Hypersonic Flows

- ***Subsonic flows:*** ***M<1.0***
- ***Transonic flows:*** ***M≈1.0***
- ***Supersonic flows:*** ***M>1.0***
- ***Hypersonic flows:*** ***M>5.0***



- *Hypersonic vehicle*

- ***Sonic boom***



b. Subsonic < 1.0

b. Sonic boom = 1.0

b. Supersonic; M>1.0

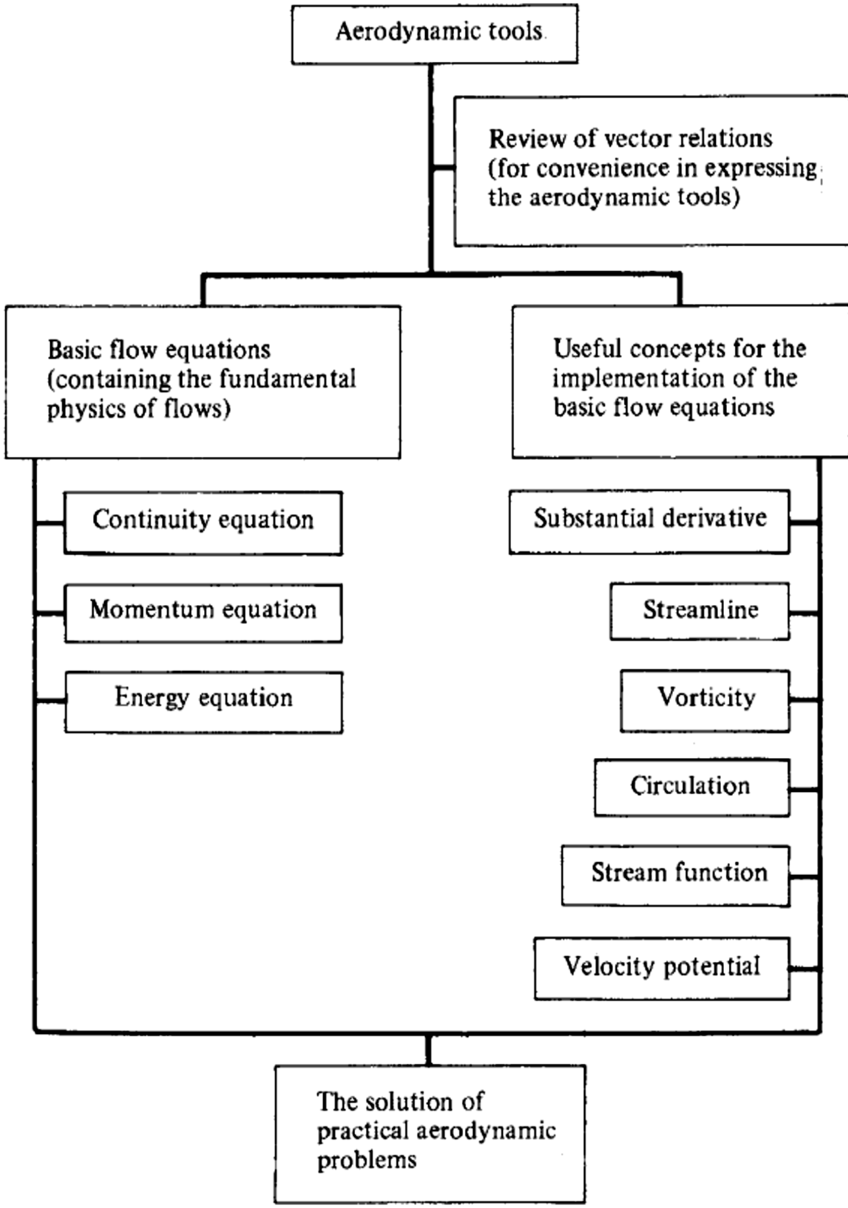
Topics to be covered in AerE310

- ***Low speed aerodynamics***
  - ***Aerodynamic principles***
  - ***Conservation laws and fundamental equations of motion***

- ***Predict lift, drag and moment (theoretical)***
  - ***Inviscid incompressible flow***
  - ***Thin airfoil theory***
  - ***Flow over finite wings***

- ***Viscous flows and boundary layers***

❑ TOPICS TO BE COVERED IN AERE310



- *How aerodynamics help make a car go faster*

- https://www.youtube.com/watch?v=mZje3H5Kt2M