Flight Mechanics/Dynamics

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Objectives of Course

- To familiarize the students with different aspects of aircraft systems
- To provide exposure of various modes of aircraft operations, their stability and control

Evaluation Scheme

- Short Quizzes : 30 %
- Mid-semester : 30 %
- End-semester : 40 %

- Short quizzes will be usually conducted after every 2-3 lectures.
- Attendance is not mandatory during live interactions.
- Students taking it as 'Audit' are required to secure passing marks.
- Dropping of course will be as per the rules of the institute.
- No Assignments
- Practice problem sets may be given at intervals.

Tutorials and Exams

Tutorial 1	29 January 2020
Tutorial 2	12 February 2020
Tutorial 3	23 February 2020
Tutorial 4	19 March 2020
Tutorial 5	9 April 2020
Mid-sem Exam	As per IITB Time Table
End-sem Exam	As per IITB Time Table

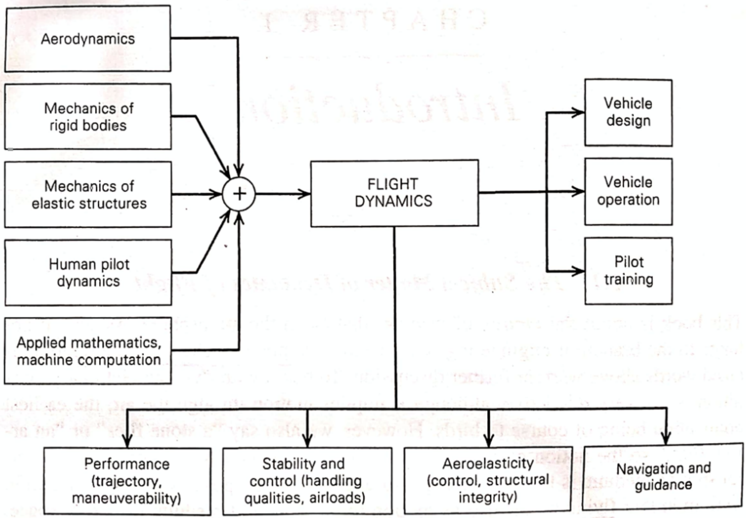
Teaching Assistants:

1. Rohit Nanavati (Ph.D student) [rohit.nanavati@iitb.ac.in]
2. Abhinav Sinha (Ph.D student) [sinha.abhinav@iitb.ac.in]
3. Prajakta Surve (Ph.D student) [prajaktasurve@iitb.ac.in]
4. Jinay Patel (Dual Degree student) [jinay.patel@iitb.ac.in]

References

1. John Anderson Jr., *Introduction to Flight*, McGraw-Hill Education, Sixth Edition, 2017.
2. Bernard Etkin and Llyod Duff Reid, *Dynamics of Flight: Stability and Control*, John Wiley and Sons, Third Edition, 1996.
3. Robert C. Nelson, *Flight Stability and Automatic Control*, McGraw-Hill Book Company, Second Edition, 1998.
4. Michael V. Cook, *Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control*, Butterworth-Heinemann, Elsevier Aerospace Engineering. Second Edition, 2007.

Office hours for discussion about doubts in course: Wednesday 2-4 PM

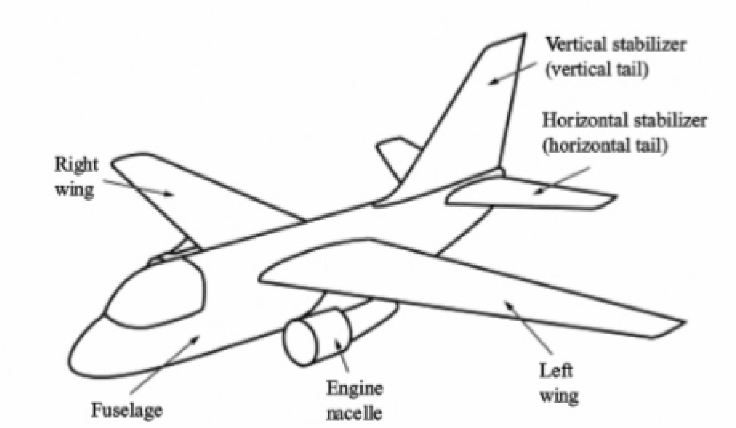


Aerodynamics
Mechanics of rigid bodies
Mechanics of elastic structures
Human pilot dynamics
Applied mathematics, machine computation
+
FLIGHT DYNAMICS
Vehicle design
Vehicle operation
Pilot training
Performance (trajectory, maneuverability)
Stability and control (handling qualities, airloads)
Aeroelasticity (control, structural integrity)
Navigation and guidance

- How do aircraft fly?
- What do you mean by performance, stability, and control of aircraft?
- What are the performance measures of aircraft?
- Why stability of aircraft is important?
- What are the different kinds of stability of aircraft?
- What are the measures of stability of aircraft?
- Which parameters govern the stability of aircraft?
- How much stability is desirable? If the aircraft have strong stability then what would be its consequences?
- How to change aircraft motion from one to another equilibrium condition?
- What are the different modes of aircraft motion?
- How control inputs affect the motion of aircraft?

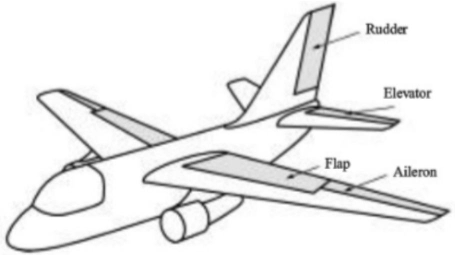
Syllabus

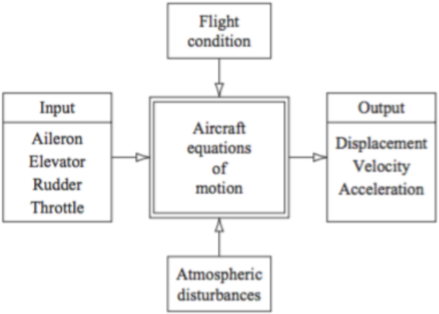
Aircraft: Brief introduction of aircraft, Performance of aircraft
Static stability and control: Equilibrium and static stability, stick fixed neutral point, Elevator, rudder, and aileron as control, Trimmed lift curve slope, Stick free static stability, Stick-free neutral point, dihedral angle, aileron control.
Equations of motion: Coordinate transformation, quaternion, Euler angles and rates; body angular velocity, body-fixed, wind, and stability axes; Equations of motion of rigid aircraft; Stability derivatives
Stability of uncontrolled motion: Decoupling of aircraft dynamics; Modes of aircraft motion: short period, phugoid, dutch roll, spiral, and roll subsidence modes.
Open and closed loop control: Response and stability of LTI systems, Response to control inputs (elevator, rudder, etc), Flight controller design.


Vertical stabilizer
(vertical tail)
Horizontal stabilizer
(horizontal tail)
Right
wing
Left
wing
Fuselage
Engine
nacelle

Flight Mechanics/Dynamics

Aircraft Control Surface





- Gravity at absolute altitude h_a

$$g = g_0 \left(\frac{r}{h_a}\right)^2 = g_0 \left[\frac{r}{r + h_G}\right]^2$$

- From hydrostatic equation,

$$\boxed{dp = -\rho g dh_G}$$

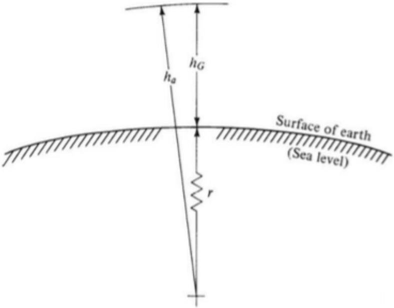
- With assumption of constant gravity g_0,

$$dp = -\rho g_0 dh$$

where h is geopotential altitude.

- To obtain relation between h and h_G,

$$dh = \frac{g}{g_0} dh_G = \frac{r^2}{(r + h_G)^2} dh_G$$



$$\boxed{h = \frac{r}{r + h_G} h_G}$$

Usually 1 % difference up to 65 km

- Equation of state, $p = \rho R T$

$$\frac{dp}{p} = -\frac{g_0}{RT} dh$$

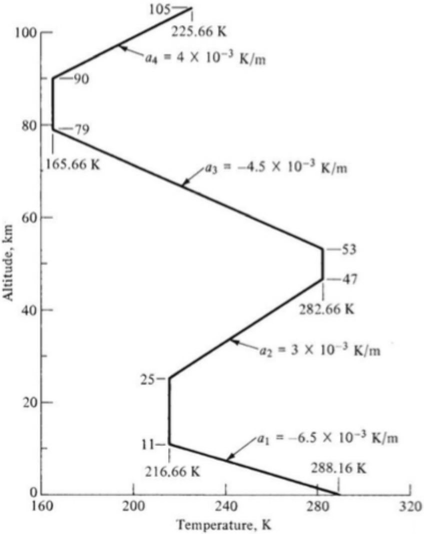
- For isothermal region

$$\frac{p}{p_1} = e^{-[g_0/(RT)](h-h_1)} = \frac{\rho}{\rho_1}$$

- For gradient layers, with $dT/dh = a$,

$$\frac{p}{p_1} = \left(\frac{T}{T_1}\right)^{-g_0/(aR)}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-[\{g_0/(aR)\}+1]}$$



- Continuity equation

$$\boxed{\rho_1 A_1 V_1 = \rho_2 A_2 V_2}$$

- Euler equation

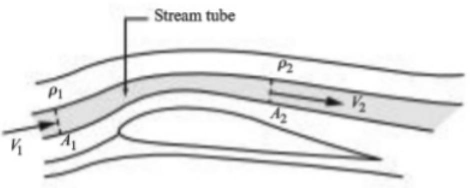
$$\boxed{dp = -\rho V dV}$$

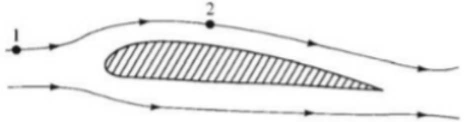
- Bernoulli equation, valid for incompressible flow only

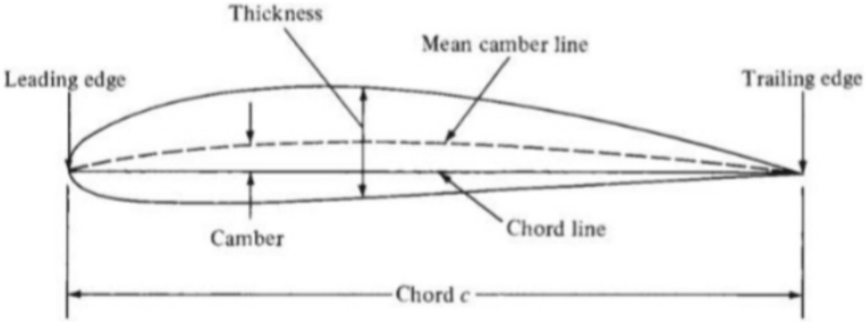
$$\boxed{p_1 + \frac{1}{2}\rho V_1^2 = p_2 + \frac{1}{2}\rho V_2^2}$$

- Speed of sound

$$\boxed{a = \sqrt{\frac{\gamma p}{\rho}} = \sqrt{\gamma R T}}$$

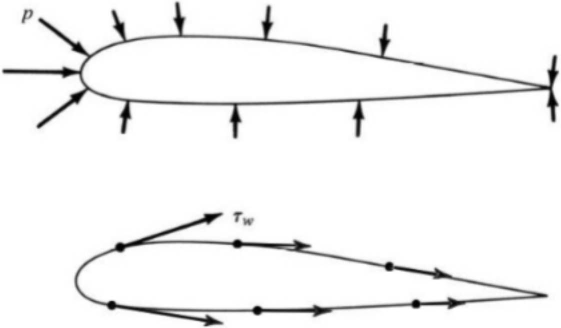




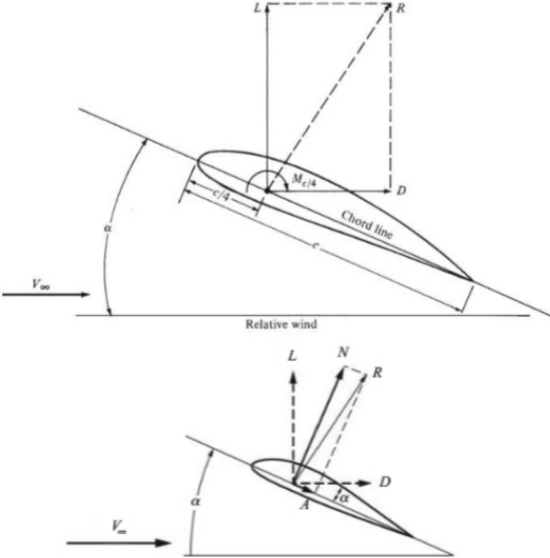


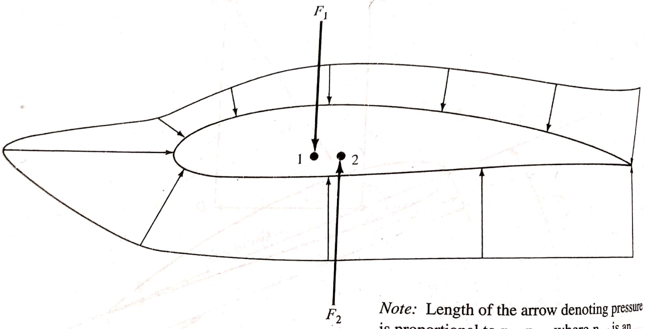
- **Mean camber line**: Locus of points halfway between lower and upper surface
- **Chord line**: Line joining leading and trailing edge
- **Chord**: Distance between leading and trailing edge
- **Camber**: Maximum distance between mean camber line and chord line, measured $\perp$ chord line

- **Pressure**: Force per unit area acting normal to the surface
- **Shear Stress**: Force per unit area tangential to the surface
- Unbalance of these pressure and shear stress create aerodynamic forces.



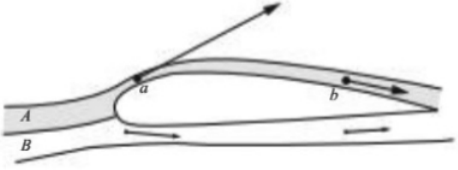
- **Relative wind (V_∞)** : Direction of free stream
- **Angle of attack (α)** : Angle between relative wind and chord line
- **Lift (L)**: Component of aerodynamic force $\perp V_\infty$
- **Drag (D)**: Component of aerodynamic force $\| V_\infty$
- **Normal and axial forces**: $\perp$ and $\|$ chord line



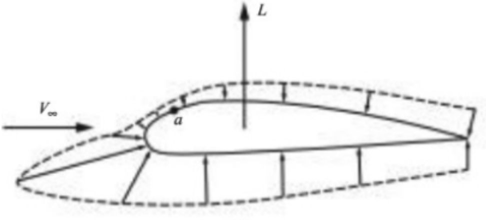


Note: Length of the arrow denoting pressure is proportional to $p - p_{\mathrm{ref}}$, where p_{ref} is an arbitrary reference pressure slightly less than the minimum pressure on the airfoil.

- **Quarter-chord point**: A point on chord at distance $c/4$ from leading edge
- $M_{c/4}$: Moment about quarter-chord point
- **Aerodynamic center**: Moments M_{ac} about this point do not vary with α.



(a)



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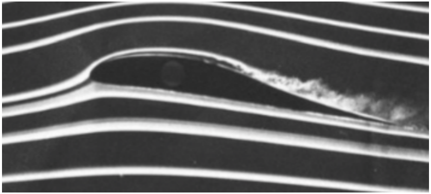

- Why pressure is high on bottom and low on top?
- Mass continuity and Newton's second law

- **Lift**:

$$\boxed{\underbrace{L}_{\text{Lift}} = \underbrace{q_\infty}_{\text{Dynamic pressure}} \times \underbrace{S}_{\text{Wing area}} \times \underbrace{c_l}_{\text{Lift coefficient}}}$$

- **Drag**:

$$\boxed{\underbrace{D}_{\text{Drag}} = \underbrace{q_\infty}_{\text{Dynamic pressure}} \times \underbrace{S}_{\text{Wing area}} \times \underbrace{c_d}_{\text{Drag coefficient}}}$$

- **Moment**:

$$\boxed{\underbrace{M}_{\text{Moment}} = \underbrace{q_\infty}_{\text{Dynamic pressure}} \times \underbrace{S}_{\text{Wing area}} \times \underbrace{c_m}_{\text{Moment coefficient}} \times \underbrace{c}_{\text{Chord length}}}$$

- **Lift, drag, and moment coefficients**:

$$\boxed{c_l = \frac{L}{q_\infty S}, \quad c_d = \frac{D}{q_\infty S}, \quad c_m = \frac{M}{q_\infty S c}}$$

Reference

1. John Anderson Jr., *Introduction to Flight*, McGraw-Hill Education, Sixth Edition, 2017.

Thank you for your attention !!!