Optimal Control, Guidance and Estimation

Lecture – 15

Overview of Flight Dynamics – I

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Aircraft Designs

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First to Fly

- Otto Lilienthal
  - First person to make repeated successful short flights
  - Used a fixed wing glider
  - Died after a crash in 1896, saying „Sacrifices must be made”

Wright Brothers

Wright brothers
- Started as glider engineers and pilots
- First engine powered flight in 1903
- First to actively manipulate the plane by control surfaces
Different airplane configurations

- Biplane:
  - More compact layout with shorter wingspan
  - Higher maneuverability
  - Very popular in the early days of aviation
  - But: more drag and less lift than a classical design with equal wing area

- Sailplane:
  - Goal of energy efficiency and flight endurance
    - Large wingspan, low weight
    - Low speed
    - Low payload
Commercial Aircrafts

- High Lift/Drag ratio
- High fuel efficiency
- High reliability & safety requirements
- Good handling quality and passenger comfort
- All weather operational capability
- Speed and agility (maneuverability) are not critical

Different airplane configurations

- Fighter aircraft:
  - Goal of high speed, high climbing rate, high maneuverability, stealthiness
    - Strong engines, short wings with high chord length, complex geometry, large control surfaces
    - High fuel consumption (and thus limited operating range)
Different airplane configurations

- Flying wing aircraft:
  - Most commonly used in the low to medium speed range
  - High stealth capabilities (low visibility for radar)
  - Fuel efficient due to low drag
  - Problem: no passenger windows (in commercial application)

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Geometry of Conventional Aircrafts

- Horizontal Stabilizer
  - Control Pitch
- Vertical Stabilizer
  - Control Yaw
- Wing
  - Generate Lift
- Jet Engine
  - Generate Thrust
- Cockpit
  - Command and Control
- Fuselage (Body)
  - Hold Things Together & Carry Payload
- Rudder
  - Change Yaw
    - (side to side)
- Elevator
  - Change Pitch
    - (up and down)
- Flaps
  - Change Lift and Drag
- Aileron
  - Change Roll
- Spoiler
  - Change Lift, Drag and Roll
- Slats
  - Change Lift
Tailless Aircraft

- On the tailless aircraft the pitch controls and roll controls must both be on the wing. There can be separate elevators and ailerons or they can be combined into one set of controls known as Elevons and still usually has a vertical Fin with a rudder.

Canard Aircraft

- Horizontal stabilizer and elevators are in front.
- Advantage: Better control characteristics (including elimination of the non-minimum phase behavior)
- Drawback: Disturbed flow pattern over the body, good aerodynamic modeling is difficult.
Force Balance in Flying Vehicles

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Basic Force Balance

- Weight
- Lift
- Drag
- Thrust
Lift

- Lift is generated by differential pressure on upper and lower side of the wing

Airfoil Theory in 2D

- There isn’t any “ideal” airfoil
- The choice of an airfoil depends on:
  - Flying speed
  - Wing loading
  - Construction method
  - Kind of flight (acrobatic, glide,...)
  - Placement on the airplane
    - Ex: tail airfoils are always symmetrical
- Standard airfoils
  - Goettingen
  - Eppler
  - Naca
  - Example: NACA 2412
Lift \[ L = \bar{q} S C_L = \left( \frac{1}{2} \rho V^2 \right) S C_L \]

- \( \rho(h) \) = atmospheric density (a function of height)
- \( V \) = relative velocity of air
- \( S \) = wetted surface area
- \( C_L \) = coefficient of lift
- \( \bar{q} = \left( \frac{1}{2} \rho V^2 \right) \): Dynamic Pressure

Dynamic pressure

Total pressure of any fluid

\[ = \text{static pressure} + \text{dynamic pressure} \]
\[ = \rho gh + \frac{1}{2} \rho V^2 \]

Dynamic pressure of a fluid represents its kinetic energy
Atmospheric density

\[ \rho = \rho_0 e^{\frac{g_0 (h-h_0)}{RT}} \]

Angle of attack

AOA

Relative Wind

V_\infty

\theta

M_\infty

\alpha

L

R

D

M_c

Chord line
**Coeff. of Lift vs Angle of attack**

Lift coefficient formula:

\[ L = \left( \frac{1}{2} \rho V^2 \right) S C_L \]

**Drag**

\[ D = \left( \frac{1}{2} \rho V^2 \right) S C_D \]

- \( C_D \) = Coefficient of drag
- \( C_D \) = profile drag + induced drag
- \( C_D = C_{D_0} + K C_L^2 \)
**Mach Number**  \( M = \frac{V}{C} \)

- \( V \) = velocity of object relative to medium
- \( C \) = velocity of sound in the medium
- \( = \) velocity of sound in air = 340 m/s at 25\(^0\) C

\[
M < 1 \quad \text{Subsonic} \quad C = \sqrt{\gamma RT} = \sqrt{\frac{\gamma P}{\rho}}
\]

- \( M = 1 \)  \quad \text{Sonic}

- \( 0.8 < M < 1.2 \)  \quad \text{Transonic}

- \( 1.2 < M < 5 \)  \quad \text{Supersonic}

- \( M > 5 \)  \quad \text{Hypersonic}

**Drag vs Mach number**

![Drag vs Mach number graph](#)
Drag

- Skin friction drag
- Pressure drag
- Induced drag

Skin friction drag

- It is caused by the interaction of the air particles against the surface of the aircraft. For the airplane, skin friction drag can be reduced, by keeping an aircraft's surface highly polished and clean.
Form or Pressure drag

- *Pressure drag* is caused by the separation of air that is flowing over the aircraft or airfoil.
- **Note:** New generation cars are designed to reduces pressure drag, which leads to better mileage.

Induced drag

- *Induced drag* is the drag created by the vortices at the tip of an aircraft's wing.
- *Induced drag* is more while maneuvering due to more flow separation over the entire body.
Thrust

- Thrust is produced by engines, which counteracts the drag and hence the airplane moves in forward direction.
- Types of engines
  - Propeller
  - Turboprop
  - Turbofan
  - Turbojet
  - Ramjet
  - Scramjet

Propulsion group types

- Jet engine
**Propeller engine**

*Spitfire*: Used by England in second world war.

**Turboprop engine**

Used by ATR flights
Turbofan engine

Airbus A380 – Largest Passenger Aircraft
Engine Used: Either Rolls Royas or GE

Turbofan engine with afterburner

LCA - Light Combat Aircraft
Kaveri: An indigenous engine under development at GTRE (Gas Turbine Research Est.) under DRDO
Ramjet Engines

_Brahmos:_ A supersonic cruise missile developed jointly by India and Russia.

Scramjet

_X-43_ is an experimental vehicle of NASA which used scramjet propulsion to reach up to MACH 9.
**Basic Force Balance**

- Weight
- Lift
- Drag
- Thrust
- Side force
Basic Moment Balance

- Rolling
- Pitching
- Yawing

Ailerons ➔ Roll
Aileron $\rightarrow$ Roll

Elevator $\rightarrow$ Pitch

Horizontal Stabilizer
Distance (L)
Center of Gravity
Elevator
Down Force (F)
Resulting Motion
Elevator ➞ Pitch

Rudder ➞ Yaw
Sensors

- **Altimeter**: Height above sea level
- **Air Data System**: Airspeed, Angle of Attack, Mach No., Air Temperature etc.
- **Magnetometer**: Heading
- **Accelerometers**: Translational motion of the aircraft in the three axes
- **Gyroscopes**: Rotational motion of the aircraft in the three axes
- **GPS**: Accurate position, ground speed
Actuators

Control Surfaces are Moved with Actuators

In modern aircraft, hydraulic systems or electric motors called actuators move control surfaces by responding to control signals sent from a flight computer connected to the control stick.

Cockpit Inputs

Actuator Piston

Actuator

Hydraulic Pressure

Stick

Throttle

Control Computers

The actuator command signal travels over a wire from the control computer to the actuator.

Actuators

“Putting it All Together”

Flight Control System

Aircraft Sensors

Sensor Measurements

Flight Control Computer

Pilot Commands

Controller

Commands

Aircraft Control Effectors

Aircraft Cockpit

- Flight Path Command
- Velocity Command
- Attitude Command
- etc.

- Orientation
- Velocity
- Attitude
- etc.

- Throttle Position
- Rudder Position
- Elevator Position
- etc.
Thanks for the Attention...!