Aircraft Performance

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16.00: Introduction to Aerospace & Design

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Lecture Outline

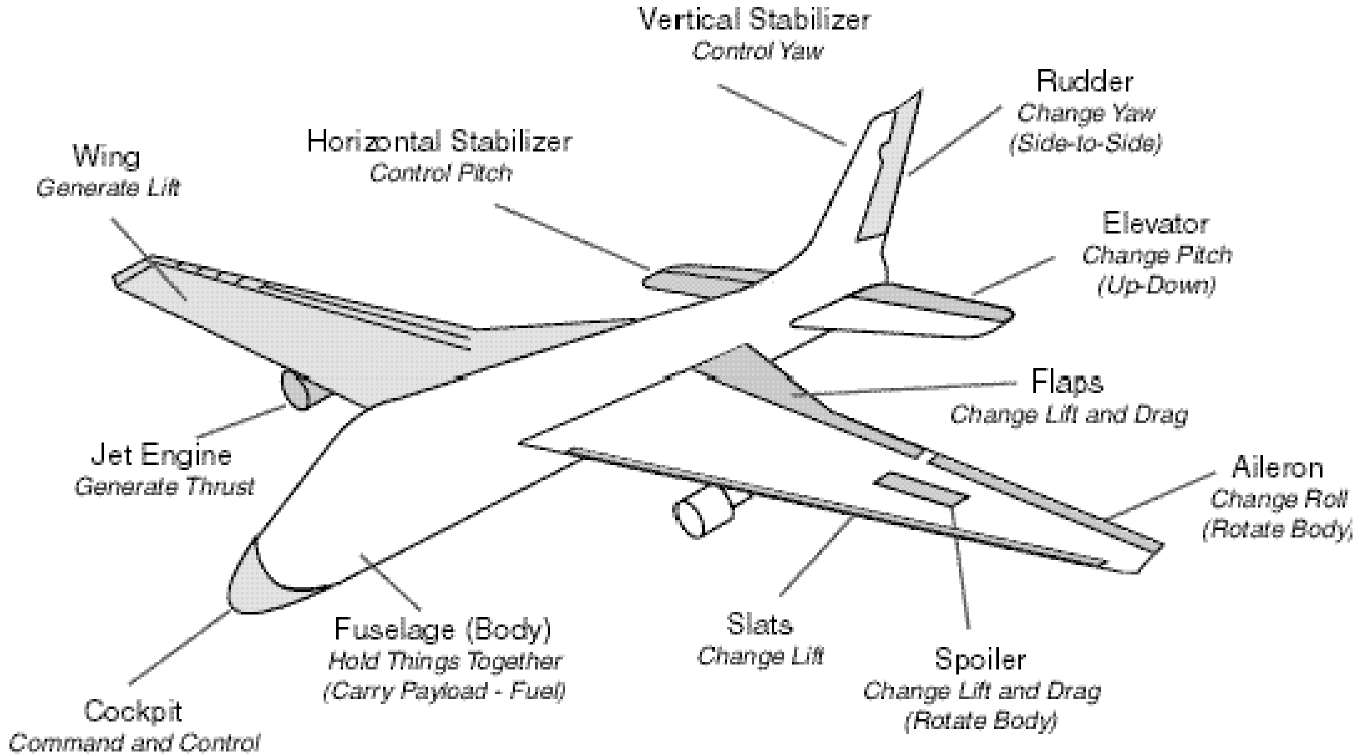
- Performance Parameters
  - Aircraft components and examples
- Equations of Motion
- Thrust-Velocity Curves
  - Stall
  - Lift-to-Drag Ratio
- Endurance & Range
- V-n Diagrams

Performance

- Note: Book errata pdf file

- Speed: minimum and maximum?
- Range: How far?
- Endurance: How long?
  – Flight dynamics

Aircraft Components



Aircraft Performance/Design Elements

- First example:
  - Semi-scale Mustang “Reno Racer”
  - ~ 750 cm span, 450 grams weight

Aircraft Performance/Design Elements

- Second example: "Omega" high performance motor-glider
- ~ 1.8 m span, 300 grams weight

Discussion Topic

- What are the differing aerodynamic design features providing the desired performance for each aircraft?
- Common features:
  - Aero controls: elevator, ailerons, rudder
  - Electric motor: identical
  - Radio receiver and servo motors: identical

Desired performance

- Reno Racer: high speed aerobatics and racing
  - 20-25 m/s velocity in level flight
  - "High g" turns and rolls

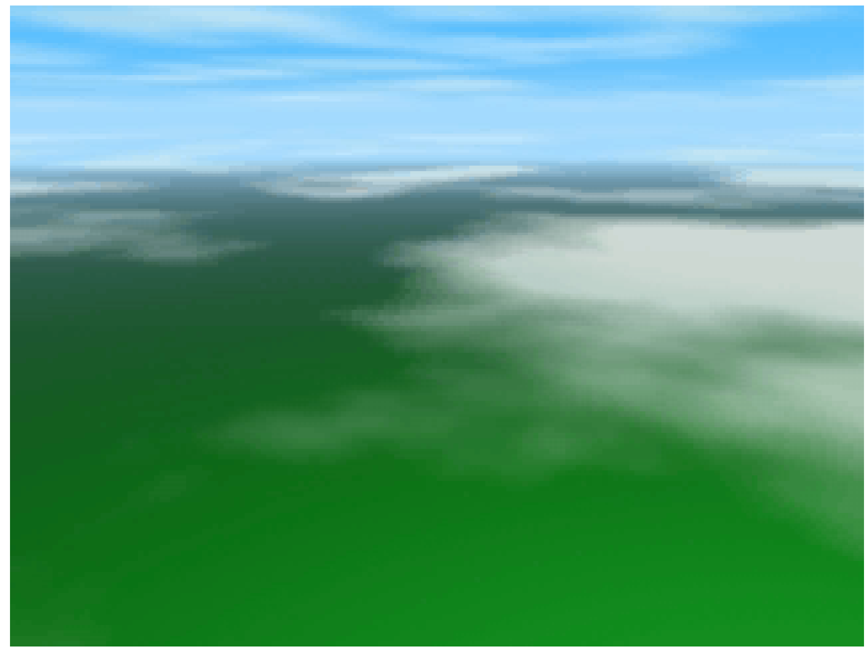
- Omega: steep rapid climbs to altitude; efficient power-off glides for extended duration

Design Elements

- Aspect Ratio (b^2/S)
  - Low or high? Why?
- Drag reduction: how attained?
- Airfoils: low or high camber? Why?
- Tail moment arm (horizontal stab area x tail length): high or low? Why?
- Wing loading (wing area/weight) high or low? What effect on flight?
- Any other differing design features?

Equations of Motion

- 2-D model of aircraft
- Lift, Drag, Weight and Thrust
- Velocity, v
- Flight path, □ or □
  - Velocity & horizontal
- Pitch angle
  - Nose & horizontal



Thrust-Velocity Curves

- The relationship between the required thrust and the velocity can be calculated for any aircraft.

1. Determine the air density ρ_∞ from the Standard Atmosphere for a given altitude h.

2. Calculate the lift coefficient C_L for a given velocity v, by recalling the definition of dynamic pressure $q = (1/2)\rho_\infty v^2$:

$$C_L = \frac{2W}{\rho_\infty v^2 S} \quad \textbf{(4.17)}$$

3. Calculate the drag coefficient from the drag polar for the aircraft.

4. Calculate the thrust required for steady level flight using

$$T = \frac{W}{(C_L/C_D)} = \frac{mg}{L/D} \quad \textbf{(4.16)}$$

Thrust-Velocity Simulation

- Simulations https://web.mit.edu/16.00/www/3/03/index.html
- Foil Sim http://www.lerc.nasa.gov/WWW/K-12/airplane/foil2.html
- Air Density Simulator http://www.flyers.org/simulators/atmospheric.htm

- Stall
- Maximum Lift/Drag

$$\left(\frac{L}{D}\right)_{max} = \frac{C_L}{(2C_L^2)/(\pi e AR)} = \frac{\pi e AR}{2C_{L,(L/D)_{max}}}$$

Table 4.1 Typical Values of the Maximum Lift-to-Drag

Type of Aircraft	$(L/D)_{max}$
Modern sailplanes	25–40
Civil jet airliners	12–20
Supersonic fighter aircraft	4–9

Range & Endurance (Breguet)

- Aerodynamics & Engines (propeller, jets)
  - m_o = a/c, kg
  - m_f = mass of fuel, kg $\qquad m = m_o + m_f$
  - $\dot{m}_f$ = fuel mass flow rate, kg/s
- Range: total distance on a tank of fuel
  - $(L/D)_{max}$ $\qquad (C_L^{1/2}/ C_D)_{max}$ or $v(L/D)$
- Endurance: total time a/c can stay aloft on a tank of fuel
  - $(C_L^{3/2}/ C_D)_{max}$ $\qquad (L/D)_{max}$

Range & Endurance

Table 4.2 Aircraft Range Comparison

Attaining Maximum Range	**Boeing 747**	**Voyager**
(1) Large fuel mass/empty mass ratio	≈ 0.7	≈ 8
(2) Large L/D	≈ 20	≈ 40
(3) Large η	≈ 0.8	≈ 0.85
(4) Low μ Low c, specific fuel COT	$\mu = 1.5x10^{-4}s^{-1}$	low c

Table 4.3 Designing for a large mass ratio.

Mass ratio, m_{fuel}/m_0	**Boeing 747**	**Voyager**
Efficient structure	redundant for safety	not redundant
Advanced materials	aluminum	graphite-epoxy (5x stronger and stiffer for given cut)
High aspect ratio	10	40
Smooth surface	riveted aluminum	molded
Fuselage, tail, etc.	large	small

A large L/D ratio is similarly obtained through the design parameters in Table 4.4

V-n Diagrams (Flight Envelope)

- Operational Velocity-Load (in g's, denoted by 'n') envelope
- Aerodynamic
- Structural
- Simulator
  - Stall limit: aerodynamic
  - Corner Velocity or Maneuver point
  - Structural limit

$$v^* = \sqrt{\frac{2n_{\max}}{\rho C_{L,\max}} \frac{W}{S}} \quad (4.78)$$

Examples

- Example 4.6, pg. 90, V-n Simulation
- Problem 4.6 Calculate the thrust required for an aircraft, modeled after a Canadair Challenger Business Jet, to maintain steady level flight of 350 knots at an altitude of 6500 meters. Assume the following characteristics for the aircraft: Weight = 16,350 kg, Wing area = 48.31, Wing span = 19.61 m, Parasite drag = C_{Do} = 0.02, Oswald efficiency factor = e = 0.8

Questions?

- Mud Cards