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# Aircraft Performance

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16.00: Introduction to Aerospace & Design

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# Lecture Outline

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

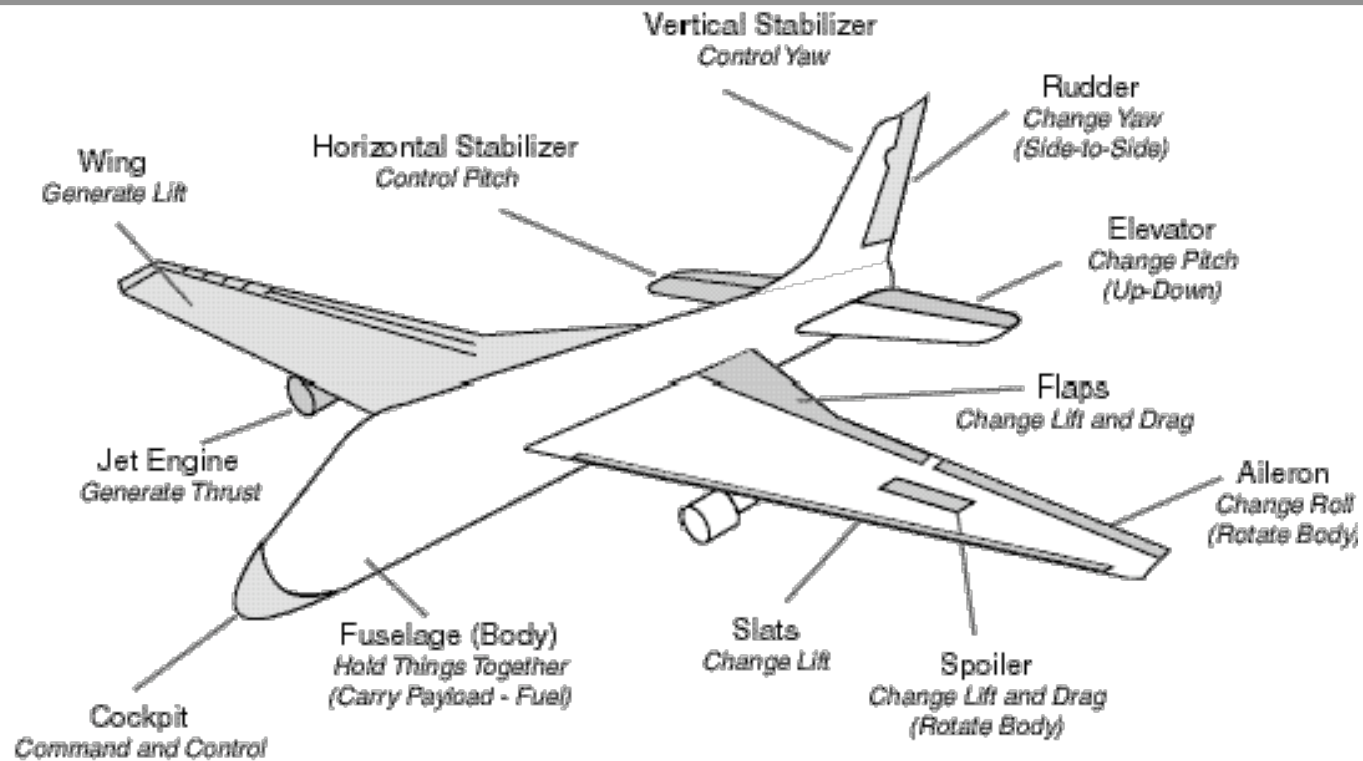
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- Note: Book errata pdf file
- Speed: minimum and maximum?
- Range: How far?
- Endurance: How long?
  - Flight dynamics



# Aircraft Components

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# Aircraft Performance/Design Elements

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



## Aircraft Performance/Design Elements

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- Second example: “Omega” high performance motor-glider
- $\sim 1.8$  m span, 300 grams weight



## Discussion Topic

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- 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



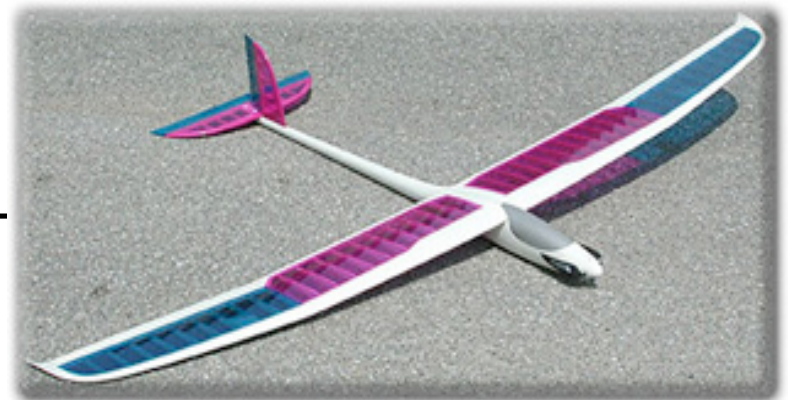
## Desired performance

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- 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

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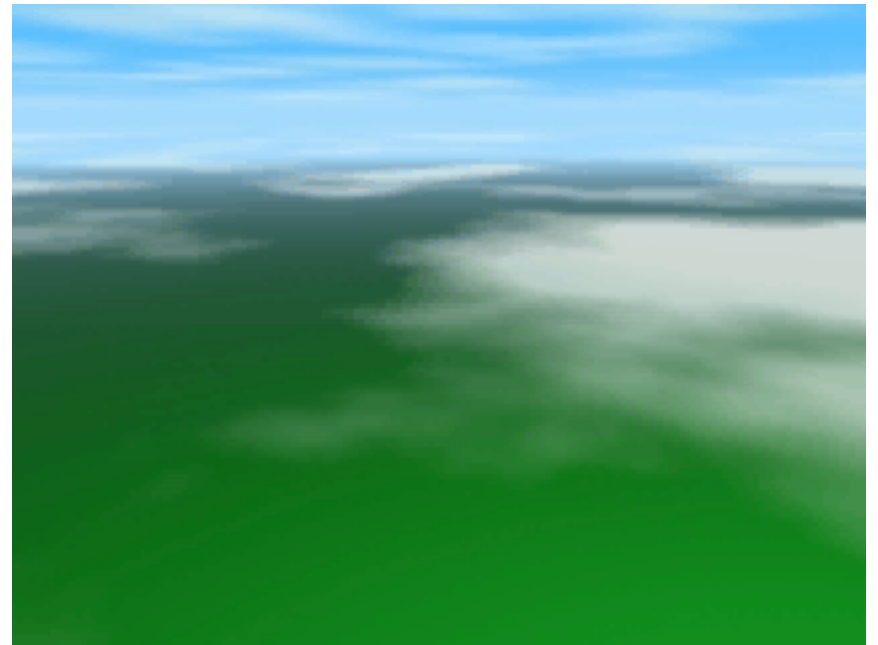
- Aspect Ratio ( $b^2/S$ )
  - Low or high? Why?
- Drag reduction: how attained?
- Airfoils: low or high camber? Why?
- Tail moment arm (horizontal stab area x tail length): high or low? Why?
- Wing loading (wing area/weight) high or low? What effect on flight?
- Any other differing design features?



# Equations of Motion

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



# Thrust-Velocity Curves

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- The relationship between the required thrust and the velocity can be calculated for any aircraft.
  1. Determine the air density  $\rho_\infty$  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  $q = (1/2)\rho_\infty v^2$ :

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

3. Calculate the drag coefficient from the drag polar for the aircraft.
4. Calculate the thrust required for steady level flight using

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



# Thrust-Velocity Simulation

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- 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

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

**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)

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



# Range & Endurance

**Table 4.2** Aircraft Range Comparison

Attaining Maximum Range	Boeing 747	Voyager
(1) Large fuel mass / empty mass ratio	$\approx 0.7$	$\approx 8$
(2) Large $L/D$	$\approx 20$	$\approx 40$
(3) Large $\eta$	$\approx 0.8$	$\approx 0.85$
(4) Low $\mu$ Low $c$ , specific fuel $COI$	$\mu = 1.5 \times 10^{-4} s^{-1}$	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)

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

- Structural limit

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



# Examples

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- 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 =  $C_{D_0} = 0.02$ , Oswald efficiency factor =  $e = 0.8$





# Questions?

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- Mud Cards

