University of BRISTOL

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Aerospace Vehicle Design And System Integration 3 AENG30013

(AVDASI3)

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Constraint Diagrams

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Content

- Constraint diagrams
  - What are they?
  - How do we construct one?
  - How do we use them to inform design?
- Coursework

Design Requirements?

Constraint Diagrams

- Requirement phase:
  - Substantial number of constraints placed on preliminary design

- Preliminary design phase:
  - Need to determine number of key wing and engine parameters
  - Aspect ratio, wing area, span, taper, aerofoils, control surfaces, etc.

- Typical to attempt to visualise constraints and allow some basic design parameters to be determined:
  - Wing loading, W/S
  - Thrust loading, T/W
  - Can be tightly coupled, e.g. take-off

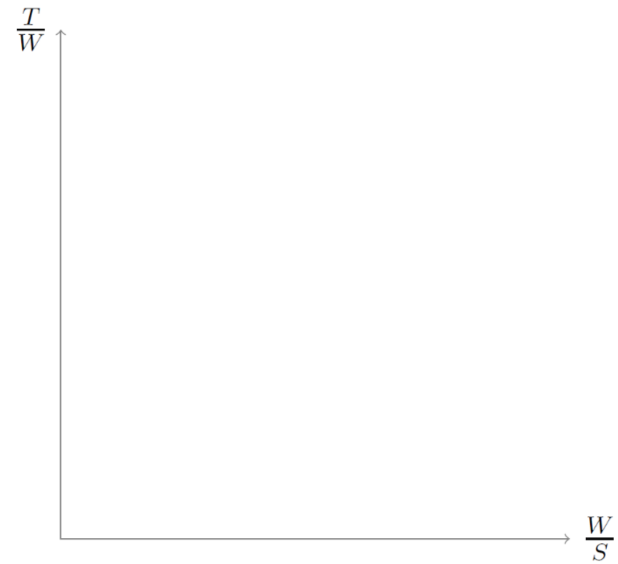
Constraint Diagrams

- Construct equations for requirements that are of the form:

$$\frac{T_0}{W_{MTOW}} = f\left(\frac{W_{MTOW}}{S}\right)$$

- Use typical cruise-liner design drivers:

1. Landing/stall speed
2. Take-off roll
3. n-G manoeuvre
4. Climb rate



Constraint Diagrams

1. Landing/stall speed

- Lift must maintain weight:

Given to us by regulations

$$L = W = \frac{1}{2}\rho V_{min}^2 S C_L^{max}$$

Since using MTOW, this is worse case scenario

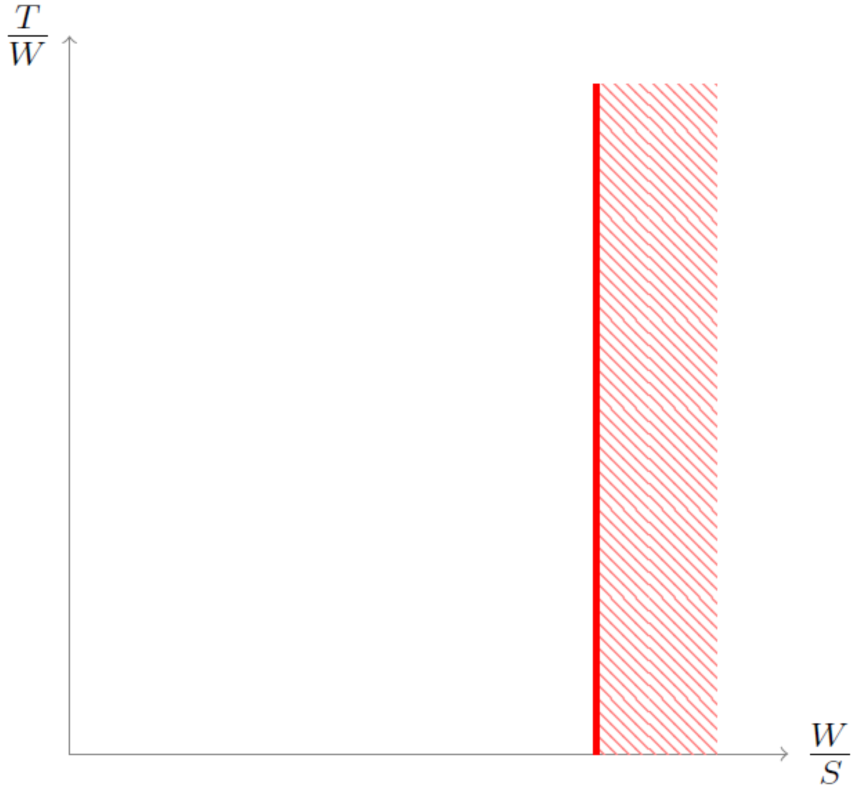
Can initially set using historical data – becomes a design parameter later

Constraint Diagrams

1. **Landing/stall speed**

- Rearrange:

$$\frac{W}{S} = \frac{1}{2}\rho V_{min}^2 C_L^{max}$$



Constraint Diagrams

2. <u>Take-off Roll</u>

- Perform simple analysis and assume worst case scenario – no lift.
- Equate work done to change in KE:

$$(T - D_{TO} - \mu W)x = \frac{1}{2}\frac{W}{g}V_{TO}^2$$

*F=mu*R, mu=0.03*

- Rearrange:

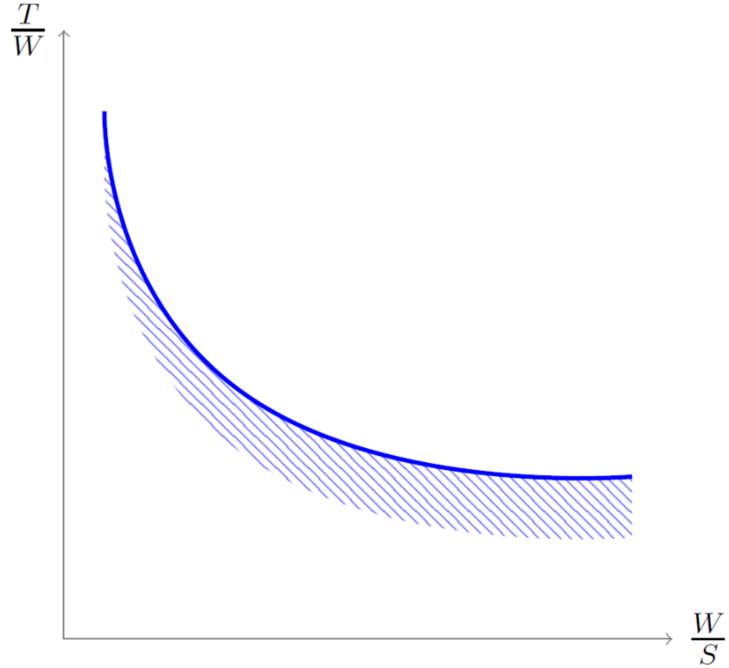
$$\frac{T}{W} = \frac{V_{TO}^2}{2gx} + \frac{D_{TO}}{W} + \mu$$

$$C_D = C_{D_0} + \frac{C_L^2}{\pi ARe}$$

Constraint Diagrams

2. <u>Take-off Roll</u>

$$\frac{T}{W} = \frac{V_{TO}^2}{2gx} + \frac{1}{W/S}\left(\frac{1}{2}\rho V_{TO}^2 C_{D_0} + \frac{\frac{1}{2}\rho V_{TO}^2 C_{L_{TO}}^2}{\pi A R e}\right) + \mu$$



Constraint Diagrams

3. <u>n-G manoeuvre</u>

- To maintain speed, T=D:

L=nW so rearrange to get Cl

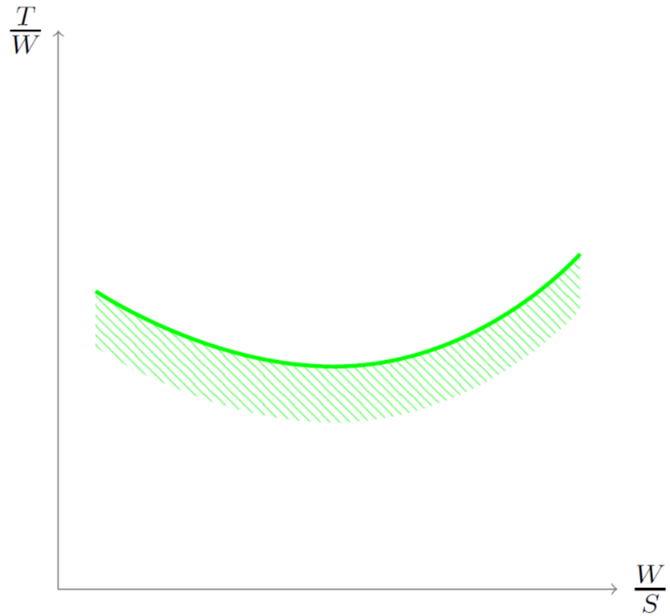
$$T_h \approx T\sigma = \frac{1}{2}\rho_h V^2 S C_{D_0} + \frac{1}{2}\rho_h V^2 S \frac{C_L^2}{\pi A R e}$$

Engine performance deteriorates with altitude

Constraint Diagrams

3. **n-G manoeuvre**

$$\frac{T}{W} = \frac{\frac{1}{2}\rho V^2 C_{D_0}}{W/S} + \frac{n^2 W/S}{\frac{1}{2}\rho\sigma^2 V^2 \pi A R e}$$



Constraint Diagrams

4. Climb rate

- Resolve forces and assume small angles:

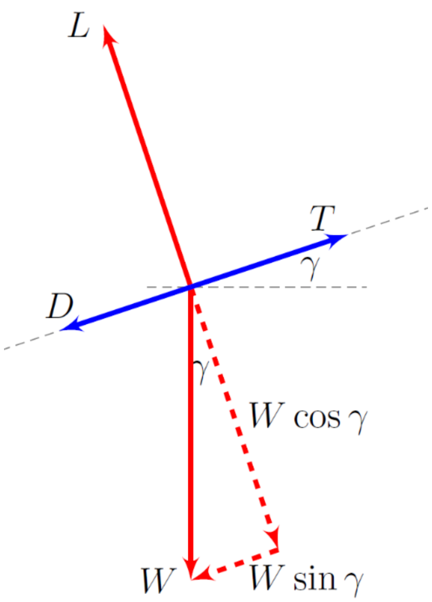
$$\gamma \approx (T - D)/W$$

- Introduce climb ratio, and assume small angles:

$$G \approx \gamma$$

- Rearrange:

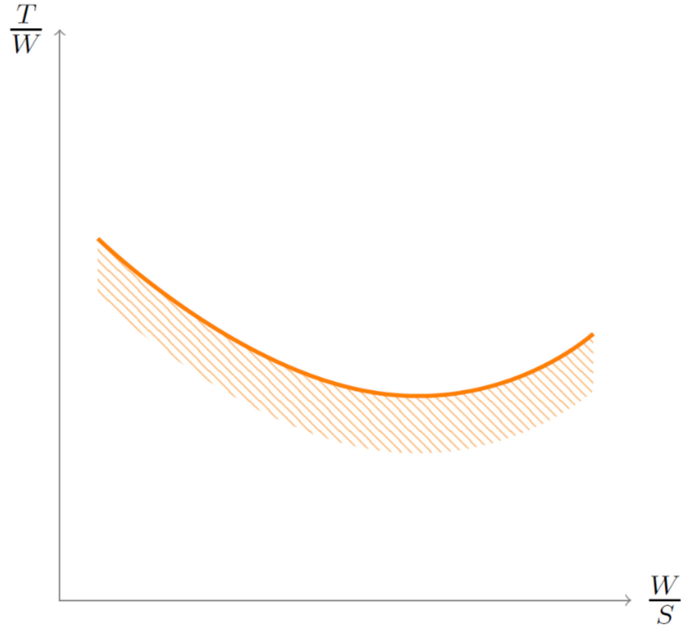
$$\frac{T_h}{W} = \frac{D}{W} + G$$



Constraint Diagrams

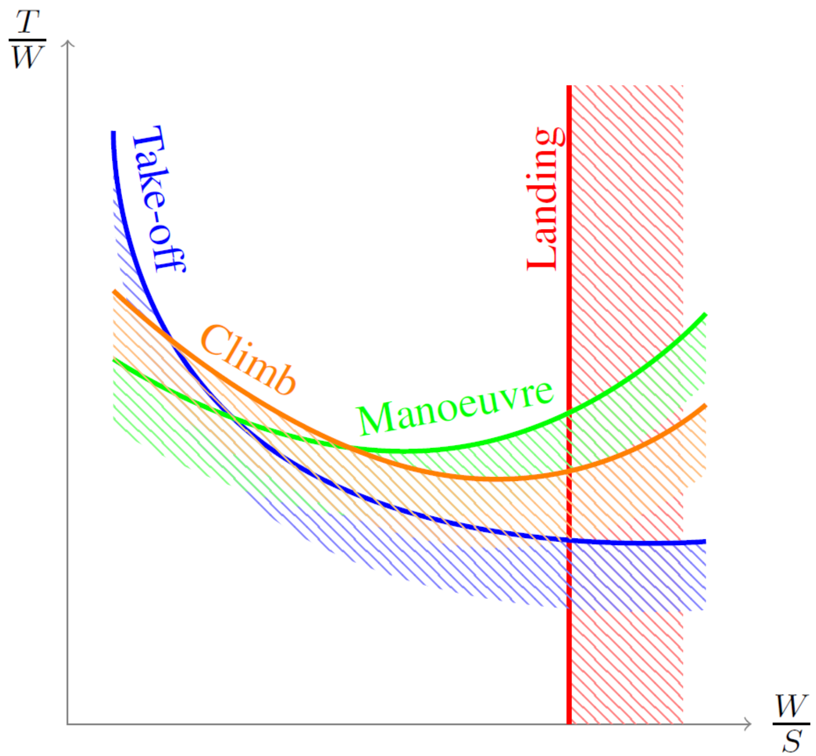
4. Climb rate

$$\frac{T}{W} = \frac{\frac{1}{2}\rho V^2 C_{D_0}}{W/S} + \frac{W/S}{\frac{1}{2}\rho\sigma^2 V^2 \pi A R e} + \frac{G}{\sigma}$$



Constraint Diagrams

- To construct whole diagram, clearly need some wing parameters such as Clmax and aspect ratio – initially base on historical data.

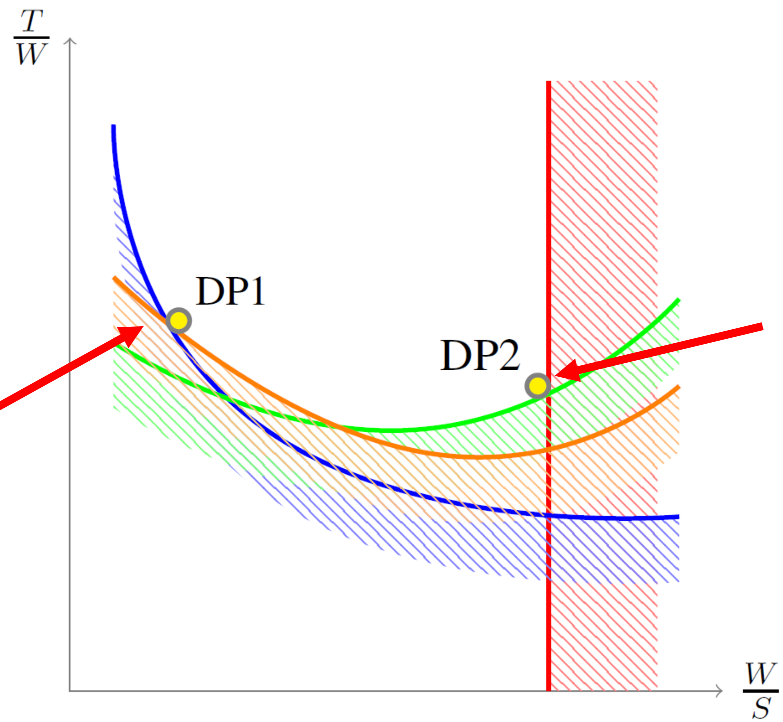


Constraint Diagrams

- Diagram **ONLY** gives method to visualise constraints
- Therefore gives **feasible region**
- Choice of W/S and T/W in feasible region driven by other factors
  - Cruise Cl and Cd
  - Span limits
  - Aspect ratio
  - High lift devices
  - Range, block time - DOCs

Constraint Diagrams

- Sensible to choose somewhere close to edge of feasible region



High W/S with lower T/W driven by manoeuvre and stall. Small wing means higher cruise Cl.

Low W/S with high T/W driven by take-off and climb. Large wing gives lower Cl in cruise but higher friction drag

Sensitivity?

Summary

- Constraint diagram is a way to visualise initial spec. requirements
- Use simple physics to relate T/W to W/S for various constraints
- Allows visibility of feasible region
- Choose T/W (engine requirement) and W/S (aerodynamic requirement) close to edge of feasible region
  - Be careful of changes to constraint lines during design - sensitivity

Coursework

- Work in pairs – recommended that stick to same pairs as before

- Due 5pm Friday 20th March via BB

- Two parts:
    1. Steady-state aerodynamics
        I. Given wing parameters, construct constraint diagram
        II. Use XFLR5 to design wing
        III. Consider performance on family of aircraft
    2. Flight mechanics

Coursework

- To get 50+ in the aerodynamics part, you must:
  - Construct the correct constraint diagram
  - Run XFLR5 to aid in the design of a wing
  - Report findings

- To get 60+ in the aerodynamics part, you must **also**:
  - Discuss design decisions and give logical justifications for those decisions
  - Write and present effectively

- To get 70+ in the aerodynamics part, you must **also**:
  - Provide critical analysis of the design process and final design
  - Write and present concisely