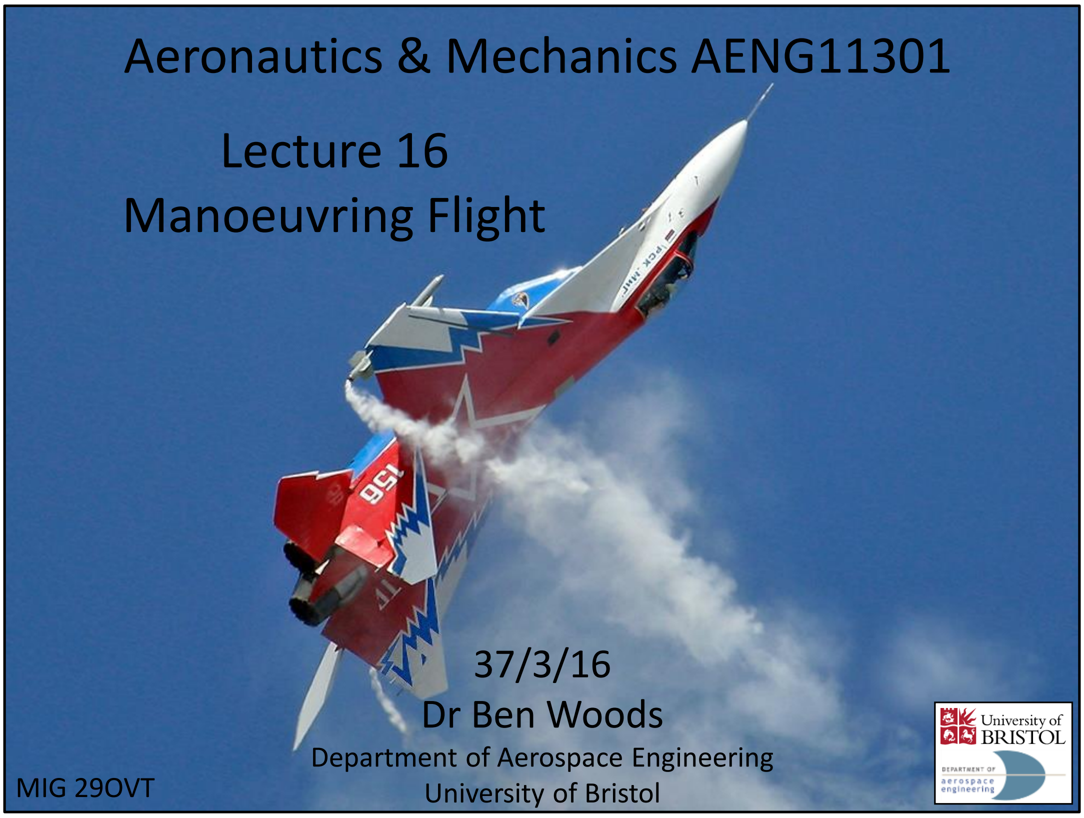


In aerobatics, Pugachev's Cobra is a dramatic and demanding manoeuvre in which an airplane flying at a moderate speed suddenly raises the nose momentarily to the vertical position and slightly beyond, before dropping it back to normal flight.
The manoeuvre is named after the Soviet test pilot Viktor Pugachev, who first performed the manoeuvre publicly in 1989 at the Paris Le Bourget air show

Outline for today

- Symmetric manoeuvres
- Load factor
- Flight envelope
  - Manoeuvre envelope
  - Gust envelope
  - Combined envelope

Aims for today

- Be able to recognize different types of symmetric manoeuvres
- Be able to define load factor
- Be able to define boundaries of manoeuvre flight envelope
- Be able to define manoeuvre point and corner speed
- Appreciate effects of gusts on an aircraft's flight envelope

Symmetric manoeuvres

Load factor

Flight envelope

Manoeuvre envelope

Gust envelope

Combined envelope

Symmetrical Manoeuvre

- motion is curvilinear
  - therefore must be a resultant force perpendicular to the flight path in order to give a normal acceleration
  - steady curved path with radius R

$$\boxed{F = ma = \frac{W}{g}\frac{V^2}{R}}$$

- only concerned here with symmetrical manoeuvres
  - variation in **lift** only
  - *vertical* manoeuvres - loop, pull-up, push-over, outside loop
  - *horizontal* manoeuvres – banked turn

Centripetal acceleration

Arrow loop from takeoff Thunderbirds 2:38 end
http://www.youtube.com/watch?v=9mroDp-30Qg

Outside loop
http://www.youtube.com/watch?v=Ugm3mLnVTH4
Magnús Norðdahl a former captain at Icelandair flying DC-3, DC-4 and DC-8 still enjoys flying, here making a low level outside loop in his CAP 10. He is 78 year old.

Load factor

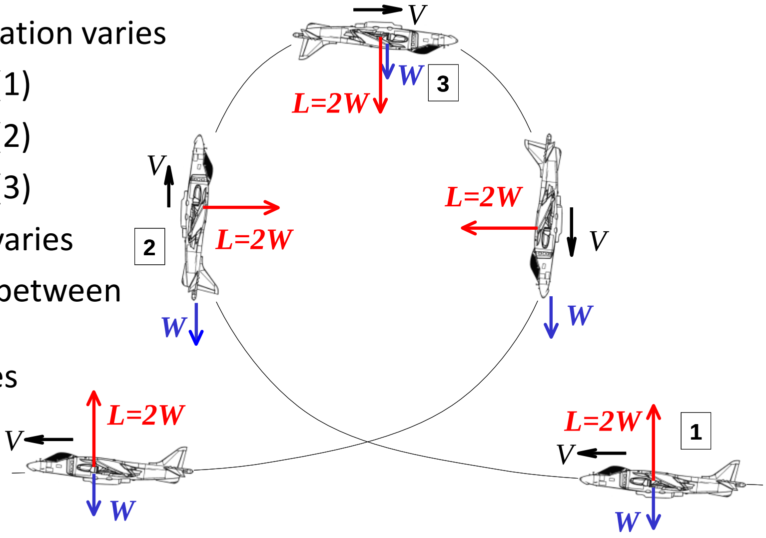
- lift force variation can be large
  - typical 1:5 speed range translates into 1:25 variation in $\frac{1}{2}\rho V^2$
  - limited by structural strength of airframe
  - limits specified in terms of **load factor** n
  - straight & level flight $\equiv$ $n = 1$

$$\boxed{n = \frac{L}{W}}$$

Centripetal acceleration

Normal Acceleration in a Loop

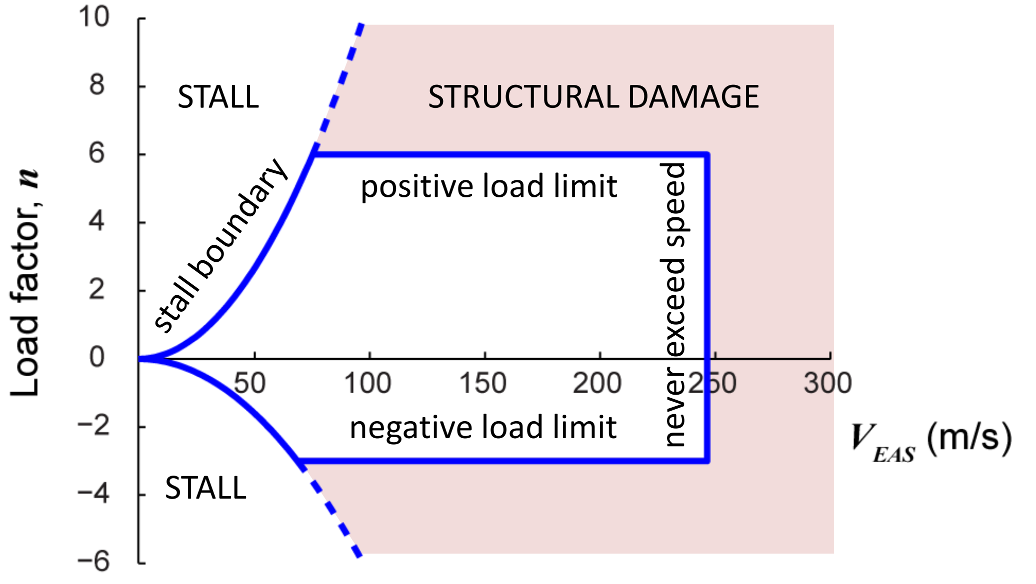
- Consider a case with: lift = $2W \rightarrow$ constant load factor n = 2
  - loading in normal direction between components of the aircraft (eg pilot and his seat) remains constant
- **normal** acceleration varies
  - 1g at point (1)
  - 2g at point (2)
  - 3g at point (3)
- radius of loop varies
  - interaction between gravity and inertia forces



Load factor regulations

Aircraft Type	Max Positive	Max Negative
Normal	3.80	1.52
Utility	4.40	1.76
Acrobatic	6.00	3.00
Commuter	3.80	1.52
Large Transport	2.50	1.00

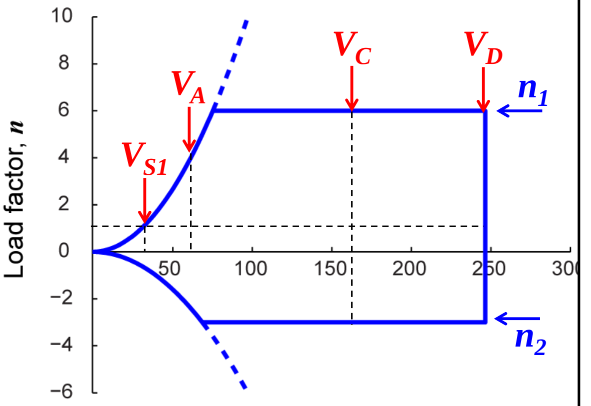
Manoeuvre Flight Envelope



Things to add:
1 g line
Manoeuvre point?
Cruise velocity?
Dive velocity?
Stall velocity in cruise

Manoeuvre Envelope Limits

- maximum positive manoeuvring load factor n_1
- maximum negative manoeuvring load factor n_2
- **Design Manoeuvring Speed** V_A
  - speed for safe application of maximum control deflection
- **Design Cruising Speed** V_C
- **Design Diving Speed** V_D
- Stall speed (flaps up) V_{S1}



Manoeuvre Point

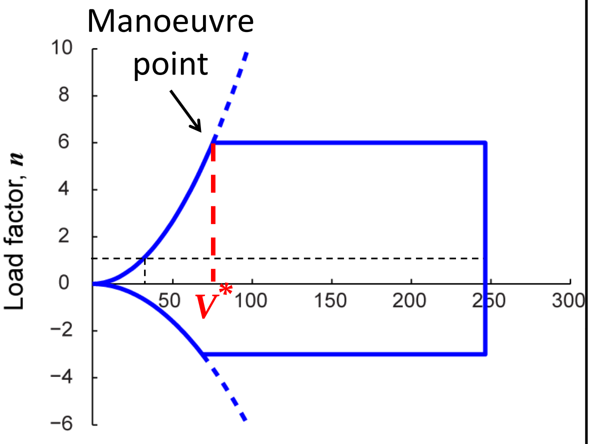
- On stall boundary:

$$L = nW = 0.5\rho V^2 S C_{L\max}$$

$$\boxed{n = \frac{\rho V^2 S C_{L\max}}{2W}}$$

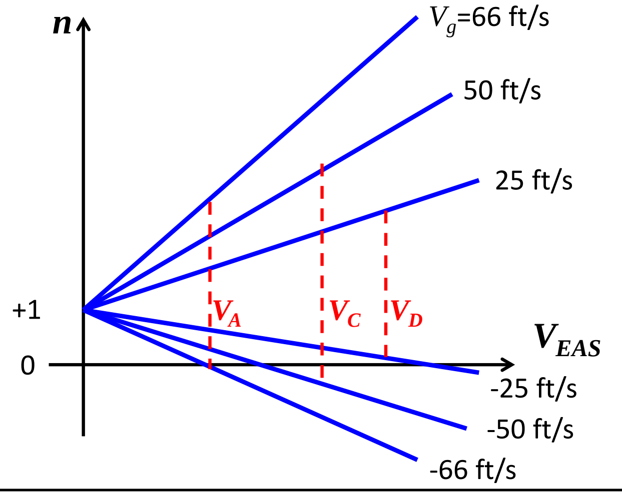
- When C_L and n both maximum then corresponds to minimum turn radius and maximum turn rate, termed the **manoeuvre point**.
- Corresponds to the **corner velocity**, $V*$

$$\boxed{V^* = \sqrt{\frac{2n_{\max} W}{\rho S C_{L\max}}}}$$



Gust Flight Envelope

- loads due to gusts (atmospheric turbulence)
  - **vertical gust velocities** , V_g defined in Joint Airworthiness Requirements (JARs)
  - corresponding load factors depend on wing lift curve slope a_1 and wing loading *W/S* and altitude



Gust Velocities

- 66 ft/s at gust penetration speed V_B
- 50 ft/s at Cruising Speed V_C
- 25 ft/s at Design Diving Speed V_D
- constant up to 20,000ft – reduce linearly up to 50,000ft
- gust velocity lines are linear and pass through +1
  - aircraft flying at velocity V meets vertical gust of v
  - wing incidence increased by v/V (since v is small)

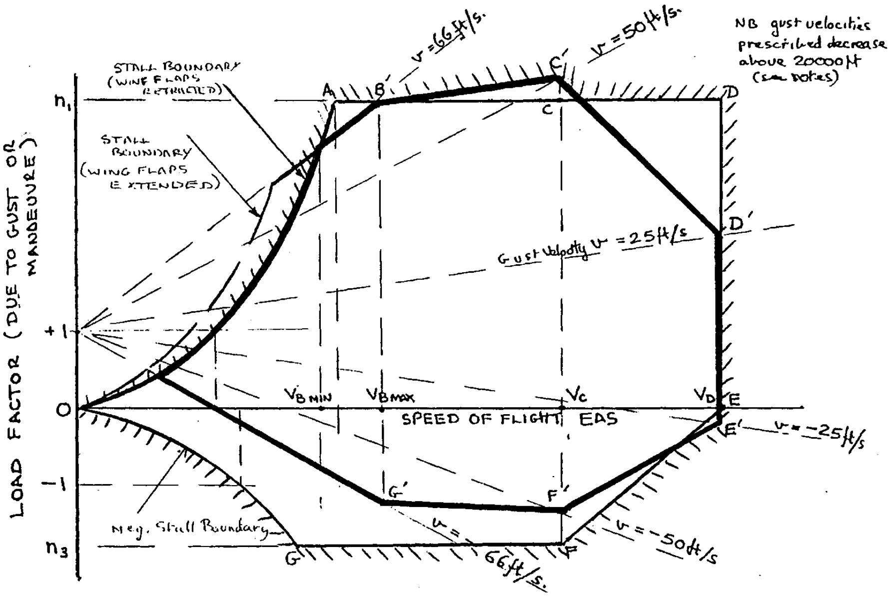
$$\Delta C_L = a_1 \frac{v}{V} \quad \Rightarrow \quad \Delta L = \tfrac{1}{2}\rho V^2 S\, a_1 \frac{v}{V} = \tfrac{1}{2}\rho V S\, a_1 v$$

  - load factor will increase from +1 to n

$$\frac{\Delta L}{W} = n - 1 = \frac{\rho V S\, a_1 v}{2W} \quad \Rightarrow \quad \boxed{n = \frac{\rho a_1 v}{2W/S} V + 1}$$

Combined Flight Envelope

- aircraft structural design loads



Example

1. Draw the manoeuvre flight envelope for an **acrobatic** aircraft with the following parameters:
   – mass = 2,300 kg
   – wing area, S = 19.3 m^2
   – C_{Lmax} = 2.0
   – -*ve* C_{Lmax}= -1.2
   – Design diving speed, V_D=250 m/s
   – Lift curve slope, a_1 = 6.3/rad
2. Calculate the total load factor if the aircraft hits a gust of 4 m/s at the design diving speed at sea level

Answers: 1) See example V-n plot 2) 4.3

The Frecce Tricolori (Italian, literally Tricolour Arrows), The team flies the Aermacchi MB-339-A/PAN, a two-seat fighter-trainer craft capable of 898 km/h at sea level (250 m/s)

Use load factor limits for aerobatic aircraft,
max positive load factor 6, max negative load factor -3

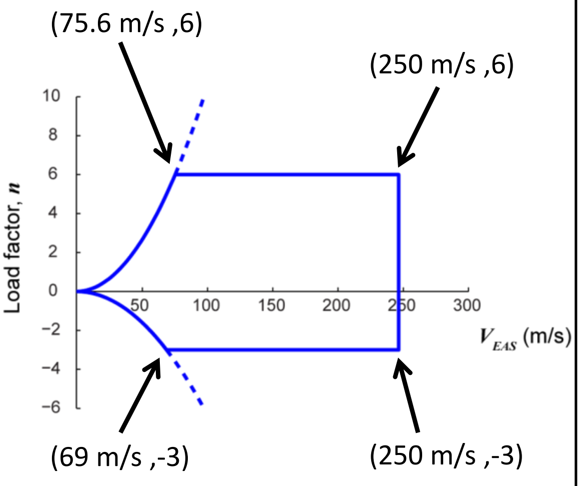
$$V^* = \sqrt{\frac{2n_{\max}W}{\rho S C_{L\max}}}$$

$$+\text{ve}\, V^* = \sqrt{\frac{2\times 6\times 2300\times 9.8}{1.225\times 19.3\times 2}}$$

$$= 75.6\ \text{m/s}$$

$$-\text{ve}\, V^* = \sqrt{\frac{2\times -3\times 2300\times 9.8}{1.225\times 19.3\times -1.2}}$$

$$= 69.0\ \text{m/s}$$



Calculate the total load factor if the aircraft hits a gust of 4 m/s at the design diving speed at sea level

$$n = \frac{\rho a_1 v}{2W/S} V + 1$$

$$= \frac{1.225 \times 6.3 \times 4}{2 \times 2300 \times 9.8/19.3} \times 250 + 1$$

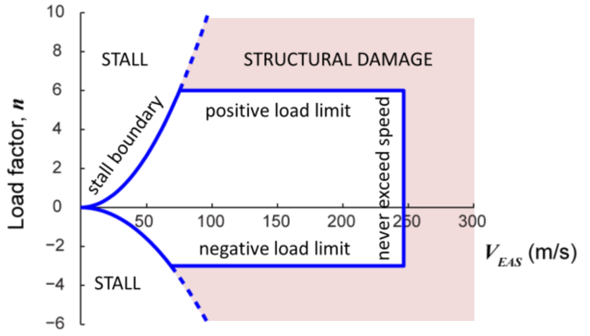
$$= 4.3$$

Summary

$$n = \frac{L}{W}$$

$$V^{*} = \sqrt{\frac{2n_{\max}W}{\rho S C_{L\max}}}$$

$$n = \frac{\rho a_1 v}{2W/S}V + 1$$



- Overlap of manoeuvre flight envelope and gust envelope defines combined flight envelope

Be able to recognize different types of symmetric manoeuvres

Be able to define load factor

Be able to define boundaries of manoeuvre flight envelope

Appreciate effects of gusts on an aircrafts flight envelope

Follow-up materials

To help with exam:

- Introduction to Flight – 6.17

To help with exam:
Introduction to Flight – 5.1-5.2

To aid in understanding:
Understanding flight – Chapter 1

For interest:
Introduction to Flight – 5.19 (explanation of lift)