Structure

Tuesday, October 10, 2017 13:20

For the glory of God

Introduction

- Forces cannot be seen, but the effects of forces can be seen or understood.
  - ↳ This is of interest in structural analysis.
- No matter how good Aerodynamics and propulsion, if the vehicle doesn't structurally hold together, all is for naught.
- The structure design of an airplane is an intricate arrangement of various structural elements.

Fundamentals of Solid mechanics

- A study of structure is built upon the science of solid mechanics.

a) Stress

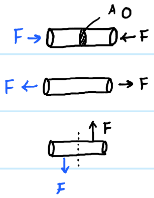
- When an external force is applied to the solid, the shape or size of the solid tends to change; however, the molecules of the solid material (being locked together by intermolecular force) resist this change in the form of an internal force.

  $(\sigma = \frac{F}{A})$

  ↳ This internal force per unit area is called as Stress.

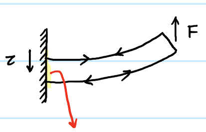
  (It ends up reaching an Equilibrium with the external force)

- There are three general classes of stress;
  - Compression
  - Tension
  - Shear



- To be more specific about compression,
  - Consider a rod with an external force F imposed on one end.
  - The force acts in a direction into the rod.
  - For the rod to remain in Equilibrium, there must be an equal and opposite force F on the other end.

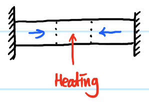
    This force is pressing into the segment.
  - By the definition, Compression stress $= \frac{F}{A}$
- Note that;
  - Compression and tension are acting perpendicular to the cross-sectional area (A).
  - Shear stress is acting tangentially to the cross-sectional area.
- Other cases
  - When the cantilever beam is bent upward by an applied load F,



- The top surface experiences a compressive stress
- The bottom surface experiences a tension stress

This juncture must be able to handle these stresses as well as the shear stress at the wall.

- Thermal stress (important to supersonic / hypersonic design)

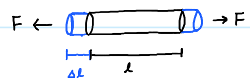


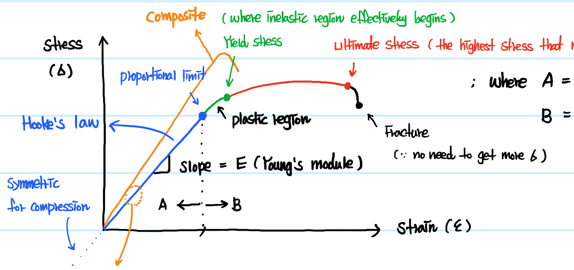
Assume that heat is added.
when the material gets warmer, its volume expands.
However, there is no room for it to move because the beam is supported between the two walls.
As a result, a compressive stress is induced in the material to produce a strain that cancels the thermal expansion.

b) Stress - Strain curve

· The curve is unique for each material and the curve reveal many of the properties of a material.

· First of all, let's define stress : $\sigma \equiv \frac{F}{A}$; strain : $\varepsilon \equiv \frac{\Delta l}{l}$ i.e.





; where A = Elastic range ↗ when the stress at any point in this region, the material returns to its original shape. There is no permanent structural damage.
B = Inelastic range ↳ when in this region, the material doesn't return to its original shape. This constitudes permanent structural damage.

For most materials, up to a certain limiting value of the stress (the yield stress), the stress is directly proportional to the strain. ∴ $\sigma = E\varepsilon$

cf. Brittle → No plastic region

c) Fatigue

· Common experience shows that when you bend a piece of metal back and forth enough times, it will break.

↳ This is an example of fatigue.

· For aircraft, various elements are repeatedly being bent back and forth by the changing loads on the structure.

e.g. The wing is bent upward by the high lift load at takeoff and is then bent downward upon landing by the weight of the wing after the lift is reduced to essentially zero.

· The prediction of the fatigue life of various componeds is vital in the design of aircraft.

↳ Such information is determined empirically by fatigue testing.

V-n diagram

· To begin with, why is V-n diagram necessary ?

- To design aircraft structure, we need to know what are loads that will be imposed on the aircraft.

- The diagram defines the strength limitation of aircraft.

· Basically, the diagram is used in either conceptual or very early preliminary design process.

· Note that ;

- Every aircraft has their own version of V-n diagram.

- The diagram only addresses loads in the vertical plane of symmetry of aircraft.

↳ ∴ ~~zero bank angle~~ (not necessary) and zero sideslip angle

- Even if you have same aircraft, V-n diagram will be different if you change a geometry, i.e. flap down.

Since the diagram uses Equivalent airspeed, the diagram will be different if altitude is changed

- Even if you have same aircraft, V-n diagram will be different if you change a geometry, i.e. flap down.
- Since the diagram uses Equivalent airspeed, the diagram will be different if altitude is changed.

  ↳ $\rho = \rho_{sea\text{-}level}$

· In order to draw the V-n diagram, we need to define different definitions of airspeed.

§. Structure (video lecture review in 2017)

· Difference between structure analysis and design

: In analysis, we will analyze stress and so forth ; however, we don't know what's going on in design. In design, we will have to figure out those values for some objectives

· Types of airspeed (knots)

a) Using pitot-tube, the difference between the dynamic and static pressure is used to determine the indicated airspeed (IAS)

b) However, the indicated airspeed is not always completely accurate. Errors are often (i.e. position error) introduced by the design of the measuring instruments. Although these errors are typically small, manufacturers provide an airspeed calibration chart for each aircraft to correct these errors. The chart allows to calculate the calibrated airspeed (CAS).

c) Another source of error in airspeed comes from an aerodynamic effect, namely compressibility. Like instrumentation error, the compressibility error can also be accounted for using an airspeed correction chart. The result of this correction is the Equivalent airspeed (EAS)

↳ It will be used for the diagram

d) The final source of error is the decrease in air density. This density error can be corrected if the pilot knows the atmospheric density at the plane's current altitude. Once density is known, the Equivalent airspeed can be converted to true airspeed

e) Finally, if we account for the wind to TAS, we will have to introduce ; (TAS)

" Ground Speed "

: It can be determined by the vector sum of the aircraft's true airspeed and the current wind speed and direction.

for example, aircraft → 40 kts ← wind 10 kts ∴ Ground speed = 30 kts

· Let's draw the V-n diagram.

smallest turn radius / highest turn rate

According to FAR, we specify some gust limit to V_D point, which is different gust line for V_C (Let's say ① is created by aircraft for V_C)

↓ Hence, they have different slope.

(Even if design cruise V is good)

② Thus, we may want to fly with this speed

limit load factor × safety factor

positive ultimate load factor

cf. The structure must be able to support ultimate loads without failure for at least three seconds

(To limit load, the structure must be able to ...

of. The structure must be able to support ultimate loads without failure for at least three seconds

(For limit load, the structure must be able to support it without any deformation)

Hence, they have different slope. (Two lines were just connected)

Note that ; (known as gust load)
loads can be also generated unintentionally by the gust.

⇒ The limit gust is extended until it intersects to Vc line.

U_{gust} ↑↑↑ → V_E (For more detail, see below)

High-speed limit (at least, $1.2 \times V_{max}$ of aircraft)

V_E (Equivalent airspeed), knots ; EAS is usually used rather than TAS

↳ The air load depends on the dynamic pressure (q_∞).

∴ EAS is used for structural design because q_∞ doesn't depend on the altitude.

→ Structural damage

→ It will be changed as type of aircraft is changed

e.g. $V_{maneuver} = \sqrt{\frac{2nW}{\rho C_{L,max} S}}$; it has W/S (Different wing loading)

$V = \sqrt{\frac{2W}{\rho S C_L}}$ for cruise

$\frac{1}{2}\rho V^2 = \frac{1}{2}\rho_\infty V_\infty^2$

{ V : True airspeed, V_∞ : Equivalent airspeed }

∴ less slope w.r.t. n (or $\uparrow U \propto \frac{1}{C_L \downarrow}$)

Hence, more further located.

$L = \frac{1}{2}\rho_\infty U_\infty^2 S C_{L,max} = nW$

$\Leftrightarrow U_\infty$ (Equivalent airspeed) $= \sqrt{\frac{2nW}{\rho_\infty S C_{L,max}}}$ or $n = \frac{1}{2W}\rho_\infty U_\infty^2 S C_{L,max}$ ∴ $n \propto U_\infty^2$

of. U_{D-D} would be somewhere V_c

How would you determine V_D ? e.g. $1.5 \times V_D = V_{flutter}$

1) Do experiment to determine $V_{flutter}$

2) $V_D \times 1.5$ would be determined by FAA for safety issue.

The impact of Gusts

- Consider an aircraft in steady and level flight ;

$$L = W = \frac{1}{2}\rho_\infty U_\infty^2 S C_L \quad ; \text{ where } U_\infty = V_E \text{ for V-n diagram}$$

$V_E \leftarrow$ (L ↑, W ↓)

- Let's say the airplane encounters a vertical gust of speed U.

→ This changes the angle of attack with an amount $\Delta\alpha$ and the lift coefficient by ΔC_L.

$V_E \rightarrow$; Here, $\Delta\alpha = \tan^{-1}\left(\frac{U}{V_E}\right) \simeq \frac{U}{V_E}$ only if small $\Delta\alpha$

$\Delta\alpha$ ↑ U

we are assuming $U \lll V_E$

- Then, the net lift generated during the gust encounter,

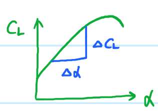
$$L_{net} = \frac{1}{2}\rho_\infty V_E^2 S (C_L + \Delta C_L)$$

$$= \frac{1}{2}\rho_\infty V_E^2 S C_L + \frac{1}{2}\rho_\infty V_E^2 S \Delta C_L$$

$$= W + \frac{1}{2}\rho_\infty V_E^2 S \Delta C_L$$

↳ If we assume the operation is in the linear region of the lift-curve.

At this point (Don't think about the gust) ∵ $L = W$ for steady-level flight



$$\therefore \frac{dC_L}{d\alpha} = \frac{\Delta C_L}{\Delta\alpha} \Leftrightarrow \Delta C_L = \frac{dC_L}{d\alpha}\Delta\alpha = \frac{dC_L}{d\alpha}\frac{U}{V_E} \text{ for small } \Delta\alpha$$

- Substitute ΔC_L into L_{net} equation,

$L_{net} = W + \frac{1}{2}\rho_\infty V_E^{2} S \left(\frac{dC_L}{d\alpha} \frac{U}{V_E} \right)$; where $L_{net} = n_{net} W$

- Dividing by W, we have ;

$n_{net} = 1 + \frac{1}{2}\rho_\infty \frac{1}{W/S} \left(\frac{dC_L}{d\alpha} \right) U V_E$; we can say n_{net} = the gust load factor

↳ This is a sort of $y = ax + 1$ (as a increases, y increases)

- In conclusion,

- n (gust) is linearly proportional to V_E (∵ That is why we drew the line)

⇒ Large load factors may occur if flying fast in gust condition.

- The incremental load factor due to gusts decreases with increase in wing loading.

⇒ All else being equal (e.g. ρ_∞) but airplanes with higher wing loading are less sensitive to gust.

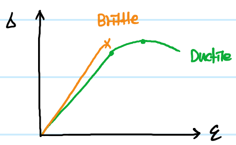
↳ Better ride quality

Mock qual with Giada

- Draw stress-strain curve for both Brittle and Ductile

↳ It is something related to plastic deformation

It is something like braking immediately without deformation.



V-n diagram drawing step by step (Prof. German)

V-n Diagram

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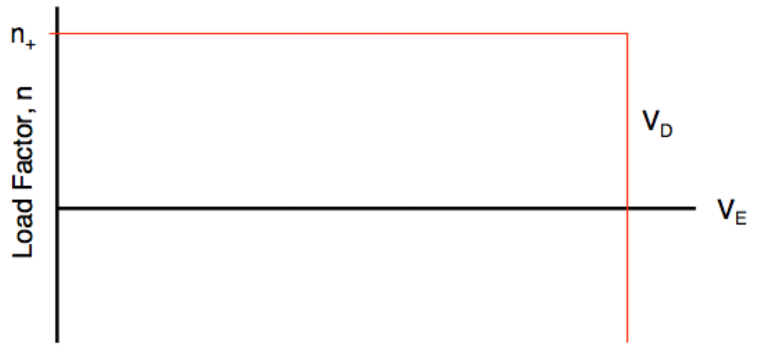
V_D - Design Dive Speed
- Upper boundary of V-n diagram speeds
- Airplane must be free of flutter, control reversal, and divergence at speeds up to 1.2 V_D
- Value defined by regulation

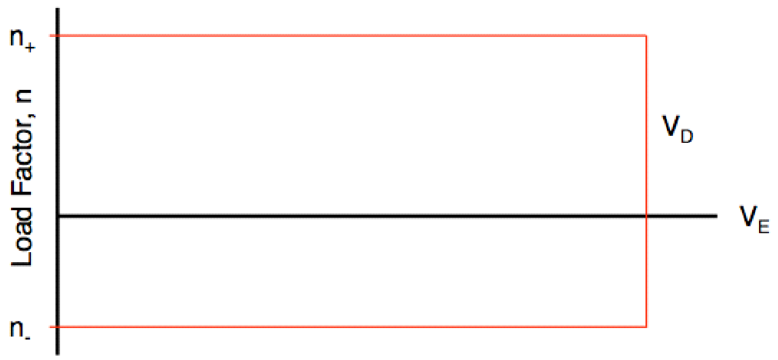
V-n Diagram

n_+ - Positive Limit Maneuvering Load Factor
- Defined by regulation
- Typically 3.8 for a normal category airplane under FAR Part 23

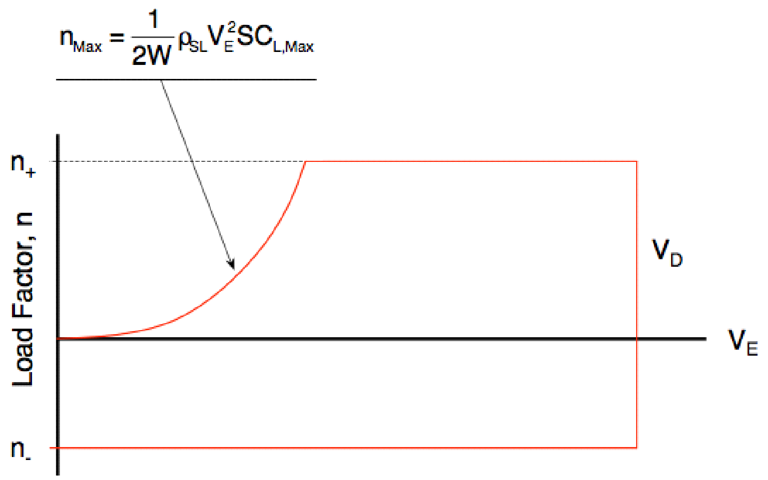


V-n Diagram

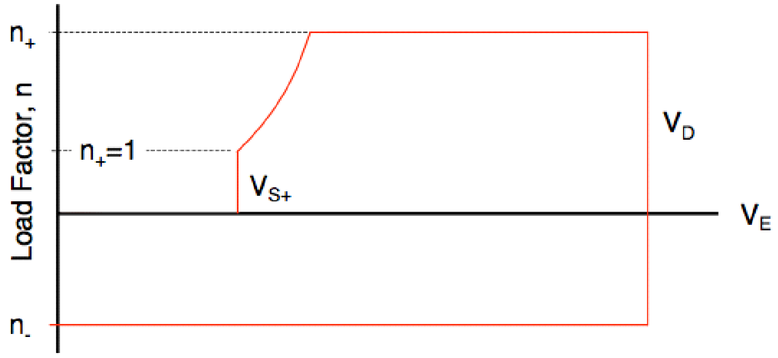
n_- - Negative Limit Maneuvering Load Factor
- Defined by regulation as a fraction of +n
- For a normal category airplane under FAR Part 23, $n_- = -0.4\ n_+$; for our example case, $n_- = -1.52$



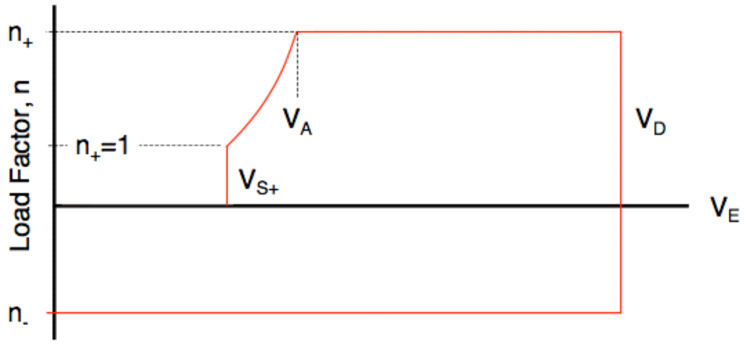
V-n Diagram



V-n Diagram

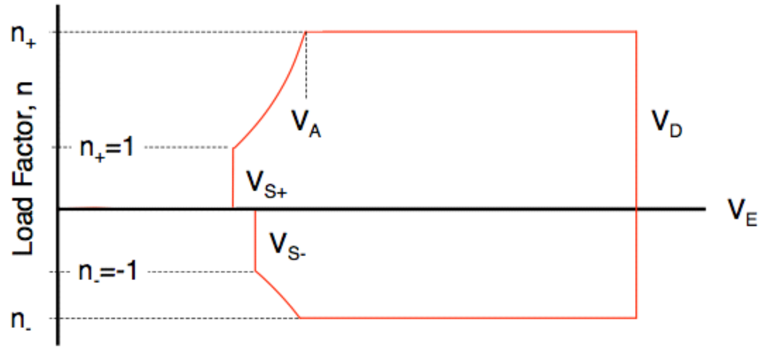


V-n Diagram



V-n Diagram

A similar set of curves can be generated for the negative values of the load factor. Since the minimum value of C_L, $C_{L,Min}$, is negative and usually smaller in absolute magnitude than $C_{L,Max}$. The later observation then leads to the conclusion that $V_{S+} < V_{S-}$.



V-n Diagram

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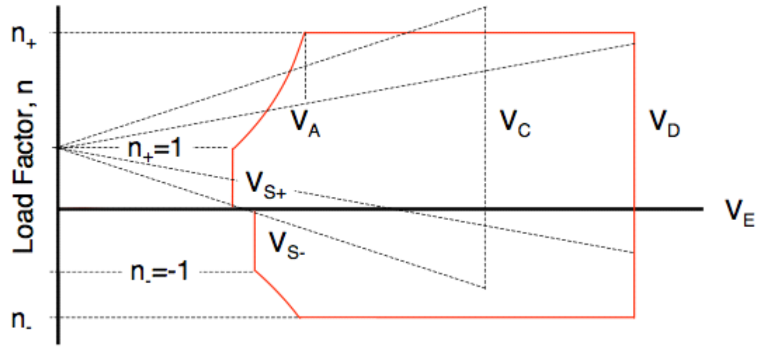
Additional gust velocities, ±U, are defined that must be sustained at speeds up to V_D:



V-n Diagram

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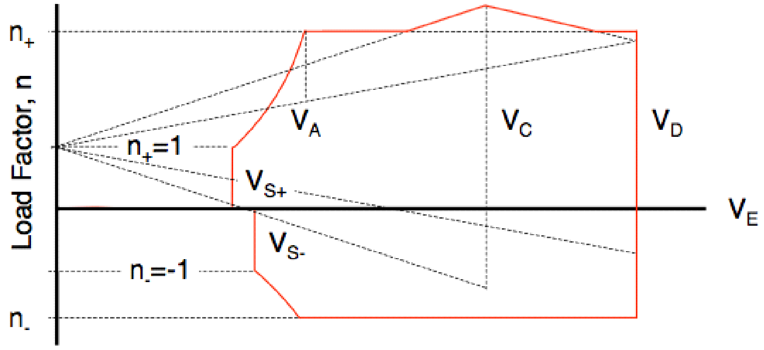

Every airplane will have its own V-n diagram; they are not generic!