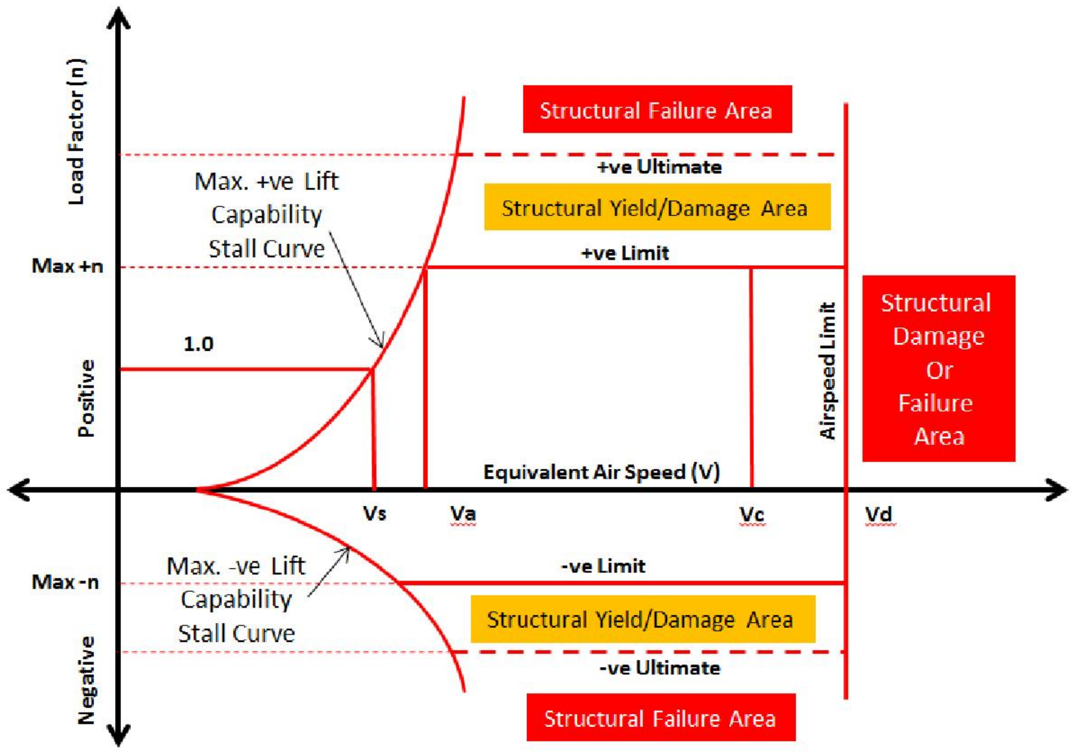
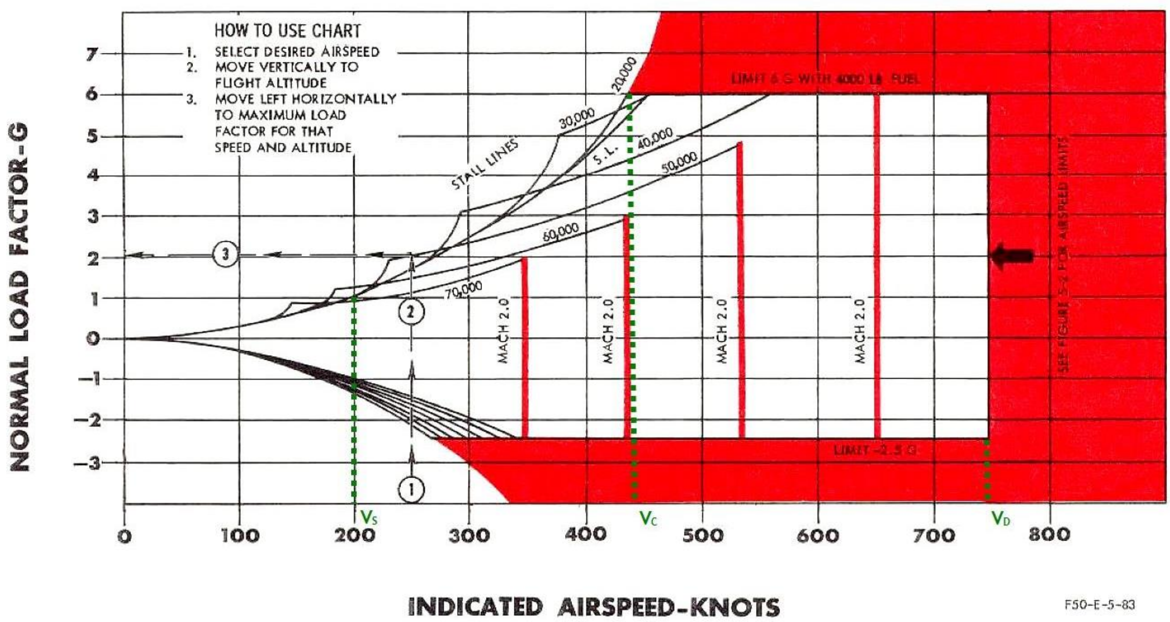
Subject Code & Name**: 19AST302 FLIGHT DYNAMICS** **Date: 10.10.2023**

DAY: **39** **Topic: The V-n Diagram**





Aircraft Ultimate Loads

V-n Diagram:

One of the most important diagrams for the flight mission profile, which defines aircraft limit loads and aircraft ultimate loads, is the Flight Envelope (V-n) diagram.

Pilots are usually trained, and required to stay within this flight envelope even if it is possible to exceed this envelope. They are warned that any exceedances could result in loss of control, stability, flutter, or create potential damage to the structure of the aircraft. Each particular aircraft type has its own flight envelope, expressed in terms of the “V-n” diagram.

V = Indicated Equivalent Airspeed

n = Limit Load Factor

The load factor is basically the ratio of the lift to the weight of the aircraft = L/W and it is expressed as a factor of acceleration due to gravity „g‟.

The figure below illustrates a typical V-n diagram for a transport category aircraft:

The aircraft must be designed to fly and land safely for every point within the flight envelope. No detrimental permanent deformation is allowed within the limit envelope, and no catastrophic structural failure that inhibits safe flight and landing is allowed (yielding and damage is allowed) within the aircraft limit to aircraft ultimate loads envelope.

Left Side Curves:

We can see in the figure above the two left side curves, these are the "stall" curves. These curves represent the Air Speed and corresponding Load Factor with increasing angle of attack to produce lift. The load factor is limited by what is called the Coefficient of Lift (Cl).

The load factors are increasing exponentially as the angle of attach increases to increase lift. Part of the reason for this is that the weight of the fuel and the weight of aircraft are not available to counter the lift force as the angle of attack increases. This limits both the lift and the speed due to structural considerations.

Airspeed “V” is plotted along the horizontal axis of the “V-n” diagram and the Load Factor "n" is plotted along the vertical axis.

Flight points in the areas to the left of these stall curves will obviously result in the stall of the aircraft. As we all know when the aircraft stalls, it results in loss of control over the aircraft, unless the pilot manages to recover, speed up under the right angle of attack and regain control and lift thus bringing the aircraft back into the Flight Envelope, PHEW!

Top and Bottom Limiting Lines:

These two inner horizontal lines represent the maximum and minimum (limit) load factors for level or cruise flight that can be achieved without structural damage or yielding under both normal and inverted flights. The aircraft is not expected to see load factors greater than these under normal operating conditions.

However, the aircraft must still be designed to fly and land safely without detrimental structural failure beyond these lines. This happens under abnormal and unexpected conditions, under aircraft ultimate loads, but structural yielding and/or damage is allowed as long as it does not impede safe flight and landing. So the two outer top and bottom dashed horizontal lines represent the maximum ultimate load factors on the aircraft.

Usually, Ultimate Load Factor = Limit Load Factor*1.5

The diagram indicates to the pilots that flight points beyond these lines will result in structural failure.

Aircraft Ultimate Loads, V-n Diagram:

Given the V-n diagram flight envelope above, there will be various gust (statistically known and also unexpected) conditions resulting in sudden yaw, roll, or pitching maneuvers to keep the aircraft stable, in addition to ultimate loads due to normal limit loads * 1.5.

All of the above combined will result in literally hundreds of thousands of load cases that a particular transport category aircraft must be certified for.

In simple terms, as a starting point, all load cases are defined as limit cases (expected flight envelope cases). Then, a typical safety factor of 1.5 is applied to these limit load cases to determine the aircraft ultimate loads.

Then there would be other ultimate emergency landing cases on land and water, or belly landing cases with the wheels up, cabin pressurization (limit, ultimate and fatigue cases).

In addition to these cases, there will be many other cases with a limit load case combined with a particular component failure (or two maybe). These are generally treated as ultimate loads with a safety factor of 1.0.

Aircraft component failures may include a large component such as an engine or an aileron, or it could be on a sub assembly level component such as a rib or a spar within a major component such as a wing.

For example, consider a standard maneuver limit case with certain aerodynamic pressure distribution on the aircraft, it may be combined with the failure of an aileron in flight. This could be an example of a “fail-safe” ultimate case that is derived from a limit case. Except the factor of safety in such a situation is typically 1.0 to avoid an overly conservative and overweight design.