# Aircraft Structures

Aerospace Design

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# Loads and Structures

- In a typical conceptual design phase of the project, it is not common to determine the loads acting on the aircraft or to carry out a detailed structural analysis, unless the proposed configuration in innovative
- At this stage of the project, structural considerations only enter in the weight estimation calculations
- Why do we need to determine the loads? In order to dimension the structure, we need to know the moments and forces acting on the structure
- Start with empirical analysis and progress to numerical high fidelity models as the project progresses

# Types of Loads

- ***Aerodynamic***
  - Maneuver
  - Gust
  - Control surface
  - Buffet
- ***Inertial***
  - Acceleration
  - Rotation
  - Dynamic
  - Vibration
  - Flutter
- ***Other***
  - Pressurization
- ***Engine***
  - Torque
  - Thrust
  - Gyroscopic
  - Vibration
  - Shock waves
- ***Landing***
- ***Take-Off***
- ***Roll***
- ***Taxi***

# Classification of Loads

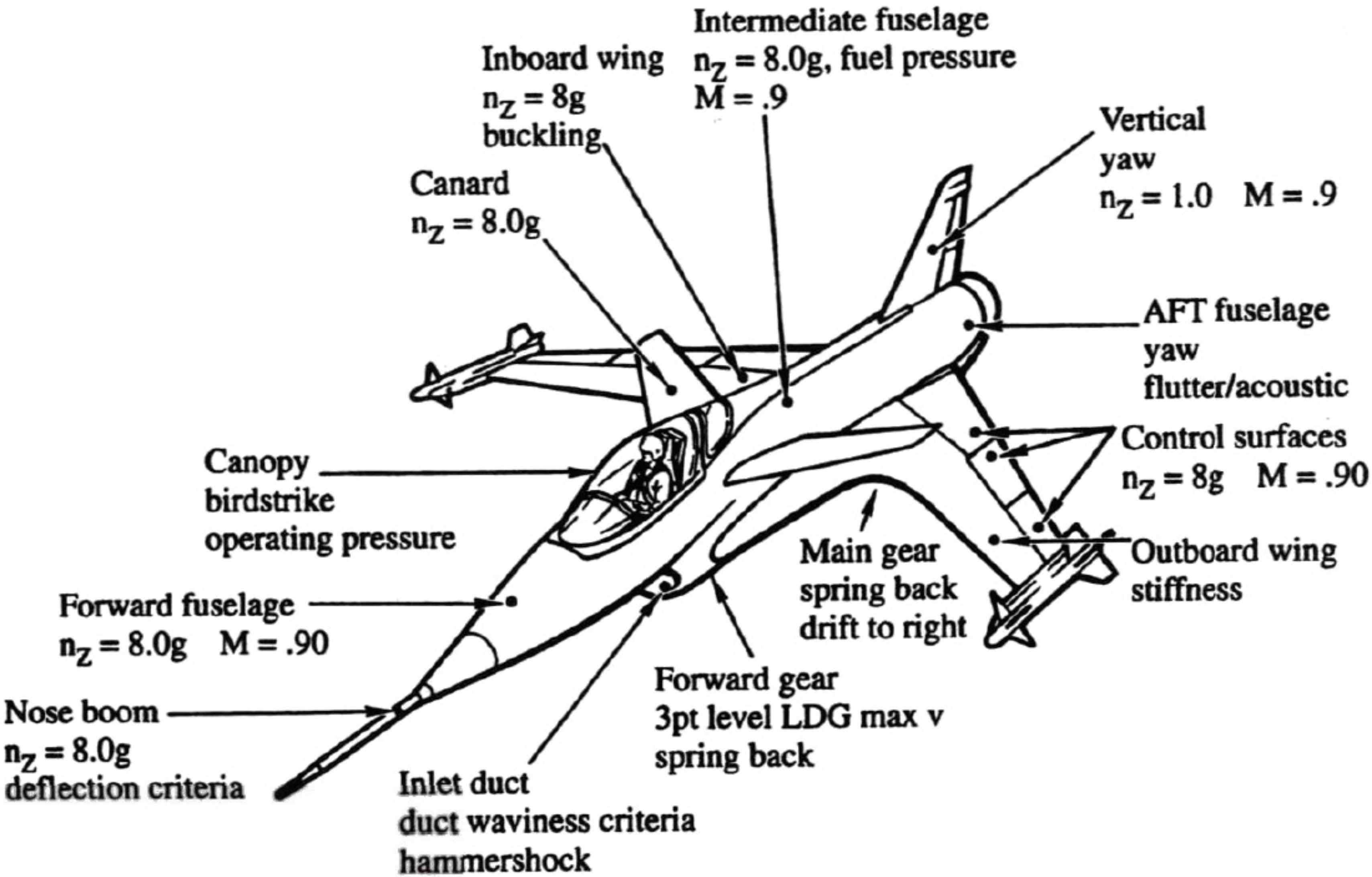
- ***Limit Load*** Maximum load that the aircraft experiences during its normal operation. These do not result in permanent deformation
- ***Ultimate Load (UL)*** Maximum load that the structural will sustain before damage. Loads above ultimate will result in permanent deformation
- ***Safety Factor (SF)*** Typically 1.5 in aircraft design

$$\boxed{\text{Ultimate Load} = \text{Safety Factor} \times \text{Limit Load}}$$

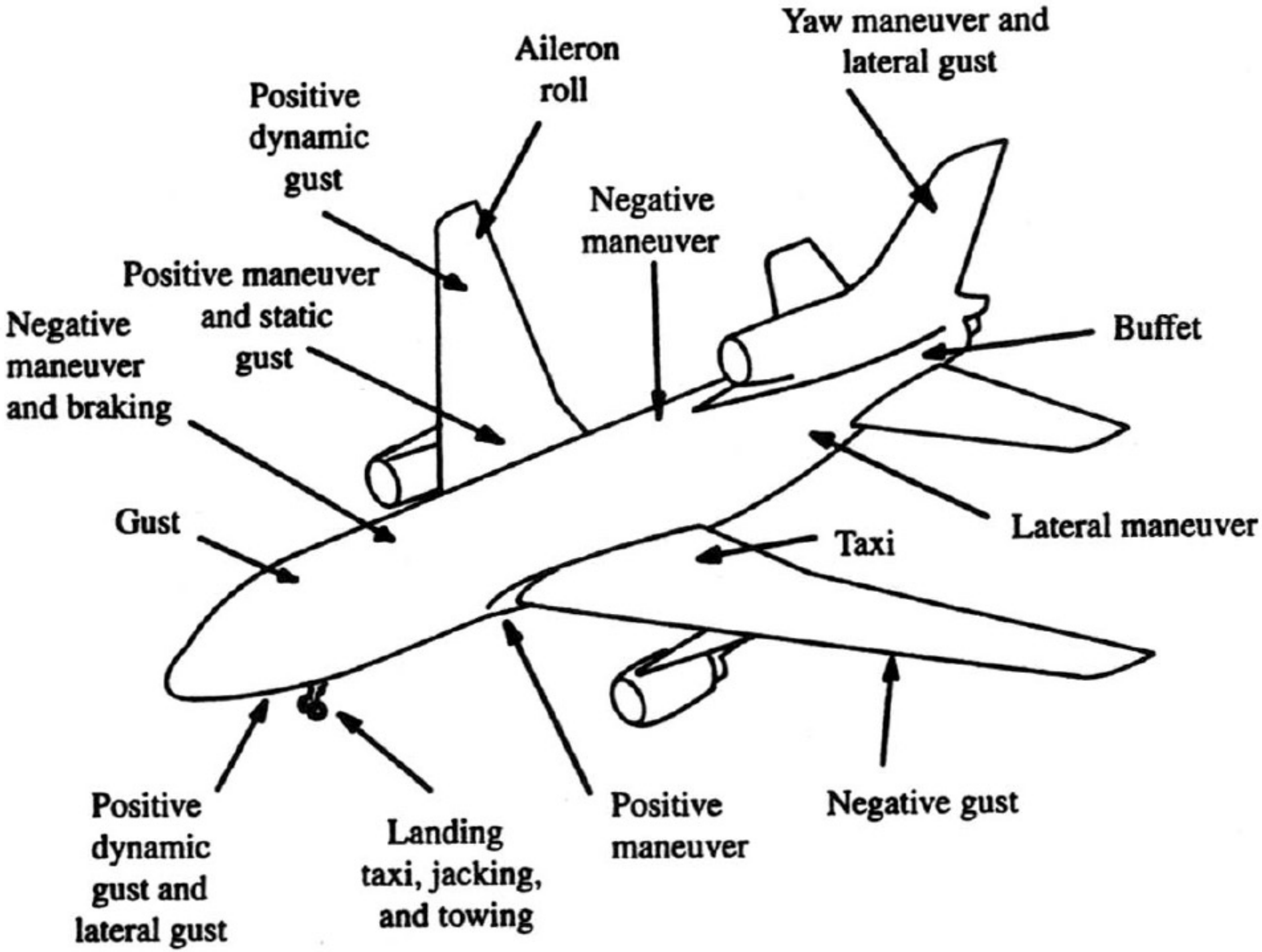
- ***Quality Factor (QF)*** Takes into account the unknowns in the quality of materials and manufacturing, typically 1.5
- ***Admissible Load*** Dimensioning Load

$$\text{Admissible Load} = \frac{\text{Ultimate Factor}}{\text{Safety Factor} \times \text{Quality Factor}} = \frac{\text{Limit Load}}{\text{Quality Factor}}$$

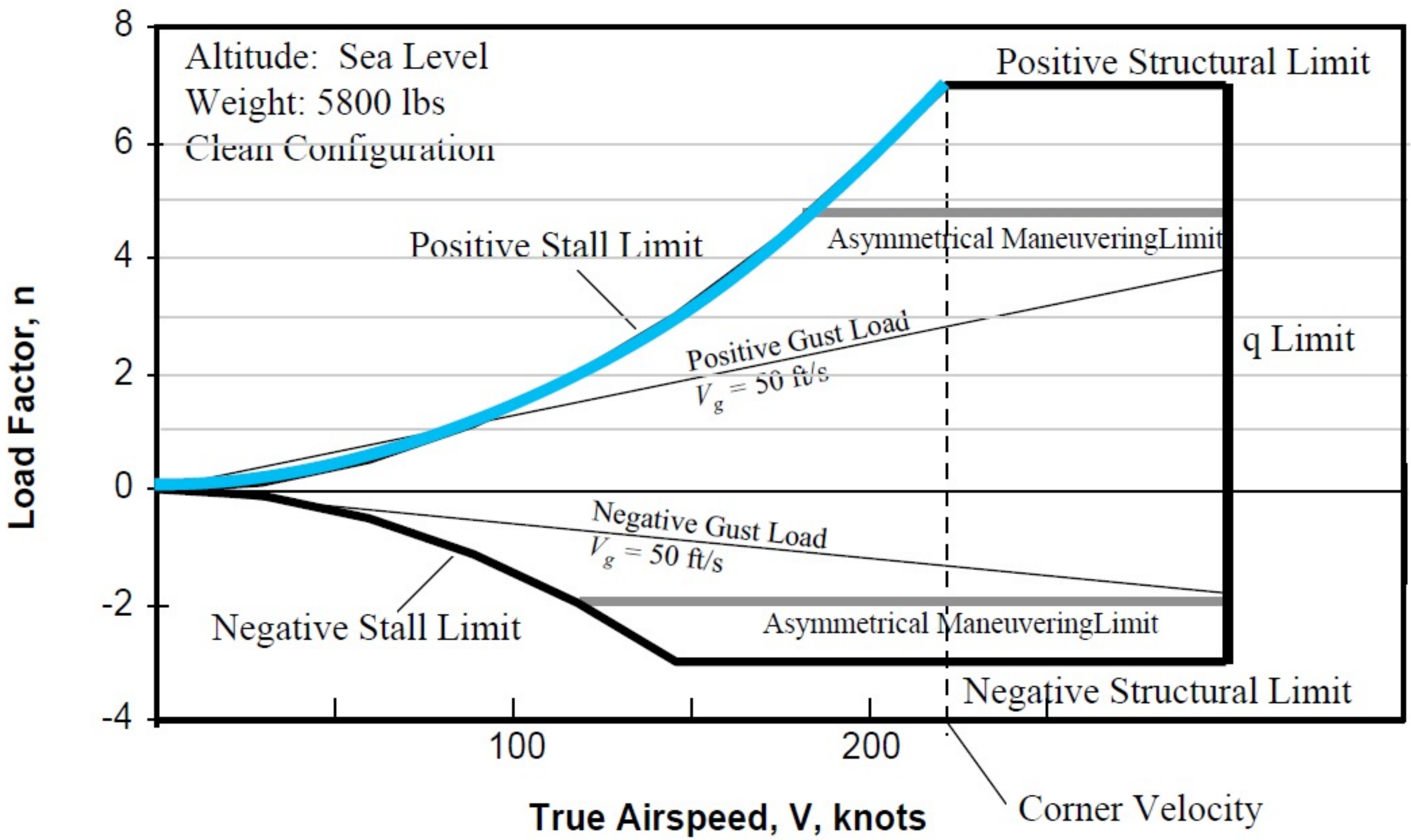
# Critical Loads



# Passive Lift Enhancement



# V-n Diagram



Altitude: Sea Level
Weight: 5800 lbs
Clean Configuration
Positive Structural Limit
Positive Stall Limit
Asymmetrical ManeuveringLimit
Positive Gust Load
$V_g$ = 50 ft/s
q Limit
Negative Gust Load
$V_g$ = 50 ft/s
Negative Stall Limit
Asymmetrical ManeuveringLimit
Negative Structural Limit
Corner Velocity
Load Factor, n
True Airspeed, V, knots
8
6
4
2
0
-2
-4
100
200

# V-n Diagram

- V-n diagrams show load factors as a function of airspeed
- Defines an envelope of expected loads that the aircraft can safely experience
- A special version can also be generated to predict loads due to gusts
- These can be combined to give you an overall picture of the loads throughout the flight envelope

## *Limit Loads*

- Defined by regulations as maximum allowable limit loads
- Normal Load Factor:

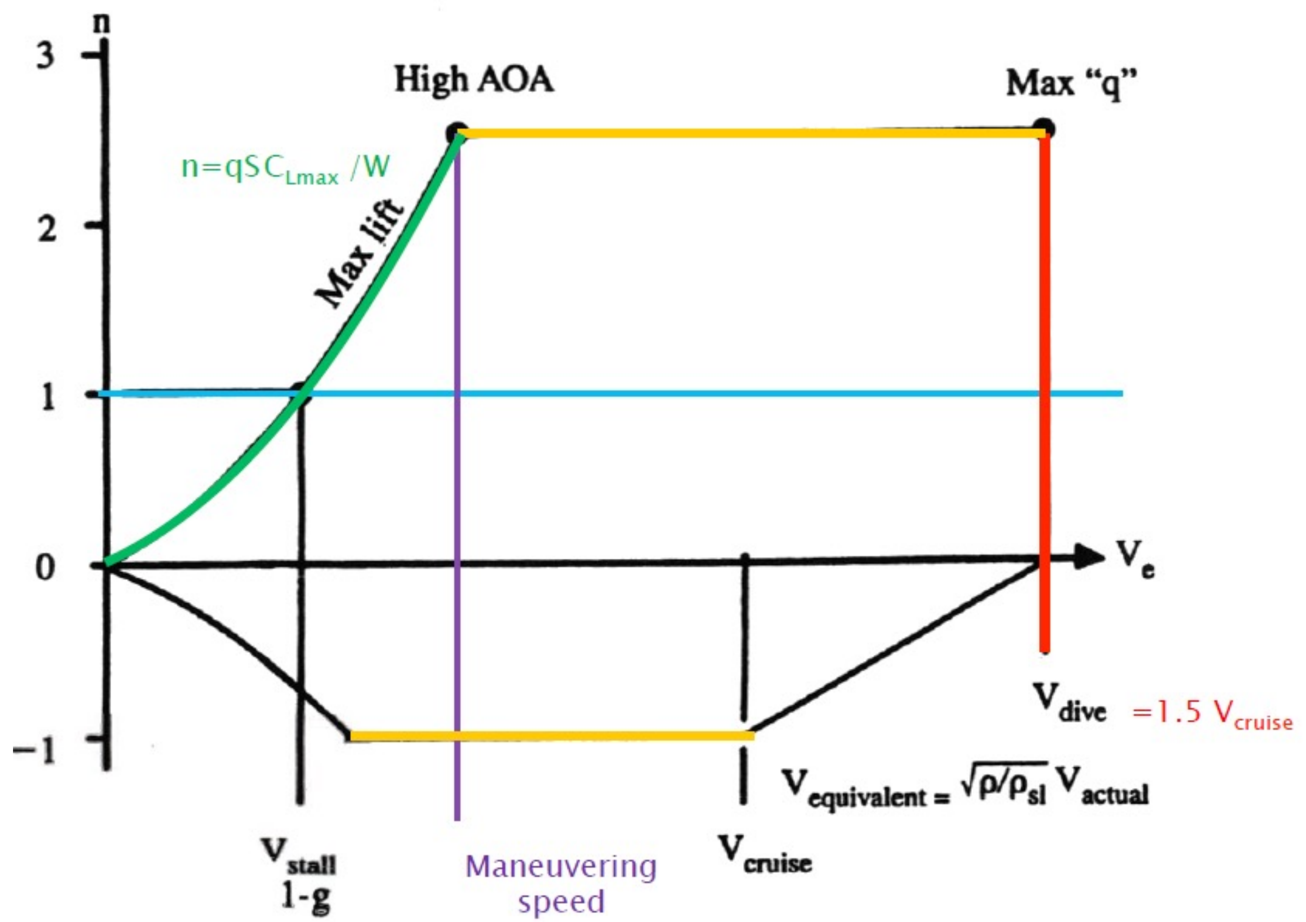
$$n_z = \frac{a_z}{g}$$

  - Typical values:

| | n+ | n- |
|---|---|---|
| General Aviation - normal | 2.5-3.8 | -1.0 to -1.5 |
| General Aviation - utility | 4.4 | -1.8 |
| General Aviation – acro. | 6.0 | -3.0 |
| “Homebuilt” | 5.0 | -2.0 |
| Transport | 3.0 to 4.0 | -1.0 to -2.0 |
| Stratigic bomber | 3.0 | -1.0 |
| Tactical bomber | 4.0 | -2.0 |
| Fighter | 6.5 to 9.0 | -3.0 to -6.0 |

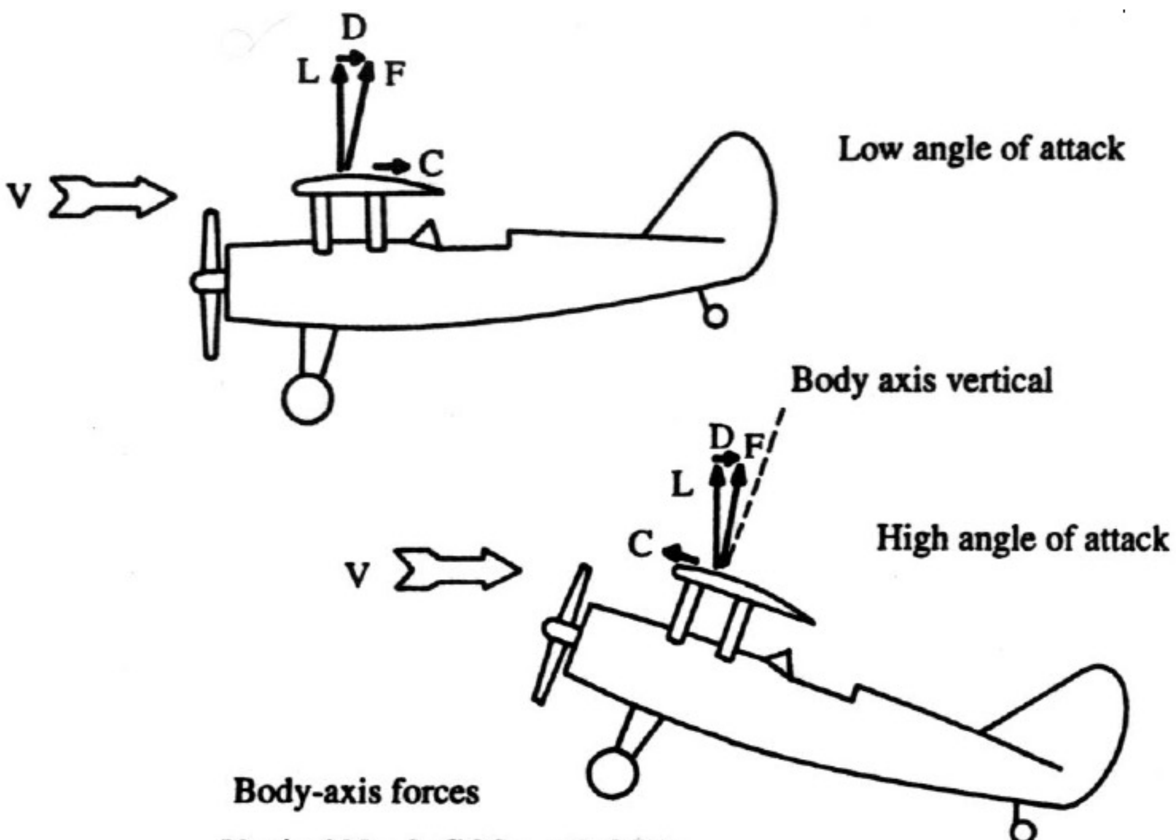
## *Maneuver Loads*

- V-n diagram



## *Maneuver Loads*

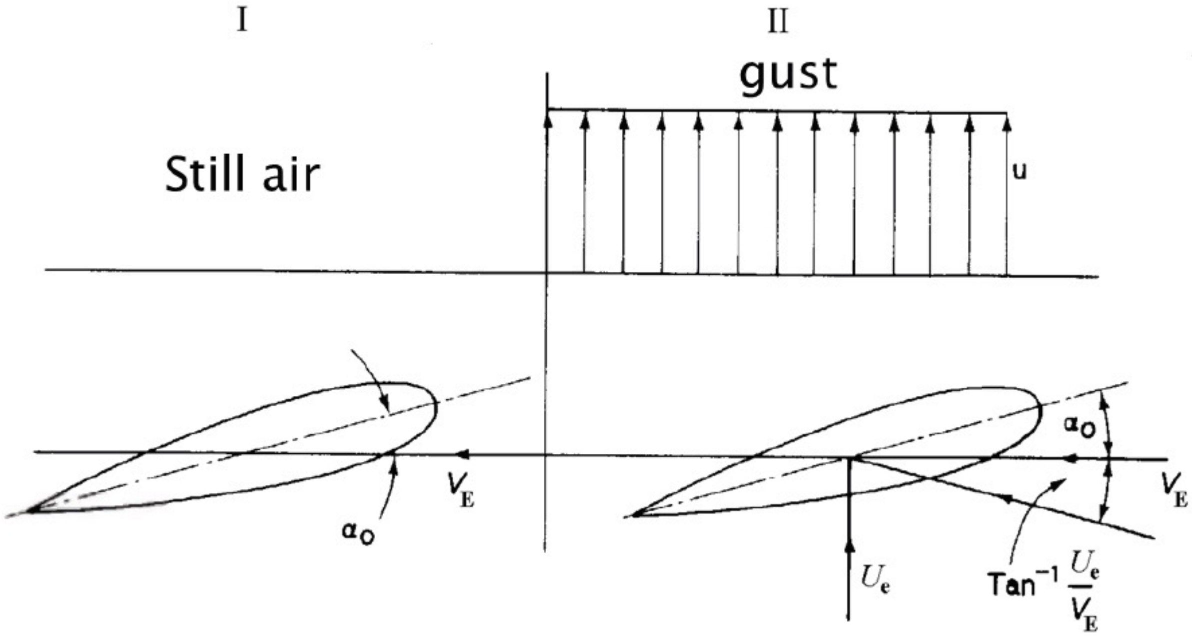
- Force on the wings may be out of plane at high angles of attack




Vertical $N = L\ COS\alpha + D\ SIN\alpha$
Chordwise $C = D\ COS\alpha - L\ SIN\alpha$

## *Gust Loads*

- Gust loads are caused by atmospheric turbulence
- The loads are calculated in terms of the "equivalent sharp-edged gust." The airplane is assumed to fly from still air instantaneously into a vertical current equal to the maximum vertical speed of the gust



## *Gust Loads*

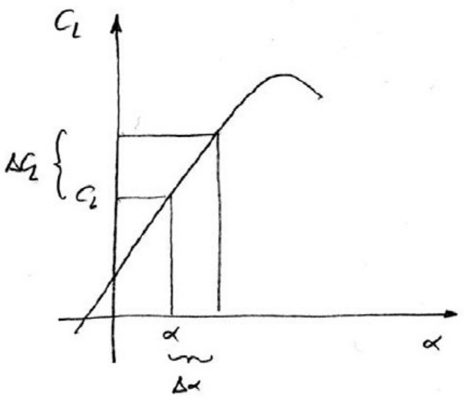
- Gust causes short term increase in forward *V* and vertical *U* velocity which in turn changes the angle of attack *α*

$$\Delta\alpha = \arctan\left(\frac{U}{V}\right) \approx \frac{U}{V}$$

- Load factor increases

$$\Delta L = \frac{1}{2}\rho V^2 S C_{L_\alpha} \Delta\alpha = \frac{1}{2}\rho V S C_{L_\alpha} U$$

$$\Delta n = \frac{\Delta L}{W} = \rho U V \frac{C_{L_\alpha}}{2\frac{W}{S}}$$



## *Gust Loads*

- Gust Speed *U* is determined from statistical flight test values, $U_{de}$ and the response coefficient, *K*:

$$U = K\,U_{de}$$

  - *K* is the attenuation factor to account for the time delay response to a gust:

$$K = \frac{0.88\mu}{5.3 + \mu}$$

$$K = \begin{cases} \frac{0.88\mu}{5.3+\mu}, & M < 1 \\ \frac{\mu^{1.03}}{6.95+\mu^{1.03}}, & M \geq 1 \end{cases}$$

- $\mu$ is the mass ratio (apparent mass) and accounts for the different response an aircraft experiences based on size:

$$\mu = \frac{2\frac{W}{S}}{\rho\, g\, c\, C_{L_\alpha}}$$

## *Gust Loads*

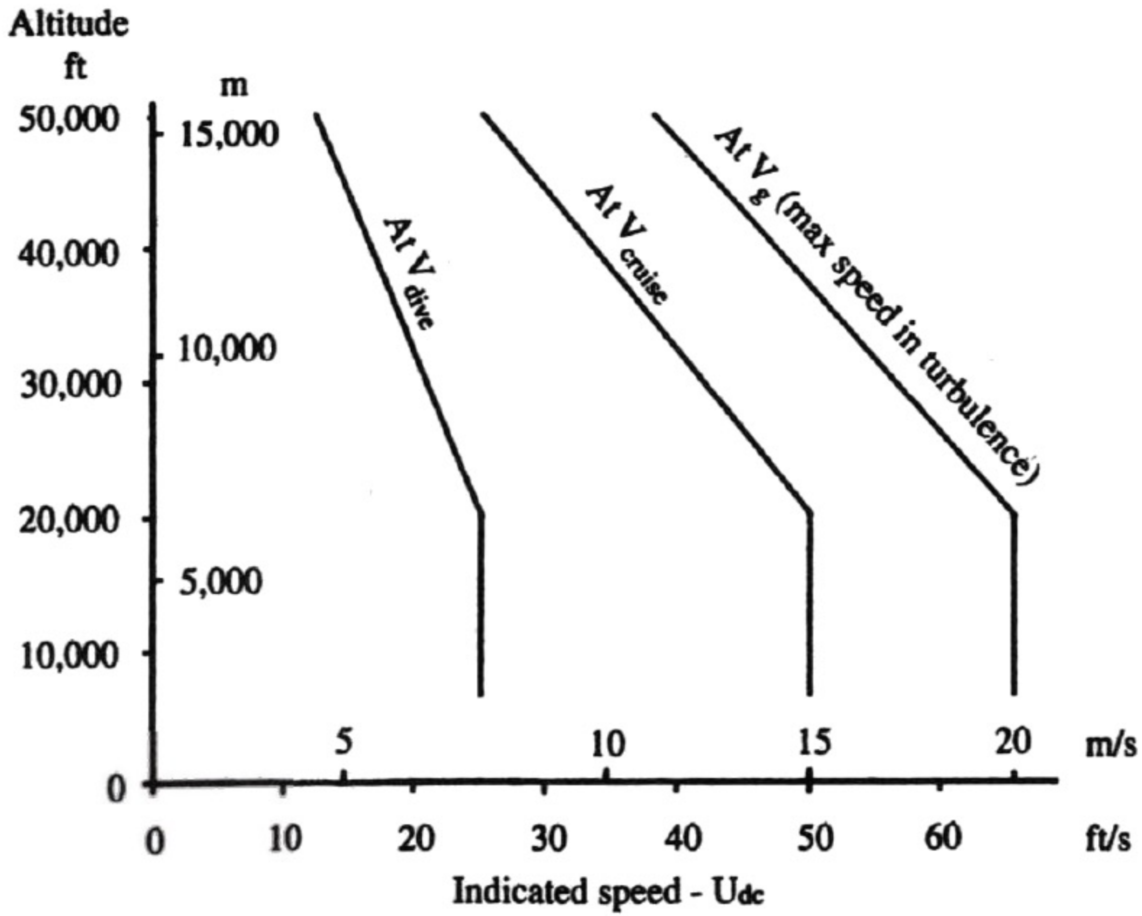
- The FAA specifies the magnitude of the gusts ($U_{DE}$) to be used as a function of altitude and speed:

| Phase | <20,000 ft | >50,000ft |
|---|---|---|
| $V_B$ (max gust) | 66 ft/s | 38 ft/s |
| $V_C$ (cruise) | 50 ft/s | 25 ft/s |
| $V_D$ (dive) | 25 ft/s | 12.5 ft/s |

- These velocities are specified as equivalent airspeeds and are linearly interpolated between 20000 and 50000 ft

## *Gust Loads*

- Gust speed:



***Gust Loads***

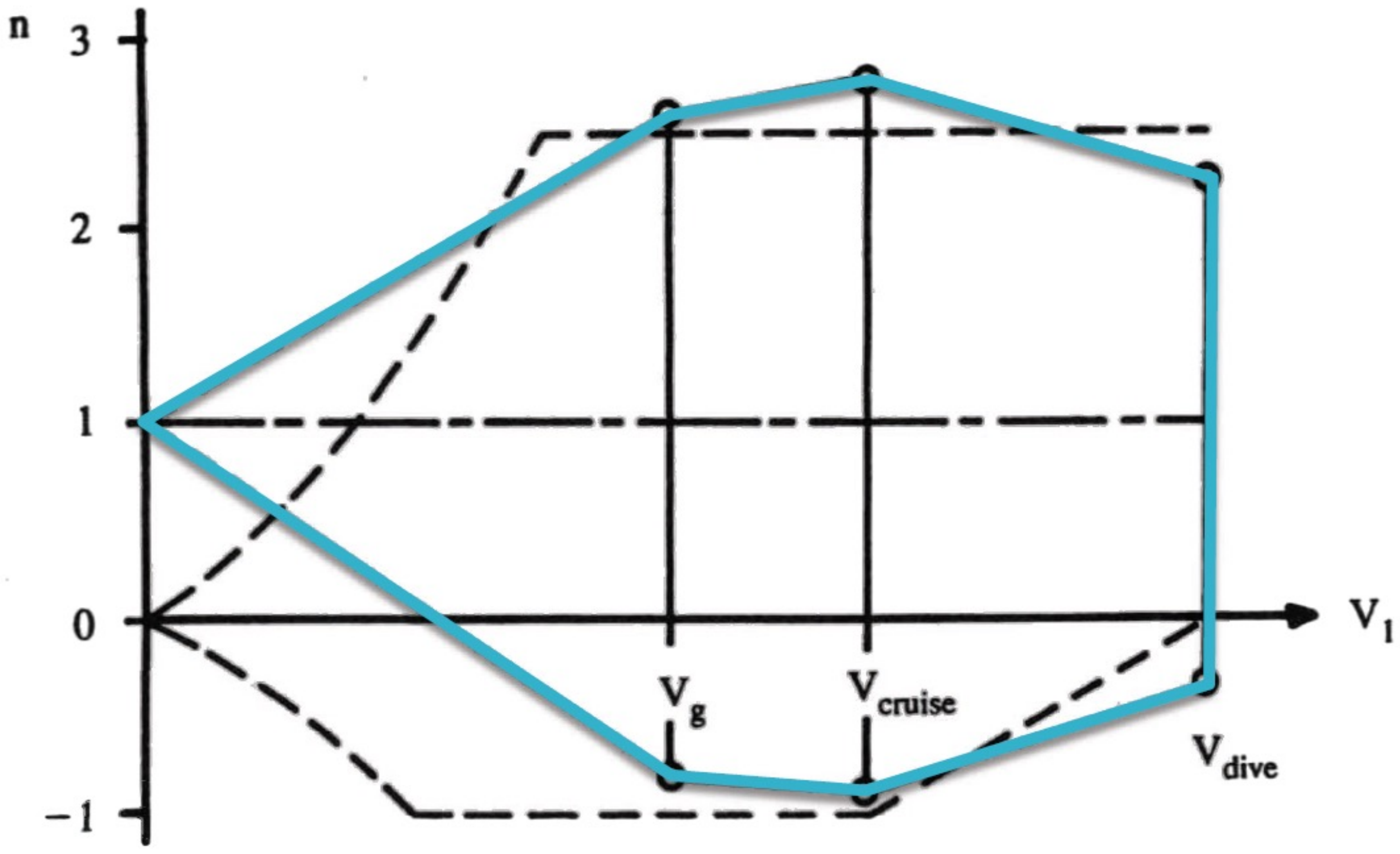
- Recall the formula for calculating load increment due to gust:

$$\Delta n = \frac{\Delta L}{W} = \rho U V \frac{C_{L_\alpha}}{2\frac{W}{S}}$$

- Therefore: $n_{\text{limit}} = n + \Delta n$

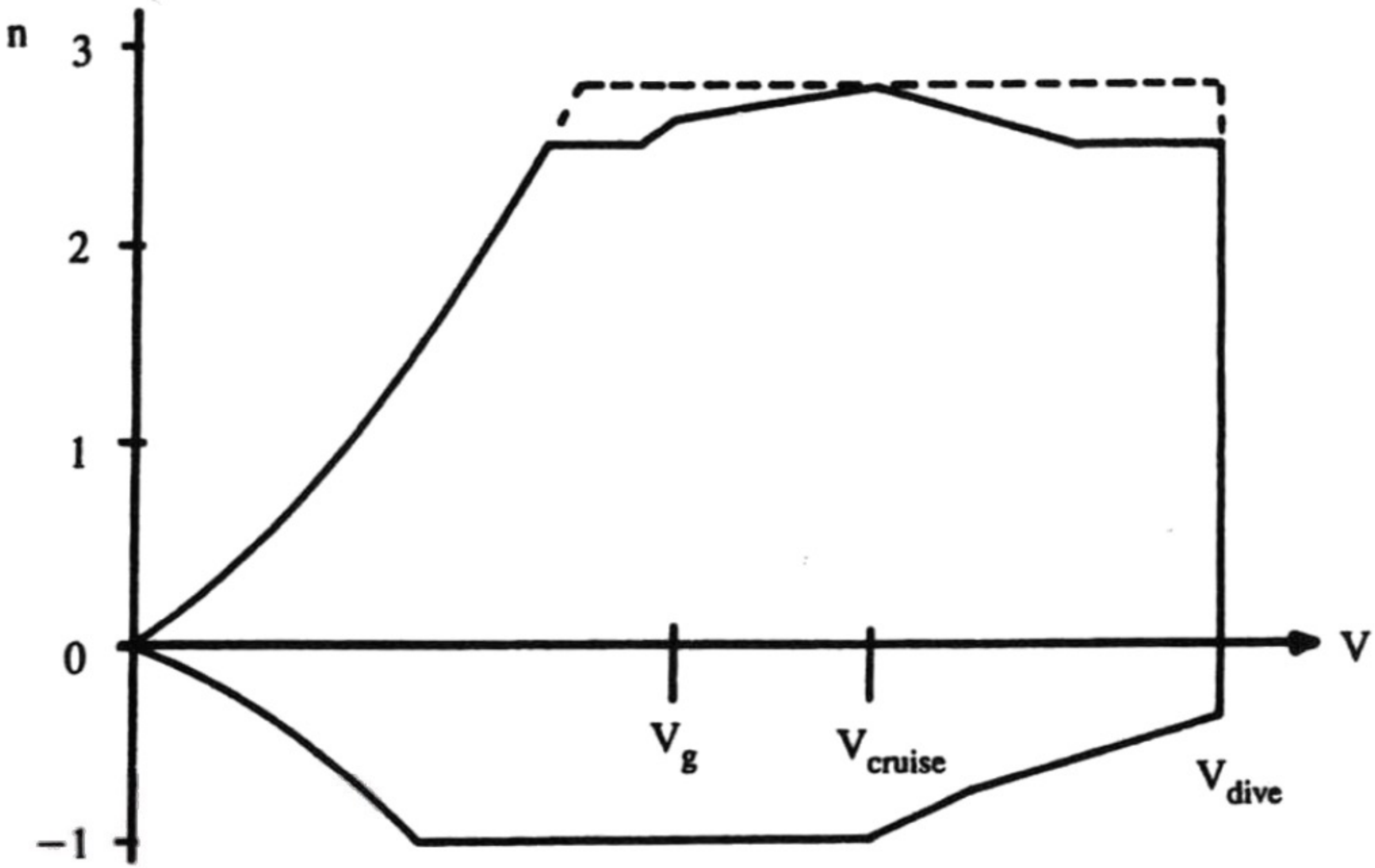
## *Gust Loads*

- V-n diagram for gust

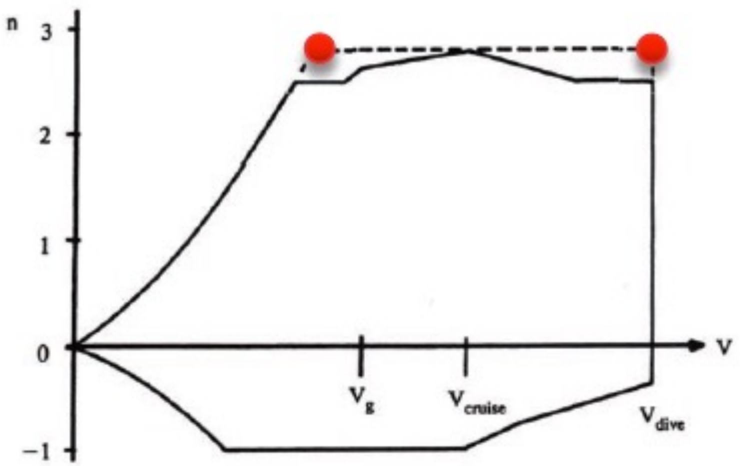


## *Gust Loads*

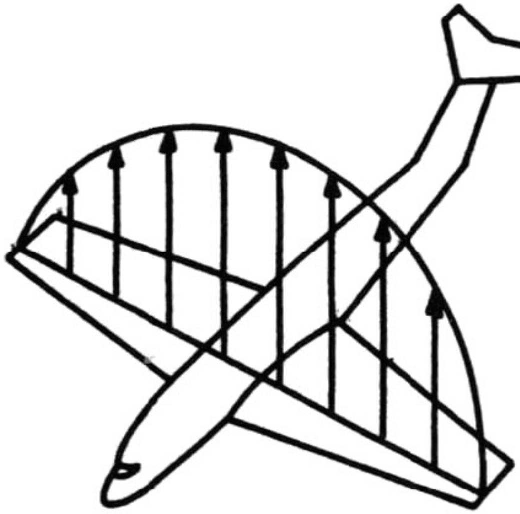
- V-n combined diagram



- Now that we have generated the load envelope we have determined the most adverse conditions
  - Usually at the limit load for $C_{L_{max}}$ or $q_{max}$
  - The next step is to calculate aero loads at the most adverse conditions and perform structural analysis



Loads in lifting surfaces:



Spanwise
lift
distribution

Chordwise
lift
distribution

Spanwise lift distribution calculated at point of interest

- Can use numerical data from lifting line, CFD, VL and other methods
- Can use approximation based on Schrenk's approximation: average between elliptical lift distribution and your planform shape, scaled so that the area under the curve equals overall lift

- ***Trapezoidal lift distribution***

$$L^T(y) = \frac{2L}{b(1+\lambda)}\left[1 - \frac{2y}{b}(1-\lambda)\right]$$

- ***Elliptical lift distribution***

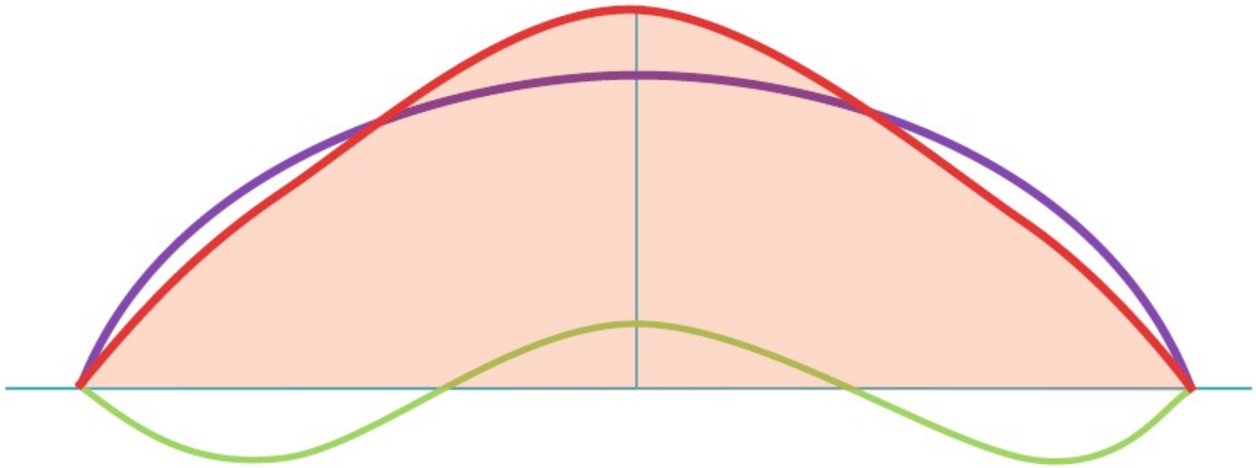
$$L^E(y) = \frac{4L}{\pi b}\sqrt{1 - \left(\frac{2y}{b}\right)^2}$$

- ***Approximated lift distribution***

$$\bar{L}(y) = \frac{1}{2}\left[L^T(y) + L^E(y)\right]$$

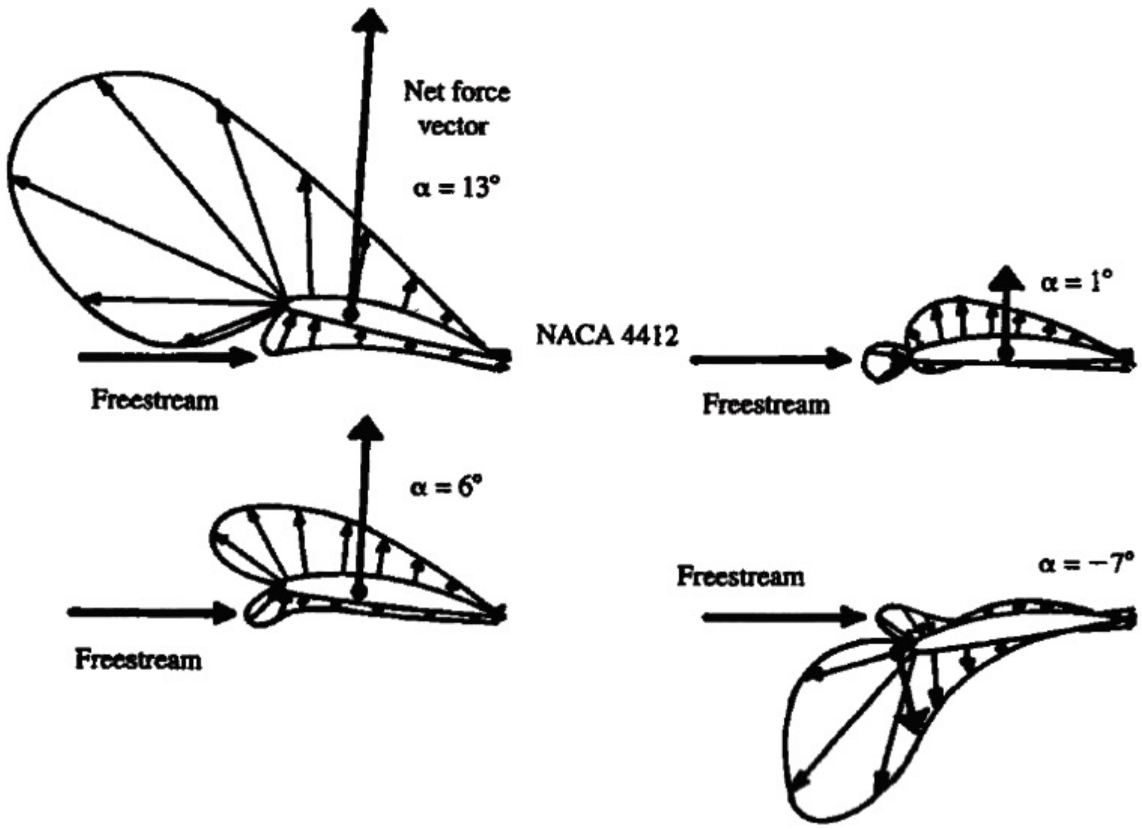
Effect of twist on spanwise lift distribution

- If large amounts of geometric or aerodynamic twist you need to account for it
- This is done by adding the lift distribution at $L$ = 0 to lift distribution at point of interest
  - You can assume that there are on induced effects and lift distribution at $L$ = 0 is due to twist only

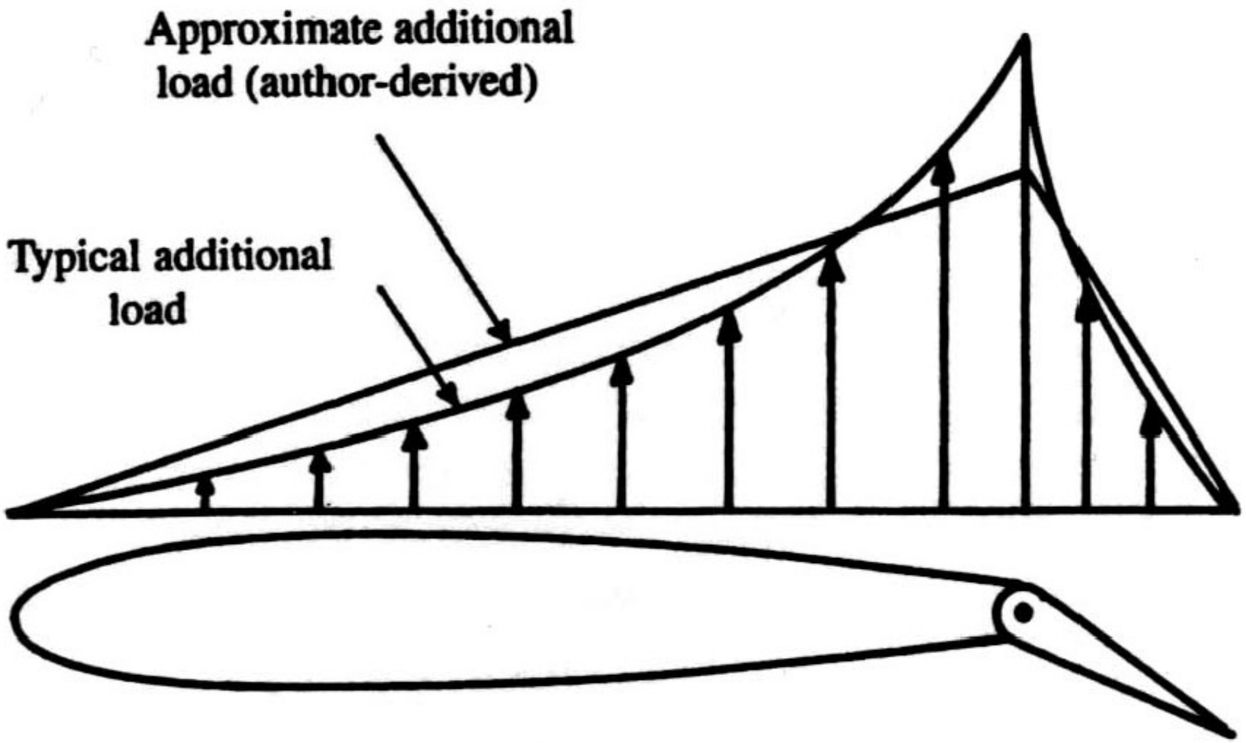


## Chordwise distribution

- Sometimes you may need to look at chordwise loading to determine local effects or torsion on the wing



Chordwise distribution due to control surfaces

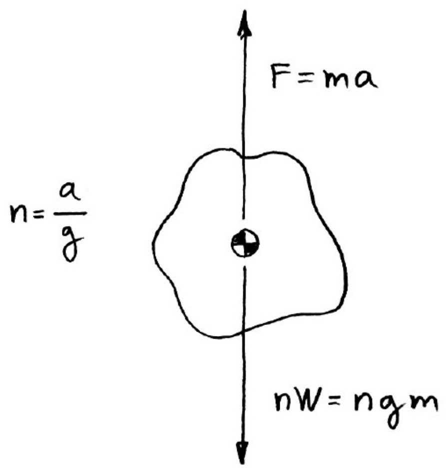


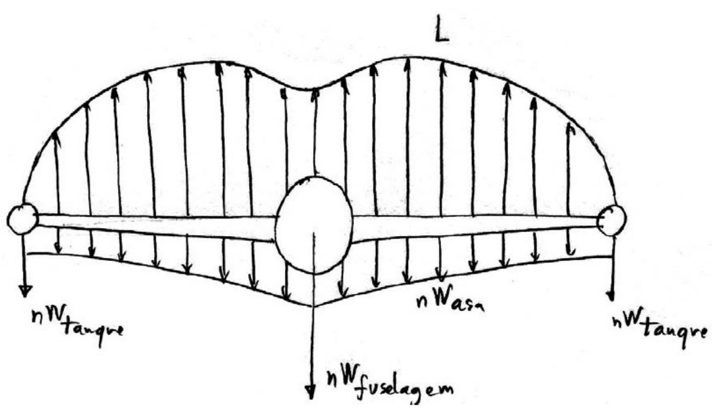
# Inertia Loads

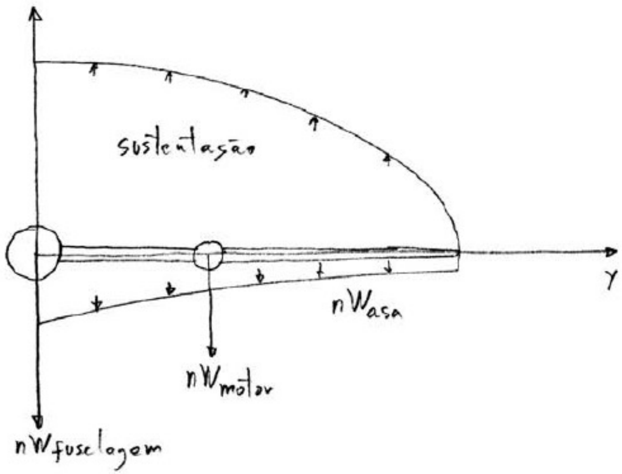
Inertial loads are due to accelerations and depend on the wings mass distribution

Calculation of inertia loads may require a more refined estimate of weight

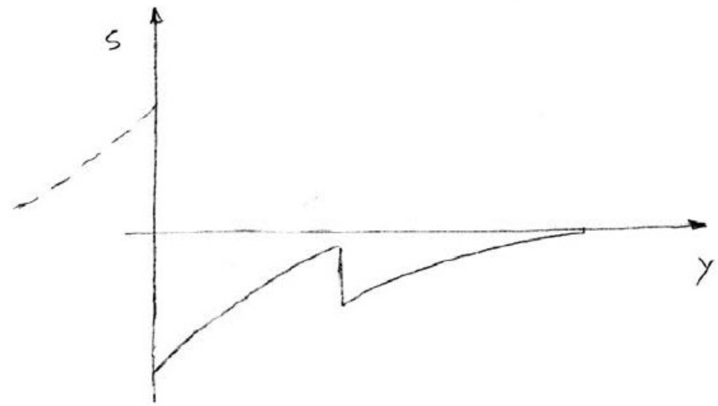
- Initial CAD models
- Empirical relations



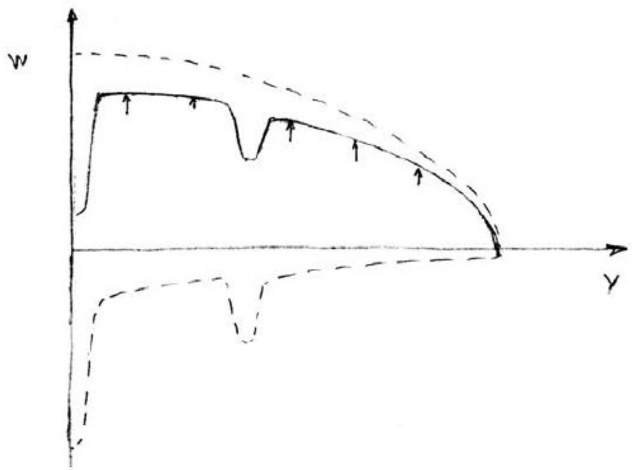





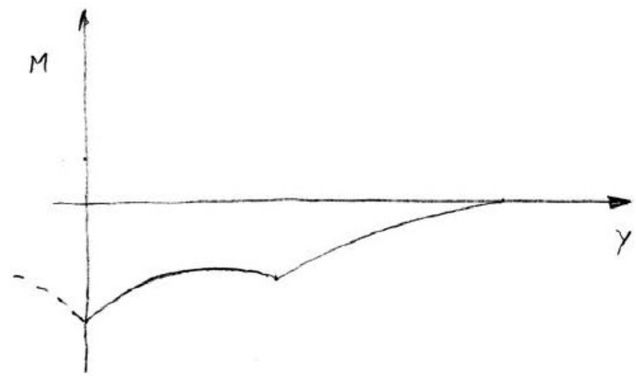
sustentação
Y
$nW_{asa}$
$nW_{motor}$
$nW_{fuselagem}$

S
Y

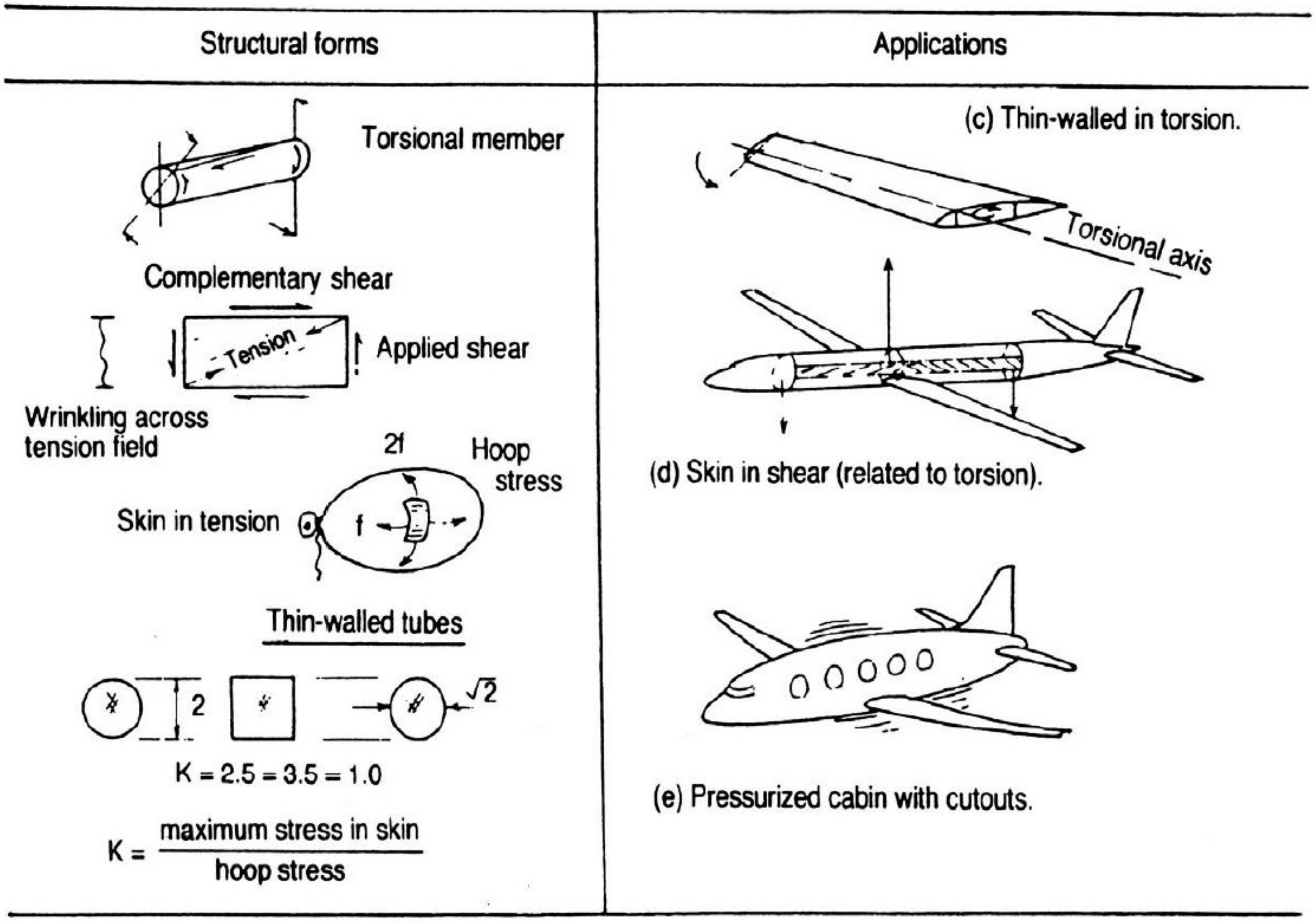



w
Y

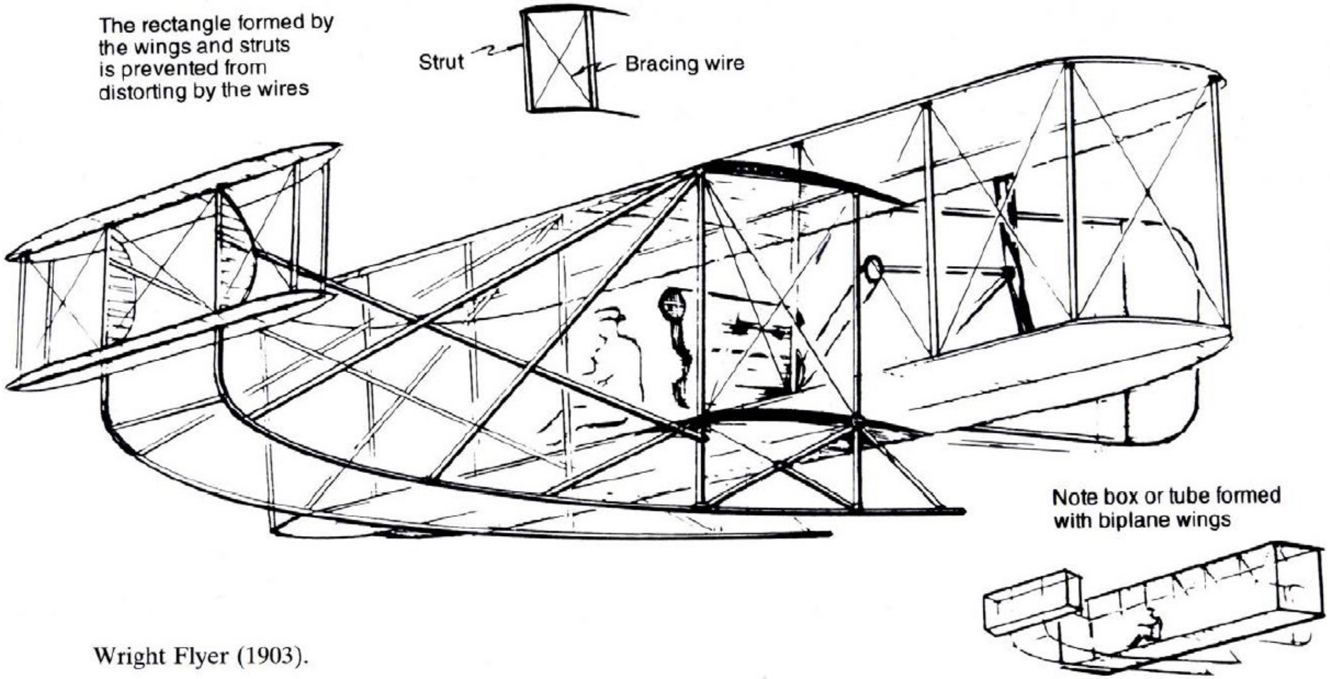



M
Y

# Structural Forms

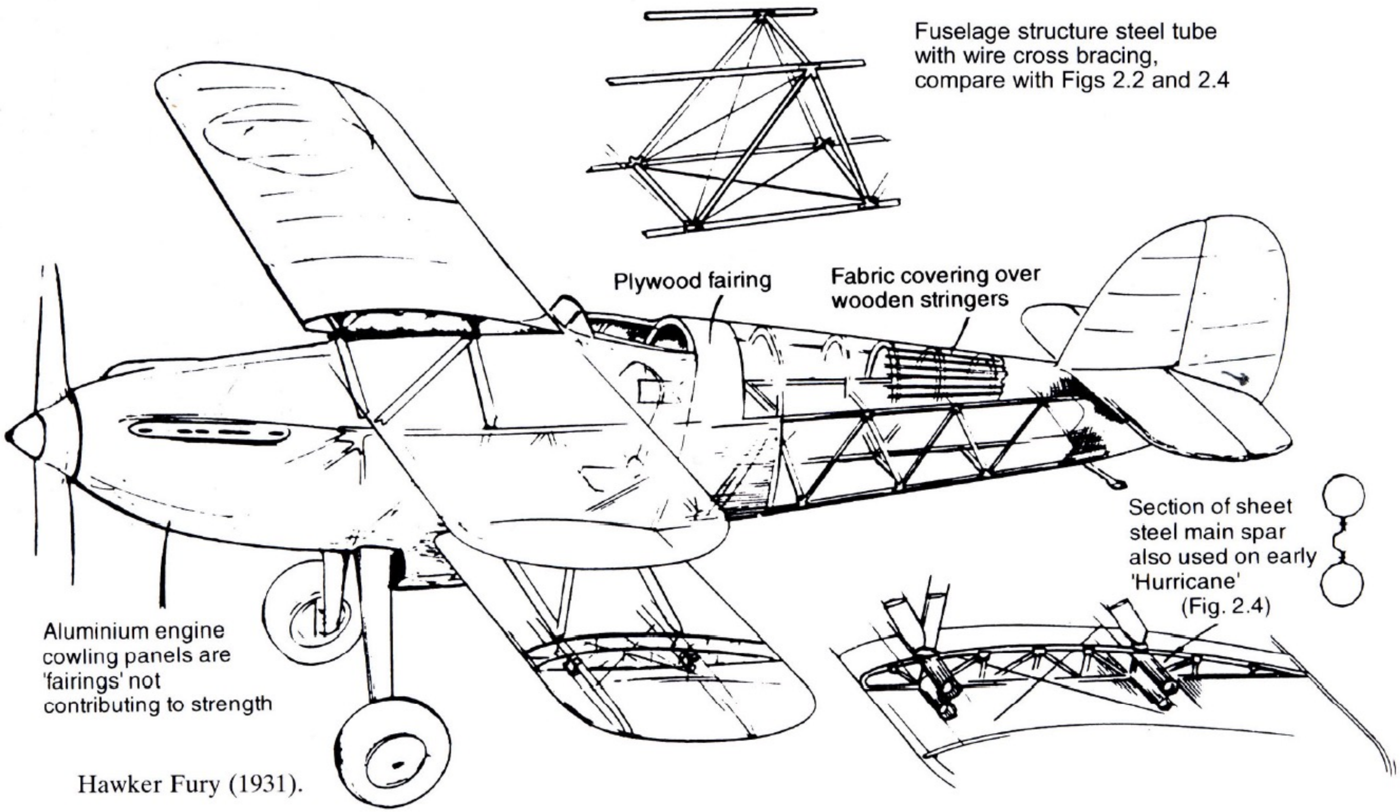


# Structural Components



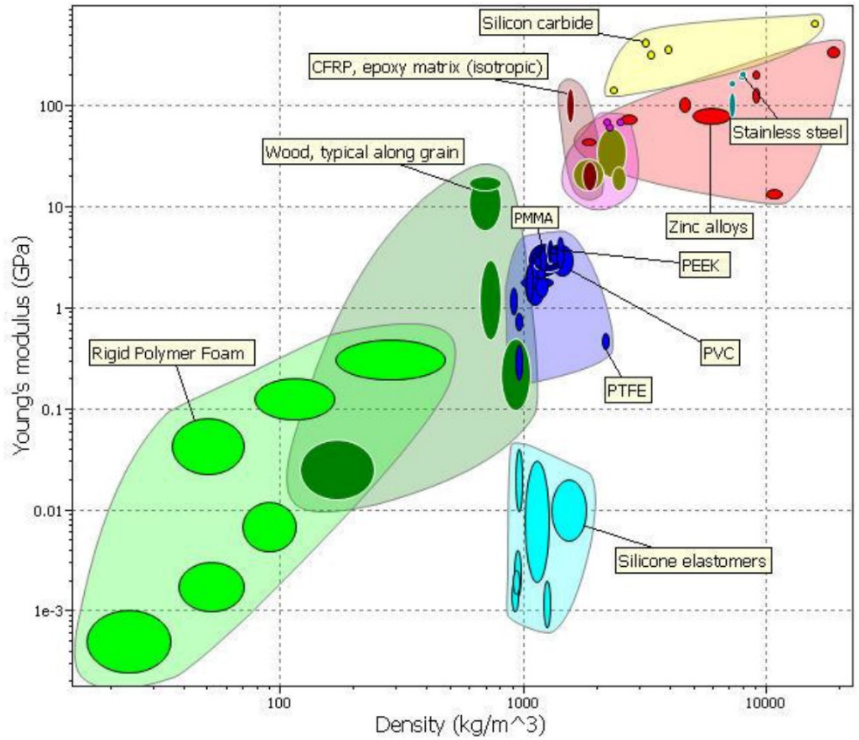

Wright Flyer (1903).

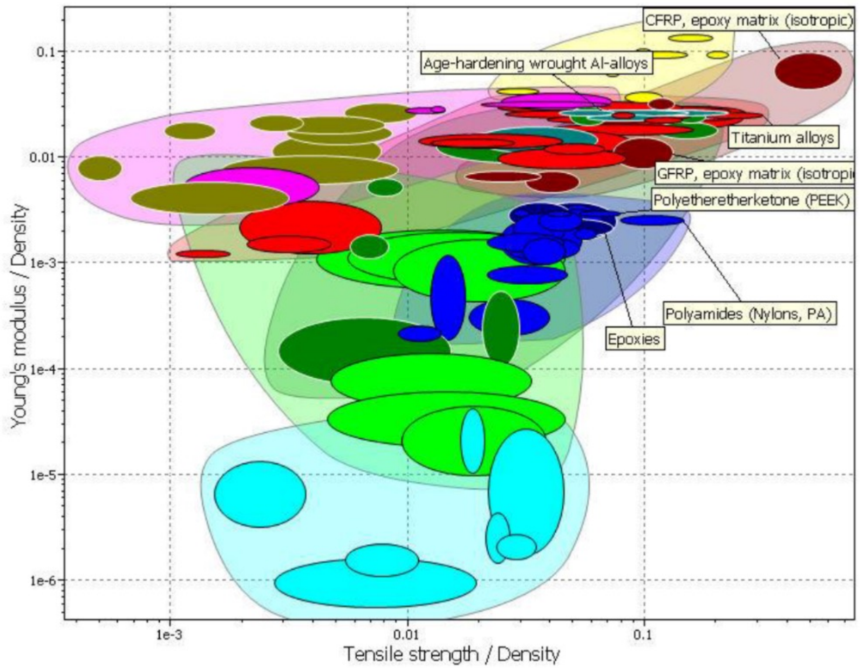
# Structural Components




Hawker Fury (1931).

# Composites

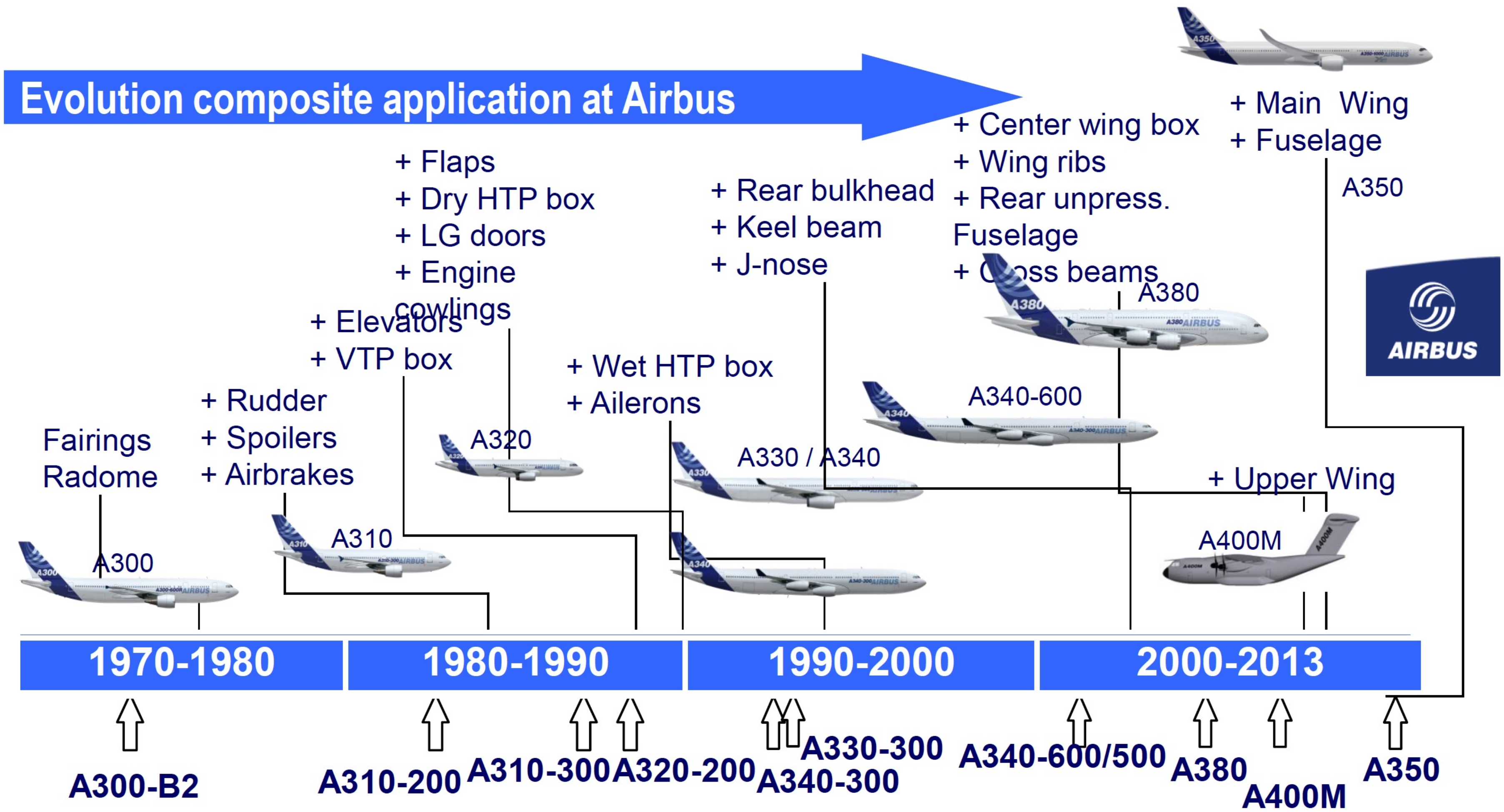



For a given stiffness, composites have low density.

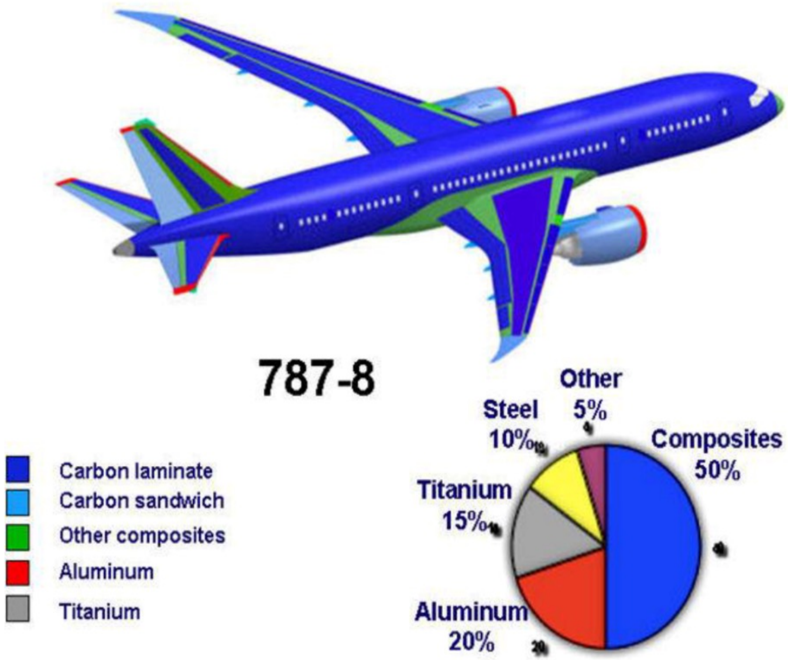
Composites have excellent specific strength and stiffness.

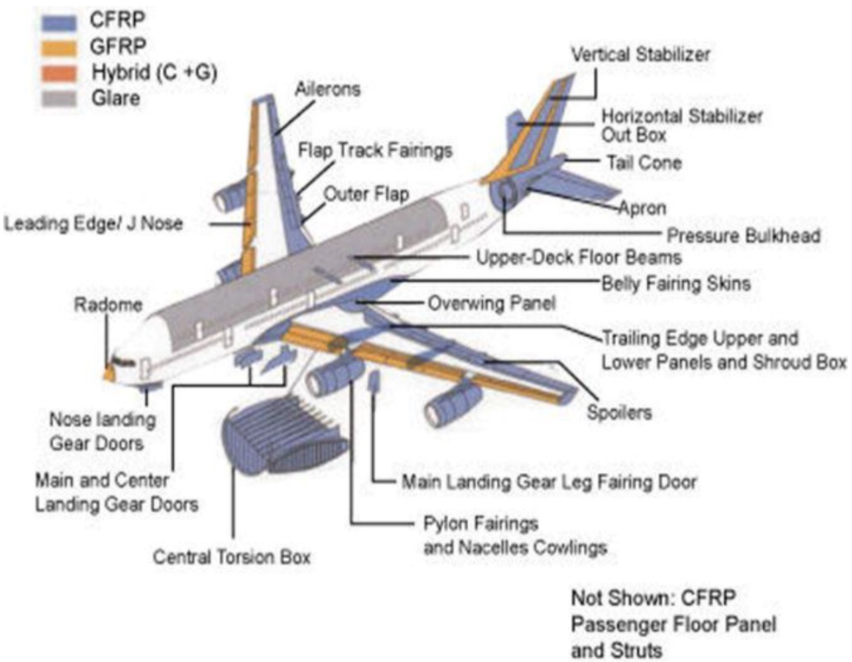
# Composites



Evolution composite application at Airbus
Fairings
Radome
A300
+ Rudder
+ Spoilers
+ Airbrakes
A310
+ Elevators
+ VTP box
+ Flaps
+ Dry HTP box
+ LG doors
+ Engine cowlings
A320
+ Wet HTP box
+ Ailerons
A330 / A340
A340
+ Rear bulkhead
+ Keel beam
+ J-nose
A340-600
+ Center wing box
+ Wing ribs
+ Rear unpress. Fuselage
+ Cross beams
A380
+ Main Wing
+ Fuselage
A350
+ Upper Wing
A400M
AIRBUS
1970-1980
1980-1990
1990-2000
2000-2013
A300-B2
A310-200
A310-300
A320-200
A330-300
A340-300
A340-600/500
A380
A400M
A350

- Composites give the OEMs the opportunity to produce lightweight structures thereby reducing fuel bills and reducing emissions.
- The cost of development and introduction of these new structures is now offset by the gains.
- Hence the increase in the usage of composites in aerostructures.




IS YOUR PLANE STRESSED OUT?