Aircraft materials

Lecture notes:

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Material selection

Material selection

Criteria

Mechanical properties
- stiffness
- strength
- toughness
- fatigue

Environment
- temperature
- humidity

Costs
- raw material
- manufacturing

Physical properties:
- density
- thermal expansion
- corrosion
- manufacturability

Material selection

Specific criteria

electrical conductivity

thermal conductivity

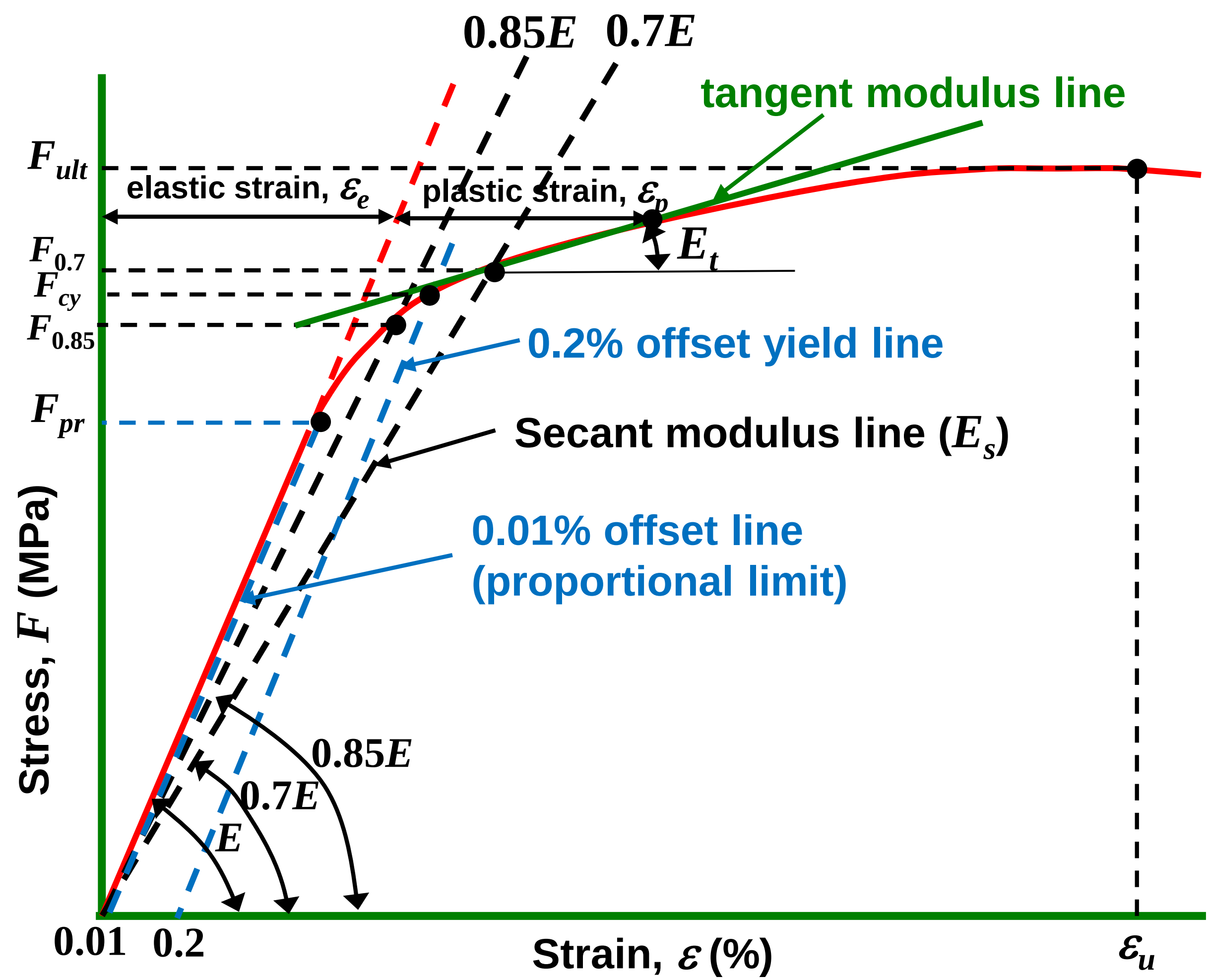
electromagnetic properties

wear

erosion and abrasion

Stress-strain curves

Stress strain curve



Ramberg-Osgood equation

The Ramberg-Osgood equation is an algebraic expression for the stress-strain curve shape that was originally defined as: ∞

$$\varepsilon = \frac{\sigma}{E} + K\left(\frac{\sigma}{E}\right)^n$$

where K and n are constants that describes the hardening behavior of the material

Notation from Ramberg-Osgood original work:

$$\sigma = F \Rightarrow \varepsilon = \frac{F}{E} + K\left(\frac{F}{E}\right)^n$$

Ramberg-Osgood equation

From the original work of Ramberg-Osgood:

$$\bar{\varepsilon} = \frac{E\varepsilon}{F_{0.7}}$$ and: $$\bar{\sigma} = \frac{F}{F_{0.7}}$$

From the original equation:

$$\varepsilon_{0.7} = \frac{F_{0.7}}{0.7E} = \frac{F_{0.7}}{E} + K\left(\frac{F_{0.7}}{E}\right)^n \Rightarrow \frac{(1-0.7)F_{0.7}}{0.7E} = K\left(\frac{F_{0.7}}{E}\right)^n$$

Therefore:

$$\frac{3F_{0.7}}{7E} = K\left(\frac{F_{0.7}}{E}\right)^n \Rightarrow K\left(\frac{F_{0.7}}{E}\right)^{n-1} = \frac{3}{7}$$

Ramberg-Osgood equation

Ramberg-Osgood equation:

$$\varepsilon = \frac{F}{E} + K\left(\frac{F}{E}\right)^n \Rightarrow \frac{\varepsilon E}{F_{0.7}} = \frac{F}{E}\frac{E}{F_{0.7}} + K\left(\frac{F}{E}\frac{F_{0.7}}{F_{0.7}}\right)^n \frac{E}{F_{0.7}}$$

Simplifying:

$$\frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + K\left(\frac{F}{F_{0.7}}\right)^n \left(\frac{F_{0.7}}{E}\right)^n \frac{E}{F_{0.7}}$$

$$\Rightarrow \frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + K\left(\frac{F_{0.7}}{E}\right)^{n-1} \left(\frac{F}{F_{0.7}}\right)^n \Rightarrow \boxed{\frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^n}$$

Ramberg-Osgood equation

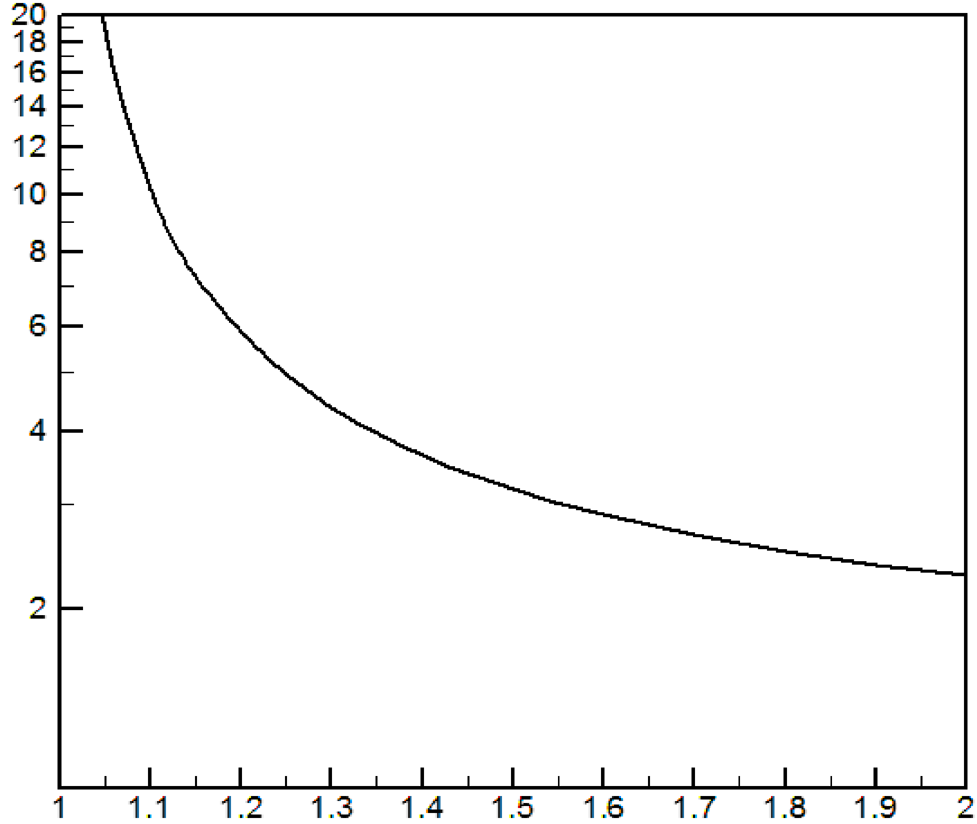
Therefore:

$$\frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^n$$

in the paper, it was proved that:

$$n = 1 + \frac{\log\left(\frac{17}{7}\right)}{\log\left(\frac{F_{0.7}}{F_{0.85}}\right)}$$

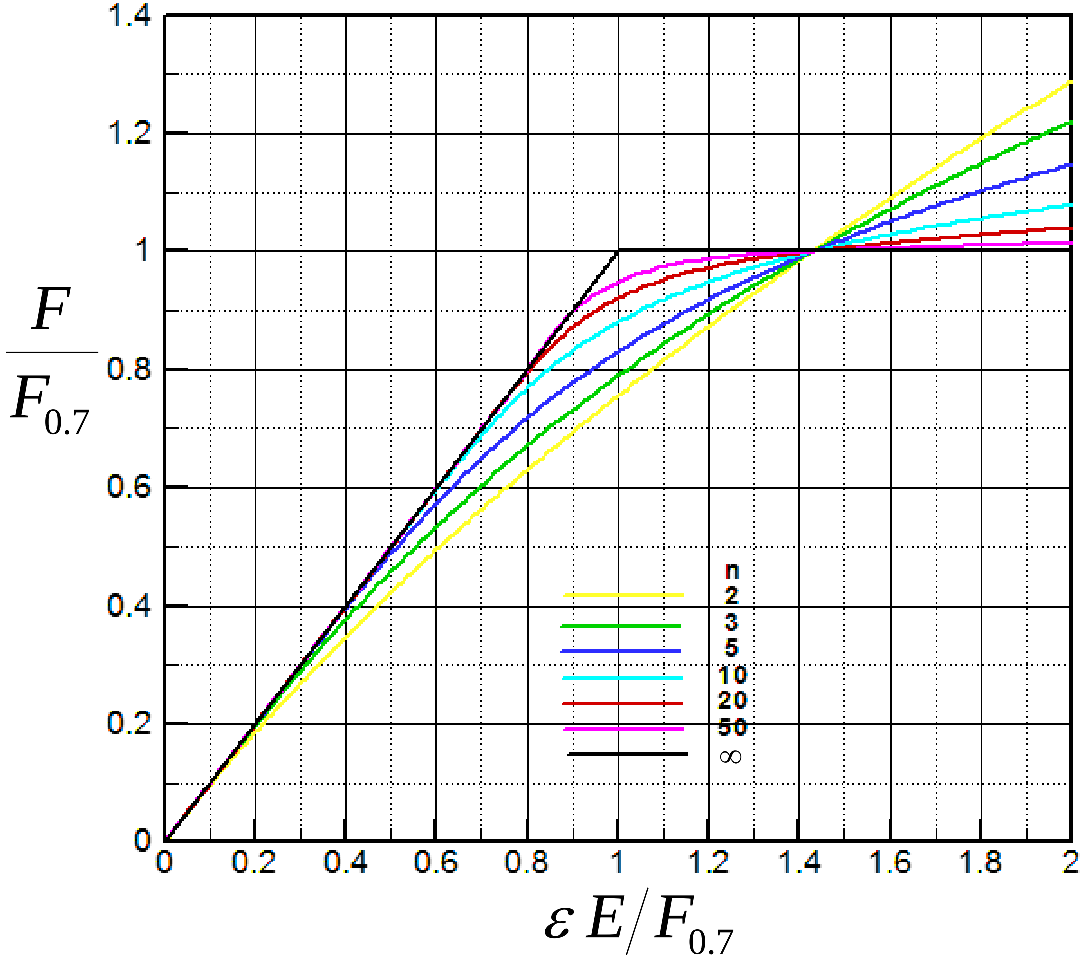
Ramberg-Osgood equation



n

$$\log\left(F_{0.7}/F_{0.85}\right)$$

Ramberg-Osgood equation



Ramberg-Osgood equation

The tangent modulus is defined by:

$$F = E_T \varepsilon \Rightarrow \frac{1}{E_T} = \frac{d\varepsilon(F)}{dF}$$

but:

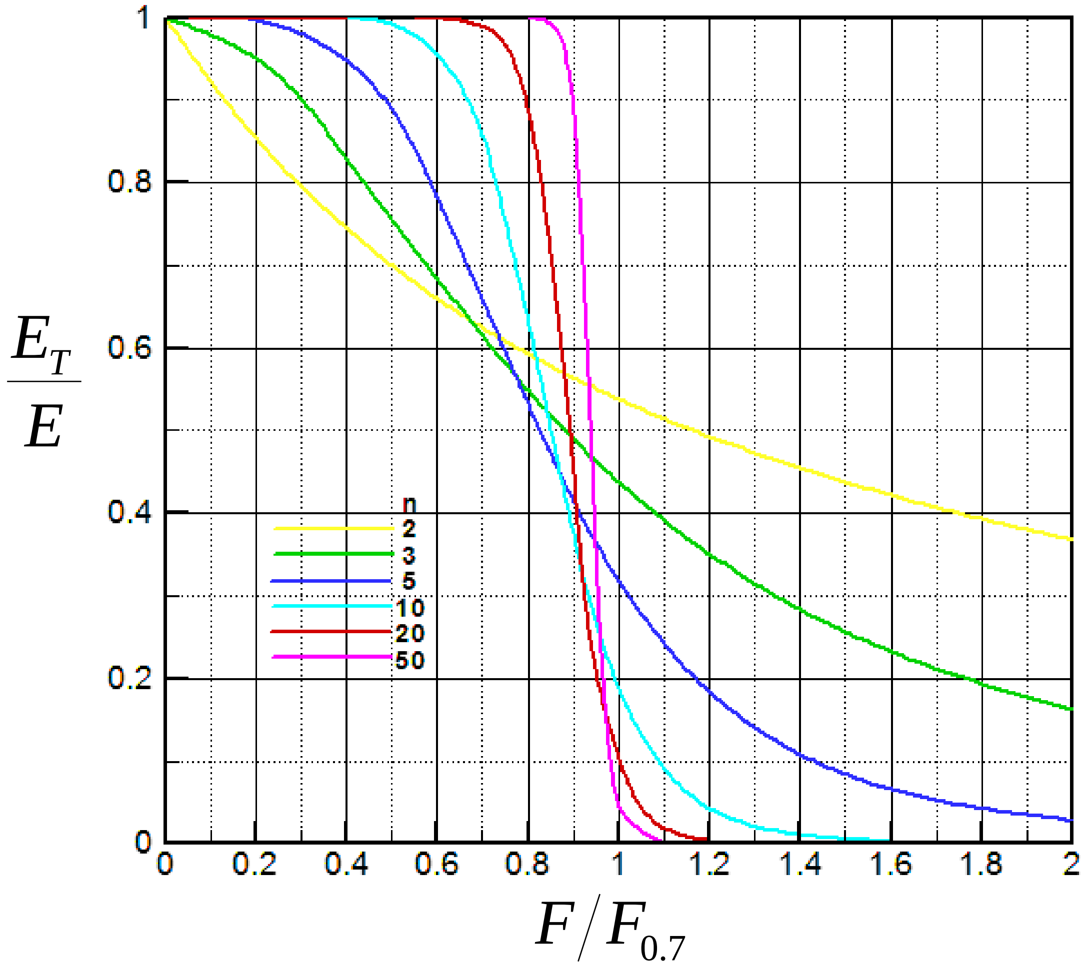
$$\frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^n$$

$$\Rightarrow \frac{d\varepsilon}{dF}\frac{E}{F_{0.7}} = \frac{1}{E_T}\frac{E}{F_{0.7}} = \frac{1}{F_{0.7}} + \frac{n}{F_{0.7}}\frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^{n-1}$$

Simplifying:

$$\frac{E}{E_T} = 1 + \frac{3}{7} n \left(\frac{F}{F_{0.7}}\right)^{n-1} \Rightarrow \boxed{\frac{E_T}{E} = \frac{1}{1 + \frac{3}{7} n \left(\frac{F}{F_{0.7}}\right)^{n-1}}}$$

Ramberg-Osgood equation



Ramberg-Osgood equation

The secant modulus is defined by:

$$E_s = \frac{F}{\varepsilon} \Rightarrow \frac{1}{E_s} = \frac{\varepsilon}{F}$$

but:

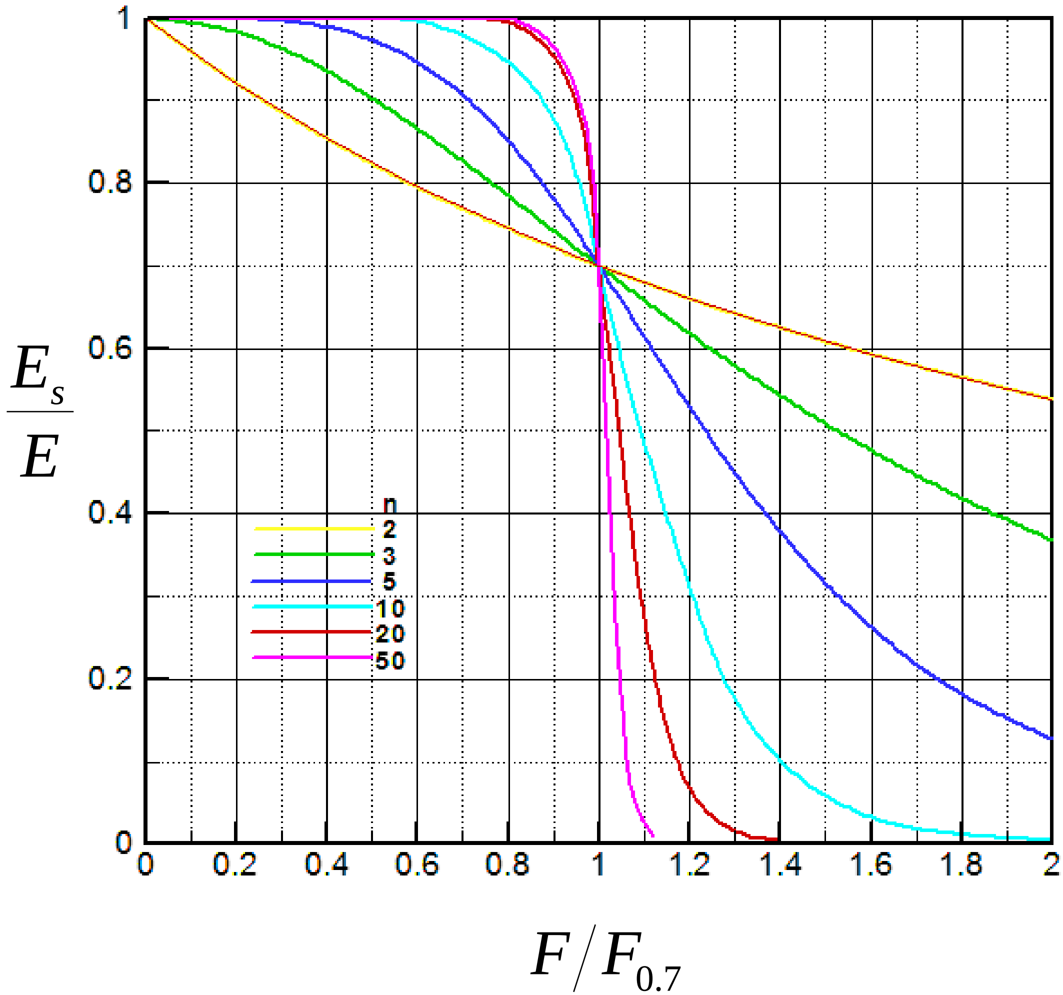
$$\frac{\varepsilon E}{F_{0.7}} = \frac{F}{F_{0.7}} + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^n$$

$$\frac{\varepsilon}{F}\frac{E}{F_{0.7}} = \frac{E}{E_s}\frac{1}{F_{0.7}} = \frac{1}{F_{0.7}}\left(\frac{F}{F_{0.7}} + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^n\right) = \frac{1}{F_{0.7}}\left(1 + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^{n-1}\right)$$

Simplifying:

$$\frac{E}{E_s} = 1 + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^{n-1} \Rightarrow \boxed{\frac{E_s}{E} = \frac{1}{1 + \frac{3}{7}\left(\frac{F}{F_{0.7}}\right)^{n-1}}}$$

Ramberg-Osgood equation



Ramberg-Osgood equation

New parameters:

$$\alpha = K\left(\frac{\sigma_0}{E}\right)^{n-1}$$

α and σ_0 (yield stress) are the new parameters

Therefore:

$$K\left(\frac{\sigma}{E}\right) = \alpha\frac{\sigma_0}{E}\left(\frac{\sigma}{\sigma_0}\right)^n$$

Substituting:

$$\varepsilon = \frac{\sigma}{E} + \alpha\frac{\sigma_0}{E}\left(\frac{\sigma}{\sigma_0}\right)^n$$

Material properties

Material properties

		Aluminum 2024	Steel AISI 1025	Titanium (MILT)
Density	g/cm^3	2.8	7.8	4.4
Modulus of elaticity	GPa	73.1	207	108
Shear modulus	GPa	28	79	42.4
Poisson ratio	-	0.33	0.30	0.30
Tensile yield strength	MPa	324	394	550
Shear strength	MPa	283	248	295
Coefficient of thermal expansion	$\mu\varepsilon/^{o}C$	23.2	11	11

Aluminum alloys

Aluminum alloys

Characteristics:

- widely used in aircraft manufacturing
- high strength/density ratio
- high stiffness/density ratio
- good corrosion resistance
- high thermal expansion coefficient
- good manufacturability (welding is difficult)
- relatively low melting temperature
- good electrical conductivity
- non-magnetic

Aluminum alloys

Applications:

- structures
- interior
- fairings

Aluminum alloys

Alloy 2024:

- heat treatable
- high strength
- good machinability
- fair corrosion resistance
- poor welding

Aluminum alloys

Alloy 7075:

- heat treatable
- strongest and hardest aluminum alloy
- good machinability
- fair corrosion resistance
- poor welding
- not very workable

Steel

Steel

Characteristics:

- high strength
- high stiffness
- poor corrosion resistance
- reasonable thermal expansion coefficient
- good manufacturability
- good for welding
- high melting temperature
- good electrical conductivity
- magnetic

Steel

Applications:

- landing gear
- highly loaded fittings
- compact parts with space constraints

Titanium

Titanium

Characteristics:

- good high strength/density ratio
- good high stiffness/density ratio
- good corrosion resistance
- reasonable thermal expansion coefficient
- very difficult manufacturability
- poor welding
- high melting temperature
- elevated cost

Titanium

Applications:

- airframes
- firewalls

Polymeric composites

Polymeric composites

Characteristics:

- good high strength/density ratio
- good high stiffness/density ratio
- good corrosion resistance
- very low thermal expansion coefficient
- good manufacturability
- no welding (bonding)
- low limit temperature
- hygroscopic
- low electrical and thermal conductivity

Polymeric composites

Applications:

- widely used in recent years
- wing
- empennage
- fuselage