Introduction to aerospace structures

The analysis and the design of aerospace structures starts from the evaluation of the loads acting on the structure.

In general, the loads can be of different nature, for instance:

1. Aerodynamic forces
2. Inertial forces
3. Loads due to the propulsion system
4. Pressure loads due to a Δp between inside and outside

- For the scopes of this course the loads will always be assumed to be known and available from previous analyses in the form of input data.

- The preliminary design phase relies upon simple idealizations of the structure. There is no sense in starting the design process with detailed, complex and costly models.
  The initial scheme should be easily understandable, provide insight into the role played by the many design variables involved in the design process, and simple enough to allow the analysis of several configurations, design loads, ...
  Note that simple does not mean simplicistic. In the initial phase too many details are not needed, so the mathematical model of the structure does not need to account for them.

Based on these considerations, a <u>beam model</u> is generally an adequate choice to begin the design process, indeed

1. Many preliminary analyses can be easily performed
2. Several details are not available yet

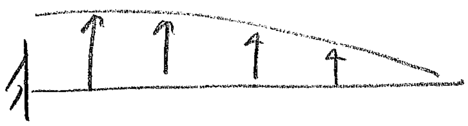
The initial scheme can be imagined as an <u>isostatic (i.e., statically determined) scheme</u>. It is known that statically indeterminate schemes lead to solutions which are function of the stiffness distribution. It turns out that the analysis of the structure could be dependent on the stiffnesses of other parts of the structure, with the effect of increasing the complexity of the initial design.

<u>The adoption of isostatic schemes allows to design the various parts of the structure independently on the others.</u>

Again, note that this is not a suboptimal strategy, but an engineering approach to begin a complex and lengthy design loop.

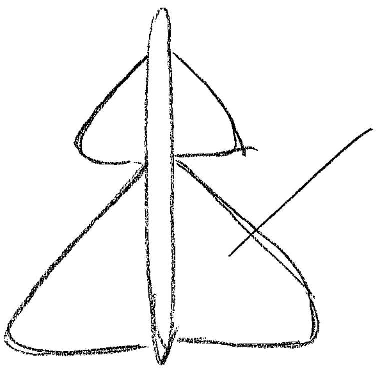
It can be useful to remark that

1. If an isostatic scheme is adopted, the internal actions are readily available from the applied loads (no information regarding the structure is needed), e.g.



The shear and the bending moment T and M do not depend on EJ, EA, GJ, GA*. (which have to be designed)

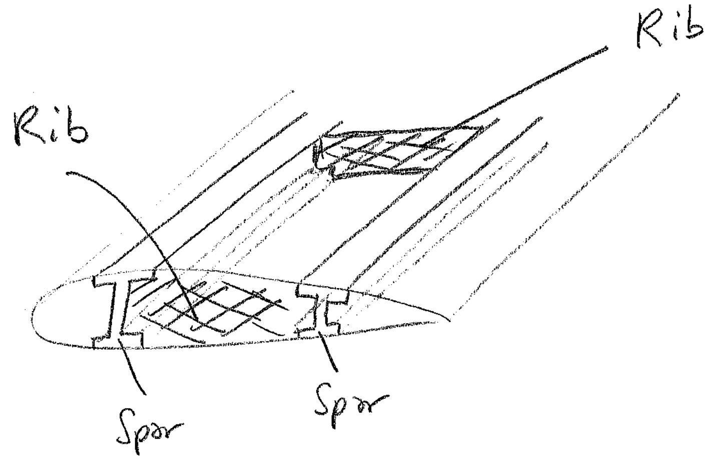
2. While in many cases a beam model is a proper choice, in some other it can be at least questionable.
Consider for instance the case of a wing with low aspect ratio



It is hard to imagine this wing as a beam!
A 2D (plate) scheme would be the most natural (and proper) choice

It is useful to briefly review the history and the evolution of aeronautical structures. The early aeronautical beams where characterized by

1. Longerons (or spars): 1 or more
2. Ribs / frames
3. Fabric cover



Ribs: transverse elements
Spars: longitudinal elements (connecting the upper and lower cover)

Thus:
- the cover was not capable of carrying or transmitting loads
- the torsional stiffness was very low (and almost due to the differential bending of the spars)

For the early, low speed vehicles the two previous remarks did not represent a strong limitation, and the structural configuration was then adequate.

The increasing speed and needs for performance of the flying vehicles of the successive generations lead to a shift of paradigm of the structural configuration

In particular, increasing velocities determined:

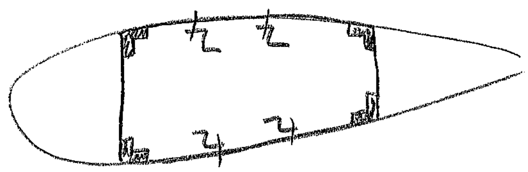
1. Higher aerodynamic loads
   - higher torsional loads
   - need for higher torsional stiffnesses
     (fundamental for coping aeroelastic problems such as static divergence or flutter)

2. Need for stiffer covers in order to guarantee proper aerodynamic shapes, not to alter the aerodynamic behaviour due to structural deformations.

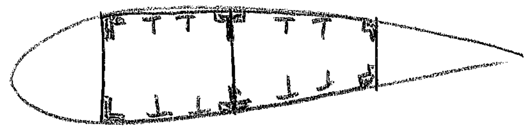
The kind of structural solutions that could address these needs where characterized by:

1. Stressed skin
2. Longitudinal stiffening elements
3. Closed-box configurations

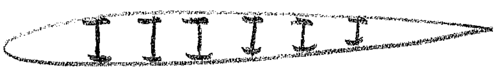
Some examples are:



1 cell design



2 cell design



supersonic profile

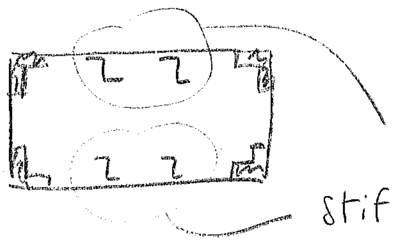
The ingredients of a modern aeronautical structure can then be identified as

1. <u>Stressed skin</u>

The skin contributes to the load-carring capabilities of the section. It is completly part of the structure.

2. <u>Longitudinal stiffening elements (stringers)</u>

In addition to the spars, longitudinal elements running along the direction of the beam axis - and denoted as stringers or stiffeners - were introduced.



They can be characterized by different sections

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chosen according to several design considerations.

In my case, the stringers

a. sustain the normal stresses (thus no more sustained by the spar only)

b. Increase the buckling load of the panels of the cover

$\sigma_{CR} \propto \frac{1}{b^2}$ $\qquad$ $\sigma_{CR} \propto \frac{1}{b_1^2}$

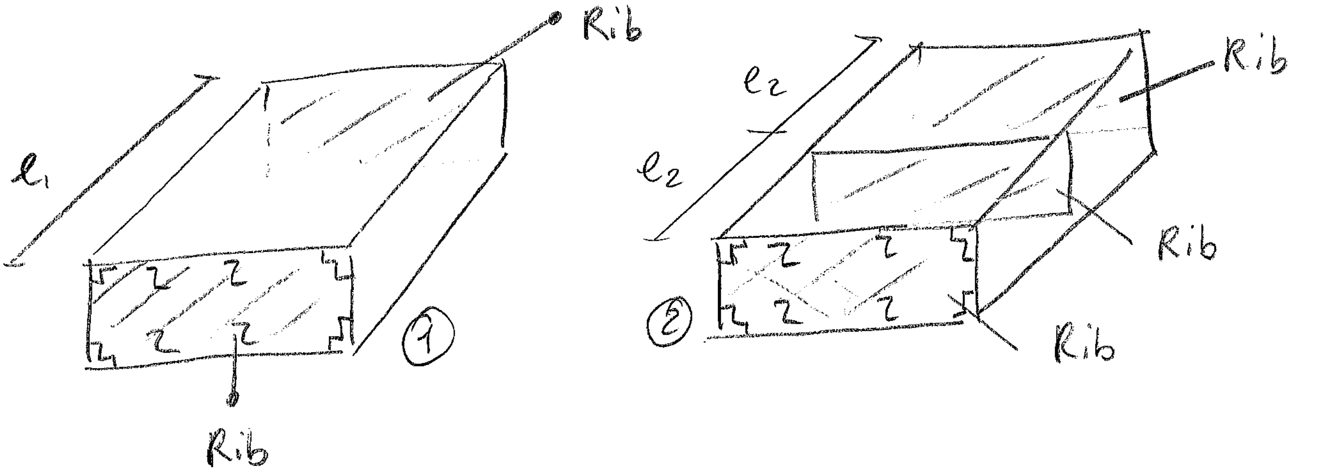
3. Ribs / frames

These are transverse elements, responsible for three main functions:

a. they allow the introduction of loads in the structure

b. they preserve the shape of the section (as seen it is highly important for aerodynamic requirements)

c. they increase the buckling load of the stiffened panels of the wing cover.



The Euler buckling load of a beam is

$$P_{CR} = \frac{\pi^2 E J}{\lambda^2} \propto \frac{1}{l_1^2}$$

$$\Rightarrow 4 P_{CR}^{(1)} = P_{CR}^{(2)} \qquad (\text{if } l_2 = l_1/2)$$

(Clearly the number of ribs cannot be increased just to improve the buckling performances. Each rib determines an increase of weight! The previous example simply demonstrates how a rib determines an increase of buckling load.)

To conclude, it is remarked that aeronautical beams and structures, as well as most of the structures used in aerospace applications, are designed to be highly efficient structures, the weight is the most crucial aspect.

In many cases - the wing boxes, are just one example - the configuration are characterized by reduced thicknesses (of the order of few millimiters; the exiguity of the thicknesses should be put in relation also with the typical dimensions of the section) and, for this reason, are commonly referred to as thin-walled structures

For thin-walled structures two aspects become relevant

1. The shear stresses and the corresponding shear deformability play an important role on the structure's behaviour.
   When dealing with thin-walled beams, the shear deformability cannot be neglected as it is commonly done for slender beams with compact sections

2. The exiguity of the thicknesses leads to buckling-prone structures; the combination of thin-walled designs with set of loads that can promote instability makes the buckling behavior an aspect of crucial importance