Designing

1 Designing considerations

1.1 Design Types

There are three types of design. In **routine design** familiar parts and devices are used. In **variant design** parts are modified in form and function. In **creative design** new parts and artifacts are designed. Next to deciding the design type, a designer also has to decide whether to use truss structures, beams or plates in his design.

1.2 Design parameters and variables

In a design, there are usually certain given **design parameters** $\mathbf{p} = [p_1 \dots p_m]^T$ and **design variables** $\mathbf{x} = [x_1 \dots x_m]^T$ which still need to be determined. The more design variables, the more decisions need to be made, and the more complex the designing process can be. If there are n design variables, then the **dimensionality of the design space** is said to be n-dimensional. That is, you can draw an n-dimensional space, in which every point represents a possible design.

1.3 Design constraints

Next to the variables, there are also certain **design constraints**. These constraints can be on the design variables (for example, the width of a beam may not be bigger than ...) or on the design outcome. However, to put constraints on the design outcome, there must be some function $g(\mathbf{x}, \mathbf{p})$ whose value is constrained to a certain value. Constraints can be drawn in the design space, to visualize which options are possible and which options are not.

In a design, stresses σ will always have bounds. Displacements δ usually also have bounds.

1.4 Design objectives

Naturally a design is not made without a reason. Certain **design objectives** are present. An example of an objective is to minimize weight.

The "goodness" of the design, being the amount in which the objective has been satisfied, must be computable. So there must be a function $f(\mathbf{x}, \mathbf{p})$ indicating how much the objective has been fulfilled. If there are more than one objectives, there is a multi-objective formulation $(f_1, f_2, \dots, f_j)$.

1.5 Design efficiency

For a safe structure, the stresses in every member may not be bigger than the maximum allowable stress: $\sigma \leq \sigma_{all}$. But for an efficient design, all members should have $\sigma = \sigma_{all}$ for at least one load condition. If this is not the case, than the cross-sectional area (or in some cases the thickness) can be changed according to

$$A_{new} = A_{old} \frac{\sigma}{\sigma_{all}}. \tag{1.1}$$

This works for statically determinate structures, but not always for statically indeterminate structures, since the stress in a member then depends on various other parameters as well.

In this way the design can be optimized as much as possible, until the design is satisfactory. Being **satisfied** with a design means that all constraints/bounds are satisfied and all design objectives are met.

1.6 Sensitivity Analysis

The **sensitivity** is the response of the design due to a change in a design variable. In a way, the sensitivity is a derivative $\frac{\partial f}{\partial x}$. However, a function is not always present, so a **finite difference approximation** can be used. The sensitivity of the stress with respect to the cross-sectional area is for example

$$\frac{\partial \sigma}{\partial A} = \frac{\sigma(A_1) - \sigma(A_0)}{A_1 - A_0} = \frac{\sigma_1 - \sigma_0}{A_1 - A_0}, \tag{1.2}$$

where $dA = A_1 - A_0$ is very small.

2 Loads and failures

2.1 Limit load and ultimate load

The **limit load** is the maximum load which the aircraft may encounter at any time during its lifetime. No yielding/permanent deformation may occur at the limit load.

The **ultimate load** is the load which may occur once in the lifetime of an aircraft. All parts must be able to carry this load without failure. Permanent deformation may occur though.

2.2 Failure criteria

The structure fails when the stresses get too high. We already know how to calculate the minimum and maximum stresses σ_1 and σ_2 in a plate. These stresses must comply to the **maximum normal stress criterion**, meaning that

$$\sigma_1 \leq \sigma_{all}, \qquad \sigma_2 \leq \sigma_{all}, \tag{2.1}$$

where σ_{all} is the maximum allowable normal stress. There is also the **maximum shear stress criterion**, meaning that

$$|\tau_{max}| \leq \tau_{all} \qquad \Leftrightarrow \qquad |\sigma_1 - \sigma_2| \leq 2\tau_{all}, \tag{2.2}$$

where τ_{max} is the maximum allowable shear stress. The **von Mises criterion** also demands that

$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 \leq \sigma_{all}^2 \tag{2.3}$$

And eventually, in some cases, there is also the **maximum strain criterion**.

2.3 Buckling

For beams under tension, only the cross-sectional area A is important. For beams under compression, also the shape matters, since buckling may occur. The maximum force which a beam can take depends partially depends on how it is connected to the structure. For example, the maximum compressive force for a simply supported column is

$$P_{max} = \frac{\pi^2 EI}{L^2}. \tag{2.4}$$

2.4 Stress Concentrations

Stress concentrations occur at discontinuities in the structure, such as holes, cracks or a change in the cross-sectional shape. At such concentrations, stresses are higher. The **stress concentration factor** K is defined such that

$$\sigma_{max} = K\sigma_{average}. \tag{2.5}$$

2.5 Load Cases

A structure could be design for just one **load case** (a way of loading it). However, some structures have multiple loads acting on them simultaneously. This is called a **combined load case**. It could also occur that multiple loads do occur, but not simultaneously. This is called a **multiple load case**.