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AN EXAMPLE OF GLOBAL STRUCTURAL OPTIMISATION WITH GENETIC ALGORITHMS IN THE AEROSPACE FIELD

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Abstract

In order to pre-size a fuselage section, an optimisation process based on genetic algorithms is developed. This method can deal with non-linear constraints and then enables us to take the instability of the stiffened panel (main fuselage component) into account. Before being applied to the case of a whole fuselage section, the optimisation method is validated through the weight optimisation of a stiffened panel subjected to compressive loads. Optimised solutions are thus assessed and compared with the ones obtained using the well-known S.Q.P method.

1 INTRODUCTION

Finding the best compromise between weight and structural performance is one of the major challenges in aeronautical structural design. The earlier the structure is optimised in the design cycle, the shorter the development cycle becomes. Hence it is crucial to elaborate a methodology to improve weight performance right from the concept phase, in order to quickly assess the effects of structural modifications.

An optimisation process, which can deal with non-linear constraint problems such as structural ones (buckling), is presented in this communication. It is first validated through the weight optimisation of a stiffened panel, which is the main fuselage component. The method is then extended to the case of a fuselage section. Both the validation of the method and its fuselage application are presented here.

2 WEIGHT OPTIMISATION OF STIFFENED PANELS

The purpose of this section is to check the capabilities of the method. It consists in minimizing the weight of a stiffened panel subject to compressive loads, with respect to the stability criteria. It then involves defining an analytical model to assess its stability performance before performing optimisation.

2.1 Buckling of the stiffened panel

When subjected to compressive loads, the skin of stiffened panels may buckle. This does not imply failure as the panel can support additional loads, but the stiffened panel behaviour becomes non-linear. Indeed, once buckled, a part of the panel skin is no longer able to withstand more loading. The stiffener and an adjacent portion of skin, then called the effective section, support the whole load until failure occurs (due to local or global instability). The Von Karman formulation [1] enables us to calculate the effective width of skin c from the compression stress applied σ_{max} ,the buckling stress of skin σ_b and the initial skin width b:

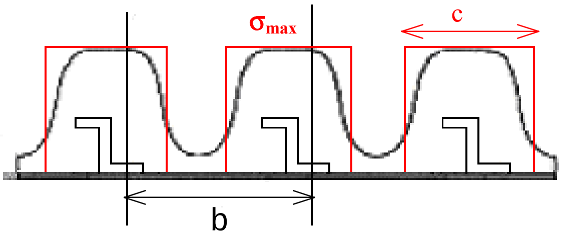


Fig.1 - Von Karman Effective width model

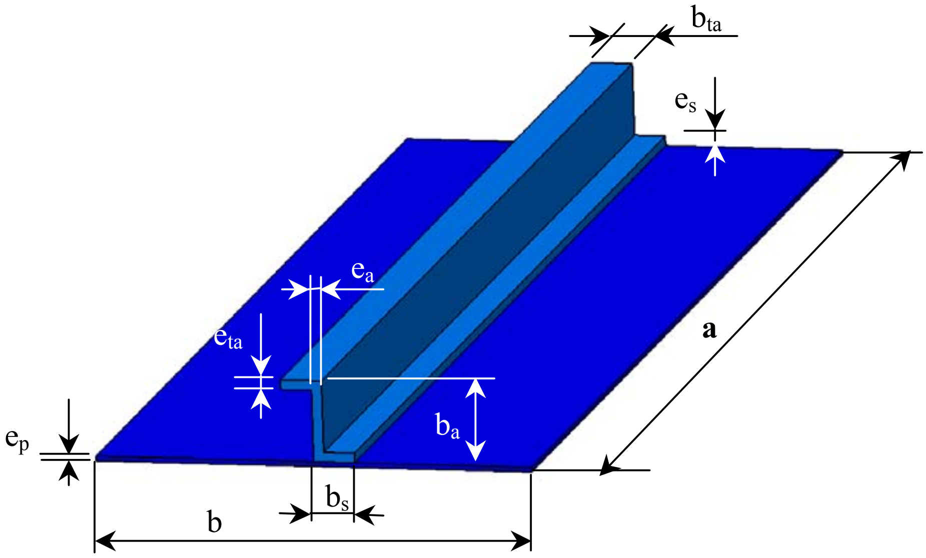
$$\text{Buckling stress } \sigma_b = KE\left(\frac{e_p}{b}\right)^2 \qquad (1)$$

$$\text{Effective width } c = \frac{b}{2}\sqrt{\frac{\sigma_b}{\sigma_{\max}}} \qquad (2)$$

Thanks to equations (1) and (2), an analytical model with plasticity correction for stiffened panel stability is developed and implemented under MATLAB software.

2.2 Weight optimisation

For the optimisation process, all the stiffened panel dimensions (Figure 2) are potential design variables as well as the skin and the stiffener materials.



b : stiffener pitch
a : frame pitch
e_p : skin thickness
b_{ta} : outer flange width
e_{ta} : outer flange thickness
b_s : inner flange width
e_s : inner flange thickness
b_a : web width
e_a : web thickness

Fig.2 - Design variables

The aim is to find one or more stiffened panels with the minimal weight verifying the following type of constraints:

- boundary constraint e.g. $1.4 < e_p < 5$
- non-linear constraint e.g. stability criteria

To solve this problem, two classes of methods have been tested:

- Gradient-based method with Sequential Quadratic Method (S.Q.P.), which was already applied in such a case [2],
- Genetic Algorithms (GA).

A major advantage of GAs is that they do not require gradient information: they can deal both with continuous and discrete design variables. However, they must be modified to take into account constraints. Thus, a parameter-less adaptative penalty scheme for GAs has been used in order to reject any design solutions that would not match stress requirements [3].
Three problems are solved here. In the first problem, the materials, the stiffener pitch *b* and the frame pitch *a* are fixed. As the S.Q.P. method requires gradient information, variables are considered as continuous. Since such accuracy is meaningless, the same problem (case 2) is solved with discrete variables: for the S.Q.P. method, the optimisation is performed with continuous variables and the final solution is rounded and tested to verify its criteria requirements. Finally, in the third case, skin and stiffener materials are also design variables with two possible values, and, here, only GA can deal with this problem.

The table below gives the best results obtained with the two methods for the same computational time.

	CASE 1 – Weight (g)	**CASE 2 – Weight (g)**	**CASE 3 – Weight (g)**
S.Q.P.	806,61	818,87	-
G.A.	815,23	817,93	787,06

Fig.3 Results optimisation summary

For each GA solution, the constraint violation is assessed and the objective function penalisation is checked. This first study validates the GA approach, and shows its ability to deal with discrete variables in the framework of constrained optimisation.

3 APPLICATION TO A FUSELAGE SECTION

The previous method is being applied to pre-size a Long Range-type fuselage section as a feasibility study. As in the case of the stiffened panel, it is necessary to assess the structure performance through margin calculation. To this end, a global analytical model has been developed. This model takes into account the specific behaviour of stiffened panels, which are prone to buckle when subjected to sufficient compressive loads as seen previously [4]. Thanks to this model, stress distributions related to fuselage loadings are calculated and compared with previously defined allowable stresses. It is then possible to assess whether the fuselage section tested withstands the loads.

Thanks to this global analytical model, stress distributions related to each pre-sizing load can be calculated for each iteration of the optimisation process. A global multi-criteria optimisation using the GA method can thus be conducted with regard to all the allowable stress constraint requirements, leading to improvements in weight performance and technology assessment (e.g. choice of materials).

4 CONCLUSION

The optimisation process presented here has been successfully tested in the case of the weight optimisation of a stiffened panel. Its extension to more general industrial cases such as fuselage section is currently in progress, and looks as though it will give promising results.

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