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ANALYTICAL METHOD FOR LIMIT LOAD CAPACITY CALCULATION OF THIN WALLED AIRCRAFT STRUCTURES

Prof. Ing. Antonin Pistek, CSc.

Institute of Aerospace Engineering,
Brno University of Technology,
Technická 2896/2,
616 69 Brno,
Czech Republic
pistek@fme.vutbr.cz

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Abstract

The paper is focused on description and comparison of different methods for limit load capacity calculation of thin walled aircraft structures – considering all possible forms of buckling and failures on nonlinear behavior of the structure under gradually increased loading. Considered were the following methods: Finite Element Method (FEM), Reduction Coefficients Method and special attention is given to so called "Gradually Increased Loading Method" – (GILM), which is an original analytical method developed by the author of this paper.

1 Introduction

The paper is focused on description and comparison of different methods for limit load capacity calculation of thin walled aircraft structures – considering all possible forms of buckling and failures on nonlinear behaviour of the structure under gradually increased loading. Methods considered include: F*inite Element Method (FEM)*, Reduction Coefficients Method and special attention is given to so called *"Gradually Increased Loading Method"* – GILM.

Generally the strength of the aircraft structure is determined by ultimate load, which expresses its capability to carry external loads up to so called ultimate loads. Since typical safety factor is f=1,5, linear stress distribution is usually valid only up to limit loads. This is not true for typical semi-monocoque thin walled structure of the wing, tail units, fuselage or other structural aircraft parts composed of

- beams,
- stringers,
- skin and webs

with significant differences in ultimate stresses. As figure 1 shows, while we can register buckling of the skin and partially webs under relatively small loading (quite often less than 20% of ultimate loads), stringers with effective skin width reach much higher value and beams the highest load carrying capacity. From this point of view, performance of the overall structure under gradually increased loading is highly non-linear up to limit load capacity, which has to be always higher then ultimate loads.

The task can be solved using several methods, for example FEM, using of commercial software systems. FEM is today modern and universal and very effective method for structural analysis of structures subjected to high intensity loading and (or) with large cut-outs or other type of geometrical non-regularities. However, FEM requires detailed simulation of the complete

structure. Therefore it is suitable for well defined structure (already developed and described) and its application is time demanding. For slim walled structures of the wing, tail units and fuselage the task can be solved on individual "cross sections" with consideration of step-by step exclusion of structural elements based on their load carrying capacity and with consideration of non-linear performance within loading.
The paper describes original analytical method based on principle of gradual increases in loading. Simplified calculation algorithm of GILM is shown in fig. 2.

Software application utilizing GILM method was created and is still used for structures typical for General aviation category aircraft. The application has simple and intelligible interface for inputs. Outputs of the software provide clear overview on loading history and structure status up to limit load capacity.

2. Description of seminocoque structures

2.1 Stiffened panel

The stiffened panel is the elementary part of most of the airframe structures with intermediate and higher loading intensity. Stiffened panel is composed of two basic structural parts: Longitudinal reinforcing members (stringers) and the skin.

2.2. Longitudinal reinforcing stringers

This is represented by stringers and longitudinal braces of fuselage shells and the spar flanges of wings. They are able to carry appreciable tensile loads and, when supported, compressive loads as well. They can carry secondary bending loads, but their bending rigidity is negligible. So it is customary to describe them as direct load carrying members.

2.3. Skin

Like all thin shells, this is best suited to carrying load in its own surface as membrane stresses. Tensile, compressive and shear loads can be carried, but reinforcement (lateral support) is required for all but the first. The thin skins used in aircraft can only sustain and transmit normal pressure over very short distances by bending. Pressurization loads in a circular section fuselage can, however, be taken by hoop tension stresses.

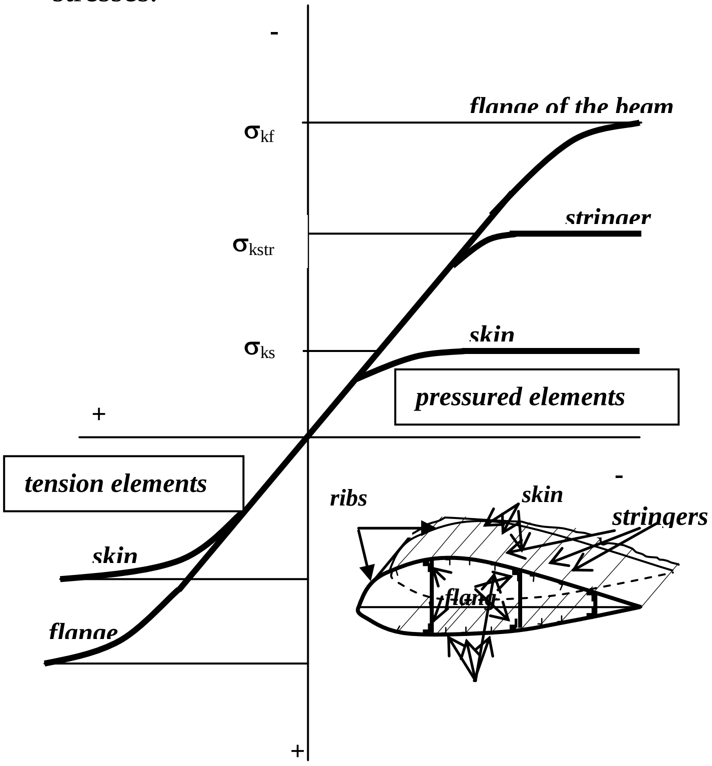

Fig.1 The typical semi-monocoque structure scheme and type of failure

3. Determination of the load capacity

The precise determination of the load carrying capacity of structure is generally optimisation design procedure. [2] Three main methods are considered. The utilization of the particular method depends especially on the level of the design (The preliminary design gives priority to velocity of the calculation on the other side the FEM are especially focused for the final design and gives the priority to the maximal accuracy. The utilization of analytical methods as well as methods based on nonlinearity behaviour independent part of structure. Still necessary to complete by any of experimental methods.

3.1 Analytical method

Analytical methods can be very useful tool in the area of the preliminary analysis because of the simplicity and high speed finding of the sufficiently good results. The analytical methods estimation of the load capacity is usually based on the determination of critical stress of individual components. (This part of design is critical for the accuracy of the calculation). Very effective tool seems to be the method **GILM,** first published by [3] and is the contents of this paper. This method allows as well as other analytical methods to find the total load capacity of the stiffened panel or cross – section of the wing or fuselage and give us a relatively precise description of the loading history.The GILM basic simplified algorithm is shown below on fig.2

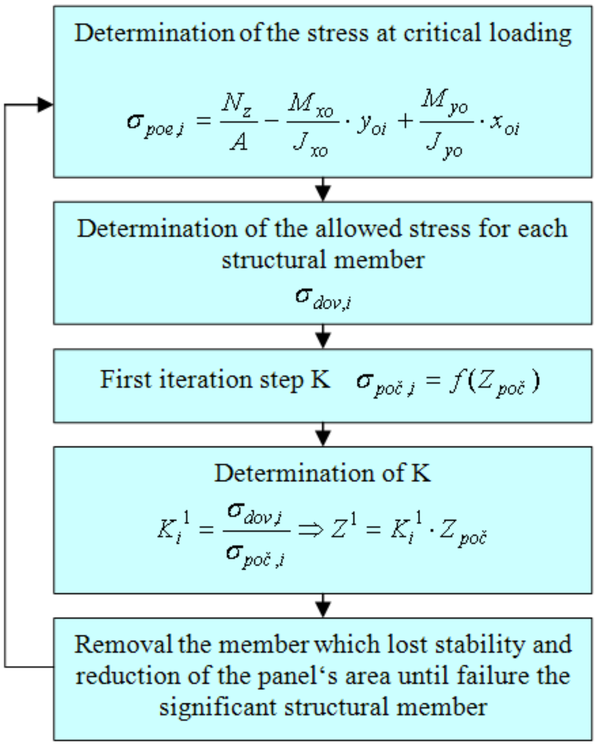

Fig.2 The algorithm of the GILM

3.2 Finite element method FEM

FE method is a very popular tool for structural analysis today. It is a very effective variation method for the design of even very complex structural parts or assemblies. In comparison with Analytical methods (in our case represented by GILM) are the FE methods more accurate but the speed of calculation is significantly slower. All FME analyses involved in this paper were made in MSC software (Patran, Nastran).

4 Conclusions

Today, finite element method (FEM) has dominant position for stress and load-carrying capacity calculations of aircraft structures. It is very effective for complex structures with shape or material non- regularities. For thin walled structures, especially in preliminary design phase and for structural optimization. GILM method is very effective, fast and high precision and still developed and practically used for different kinds of applications. Exist many practical GILM application which are verified by results of tests. The program (STAUNO) is developed in FORTRAN and have interactive output options and modification also changes are mainly applied in optimizing the initial design . The program has a special preprocessor (PREPUNO 1.3) for the preparation and control of the input data.

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Contact Author Email Address

Prof. Ing. Antonin Pistek, CSc.
pistek@fme.vutbr.cz