Mass optimisation of turbofan engine casing made of sandwich structure

Szymczyk Elżbieta [1,a)], Jerzy Jachimowicz [b)], Wiesław Szymczyk [c)]

[1]*Department of Mechanics and Applied Computer Science,*
Faculty of Mechanical Engineering, Military University of Technology
Urbanowicza Street 2, 00-908 Warsaw, Poland
e-mail: kmiis@wat.edu.pl

[a)] elzbieta.szymczyk@wat.edu.pl
[b)] jerzy.jachimowicz@wat.edu.pl
[c)] wieslaw.szymczyk@wat.edu.pl

Abstract. A constant attempt to obtain the lowest possible aircraft mass is the reason for using materials of high specific strength and stiffness in the aerospace industry. The object of analysis is the casing of F124 turbofan engine. The axially compressed cylindrical part of this casing is considered. The aim of the paper is analysis of possible benefits of replacing the original/actual metal casing with a sandwich structure. A sandwich structure in the form of a metal-fibre laminate of titanium alloy faces and a flax fibre unidirectional laminate core is proposed. Analytical optimisation of a sandwich structure was performed including a correction of the critical load obtained based on numerical analysis. The best mass efficiency was obtained for a core to faces thickness ratio equal about 4.

INTRODUCTION

A constant attempt to obtain the lowest possible aircraft mass is the reason for using materials of high specific strength and stiffness in the aerospace industry. High strength titanium (e.g. Ti6Al4V) or aluminium alloys (e.g. 2024T3) as well as composite laminates (e.g. CFRP or FML) and sandwich structures are examples of such materials.

The object of analysis is the casing of F124 turbofan engine. Analysis of load conditions indicates that a dimensioning load case is crash landing, while an axis component of inertial load is about 30g [MIL-HDBK]. Therefore, the axial load is considered in this paper.

The casing of F124 engine is built of thin metal sheets in order to reduce its weight. In the original structure, a triangle waffle ribbing is used to increase the casing stiffness with a minimum mass growth. The casing is made of titanium alloy (Ti6Al4V). It consists of one cylindrical and two conical parts. The cylindrical part is more flexible for buckling, therefore it is considered in the paper.

The aim of the paper is analysis of possible benefits of replacing the original/actual metal casing with a sandwich structure. A sandwich structure in the form of a metal-fibre laminate of titanium alloy faces and a flax fibre unidirectional laminate core is proposed.

MASS ANALYSIS

A plain cylindrical shell made of titanium alloy was selected as a reference structure for mass optimisation of a sandwich structure. The critical load of a plain metal cylindrical shell is given with a well-known formula (1). In the case of a sandwich structure (a metal-fibre laminate) presented in Fig. 1, the critical load can be estimated with formula (2).

$$P_{cr} = 2\pi k E_{\delta} h^2 \tag{1}$$

$$P_{cr} = 2\pi k E_{\delta} \delta^2 \cdot \alpha \sqrt{(1+\xi_2\eta)(1+3\eta+3\eta^2+\xi_1\eta^3)} \tag{2}$$

where E_{δ} - Young Modulus of metal alloy and face sheet material, E_i - Young Modulus of a laminate core in i direction (*1* - axial direction, *2* - hoop direction), h - thickness of a metal shell, δ - overall thickness of face sheets, H - thickness of a laminate core, $\eta = H/\delta$, $\xi_i = E_i/E_{\delta}$, $\alpha \leq 1$ - coefficient dependent on a laminate configuration and its shear Modulus (for isotropic material $\alpha = 1$).

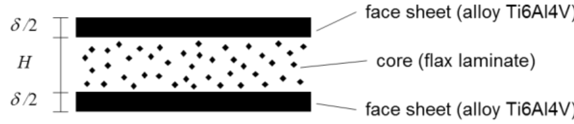

Fig. 1. Sandwich structure, thickness notation

Mass efficiency of materials used in the aircraft industry is studied in [1]. A mass ratio N of a sandwich to plain structure with an assumed fixed value of the critical load (a factor of mass efficiency) is given with formula (3).

$$N = \frac{m_{sandwich}}{m_{plain}} = \frac{(1+\lambda\eta)}{\sqrt[4]{\alpha^2(1+\xi_2\eta)(1+3\eta+3\eta^2+\xi_1\eta^3)}} \tag{3}$$

where ρ_{δ} and ρ_H – density of titanium alloy and flax laminate, respectively, $\lambda = \rho_H/\rho_{\delta}$.

For selected material properties of titanium alloy and flax laminate [2] $\lambda = 0.296$, $\xi_1 = 0.434$ and $\xi_2 = 0.0702$. If a critical load coefficient $\alpha = 1$ then a factor of mass efficiency N achieves the minimum value equal to 0.657 for $\eta = 7.83$ (Fig. 3a).

In practice, coefficient $\alpha = \alpha(\eta)$ depends on a core material and thickness ratio. The influence of a core to overall sandwich thickness ratio was obtained from (3) and numerical calculation of the critical load for a cylindrical shell made of a metal-fibre laminate (its numerical model is described in [2]).

Taken into consideration a functional form of coefficient $\alpha(\eta)$ caused a significant change in an optimal solution: the extremum of mass ratio N equal to 0.688 was obtained at point/argument $\eta = 4.31$ (Fig. 3b).

In the case of a sandwich structure, a shift of titanium layers from a neutral surface of the shell is significant since it causes a decrease in their overall thickness compared to a reference plain structure (without decreasing its bending stiffness and critical load).

The conclusions drawn from performed analysis are the following. The best mass efficiency was obtained for a sandwich structure (made of titanium alloy faces and flax fibre core) of a core to faces thickness ratio equal to 4.31. It means that a shift of a titanium layer from a neutral surface of the shell is 4.31 times as large as its thickness. In this case, the overall thickness of a shell increases by approximately 60% compared to a plain shell, however, at the same time a 70% decrease in the titanium layers thickness can be obtained.

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