Iterative design of aircraft airframe components and assemblies

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Abstract. The rationale for the purpose of this article is the need to reduce the weight of aircraft structures while increasing strength, as well as reducing the time spent on design. Weight reduction leads to an increase in the take-off weight of the aircraft, which has a positive effect on the efficiency of the aviation complex. This method consists in iterative modeling of loads acting on the structure in CAM programs. The iterative design method is applicable at all stages of the development of airframe units. It allows you to see the areas with the lowest and highest stresses. The underloaded parts of the structure are lightened, and the overloaded ones are strengthened. Thus, the refinement of geometric parameters is achieved, and it also becomes possible to optimize the cons. The iterative method makes it possible to reduce the design time of components and assemblies, to obtain a more perfect design in terms of mass and strength characteristics, as well as to automate the process of developing components and assemblies using hardware and software tools. The approaches proposed in this paper make it possible to create an electronic product layout that can be used throughout the entire product life cycle, which reduces the amount of human, material and financial resources used.

1 Introduction

The purpose of design is to find the interrelated values of product parameters, providing the achievement of the extremum of the chosen criterion of optimality [1,2]. Traditionally, the following division of the design process into stages during the product life cycle (Fig. 1) is used to achieve this task.

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Often in the early stages of design the accuracy of calculations is low, which leads to large time and cost expenditures (Fig. 2).

The search for the most appropriate solution at all design stages is called an optimization task, which is relevant closer to the final design stages. However, if we start the optimization process at the stage of airplane formulation, continuing optimization work throughout the entire design process, more rational solutions can be achieved [3-5]. So, by iterative approach to optimization process (new approach to design of power schemes, aggregates, assemblies and parts) it is possible to get Pareto optimal set of designs at once taking into account limitations on mass, strength, to have an idea of necessary materials etc.

This paper considers an iterative approach to optimization of assemblies and parts using CAD and CAE software.

In practice, the decision to select the strength design is heuristic, based on experience, intuition, and using reference materials and theistic data [6]. The study of the structural properties of the designed object is more reliable if the finite element method (FEM) is used in the design [7,8]. Previously, this method was inefficient due to insufficient computational performance, but now three-dimensional continuum models of variable
density make it possible to determine the behaviour of a structure under load in a short period of time.

The aim of this work is to improve the accuracy in the design of geometrically complex structures needed to minimize mass while ensuring strength, stability and stiffness in a comprehensive manner.

To describe the iterative optimization method, the methods of mathematical modeling (FEM), optimization methods, and general approaches to the study of solid mechanics of deformation are used.

Let us consider application of this method using the flap bracket design as an example. The design calculation begins with determining the parameters of the bearing and the connecting bolt by the breaking load and the effective shear force $P_\Sigma = \sqrt{P_x^2 + P_y^2 + P_z^2}$ and $P_{\text{shear}} = \frac{P_x}{2}$ respectively, where $n$ is the number of shear planes.

Based on the condition of buckling strength, the dimensions of the eye lug for the bearing are determined:

$$\sigma_{\text{buckling}} \leq \left[\sigma_{\text{buckling}}\right], \quad \sigma_{\text{buckling}} = \frac{P_{\text{buckling}}}{F_{\text{buckling}}} = \frac{P_{\text{buckling}}}{D \cdot B}, \quad P_{\text{buckling}} = -P_y \cdot x_b + P_x^2 - P_x \cdot 20 \frac{H_{\text{buckling}}}{H_{\text{buckling}}^2}.$$

Also, the eye lug is tested for rupture: $\sigma_{\text{rupture}} \leq \left[\sigma_{\text{rupture}}\right]$ the calculated destructive tensile stresses of rupture. $\sigma_{\text{break}}$ — effective breakdown stress, $\left[\sigma_{\text{rupture}}\right]$ — design destructive tensile stresses.

The effective breaking stresses will be found using the formula:

$$\sigma_{\text{rupture}} = \frac{P_{\text{rupture}}}{F_{\text{rupture}}} = \frac{P_{\text{rupture}}}{2 \cdot B \cdot x}.$$

Calculated fracture stresses: $\left[\sigma_{\text{rupture}}\right] = K_{\text{rupture}} \cdot \sigma_B$.

The lifting eye lug is dimensioned according to the destructive shear stresses:

$$\tau_{\text{shear}} \leq \left[\tau_{\text{shear}}\right],$$

where: $\left[\tau_{\text{shear}}\right] = \tau_B = K \cdot \sigma_B$.

The effective tangential stresses are determined by the Zhuravsky formula. The flux of tangential forces, according to the Zhuravsky formula, will be equal to:

$$q_Q = \frac{Q \cdot S_{\text{section}}}{l_{\text{section}}} = \frac{P_y \cdot S_{\text{section}}}{l_{\text{section}}}, \quad \text{where} \quad S_{\text{section}} = F_{\text{section}} \cdot y_{\text{section}}, \quad l_{\text{section}} = \frac{B \cdot h^3}{12}.$$

Determination of belt thickness at the most loaded section (near the base of the bracket) by tensile strength condition: $\sigma_{\text{tensile}} \leq \left[\sigma_{\text{tensile}}\right]$, where $\sigma_{\text{tensile}} = \frac{N}{F_{\text{belt}} \cos(\alpha)} = \frac{P_y \cdot x_i - P_x \cdot c}{H_{\text{belt}} \cdot b_{\text{belt}} \cdot \cos(\alpha)}$.

Determination of the thickness of the wall of the bracket by the shear condition: $\tau_{\text{shear}} \leq \left[\tau_{\text{shear}}\right]$ where: $\tau_{\text{shear}} = \frac{q_y}{H_{\text{shearmin}} \cdot \delta_{\text{shear}}}$. Check of bracket girdle for local buckling using Euler formula: $\sigma_{\text{critical}} = \frac{b_{\text{boom}}}{t_{\text{belt}}}$. 


Determine the critical stresses of local buckling: \( \sigma_{\text{critical}}^E = \frac{k \cdot E}{(B_{\text{boom}} / b_{\text{belt}})^2} \) and refine using the formula: \( \sigma_{\text{critical}}^\text{local} = \sigma_\nu \cdot \frac{1 + \nu}{1 + \nu + \nu^2} \).

Determination of the parameters of the bracket base eye lug under the condition of buckling strength: \( \sigma_{\text{buckling}} \leq \sigma_{\text{buckling}} \), where \( \sigma_{\text{buckling}} = \frac{R}{f_{\text{buckling}}} = \frac{R}{d_{\text{screw}}^a b_{\text{base}}} \).

Determination of the thickness of the bracket base by the local bending of the eye lug under the condition of flexural strength:

\[
\sigma_{\text{bending}} \leq \sigma_B, \text{ where } \sigma_{\text{bending}} = \frac{M_{\text{bending}}}{w} \frac{N_{\text{screw}} b}{I_{\text{base}}^2}.
\]

During the initial calculation, the following geometry was obtained (Figure 3), which satisfies the strength conditions, but when it is loaded in the CAM software, one can see unacceptable for the bracket deformations of the eye lug and belts (Figure 4).

Fig. 3. Flap bracket model.

Fig. 4. Displacements after load application.
This shows that traditional designs and calculation methods are not matching with the required loads.

The iterative design method involves loading the model at each stage of the calculation and monitoring the areas of unacceptable displacement and areas of excess material. After considering sections with critical deformations, the second iteration is carried out. The change in the design of the bracket consists in increasing the width of the belts, adding a stiffening rib at the eye lug and reducing the thickness of the bracket bottom. This redistributes the mass in order to reduce it.

The loading of the second iterative model shows that the bending in the XOZ plane is preserved, but the displacement values have become smaller, but they are still unsatisfactory. The geometry of the bracket model is changed again, a rib on the wall is added, and the bottom is reinforced (Fig. 5).

![Fig. 5. Loading after the second iteration.](image)

Lightening is carried out by reducing the wall thickness, a cut-out is added, and ribs on the belts are added to ensure strength (Fig. 6).

![Fig. 6. Loading after the third iteration.](image)

The iterations are repeated until the stresses, deformations, and mass properties that satisfy the requirements are reached.
2 Conclusion

The rational choice of the main parameters of parts and assemblies of aircraft structures and their optimization in accordance with the selected criterion depends on many factors. With the help of software and hardware tools, the design stages, consisting of numerous iterative processes are automated.

The approaches proposed in this paper make it possible to form a digital mock-up for use at all stages of the life cycle. This reduces the use of human, material and financial resources.

References


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