MASS OPTIMIZATION FOR STRUCTURAL MEMBERS IN AN AIRCRAFT WING USING NUMERICAL TECHNIQUES

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ABSTRACT

In an Aerospace industry, reduction of mass is having a greater significance. In this paper the main objective is to reduce the mass of the structure and without getting effected to system parameters like deflections and stresses on the members. Structure is chosen from an existing fighter aircraft and it is generated by a high level of literature study. Modelling is done using a coordinate data of aerofoils and systematic approach of twist angle of structure. The basic model is created in modelling software Pro-E and it is parameterised in analytical software Analytical parametric design language (APDL). Parametric code is developed for optimization study which is an input source code contains all design variables, constraints and objectives. Design variables are number of ribs and Spars and the specific Constraints are considered on the response of the structure such as equivalent stress at the root and deflection of the structure at the tip of the structure.

Load cases are calculated and which is analysed to meet the stiffness criteria and strength requirement of the structure. The initial finite analysis is carried out using FEM tool ANSYS and the results are well within the bounds. In order to satisfy the ultimate objective is minimising the mass of structure, using optimization techniques the initial solution is coupled with optimization software Visual DOC. The model is virtually having several designs in the constructive domain space.

Two methods are used for optimization i. e., Modified method of feasible directions and Broydon-Fletcher-Goldfrab-Shanno (BFGS). These methods work on gradients calculations in Optimization. This optimization method uses forward finite difference calculations to obtain a numerical estimation of required gradients. By this approach objective is achieved, design variables are concluded and the structural constrains are within the threshold.

KEYWORDS: Twist Angle, Design Variables, Constraints, Spars, Ribs, VisualDOC & Optimization

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INTRODUCTION

The main concept of paper is to reduce the mass of the wing and detail study of internal and external structure of wing. The important components spars and ribs are designed with respect to specified data of supersonic aircraft. Optimization is initiated by varying design parameters. In order to satisfy all the parameters are within the limits and should not violate the constraints i. e. deflection at the wing tip and equivalent stress at the root of wing. Initial thickness for ribs, spars and skin are assigned by structural idealization and with technical approach.

Parametric design coding is developed for this problem including generation of ribs and spars by spacing ratio of ribs and spars. Twisting may be applicable in this problem which is already assigned at 3.3o initial towards forward at wing tip for the basic wing model. After assigning all the pre-processing entities then the model is evaluated.

The defined parameters are calculated by using finite element method and post processed entities are obtained by finite element analysis. Stresses and deflections are the main constraints in the problem and mass is objective function.

The main phenomenon is reduction of mass by using structural optimization techniques such as modified method of feasible direction and Broydon Fletcher Gold Frab and Shanno these two methods are used in this paper with respective that defined parameters are controlled by gradient calculation with gradient based optimization. The gradients are calculated with function of objective and constraints.

LITERATURE SURVEY

The critical element of an aircraft is design of wing. Several factors influence the selection of material of which strength allied to lightness is the most important. Aluminum and titanium materials are well known for their excellent combination of high structural stiffness and low weight, because of higher stiffness-to-weight or strength-to-weight ratios.

In an aircraft wing structure ribs and spars are provided to support and give rigidity to the wing section. Although the major focus of structural design in the early development of aircraft was on strength, Non-structural design also deal with reduction of mass, fail-safety, fatigue, corrosion, maintenance and inspect ability, and predictability. Modern aircraft structures are designed using a semi-monocoque concept. A basic load-carrying shell reinforced by skin construction supported by spars and ribs in the surfaces. Modern finite element models of aircraft components include tens-of-thousands of degrees-of-freedom and are used to determine the required skin thicknesses to avoid excessive stress levels, deflections, strains, or buckling. The goals of detailed design are to reduce or eliminate stress concentrations, and decreasing the deflection of wing with increasing the structure or placements of structural members. Fail-safe design is achieved through material selection, proper stress levels, and load path, structural arrangements which maintain high strength in the presence of deflection.

The configuration is one with extremely blended wing; with low aspect ratio trapezoidal mid-wing is fitted, with large leading-edge root extensions and blending into the fuselage creating a single lifting body. The wing design is an iterative process and the selections or calculations are usually repeated several times.

DESIGN SPECIFICATIONS AND LOADS

Load Specifications

Case 1:

Actual wing loading	=	401kg/m ²	
Total wing	=	62m ²	
50% starboard wing	=	21+10m ²	
8%Fuselage area	=	10m ²	
Area of port wing	=	21m ² (Estimated)	=>17m ² (Actual)
	=	401*21	=>401*17

$$\begin{aligned} &= 8421 \Rightarrow 6817 \\ &= 82 \text{ KN} \Rightarrow 66 \text{ KN} \end{aligned}$$

Geometrical Configurations

The actual CAD model was generated in pro-E with specific dimensions of supersonic aircraft root chord, tip chord, span and twisting angle. Thus the generated model was exported as Para solid file to ANSYS.

Figure 1: Supersonic Aircraft. Image courtesy: Wikipedia

Figure 2: Basic Wing Model

Figure 3: Wing Internal Structure

The above Figure 2 shows the basic wing model and Figure 3 shows basic dimensions of the wing in mm. Figure 4 shows the Location of Spars and Ribs of the structure with particular station points, thicknesses and all geometrical information.

The plan form of wing is shown in Figure 3. The aerofoil is subject to supersonic aircraft with constant thickness to chord ratio along the span. The wing has a linear lofted twist of 1.5o at the centre line of the wing to -3.3° at the tip. It is through wing with a span of 14.7 m. The centre line chord of wing is of 5.07m, and tip chord of 1.92m. The area of port wing is 17 m² with an aspect ratio of 2.6.

METHODOLOGY

Flow Chart

Material Description

Titanium is assigned for the internal structure of wing i. e., ribs and spars as shown in Figure 13. Aluminium are assigned for the skin. Material properties for the entire structure are given in the table 1 with different entities.

Table 1: Component Specifications

Component	Material	E (Gpa)	Y. S (Mpa)	UTS(Mpa)	Density (Kg/m3)
Skin	Aluminium	72.5	400	455	2796
Spars& Ribs	Titanium	106	276	345	4512

E = Young's modulus (Gpa)

YS = Yield strength (Mpa)

UTS = Ultimate tensile strength (Mpa)

Dens = Density (kg/m3)

PROBLEM DEFINITION

Optimization Setup and Interfacing of Visual DOC with external analysis program ANSYS. The optimization setup is given with respect to defined problem. Here Visual DOC provides a flexible means for coupling an analysis program to the optimizer. The interface between Visual DOC and ANSYS analysis program that reads input code and output response with this process initial testing is executed. The interface is designed in a manner, performing a programming called genesis. The purpose of this setup is to calculating the gradients and updates the matrix. Genesis is

solver to Visual DOC and ANSYS used as the analysis program to calculate the mass of the structure, the maximum displacement and the stresses at particular location as defined in the parameter set.

Gradient based optimization is chosen for desired objective, two methods of optimization techniques that play a major role in minimization of mass. The gradient calculation has predicted by forward difference.

The techniques used in Visual DOC have been selected because they are reasonably robust and because they allow for considerable flexibility in formulating the design problem.

There are three important tasks are involved in this problem, initial task is assigning design variables and secondary task assigning the constraints and final task is to assign the objective function. These values are calculated using technical approach with particular conditions.

Minimize (Objective)

Total Mass of the structure

Subjected to

Maximum deflection at tip

$$\text{Constraint-1} \leq 0.05$$

Von Mises stress at location of Coordinates (2.91, 0.62,-0.1)

$$20 \leq \text{Constraint-2} \leq 40$$

Design Variables

$$\text{Thickness of the Spars} \quad 0.005 \leq \text{Design variable-1} \leq 0.06$$

$$\text{Thickness of the Ribs} \quad 0.005 \leq \text{Design variable-2} \leq 0.06$$

$$\text{Thickness of the skin} \quad 0.005 \leq \text{Design variable-3} \leq 0.06$$

RESULTS

The results obtained from the optimization are categorized below.

Figure 5: Design Variable 1 (Thickness of Spars)

Figure 6: Design Variable 2 (Thickness of Ribs)

Figure 7: Design Variable 3 (Thickness of Skin)

Figure 8: Constraint 1 (Deflection)

Figure 9: Constraint 2 (Von Mises Stress)

Figure 10: Best Objective (Mass)

FE Simulation Results

Figure 11: Detailed Model of Wing

Figure 12: Model with Loads and Boundary Conditions

Figure 13: Internal Structure of Wing

Figure 14: Deformation of Wing with Detailed Grids

Figure 15: Vonmises Stress Plot of Wing

Numerical Expressions

BFGS Method algorithms to solve a global matrix, From an Initial guess X_0 an approximate Hessian Matrix B_0 the following steps are repeated as X_K converges the solution

- Obtain a direction P_K by solving $B_K P_K = -f \nabla (X_K)$.
- Perform a one dimensional optimization to find a step size α_K , $\alpha_K = \arg \min f (X_K + \alpha P_K)$.
- Set $S_K = \alpha_K P_K$ and update $X_{K+1} = X_K + S_K$
- $Y_K = \nabla f (X_{K+1}) - \nabla f (X_K)$.
- B_{K+1} , $f(x)$ denotes objective function to be minimised. B_K is the inverse of the matrix

Modified method of feasible directions technique having the features rapidly obtains an optimum design, handles inequality and equality constraints, and satisfies constraints with high precision.

- $q=0, \underline{x}=\underline{x}^0$
- $q=q+1$
- Evaluate $F(x)$ and $g_j(x)$; $j=1,2,\dots, M$
- Identify the set of critical constraints, J
- Calculate $\nabla F(x)$
- Determine the feasible search directions, S^q
- Perform 1D search to find a^* , Set S^q
- Check for convergence; if not converged, go to Step 2

If no constraints are active or violated, the unconstrained Conjugate Gradient method is used.

OPTIMIZATION MAIN FUNCTION RESULTS

Table 1

Iterations	Ribs	Spars	TCK_SPAR	TCK_RIBS	TCK_SKIN	Usum	Seqv	Mass
1	9	5	0.05	0.05	0.05	0.017	7.20E+06	-Not considered for Solution-
5	9	5	0.05	0.0501	0.05	0.017	7.20E+06	-Not considered for Solution-
10	9	5	0.0417462	0.0382188	0.005	0.075	3.97E+07	-Not considered for Solution-
15	8	5	0.0436144	0.0408854	0.008770	0.050	2.48E+07	2381.19
20	9	5	0.0436144	0.0408854	0.008870	0.051	2.46E+07	2391.62
25	9	5	0.0430854	0.0401298	0.0082204	0.052	2.62E+07	2300.73
30	9	5	0.0431854	0.0401298	0.0082204	0.052	2.62E+07	2302.17
35	9	5	0.0417648	0.0382447	0.0069903	0.059	3.00E+07	2114.83
40	8	5	0.0429222	0.0398968	0.0080684	0.053	2.66E+07	2277.75
45	9	5	0.0428405	0.0397801	0.0074763	0.056	2.83E+07	2212.49
50	9	5	0.0429222	0.0398968	0.0080684	0.053	2.66E+07	2277.75
55	9	5	0.0428970	0.0398608	0.0078857	0.054	2.71E+07	2257.62
60	9	5	0.0428892	0.0398496	0.0078293	0.054	2.72E+07	2251.4

CONCLUSIONS

This paper concludes that mass of the structure is optimized and design variables are varied within the limits and also response constraints i.e., stresses and the deformation of the wing structure are within bounds.

The structure has optimally satisfies the strength and stiffness criteria, even though there is a scope for optimization by redesigning components such as Skin, Ribs and Spars. The design was analysed by using Finite element analysis considering shell elements.

The results obtained from the optimization are verified. Objective mass is minimized to 10% in terms of kilograms similarly design variables thickness of the skin decreases from 0.05 to 0.007, thickness of spars decrease from 0.05 to 0.039 and thickness of the ribs from 0.05 to 0.042 meters. Constraints that are varies within boundaries i. e., the deflection (USUM) of the wing is considered as a primary constraint which varies from 0.017 to 0.054 meters and VonMises stress at node (2.91, 0.62,-0.1) is considered as the secondary constraint which varied from 7 to 27 Mpa.

Finally, the model is verified with all constraints which are satisfied and design variables are settled within the boundaries.

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