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Optimization of a Simple Aircraft Wing by Weight Minimization using ANSYS

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Abstract

In the current generation, aircrafts became the fastest mode of transportation for goods and passengers. In such a situation, sophistication of the airplanes is also moving at a rapid pace. The main reason for the flight of airplane is the lift force over the wings. The better the wings are, the better the lift will be. The improvement in the flight of aircraft and efficiency of aircraft can be done by proper design of these wings. This can be done by either optimization of wing structure which reduces the drag force over the aircraft or by optimizing the weight of the wings which enable the aircraft to fly easier or both of the above. Hence in this project, we are concentrating on the optimization of these wings which benefits to the better working of airplane. Here we consider a wing-like structure consisting of spars, ribs, reinforcements and skin is optimized considering weight minimization. The wing carries a uniformly distributed load along the span.

Keywords: *Aerospace designs, finite elements, modal and buckling analysis, structural optimization*

INTRODUCTION

Structural and multidisciplinary optimization has been gaining collective attention in recent years for their acknowledged contributions made to design enhancement, especially in early stages of product development. Grihon and Mahé (1999) presented a study where a simplified expression of the operating cost combining cruise drag and wing weight was minimized. Their work has the outstanding advantage of dealing directly with wing plan form, which enables designers to assess their product efficiency very early in the development process, and modeling the entire wing structure through finite elements.

Although design optimization has been acknowledged as an effective procedure, it is not widely used as a standard design tool for various reasons. Non-technical reasons include difficulty in creating design data and lack of time to educate engineers to perform optimization. Those engineers spend most of their time modifying and analyzing their designs and making iterative changes, rather than modifying designs using optimization techniques. However, since there is enormous pressure to shorten the “time to market”, while enhancing the quality of product at the same time, those attitudes are graduallychanging and/or are under pressure to be changed.

LITERATURE REVIEW

Before starting this project, some of published literatures and previous researches have been reviewed to build up a solid background in the area of simulation and designing.

Grihon and Mahé [1] presented a study where a simplified expression of the

operating cost combining cruise drag and wing weight was minimized.
Garcelon and Balabanov [2] developed a static aero elastic approach where they divided the optimization problem into structural and aerodynamic optimization and an iterating strategy was devised until a given convergence criterion was met. The difficulty was that interface issues came into picture since wing deformation results in aerodynamic load variation.

Anderson and Venkaya pointed the importance and roll of conceptual and preliminary design optimization in multidisciplinary design optimization of airframe.

Giles developed an equivalent plate model to analyze the response of the wing box structures with general plan-form geometry.

Bushnell studied the stiffened composite panels and developed a design optimization strategy using PANDA2 to develop the weight of locally buckled panels. He also investigated the minimum weight design of a stiffened panel via PANDA1 and then evaluated the optimized panel via STAGES.

Butler et al. have conducted optimum design and parametric study of stiffened wing panels with practical loading. He then used sequential use of multidisciplinary design optimization approach and panel sizing methods to design aircraft wing.

Pistek and Hobza have designed stiffened panels using the mathematical programming technique. Wu et al. have conducted compressive study on testing and design of "Z-type" stinger stiffened compression panels.

Abdo et al. described a methodology for the conceptual design of structural compression panels of the wing-box assuming that the applied design loads are known. Their methodology is based on the ad-hoc classical assumption that an acceptable compression design panel may be obtained when the applied stress is equal to the general instability stress and the individual plate element instability stress.

Garcelon, J.H., Balabanov, V. and Sobieski, J., demonstrated a technique for aero elastic MDO that couples aerodynamic optimization with structural optimization as a sub-optimization problem. The organization complexity of MDO is reduced by the sub- optimization problem.

De Faria, A.R. and Hansen, J.S. proposed a technique to optimize structural components for buckling when the applied loads are partially unknown or unpredictable.

METHODOLOGY

Rectangular Wing

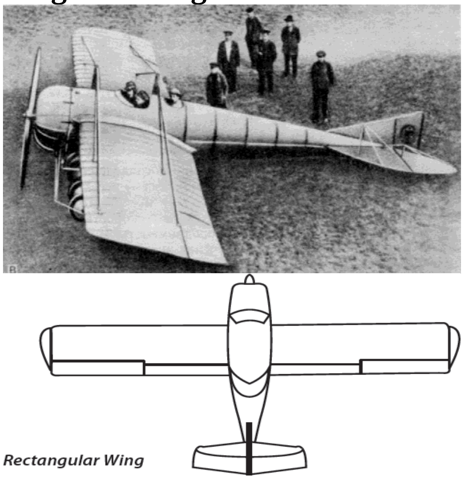


Figure 1: *Rectangular wing model.*

Nomenclature of Wing

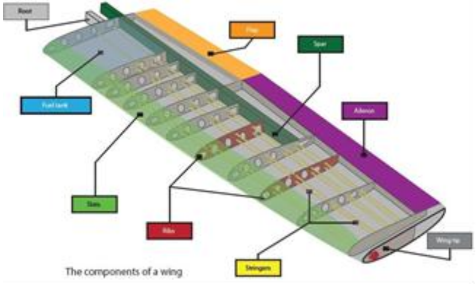


Figure 2: *Components of a wing.*

Optimization Definition

Optimization is the process to find the best compromise among several often conflicting requirements, as in engineering design.

The wing model is optimized considering the following optimization problem:

Problem Definition

Aircraft wing consists of many parts such as ribs, spars, etc., which are located at fixed distances, as a result weight of the wing increases. To overcome this, wing is optimized by varying the position of the ribs and changing the thickness of the spars.

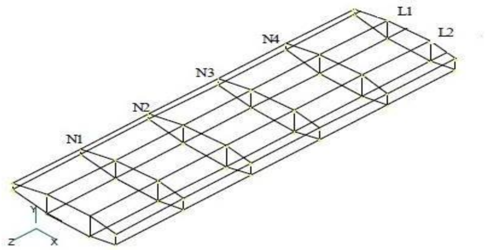


***Figure 3:** A simple model of aircraft wing with spars and ribs.*

Material Properties

The selection of materials for the aircraft is based on the density, availability, cost, weight and strength of the material used which is subjected to loading. The selection of material is to be done on the basis of its chemical stability and wear resistance. In our project, the main reason in selecting aluminium is its light weight and strength.

Aluminium is most commonly used and commercially available metal. Its light weight and high strength-to-weight ratio make it a good choice for everything from aircraft to flashlights to jigs to just about anything else you can make out of metal.

Pure aluminium, primarily seen in the 1xxx series of wrought aluminium alloys, has little strength, but possesses high electrical conductivity, reflectivity, and corrosion resistance.

The properties of aluminium alloy are given in the following Table 1.

***Table 1:** Properties of aluminium.*

Property	Value
Density	2770 kg/m^3
Coefficient of Thermal Expansion	2.3e-005 /°C
Specific Heat	875 J /Kg °C
Compressive Yield Strength	280000000 Pa
Tensile Yield Strength	280000000 Pa
Tensile Ultimate Strength	310000000 Pa
Young’s Modulus	71000000000 Pa
Poisson’s Ratio	0.33
Bulk Modulus	69608000000 Pa
Shear Modulus	26692000000 Pa
Relative Permeability	1

Speed Required

The following Table 2 gives a list of different aircrafts and their takeoff speeds.

***Table 2:** Take off speeds of varoius aircrafts.*

Sr. No.	Aircraft	Takeoff Speed
1	Boeing 737	250 km/h
2	Boeing 757	260 km/h
3	Airbus A320	275 km/h
4	Airbus A340	290 km/h
5	Boeing 747	290 km/h
6	Concorde	360 km/h

Modeling

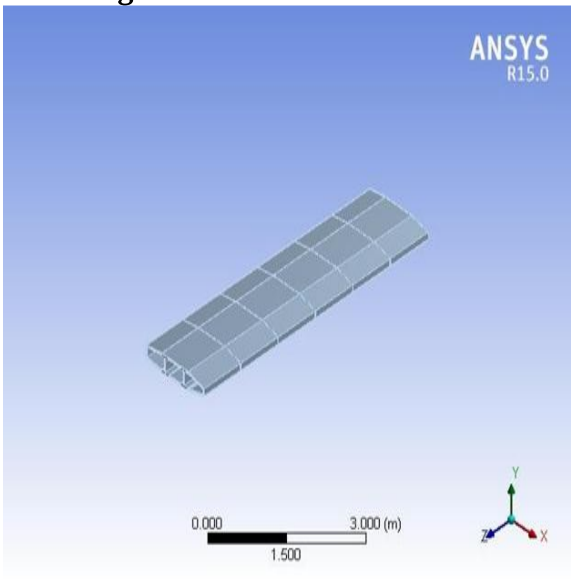
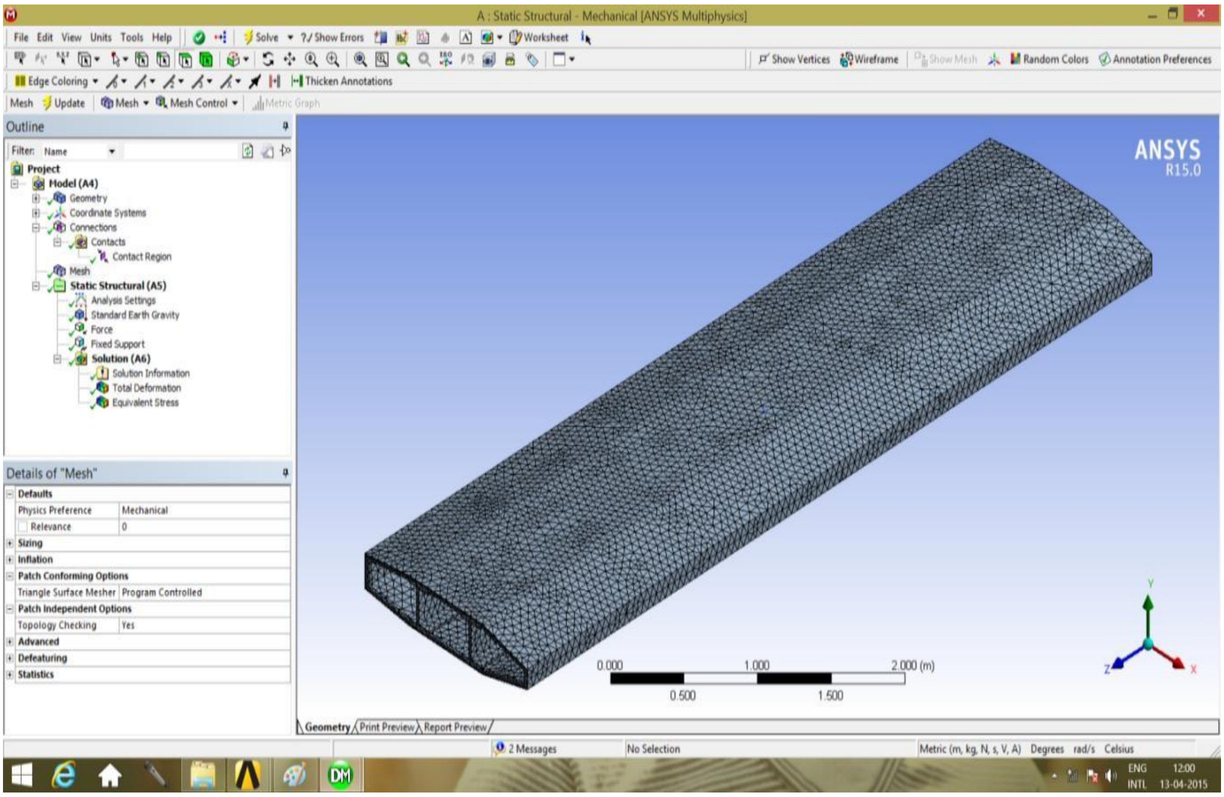


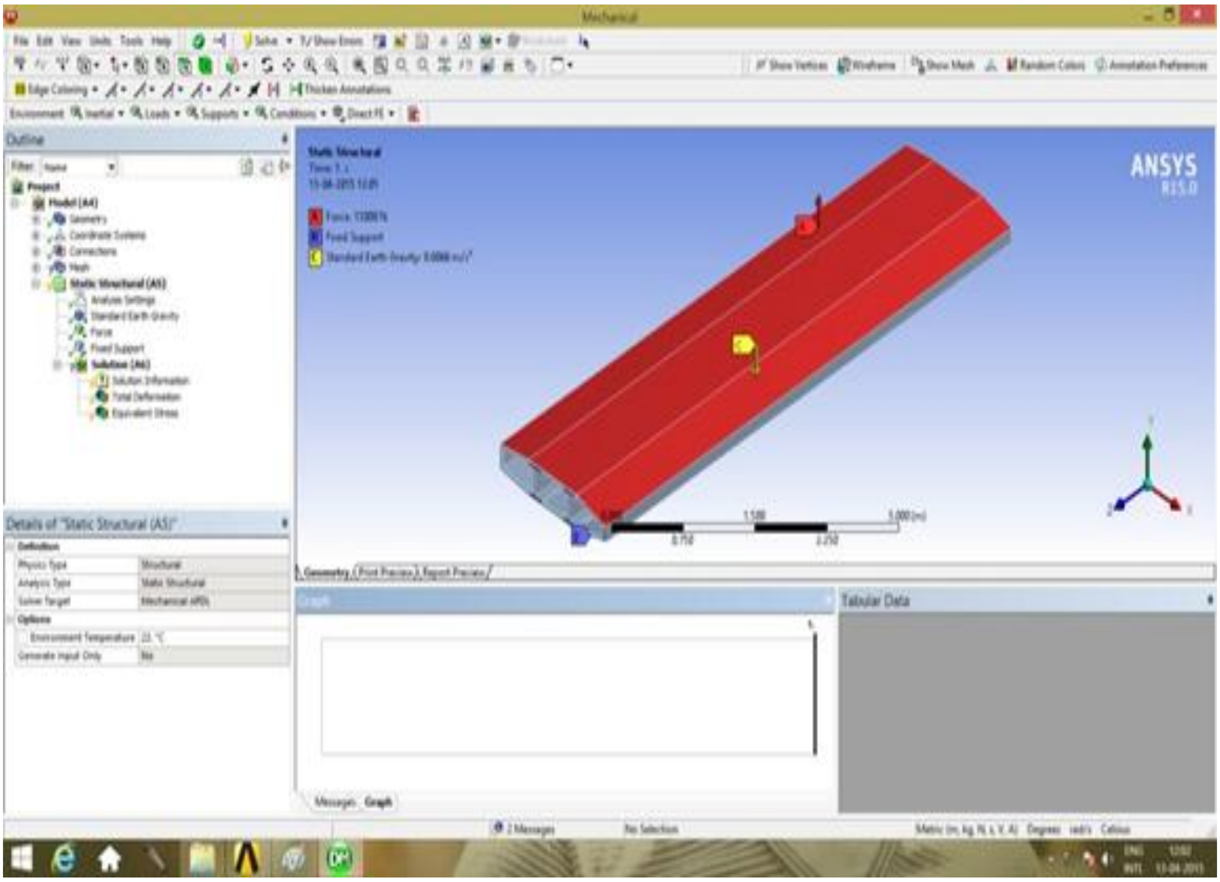
***Figure 4:** Wing model created in ANSYS workbench.*



Details of "Mesh"

Defaults	
Physics Preference	Mechanical
☐ Relevance	0
Sizing	
Inflation	
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Defeaturing	
Statistics	

***Figure 5:** Meshing of wing.*



Details of "Static Structural (A5)"

***Figure 6:** Fixing of faces of wing to apply loads.*

RESULTS

Static analysis for aluminium using finite element analysis.

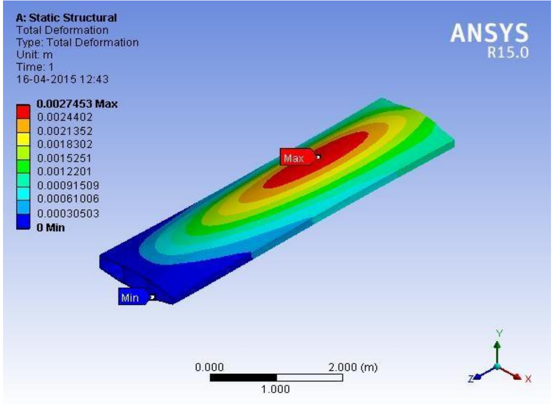


Figure 7: *Total deformation of the wing.*

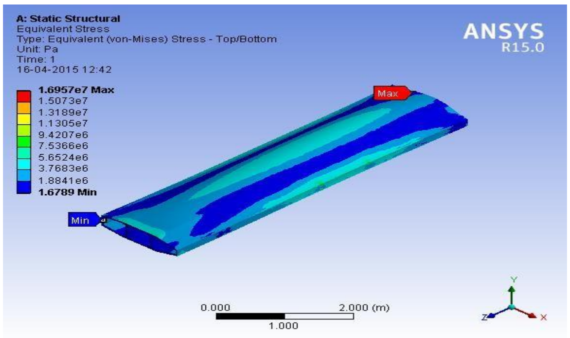


Figure 8: *Equivalent (Von Mises) Stress.*

Optimization

This section describes the chosen Optimization type and the generated candidates and charts.

Parameters

The explored design space is defined by the range of variation of the following 3 input parameters.
The ranges of different parameters are shown below

Table 3: *Input parameters considered for optimization.*

Sr. No.	Name	Lower bound	Upper bound
1	Rib 3	270	330
2	Rib 4	360	440
3	Spar	0.8	1.2

Table 4: *Experimental results.*

Sr. No.	Parameter 1 (cm)	Parameter 2 (cm)	Parameter 3 (cm)	Deformation (m)	Geometry mass(kg)	Maximum stress(Pascal)
1	300	400	0.95	0.00830308	959.002529	25993454.9
2	270	360	0.95	0.00770357	975.1795549	28365787.23
3	330	360	0.95	0.007204689	991.3512469	27873773.32
4	270	440	0.95	0.006937602	1018.292214	28004027.38
5	330	440	0.95	0.006894279	1025.473969	27755293.65
6	270	400	0.8	0.006967517	1014.700941	28056125.84
7	330	400	0.8	0.008684275	950.0129876	27020081.24
8	270	400	1.1	0.007633867	978.7737252	26825396.41
9	300	400	1.1	0.007039777	1008.116257	28581507.95
10	300	360	0.8	0.007135082	997.3394089	28488084.76
11	300	440	0.8	0.006758942	1045.816555	27735818.66
12	300	360	1.1	0.007163255	991.9500961	27492266.54
13	296.7	440	1.1	0.006746022	1047.012914	25985384.62

Table 5: *Candidate points of the optimization study.*

	Parameter1 (cm)	Parameter2 (cm)	Deformation (m)	Geometric Mass (kg)	Maximum Stress (Pascal)
Candidate Point 1	295.5	386.65	0.81915	950.01	2.702E+07
Candidate Point 2	327.9	362.28	0.81709	948.81	2.8016E+07
Candidate Point 3	279.3	435.4	0.81606	948.21	2.8163E+07

Table 6: *Optimal values.*

Values	Rib 3 (cm)	Rib 4 (cm)	Spar (thickness) (cm)	Deformation (m)	Geometric Mass (kg)	Maximum Stress (Pascal)
Initial	300	400	1.0	0.0027453	1058	1.6957E+07
Final	279.3	435.4	0.8	0.81606	948.21	2.8163E+07

CONCLUSIONS

In this parametric study, the aircraft wing model was designed to a light weight, comfortable model which is also cost effective than some of the existing models around the world. On testing the wing by applying uniformly distributed load, the equivalent stresses and the total deformations are calculated. The design of experiments was generated using central composite design method and subsequent optimization is carried out using screening method. Duly considered Aluminium material has the values of weight as 1050kg, 25985384.62 equivalent stresses. Now these values are optimized by 10% to the originally obtained values. The optimized values are, weight of leg is 948.2 kg, equivalent stresses are 2.8163E+07 and deformation is 0.81606m. Optimization problem was investigated in this paper. It is noticed that even though the basic geometry and the same sets of design variables are used, problem has radicaldifference with respect to design sensitivity. Optimized Problem possesses high sensitivity with respect to sizing design variables. Generally, it is not possible to determine beforehand which subset of design variables will be dominant in terms of sensitivity. Nevertheless, a preliminary sensitivity analysis could certainly be helpful to identify relevant subsets.

FUTURE SCOPE

Apart from our work, this project can be further extended by doing the following research:

- Weight can be further optimized by changing positions of spar and ribs at a time simultaneously.
- And also the weight can be optimized by using other engineering materials like alloys which provides better properties.

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