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Material sustainability investigation on Prototype aircraft wing structure frame with different materials

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Abstract: Airfoil is a shape adopted for wings of airplane that are designed to enhance lift by changing the speed at which air moves over the wings. Air will be passing faster over the top section, and it will lower at the bottom section. An axi-symmetric NACA2414 airfoil is used for the development for achieving optimum lift coefficient and creates the lowest drag for minimum angle of attack. The model has been developed using AutoCAD software and structural analysis performed using Solidworks software to evaluate the material sustainability and the results were compared using different materials. Stress contours analyzed and recorded 9 % less from AISI 4130 normalized steel and Aluminum alloy materials.

***Keywords**: NACA2414 airfoil, structural analysis, Sustainability, AISI4130 Normalized Steel, Alloy materials.*

1. INTRODUCTION

Naval aircraft is built to perform specified requirements and is to have the comfort of a passenger transportation and maneuverability of a fighter aircraft [1]. To achieve these demands, the aircraft should be high powered, and with a strong structure. The main factors to consider in aircraft structures are materials, sustainability, weight and reliability. These factors will determine the requirement met by the materials. Materials used to construct the aircraft are reliable and it will reduce the possibility of sudden and dangerous failures. Several forces and structural stresses act on the aircraft structure when it is dynamic condition and static also [2]. When it is in static, the load is weight of the aircraft and act on the landing gear.

In dynamic condition, any movement that causes acceleration or deceleration, increases the forces and fluctuating stresses on the structure of the wings and fuselage too [3]. The aircraft should be built using the materials that are lighter and stronger. Various important metals used for the aircraft are aluminum, magnesium, titanium, steel and its related alloys. As wings develops majority portion of the lift, they have to be designed with proper materials and stable structure. To achieve this shape, the wing is a frame structure should be made up of spars and ribs and covered with metal as a skin.

A typical naval wing structure is chosen in this investigation for the structural analysis that can be evaluated for stresses, strain and deformations with different materials to estimate the sustainability of each material [3]. Lighter aircraft with good strength is the motive of aviation industry. This could be achieved by choosing the proper materials for the construction of wing and other parts of the aircraft is the motive of the researchers. Enormous researchers concentrate on the materials used for the various parts of the aircraft [4], [5] . A little consideration for the wind shields are made of glass epoxy materials and other parts demand light weight and more strength to meet the fuel economy of the industry. Bruhn et. al., illustrated basic review of new structural technology for various developments of technology and its applications related to the development of technology in practical elements of the structure [6]. The author presented the structural elements design and procedures from micromechanics of fiber matrix interaction to the use of composite laminations and methods of joining. Authors explained various modes of failure, failure criteria statement and testing methodologies for the evaluation of experimental methodologies of composite material needed for the industry. Olsman narrated influence of a cavity on the dynamic response of an airfoil. In this regard, the author developed an analytical model and to evaluate the reduced frequency level and it is validated by measurements carried out for a standard airfoil without cavity [7]. Brain et. al., presented the innovative approach of the finite element models for airframe concepts which includes the airfoil surface and fuselage. Conceptual Design Shop (CDS) software is used to fill the gap between Pastran Command Language and Finite Element (FE) modelling to substantially connect wings and tails in the airframe structure models [8]. Behzad et. al., suggested the combination of several approaches in noise reduction for the aviation industry [9]. The authors discussed various methods and techniques to acoustic efficiency of airframe structures and to reduce the noise for various researchers. Sadrehaghighi explained about various airfoil sections that are designed to delay and minimize drag with analytical results [10]. Rajendran et. al., narrated about the morphing of airfoil such that combination of materials in the wing prototype that are developed using the approach of additive manufacturing for effective flexibility of the structure [11]. Paul et. al., developed box - wing aircraft and it is exclusively special advantage of aerodynamic efficiency over the conventional aircraft [12]. Asri et. al., identified the mode shapes and the associated natural frequencies of the typical aircraft wing structure for two different aluminum alloys AA-7075-T6 and AA-2024-T3. The results are compared and proving that AA-7075-T6 is the best suited material with lower frequency levels compared with AA-2024-T3 [13]. Vijayan et.al., performed modelling of morphed wing with ribs and spars using CATIA V5 software and analysis in ANSYS software with composite materials [13]. Tianshu Liu, explained formation of lift executed based on numerical simulations of a viscous starting flow, and the evaluate of the flow spectrum near the trailing edge [14].

However, among the researchers, the concept of typical structural analysis comparisons with different materials like titanium alloys and aluminum alloys is not carried out for the material sustainability investigations. The model outer frame is considered for fixed geometry and top of the frame ribs is loaded with a pressure of 50 N/mm^2 on each rib and bottom ribs with 409.1 N/mm^2. The entire model is discretized for effective solution and with an aspect ratio from 40 to 49 with a total element of 7091 and auto created nodes of 16319. In this research author made an attempt to evaluate the structural stresses and deformations with the loading conditions. For the solution, it has been chosen FFE Plus solver and the results of airframe structure for the deformation, von Mises stress and total strains are compared with graphs.

2. Methods

The criteria in selection of materials for the aircraft depends on the load, weight and fuel economy. Hence lighter materials with same stiffness and strength are more preferable for the aircraft wing structure is the goal of the researchers.

The aim of this article is to investigate the sustainability of materials used for aircraft structures which demands light weight and good strength. In this context, from the available wide range of materials available in the market, AISI4130 Normalized steel, Ti- 3Al- 8V- 6Cr- 4Mo- 4Zr-Titanium alloy and 1060 Aluminum alloy materials are considered for the structural analysis of the proposed aircraft wing structure in this research. Material properties are listed in Table: 1.

Table: 1 Material properties

S.No.	Material	Yield Strength (N/mm^2)	Density (kg /m^3)	Poission's Ratio	Young's Modulus (N/mm^2)
1	AISI4130 Normalized Steel	460	7850	0.285	205000
2	Ti- 3Al- 8V- 6Cr- 4Mo- 4Zr-Titanium alloy	1034.21	4820	0.33	104000
3	1060 Aluminum alloy	27.57	2700	0.33	69000

The fundamental properties chosen for the analysis are yield strength, density, poison's ratio and young's modulus that are needed as input parameters to perform the analysis by the software. Yield strength is an important property of the materials in engineering when designing the structural components to estimate the peak stress value of the material which can with stand without plastic deformation failure. This can be used to estimate the structures that are designed to withstand the loads beyond the estimated operating conditions and reduce the unexpected failures. Yield strength is a key factor in evaluating and assessing the integrity of the structure to estimate the material behavior with various loading conditions and supports to prevent unusual failures.

The methodology of the structural analysis is performed after basic modelling of the structure is performed. Then the material is chosen based on the literature evidences. The boundary conditions are applied like fixed boundary and the loads are applied on the structure. Finally, the model is discretized/meshed to have an optimum size of the particle and it should be with converging criteria for getting good results like deformations, stresses and strains.

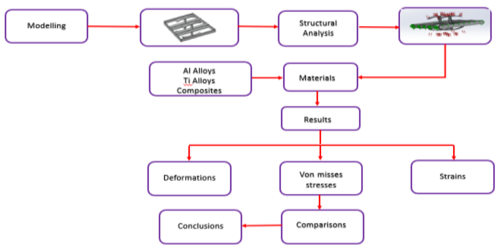

Figure 1. Schematic representation of Structural Analysis

The schematic approach of the structural analysis is illustrated in the fig: 1 to compare the results of each material with their unique properties. For the executions of the analysis, the airframe structure is modelled with frame, internal ribs. Then the frame is applied the fixed boundary conditions and the ribs with the loads as in fig: 2. As a part of structural analysis, the stresses are evaluated and compared with the yield strength of each material to ensure the stresses are well within the limits.

3. Results and Discussion

Lighter aircraft with good strength is the motive of aviation industry. This could be achieved by choosing the proper materials for the wing structure is an attempt made in this investigation. To develop this concept, a naval aircraft wing structure which is experiencing elevated pressure at the bottom of the wing and significantly much lesser pressure at the top of the wing with a relusltant in pressure equal to 718.2 pascals (15 pound per square foot) for passenger flight are chosen.

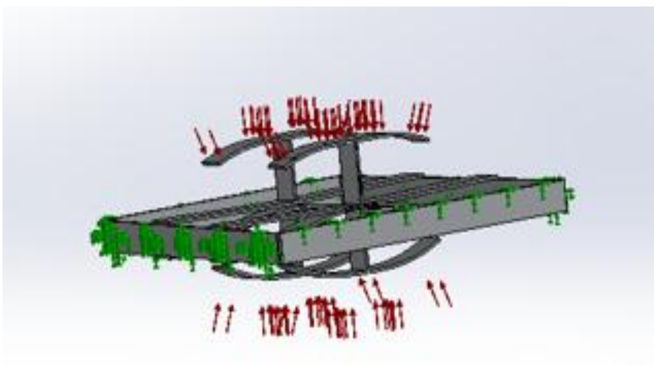

Figure: 2 Aircraft wing structure with boundary conditions

A typical structural analysis is performed using Solidworks software for the wing structure with the given boundary conditions for the pressure below and above the wing as shown in fig: 2.

A typical aircraft wing structure is analyzed with different materials as explained in table: 1 and the results were compared for total deformation, Von-Mises stresses and total strain.

Deformation of a material is an important aspect to understand how the material deform against applied load and to predict that the final product whether meets the performance requirements. Deformation is a key factor to evaluate the structural integrity and to behave stable elastic deformation condition of the material. The standard deformation testing methods, such as tensile testing, compression testing and hardness testing. These testing methods provides valuable information on a material's strength, ductility and other mechanical properties. As in fig: 3, the deformation results of 1060 Aluminum alloy material indicates the various values from the minimum value of $1x10^{-3}$ mm which is in blue color to a maximum value of 4.688 mm and in red color. The red color of the contour indicates the component is critical in that location and it may lead to plastic deformation in that region.

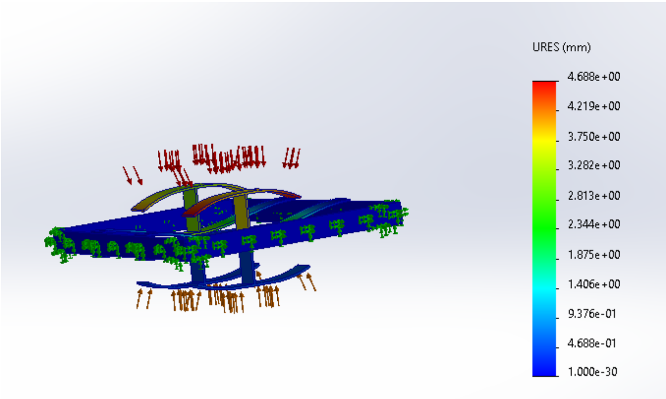

Figure: 3 1060 Aluminum alloy deformation contour

Von Mises stress is a measure used in engineering materials to estimate the yielding strength of materials against various loads. Von Mises stress takes into account the combined effect of tensile stress, compressive stresses and shear stresses and gives a scalar value that indicates the equivalent uniaxial stress that will cause the same deformation. This stress is used as a criterion that predicts the yielding of ductile materials. This stress gives the overall information whether the material can withstand the combined effects of different types of loading conditions. Von Mises stress is commonly used in finite element analysis and numerical simulations, used to estimate the structural integration to estimate the potential failure points in a structure. As in fig: 4, the deformation results of 1060 Aluminum alloy material indicates the various values from a minimum value of $6.485x10^{-4}$ pascals which is in blue color to a maximum value of $3.912x10^{6}$ pascals and in red color. The red color of the contour indicates the component is critical in that location and it may lead to plastic deformation in that region which will give the sustainability of the material against safe yielding value of $2.757x10^{7}$ pascals.

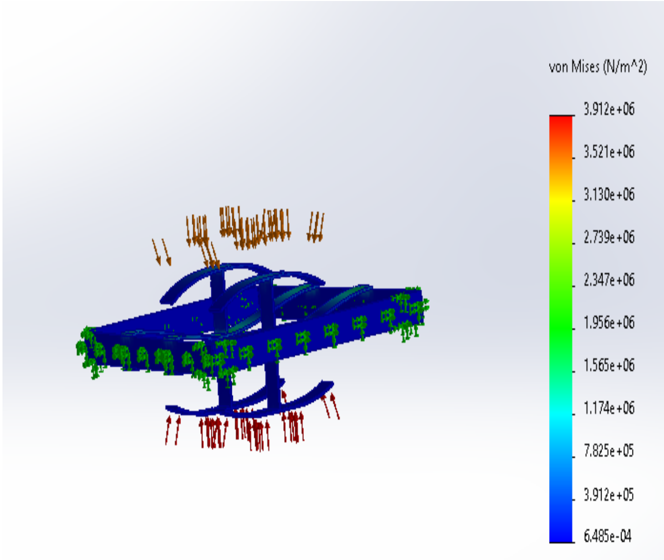

Figure: 4 1060 Aluminum alloy Von-mises stress contour

Equivalent Strain is a fundamental criterion in structural analysis and it is interconnected with stress through the modulus elasticity of the material analyzes how a material will deform in response with the applied loads. Similar testing methods like deformation testing and monitoring the strain supports and predict any deviation from the expected material behavior, ensuring that the material meet specified standards set by, "Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA)". As in fig: 5, the strain results of 1060 Aluminum alloy material indicates the various values from a minimum value of $2.271x10^{-14}$ which is in blue color to a maximum value of $3.088x10^{-5}$ and in red color. The maximum strain indicates the yielding or ultimate failure of the material in that region.

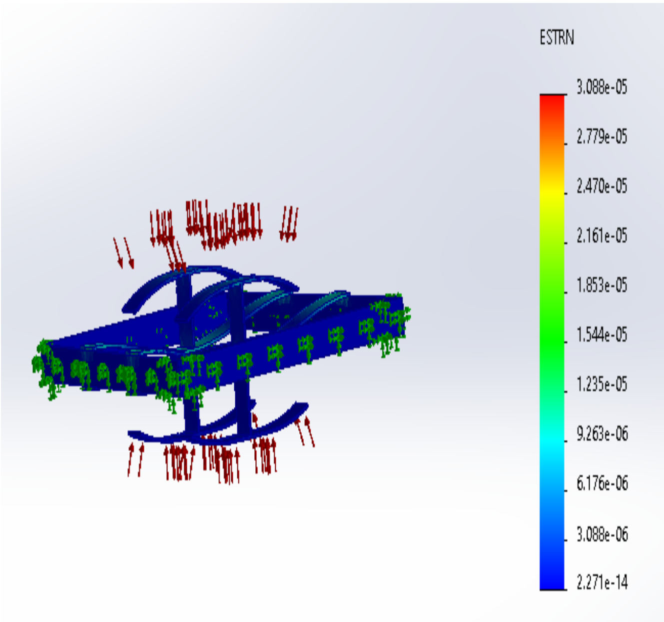

Figure: 5 1060 Aluminum alloy strain contour

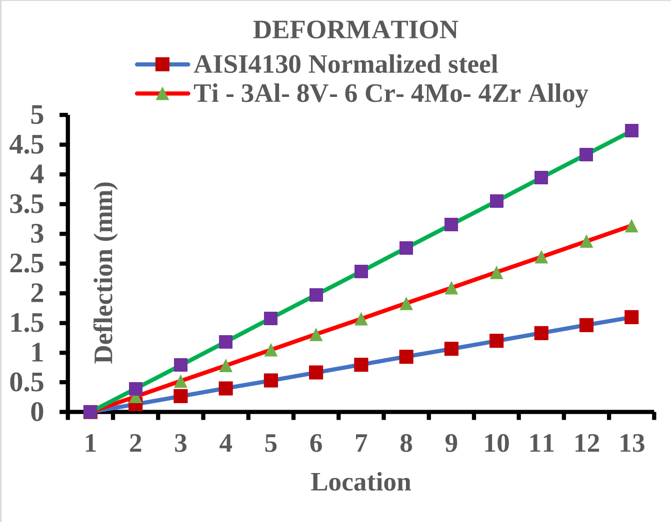

Figure: 6 Deformation results

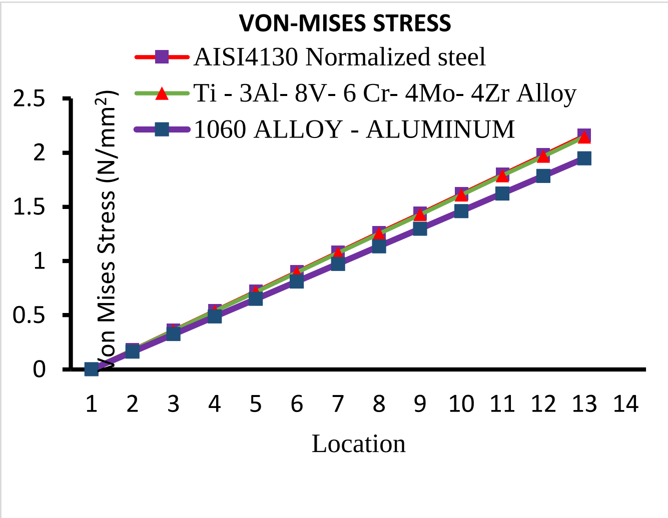

Figure: 7 Von-mises stress results

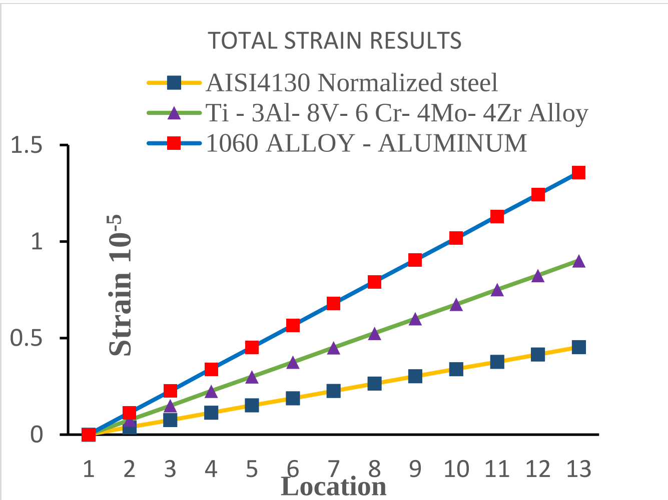

Figure: 8 Total strain results

The results are plotted with graphs for deformation, von-Mises stress and strain for , AISI4130 Normalized steel, Ti- 3Al- 8V- 6Cr- 4Mo- 4Zr-Titanium alloy and 1060 Aluminum alloy materials as in fig: 6 to fig:8. As in fig:6 and fig: 8, the deformations and strains of 1060 Aluminum alloy material is comparatively more with Normalized steel and titanium alloys, but the von Mises stresses are significantly less as in fig: 7, indicating aluminum alloy is more preferable material considering light weight needed for aviation industry [15].

4. CONCLUSIONS

The results are analyzed and the variation is slightly less in von-Mises stresses between AISI4130 Normalized steel and Ti-3Al- 8V- 6Cr- 4Mo- 4Zr-Titanium alloy. But a significant variation is observed for 1060 aluminum alloys with a difference of 9% observed even though the deformation is more but 1060 aluminum alloy is light material. It is concluded that the 1060 aluminum alloys may be used for the wing structure material. In future typical invented composite material may also be used for the structures.

5. List of Abbreviations

FFE	Field Force Engineering
FAA	Federal Aviation Administration
EASA	European Aviation Safety Agency
URES	Resultant displacement
ESTRN	Equivalent strain
AISI	American Iron and Steel Institute
CDS	Conceptual Design Shop
FE	Finite Element

6. DECLARATIONS

6.1 Availability of data and material

a). The material properties are chosen from the Solidworks software for AISI4130 Normalized steel and Ti- 3Al- 8V- 6Cr- 4Mo- 4Zr-Titanium alloy [Dassault Systemes SolidWorks Educational Edition 2016-17].

b). Loading of Pressure based on the literature available from the google search [https://www.quora.com/What-is-the-exact-pressure-on-the-top-and-bottom-of-a-wing-when-an-airplane-is-flying#:~:text=The%20average 20pressure%20differential%20itself, psi%20and%200.8%20psi%20respectively.].

c). https://www.chevron.com/-/media/chevron/operations/documents/aviation-tech-review.pdf

d). https://eng.libretexts.org/Bookshelves/Civil_Engineering/Structural_Analysis_(Udoeyo)/01%3A_Chapters/1.02%3A_Structural_Loads_and_Loading_System

6.2 Competing Interests

Title of the Manuscript: "Material sustainability investigation on Prototype aircraft wing structure frame with different materials"

Authors: Nidamanuri Sreenivasa babu[1], Raja Govindan[2], Abdullah Salim said AL-Eisee[3], Salim Khamis Ali Al-Amrani[4], Obaid Mubarak Al-Qaidi[5], Abdullah Rashid Harib Al-Essai[6]

We are willing to confirm the statement that no known conflicts of interest related with this publication and there is no significant financial aid for this work that could have influenced its outcome.

We are also wishing to finalize that the manuscript that has been read, accepted and approved by all named authors. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We are pretty well known that the author for correspondence is the sole contact for the editorial process (including Editorial Manager and direct communications with the Office). He/she is solely responsible for any type of communication with the other authors about progress, revised submissions, and final approval of proofs**.**

6.3 Funding

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6.4 Author's contributions

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a. Nidamanuri Sreenivasa babu: Conceptualization, Investigation, Writing -Original Draft,
b. Raja Govindan: Methodology and Data Analysis.
c. Abdullah Salim said AL-Eisee: Model Fabrication and Formal Analysis.
d. Salim Khamis Ali Al-Amrani: Material selection and visualization.
e. Obaid Mubarak Al-Qaidi: Data compilation and Formal Analysis.
f. Abdullah Rashid Harib Al-Essai: Characterization work analysis.

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