Weight Optimization Of Empennage Of Light Weight Aircraft

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Abstract: The objective of the research is to optimize the empennage of a light weight aircraft such as Zenith aircraft. The case is specified by a unique set of geometry, materials, and strength-to-weight factors. The anticipated loads associated with the empennage structure are based on previous light aircraft design loads. These loads are applied on the model to analyze the structural behavior considering the materials having high strength-to-weight ratio. The 3D modeling of the empennage is designed using PRO-E tools and FEA analysis especially the structural analysis was done using ANSYS software to validate the empennage model. The analysis shall reveal the behavior of the structure under applied load conditions for both the optimized structure and existing model. The results obtained using the software are attempted to validate by hand calculations using various weight estimation methods.

Index Terms: Empennage, Zenith STOL CH 750 light sport utility airplane, Aircraft structures and materials, PRO-E, ANSYS, Composite materials, Weight estimation methods.

1 INTRODUCTION

The use of composite materials in the primary structure of aircraft is becoming more common, the industry demand for predicting and minimizing the product and maintenance cost is rising. However, the selection for the design and associated manufacturing process in the early design stage is so far largely experience and knowledge based and partly a political decision which creates a high cost. There is, therefore, a need to develop an approach for the optimal design of a minimum weight composite wing box structure, subject to design requirements, materials, manufacturing process, and bearing in mind the cost constraints in the early stages of development. The study first carried out structural requirements and design goals for the empennage of a light weight aircraft which is generally fuselage mounted type. The empennage has been designed for performing various stability control functions. In order to obtain a high efficiency model, endeavors were made to make the empennage as light as possible as well as with a high structural strength to weight criteria. The proposed methodology was considered for minimum weight empennage model under applied loading conditions. The material is organized around the major tasks in empennage design:

1) Empennage configuration (structure characteristics and dimensions as related to the aircraft requirements are considered and compared from the previous light weight aircraft models);
2) Material selection (structural loading, ultimate strength mode of failure, fatigue, configuration, environmental effects, and light weight);
3) Empennage modeling and analysis (safety factor, applied loads, structural analysis).

These tasks are considered in the order and manner in which the designer must handle them. Within these task areas, the critical aspects of the structural, performance, and physical boundary requirements that the structure design must satisfy are presented and the detail procedure for modeling the empennage structure is also presented. The model is then exported into the analysis software to conduct the analysis. The analysis on the empennage model is conducted representing that the model when an advanced material such as Carbon fiber is considered in place of aluminum is suitable for optimizing the weight and proved to be effective. The structure whose weight is as light as possible without any compromise in strength and stiffness is called optimal structure. Hence, growth factor, which is relationship between total weight and the payload, should be as low as possible. Materials with a high strength to weight ratio can be used to reduce weight. Lt = L/t, known as specific tensile strength or break-length, where a bar of constant cross-section will fail due to its own weight. Materials that are applicable as thin-walled structures can be used. The E-modulus is the important factor for composites and so is the shear modulus G. The specific modulus of elasticity E/w is measure of a structure’s stiffness in relation to its weight.

1.1 SCOPE

The research aims at optimizing the weight of an empennage structural assembly that will tolerate the different loads-operational loads, aerodynamic loads, tie-down force etc. The objective is to provide a simple yet durable light weight structure that can distribute the aerodynamic forces produced by the tail surfaces to the airframe through the most efficient load path. The critical aspects of the structural, performance, and physical boundary requirements that the empennage model must satisfy are presented and the detail procedure for modeling the empennage assembly using PRO E tools and the calculations required to optimize the weight are also presented. Then the model is exported into ANSYS software for structural analysis. The analysis on the EMPENNAGE model is conducted using ANSYS10.0 tools representing that the model designed when an advanced material such as Carbon-fiber is considered in place of aluminum is suitable for reducing the structural weight and increasing the strength and hence optimizing the overall weight of the empennage structure.

PROPOSED METHODOLOGY: The advantages of carbon fiber provide the structure of the empennage with greater strength hence the weight of the structure can be optimized by replacing the existing material aluminum with the carbon fiber.

WHAT IS LOSSSING A POUND (weight of an aircraft) WORTH?

- Reduces fuel consumption.
- Increases a plane's range.
- Reduces wear on key parts such as landing gear.
2 ABOUT EMPENNAGE STRUCTURE
There are three types of empennage configuration: T-tail, V-tail and conventional tail. The most commonly used empennage configuration is a T-tail where engines are positioned on the rear of the fuselage or on high-wing aircraft when the horizontal stabilizer may be located in the wing wake. The demerits of T-tails are that it needs larger structural components resulting increased weight and complexity undesirable in aircraft design. As V-tails results in an undesirable rolling moment in the opposite direction of the desired turn they are scarcely used. So there’re only two surfaces instead of three.

![Figure 1. T-tail empennage configuration.](image1)

Figure 1. T-tail empennage configuration.

![Figure 2. V-tail empennage configuration.](image2)

Figure 2. V-tail empennage configuration.

![Figure 3. Conventional tail](image3)

Figure 3. Conventional tail

The vertical tail assembly is a lightweight and stiff structure that maintains proper airfoil shape under the applied proper loads. The aerodynamic load is distributed on the skin of the aircraft to produce shear torsion and bending moment at the fuselage interface. It reduces aerodynamic sideslip and provide direction stability. The rear part of the vertical tail is movable called the rudder that causes yawing. Generally navigational radio or air band receiver antennas are located on or inside the vertical tail. The aircraft having 3 jet engines houses central engine in the vertical tail. There’re two types of vertical stabilizer-single conventional tail where vertical stabilizer is located vertically and horizontal stabilizer is fixed to the rear of the fuselage; T-tail where horizontal stabilizer is placed at the top of the vertical stabilizer. T-tails are often used in the fuselage mounted engine configuration so that horizontal stabilizer remains away from the engine exhaust plume. The challenges behind T-tail configuration comes in to picture with respect to undesired pitch-up at high AOA as a result of the reduction in the horizontal stabilizer’s lifting capability as it immerses in the wake of the wing at the moderate AOA. T-tail also causes structural challenges since loads on the horizontal stabilizer have to be transmitted through the vertical tail.
2.2 Internal Parts of Empennage Structure

RIBS AND SPARS: Aircraft is not aerodynamically fit unless the tail is designed to maintain its shape event at extreme stress. Tail is nothing but a framework of ribs and spars. Spars, the main component of the wing, runs lengthwise along the tail and so can carry all the weight of the tail. During flight when the force of the air acts against the skin, this force is transmitted to the ribs and then to the spars. There are two types of spars- the front spar and the rear spar. The front spar is located near the leading edge while the rear spar is about two-thirds the distance to the trailing edge. Depending on the design of the flight loads, some of the all-metal wings have as many as five spars. (ref 10). Spars are given for a purpose to resist bending and axial loads.

The ribs are those parts of the tail that provide airfoil shape. There are some ribs that can bear flight stress called compression ribs. Ribs are made out of wood, metal, plastic, composites and foam.

3 MODELING AND DESIGN CONSIDERATION

Generally, the empennage configuration used for the light sport aircraft is the conventional type which is specifically the fuselage mounted type. Here, in this case the exiting plane Zenith STOL CH 750 is considered for the design dimensions, configurations etc for modeling the empennage structure to further conduct the analysis for the weight optimization. The detail description of this aircraft including the dimensions and the empennage structure configurations of this aircraft considered are discussed below. STOL CH 750 aircraft was built as STOL vehicle to satisfy the pilot needs. Designer Chris Heintz has designed it to make light weight aircraft that can yet functions like passenger aircraft in a short-field. The aircraft has fixed leading-edge slats for high lift, full-span flaperons (both ailerons and flaps), an all-flying rudder, and durable all-metal construction. Also it has a wider cockpit, larger payload, more robust landing gear, and greater visibility.
DESIGN SPECIFICATIONS AND REQUIREMENTS OF THE AIRCRAFT

SPECIFICATIONS STOL CH 750
WING SPAN 29ft.10in (9.1m)
HEIGHT (rudder tip) 8ft.8in (2.6m)
WING AREA 144 sq.ft (13.4 sq.m)
WING AREA 4ft.10in (1.5m)
WING CHORD 4ft.10in (1.5m)
LENGTH 21ft.10in (6.7m)
HORIZONTAL TAIL SPAN 8ft.5in (2.6m)
HORIZONTAL TAIL AREA 22.2 sq.ft (2sq.m)

SPECIFICATIONS STOL CH 750
EMPTY WEIGHT 775 lbs (350kg)
DESIGN GROSS WEIGHT 1440 lbs (652kg)
GROSS WEIGHT (LSA Limit) 1320 lbs (600kg)
USEFUL LOAD (LSA) 545 lbs (250kg)
WING LOADING (LSA) 9.15 lbs/ft² (44.8m²)
POWER LOADING (LSA) 13.2 lbs/bhp (6kg/bhp)
DESIGN LOAD FACTOR (ultimate) +6g / -3g
NEVER EXCEED SPEED (VNE) 125mph (200km/h)
CABIN WIDTH 42 inches (100cm)
CABIN WIDTH (bubble doors) 50 inches (1.27m)
FUEL CAPACITY (std., dual wing tanks) 24 US gallons (90litres)
SUITABLE POWER / Max engine weight) 80-140hp. / 300 lbs. installed

STOL CH 750 PERFORMANCE Continental 0-200-100hp
@ gross weight 1,320 lbs (LSA limit)
TAKE-OFF ROLL 100 Feet (30m)
LANDING ROLL 125 Feet (38m)
MAX.CRUISE,Sea level 100mph (162km/h)
STALL,flaps down 35mph (56km/h)
RATE OF CLIMB 100fpm (5.1m/s)

SPECIFICATIONS STOL CH 750
SERVICE CEILING 14,000+ feet (4,200+m)
RANGE (standard,no reserve) 440 miles (710km)
ENDURANCE (standard,no reserve) 4.4 hours
Figure 8. Three views and dimensions of Zenith STOL CH 750

Cabin Width: 42 inches (1.09 m.)
With the bubble doors: 50 inches (1.27 m.)

Sketches not to scale.
Dimensions are approximate figures.
AEREOIL CONFIGURATION

NACA 4-digit airfoils: The calculation of these classical airfoils is easy because their shape and the associated camber lines are defined by rather simple formulas. The maximum thickness is located at $x / c = 30\%$, whereas the maximum camber is typically located at $x / c = 40\%$.

The camber lines are composed of two parabolic arcs, which are joined with equal tangents, but a kink in the curvature. This kink can be seen in the velocity distributions, especially when the position of the maximum camber is different from the common 40% chord station.

Figure 9. Airfoil nomenclature

Naming Scheme
The first two integers define the camber line, while the last two integers define the thickness.

- 1st digit: maximum ordinate of camber $100 \% f / c$
- 2nd digit: location of maximum camber $10 \% x / c$
- 3rd and 4th digit: maximum thickness $100 \% t / c$

- HORIZONTAL STABILIZER-NACA 4412 (NEGATIVE CAMBERED AEROFOIL)
- ELEVATOR-NACA 0012 (SYMMETRIC AEROFOIL)
- VERTICAL STABILIZER-NACA 0012 (SYMMETRIC AEROFOIL)
- RUDDER-NACA 0012 (SYMMETRIC AEROFOIL)

Table 1: Airfoil configuration used for empennage

<table>
<thead>
<tr>
<th>Airfoil</th>
<th>Thickness</th>
<th>Dihedral</th>
<th>Incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing</td>
<td>NACA 650-18 (modified)</td>
<td>16.67%</td>
<td>1.25 deg</td>
</tr>
<tr>
<td>Ruddervator (root)</td>
<td>NACA 0012</td>
<td>15.55%</td>
<td>90 deg</td>
</tr>
<tr>
<td>Ruddervator (tip)</td>
<td>NACA 0012</td>
<td>10.55%</td>
<td>90 deg</td>
</tr>
<tr>
<td>Horizontal Stabilizer</td>
<td>NACA 4412 Inverted</td>
<td>14.65%</td>
<td>0 deg</td>
</tr>
</tbody>
</table>

WHY NEGATIVE CAMBERED AIRFOIL?

- Negative camber creates a negative lift at zero angle of attack in order to increase the main wings lift
- Negative cambered airfoil has the ability to generate a lift in a short runway distance.

Figure 10. Short take off and landing

Table 2: Control surfaces configuration

<table>
<thead>
<tr>
<th>Control Surface</th>
<th>Spanwise extent</th>
<th>Chordwise extent</th>
<th>Deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ailerons</td>
<td>100%</td>
<td>14%</td>
<td>+/- 13 deg</td>
</tr>
<tr>
<td>Flaps</td>
<td>100%</td>
<td>14%</td>
<td>0 to 15 deg</td>
</tr>
<tr>
<td>Ruddervator</td>
<td>100%</td>
<td>100%</td>
<td>+/- 23 deg</td>
</tr>
<tr>
<td>Elevator</td>
<td>100%</td>
<td>50%</td>
<td>+28 / -30 deg</td>
</tr>
</tbody>
</table>

3.1 Empennage structure modeling
The modeling of the empennage structure involves various which specified below

- Generating the airfoil coordinates for all the airfoils considered for the empennage components using the javafoil software.
- Modeling the components of the empennage such as the horizontal stabilizer, elevator and rudder separately using PRO-E tools.
- Finally, the components modeled are called into the assembly features provided in the PRO-E software and perform the final assembly of the empennage providing the movable mechanisms to the movable components such as the rudder and elevator.

Generating the airfoil coordinates
Airfoil co-ordinates can be obtained using JAVAFOIL software. It’s a simple program which is used for the analysis of airfoil in subsonic flow. It calculates lift, drag and moment characteristics of airfoils. Firstly, program computes velocity distribution on airfoil surface using potential flow analysis module. Integrating the pressure distribution along the surface,
we can find lift and pitching moment coefficient. Also JAVAFOIL helps know the flow behavior at vicinity to airfoil surface (the boundary layer). It solves a set of differential equations to find the various boundary layer parameters which is applicable in calculation of the drag of an airfoil. Both analysis steps when repeated for each angle of attack yields a complete polar of the airfoil a given Reynolds number. GUI (Graphical User Interface) available in this software is easy to use.

**STEPS TO GENERATE THE AIRFOIL COORDINATES IN JAVAFOIL**

1. Open JAVAFOIL SOFTWARE
2. Enter the name of the airfoil (eg. NACA 0012)
3. Enter the number of points to be generated.
4. Using the airfoil nomenclature enter the values for thickness, camber and the camber location.
5. Click on the create airfoil to generate the coordinates

**Figure 11. Generating the NACA 0012 airfoil coordinates**

**Figure 12. \( c_l vs c_d \) graph for NACA 0012**

**Figure 13. \( c_l vs c_d \) graph for NACA 4412**

**Figure 14. Generating NACA 4412 airfoil coordinates**

**Exporting airfoil geometry**

JAVAFOIL can write airfoil geometry from the following file types:

- *.txt
  multi-element airfoil geometry in form of simple two columnar x-y coordinate sets arranged in two columns. Multi-element airfoils must be separated by a pair of x and y-values larger than 999.
- *.xml
  multi-element airfoil geometry in JAVAFOIL’s hierarchically structured xml format.
multi-element airfoil geometry in AutoCad drawing exchange format. Many CAD programs can read this file format, but the interpretation is not always perfect.

*.igs or *.iges
multi-element airfoil geometry in Initial Graphics Exchange Standard format. Many CAD programs can read this file format.

Note that JAVAFOIL selects the output file format according to the file name extension.

3.1 MODELING THE EMPENNAGE STRUCTURE
Modeling of the empennage structure is done using the PRO-E tools. Creo Elements/Pro (formerly Pro/ENGINEER), PTC’s parametric, integrated 3D CAD/CAM/CAE solution, is nowadays being used in different mechanical, design and development companies. Pro/ENGINEER was first created by Dr. Samuel Geisberg in mid-1980s and was first rule-based constraint applied software (sometimes called "parametric" or "variational") 3D CAD modeling system. The parametric modeling which PRO-E software uses means it uses parameters, dimensions, features, and relationships to capture intended product behavior and create a recipe which enables design automation and the optimization of design and product development processes. Creo Elements/Pro has a complete set of design, analysis and manufacturing capabilities on one, integral, scalable platform. The PRO-E includes Solid Modeling, Surfacing, Rendering, Data Interoperability, Routed Systems Design, Simulation, Tolerance Analysis, and NC and Tooling Design.

Engineering Design
Creo Elements/Pro has a wider range of tools that enable the generation of a complete digital representation of the product being designed. Apart from the general geometry tools it can also generate geometry of other integrated design disciplines such as industrial and standard pipe work and complete wiring definitions. It also has several industrial design concepts ranging from Conceptual industrial design sketches, reverse engineering, comprehensive free-form surface tools.

Analysis
Creo Elements/Pro provides different analysis tools like-thermal, static, dynamic and fatigue finite element analysis along with other tools all designed to help with the development of the product. Human factors, manufacturing tolerance, mould flow and design optimizations are included in the tools. The design optimization can be done with it for optimal structural modeling at geometry level along with a FEA approach.

Manufacturing
It provides sets of tools for manufacturing as well in the form of tooling design and simulated CNC machining and output.

STEPS FOR MODELING:
OPENING A NEW FILE

- Use CTRL+N (tools) or
- File new
- Enter the part name
- Uncheck default template (to change the units as default units are in inches). Enter the units desired to follow throughout the modeling. (here, dimensions are in mm)
- done

The key points (coordinates of the airfoil) are saved in the notepad. Change the extension of the notepad file with ‘.pts’ and save it. Now the key points are ready to import.

IMPORTING THE POINTS
- Go to points
- Click on offset co-ordinate system
- Select the part co-ordinate system
- Import
- Browse for the saved file (containing key points)
- done

(Keypoints get imported)

JOINING THE KEYPOINTS USING CURVE
- Select the Datum curve
- Select the option thru points
- Done
- Spline
- Select the starting point of the curve

(The required curve is drawn through the selected key points)
Switch off the points display to find the curve clearly.

TO EXTRUDE THE 2D CURVE TO REQUIRED DISTANCE
- EXTRUDE

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Switch off the points display to find the curve clearly.

TO EXTRUDE THE 2D CURVE TO REQUIRED DISTANCE
- EXTRUDE

SOLID MODELLING SURFACE MODELLING
- At the top left corner select if the model is solid or surface (In this case solid mode should be switched on)
- Give the extrusion distance (10mm)
- Done

Figure15. Extruded aerofoil section (rib)
DEFINING THE REFERENCE PLANE
- Go to placement (top left corner)
- Define or Right click and hold
- Define internal sketch
- Select the reference plane (it converts to sketcher)
- Sketch tool
- Click on the use option
- Select single
- Done

For finding any open sections, go to sketcher diagnosis on the top left. The closed areas will be found shaded. Close the open sections if any.

MODELING THE RIBS
- select extrude option (model tree)
- pattern
- select the direction option (top left)
- select the plane
- Give the distance of extrusion.

To model one more rib at another distance
- Go to extrude feature
- Select the plane
- Enter the number instances to be produced (including the parent element)-6
- Give the distance between them (520mm)

MODELLING THE SPAR
- Go to predefined patterns
- Sketcher tools
- Palette
- Profiles
- Select I-section
- Double click on the I-section icon
- In order to do SCALING, use the control point to move and scale By default the scaling to set to 1:1 In this case dimensions of I-section are 8x10 with 2mm thickness of flange and 2mm thickness of web.
- Extrude the pallete to last airfoil surface using the option extrude to last surface/point/curve (top left)

In order to regenerate after assigning new dimension, ctrl + G

Palette → delete segment/corner/divide→ constrain→ coincide

The same procedure is followed to produce the skeleton of the rudder as well as the elevator following the specified dimensions. The model of skeleton of rudder is shown in the figure below.

Figure17. Ribs with spar (Rudder)

CREATING HOLES IN THE RIBS
- Use HOLE option
- Click on the location to create hole
- Enter the value of diameter (30mm)
  To produce more than one hole similar to the one created
- Right click (model tree)
- Pattern
- Select direction and enter the number of instants to be created.

Figure18. Model of skeleton of horizontal stabilizer

Figure16. Ribs and rear spar of elevator
FINAL ASSEMBLY OF THE EMPENNAGE STRUCTURE

- Open assembly in PRO-E
- Click on assembly icon → add...
- Import the geometry (part file of the model created in the earlier steps)
- Constrain the part using different options existing in the software according to the position of the part. The constrain options are namely mate, align, insert, coordinate system, tangent, point on surface, edge on surface, fix, default etc.
- Now call the other part to be assembled with the previous part using the same options as mentioned above.
- Assemble the parts imported according to the specified model.
- For the movable parts assembly, a simple shaft mechanism is to be modeled. For this purpose thin cylindrical rods are separately modeled in part modeling and then inserted into the movable parts such as elevator and rudder (in this case) in the assembly modeling.

The final assembly of the empennage structure is shown in the figure below. The elevator is kept inclined at an angle in order to represent it as a movable component. The color of the vertical stabilizer is changed to discriminate it from the horizontal stabilizer components (this is done only to make the structure easily understood to the readers)

4 ANALYSIS OF EMPENNAGE STRUCTURE

Now the model is imported in ANSYS for static analysis.

4.1 Static structural analysis results

Steps to conduct analysis in ANSYS Workbench

- Open ANSYS Workbench
  Start → Programs → ANSYS 12.0 → ANSYS Workbench
- Double click on Static Structural (ANSYS)
- Double click on engineering Data to edit → add required materials → return to project
- Right click on geometry → import geometry → browse for the CAD file
- Right click on Model → edit → a new mechanical window will open
- Open geometry tree → click on part → set the required material
- Select point/edge/face → right click → insert loading condition (fixed, DOF, pressure, force etc)
- Click on mesh → set coarse to fine to obtain perfect mesh → then right click on mesh → generate the mesh
- Go to solution → solve
- Insert various results for example equivalent stress, equivalent strain, total deformation, directional deformation etc → right click on solution → resolve all → click on the particular result to visualize the results
- Click on print view to print the results or click on the report generate to generate a detailed report of analysis session.
ALUMINIUM

Table 3: Properties of Aluminum

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Yield Strength (Pa)</td>
<td>2.8e+008</td>
</tr>
<tr>
<td>Tensile Ultimate Strength (Pa)</td>
<td>3.1e+008</td>
</tr>
<tr>
<td>Compressive Strength (Pa)</td>
<td>2.8e+008</td>
</tr>
<tr>
<td>Young's Modulus (Pa)</td>
<td>7.1e+010</td>
</tr>
<tr>
<td>Poisson's Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Bulk Modulus (Pa)</td>
<td>6.9608e+010</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2770</td>
</tr>
<tr>
<td>Shear Modulus (Pa)</td>
<td>2.6692e+010</td>
</tr>
</tbody>
</table>

4.2 ELEVATOR STRUCTURAL ANALYSIS RESULTS (Aluminum)

Table 4: Geometrical properties of elevator (aluminum)

<table>
<thead>
<tr>
<th>Geometrical Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m³)</td>
<td>1.7867e-002</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>49.492</td>
</tr>
</tbody>
</table>

Table 5: Pressure loading definition of elevator

<table>
<thead>
<tr>
<th>Definition by Normal To</th>
<th>Pressure1</th>
<th>Pressure2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>5. Pa</td>
<td>10. Pa</td>
</tr>
<tr>
<td>(ramped)</td>
<td>(ramped)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 21. Total Deformation of elevator when aluminum is considered

Figure 22. Equivalent Elastic Strain of elevator when aluminum is considered

Figure 23. Equivalent Stress of elevator when aluminum is considered
ANALYSIS RESULTS OF ELEVATOR (Aluminum)

Table 4. Results of structural analysis (aluminum)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOTAL DEFORMATION</th>
<th>EQUIVALENT ELASTIC STRAIN</th>
<th>EQUIVALENT STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0 m</td>
<td>1.5758e-011 m/m</td>
<td>1.1188 Pa</td>
</tr>
<tr>
<td>Maximum</td>
<td>9.1272e-006 m</td>
<td>3.9726e-007 m/m</td>
<td>28205 Pa</td>
</tr>
</tbody>
</table>

4.3 HORIZONTAL STABILIZER STRUCTURAL ANALYSIS RESULTS (Aluminum)

Table 5. Geometrical properties of Horizontal stabilizer (Aluminum)

<table>
<thead>
<tr>
<th>Geometrical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume: 5.3824e-002 m³</td>
</tr>
<tr>
<td>Mass: 149.09 kg</td>
</tr>
</tbody>
</table>

Table 6. Pressure loading definition for horizontal stabilizer

<table>
<thead>
<tr>
<th>Definition by</th>
<th>Normal To Pressure1</th>
<th>Pressure2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnitude</td>
<td>-50. Pa (ramped)</td>
<td>70. Pa (ramped)</td>
</tr>
</tbody>
</table>

Figure 24. Total Deformation of horizontal stabilizer when aluminum is considered

Figure 25. Equivalent Elastic Strain of horizontal stabilizer when aluminum is considered

Figure 26. Equivalent Stress of horizontal stabilizer when aluminum is considered

ANALYSIS RESULTS OF HORIZONTAL STABILIZER (Aluminium)

Table 7. Results of horizontal stabilizer structural analysis (aluminium)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOTAL DEFORMATION</th>
<th>DIRECTIONAL DEFORMATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0 m</td>
<td>-1.2408e-007 m</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.7438e-004 m</td>
<td></td>
</tr>
</tbody>
</table>
4.4 RUDDER STRUCTURAL ANALYSIS RESULTS (Al)

Table 8. Geometrical properties of Rudder (Aluminium)

<table>
<thead>
<tr>
<th>Geometrical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>1.8749e-002 m³</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>51.935 kg</td>
</tr>
</tbody>
</table>

![Figure 27. Equivalent Elastic Strain of rudder when aluminium is considered](image)

![Figure 28. Equivalent Stress of rudder when aluminium is considered](image)

ANALYSIS RESULTS OF RUDDER (Aluminium)

Table 14. Results of rudder structural analysis (aluminium)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOTAL DEFORMATION</th>
<th>EQUIVALENT ELASTIC STRAIN</th>
<th>EQUIVALENT STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimun</td>
<td>0. m</td>
<td>1.6338e-013 m/m</td>
<td>1.16e-002 Pa</td>
</tr>
<tr>
<td>Maximum</td>
<td>9.8148e-011 m</td>
<td>3.5483e-010 m/m</td>
<td>25.193 Pa</td>
</tr>
</tbody>
</table>

CARBON FIBRE

Table 15. Properties of carbon fiber

<table>
<thead>
<tr>
<th>Tensile Ultimate Strength</th>
<th>Young's Modulus</th>
<th>Poisson's Ratio</th>
<th>Density kg m^-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1500</td>
<td>135</td>
<td>0.30</td>
<td>1740</td>
</tr>
</tbody>
</table>

4.4 ELEVATOR STRUCTURAL ANALYSIS RESULTS (Carbon fibre)

Table 16. Geometrical properties of elevator (carbon fibre)

<table>
<thead>
<tr>
<th>Geometrical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
</tr>
<tr>
<td>1.7867e-002 m³</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>35.017 kg</td>
</tr>
</tbody>
</table>
**Figure 30.** Equivalent Elastic Strain of elevator when carbon fibre is considered

**Figure 31.** Equivalent Stress of elevator when carbon fibre is considered

**Figure 32.** Total Deformation of elevator when carbon fibre is considered

**ANALYSIS RESULTS OF ELEVATOR (Carbon fibre)**

**Table 17.** Results of Elevator Structural Analysis (Carbon fibre)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOTAL DEFORMATION</th>
<th>EQUIVALENT ELASTIC STRAIN</th>
<th>EQUIVALENT STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minum</td>
<td>0.00 m</td>
<td>1.5411e-011 m/m</td>
<td>1.1188 Pa</td>
</tr>
<tr>
<td>Maxum</td>
<td>9.1272e-006 m</td>
<td>3.8849e-007 m/m</td>
<td>28205 Pa</td>
</tr>
</tbody>
</table>

**4.5 HORIZONTAL STABILIZER STRUCTURAL ANALYSIS RESULTS (Carbon fibre)**

**Table 18.** Geometrical properties of Horizontal stabilizer (Carbon fibre)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>5.3824e-002 m³</td>
</tr>
<tr>
<td>Mass</td>
<td>107.64 kg</td>
</tr>
</tbody>
</table>
Figure 33. Equivalent Elastic Strain of horizontal stabilizer when carbon fibre is considered

Figure 34. Equivalent Stress of horizontal stabilizer when carbon fibre is considered

Figure 35. Total Deformation of horizontal stabilizer when carbon fibre is considered

### Analysis Results of Horizontal Stabilizer (Carbon fibre)

<table>
<thead>
<tr>
<th>TYPE</th>
<th>TOTAL DEFORMATION</th>
<th>DIRECTIOINAL DEFORMATION</th>
<th>EQUIVALENT ELASTIC STRAIN</th>
<th>EQUIVALENT STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0. m</td>
<td>-1.2408e-007 m</td>
<td>7.3358e-011 m/m</td>
<td>5.3259 Pa</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.7438e-004 m</td>
<td>3.4113e-006 m/m</td>
<td>2.4767e+005 Pa</td>
<td></td>
</tr>
</tbody>
</table>

### 4.6 Rudder Structural Analysis Results (Carbon fibre)

Table 20. Geometrical properties of Rudder (Carbon Fibre)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>1.8749e-002 m³</td>
</tr>
<tr>
<td>Mass</td>
<td>39.643 kg</td>
</tr>
</tbody>
</table>
Figure 36. Equivalent Elastic Strain of rudder when carbon fibre is considered

Figure 37. Equivalent Stress of rudder when carbon fibre is considered

Figure 38. Total Deformation of rudder when Carbon fibre is considered

ANALYSIS RESULTS OF RUDDER (Carbon fibre)

Table 20. Results of Rudder Structural Analysis

<table>
<thead>
<tr>
<th>Type</th>
<th>TOTAL DEFORMATION</th>
<th>EQUIVALENT ELASTIC STRAIN</th>
<th>EQUIVALENT STRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>0. m</td>
<td>1.0935e-013 m/m</td>
<td>1.0497e-002 Pa</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.3501e-011 m</td>
<td>2.4333e-010 m/m</td>
<td>23.36 Pa</td>
</tr>
</tbody>
</table>

4.7 Validation of results obtained using software with hand calculations

ALUMINIUM

<table>
<thead>
<tr>
<th></th>
<th>Elevator</th>
<th>Horizontal stabilizer</th>
<th>Rudder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume(m^3)</td>
<td>1.7867e-002</td>
<td>5.382e-002</td>
<td>1.8749e-002</td>
</tr>
<tr>
<td>Mass(kg)</td>
<td>49.492</td>
<td>149.09</td>
<td>51.35</td>
</tr>
</tbody>
</table>

CARBON FIBRE

<table>
<thead>
<tr>
<th></th>
<th>Elevator</th>
<th>Horizontal stabilizer</th>
<th>Rudder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume(m^3)</td>
<td>1.7867e-002</td>
<td>5.382e-002</td>
<td>1.8749e-002</td>
</tr>
<tr>
<td>Mass(kg)</td>
<td>31.088</td>
<td>93.6469</td>
<td>32.6232</td>
</tr>
</tbody>
</table>
STATISTICAL GROUP WEIGHTS METHOD (WEIGHT CALCULATIONS)

\[ W_{\text{horizontal\ tail}} = 0.016(N_2 \cdot W_{\text{dg}})^{0.414} \cdot q^{0.168} \cdot s_{\text{ht}}^{0.896} \cdot (100t/c) / \cos \Lambda \]

\[ W_{\text{vertical\ tail}} = 0.073(1 + 0.2(H/H_t)) \cdot (N_2 \cdot W_{\text{dg}})^{0.376} \cdot q^{0.122} \cdot s_{\text{vt}}^{0.873} \cdot (100t/c) / \cos \Lambda \]

Where: \( N_2 \) = ultimate load factor = 1.5, limit load factor, \( W_{\text{dg}} \) = design gross weight, lb, \( q \) = dynamic pressure at cruise, lb/ft², \( S_{\text{ht}} \) = horizontal tail area, ft², \( \Lambda \) = wing sweep at 25% MAC, \( H/H_t = 0.0 \) for conventional tail; 1.0 for “T” tail, \( S_{\text{vt}} \) = vertical tail area, ft². (ref 14)

1. HORIZONTAL TAIL
   - Aspect ratio = \( b^2 / s \)
   - Wing span = 2.6m
   - Wing reference area = 0.80m x 2.6m = 2.08m²
   - Aspect ratio = 3.25
   - Wing reference area = 2.08m² = 22.389ft²

2. VERTICAL TAIL
   - Aspect ratio = \( b^2 / s \)
   - Wing span = 2.6m
   - Wing reference area = average chord x wing span
   - Average chord = \( (C_{\text{tip}} + C_{\text{root}}) / 2 \)
   - = 0.5
   - Wing reference area = 0.5 x 1.76
   - Wing reference area = 0.3411 lb/ft²
   - Aspect ratio = 3.52

3. Dynamic pressure \( q = \frac{1}{2} \cdot \rho \cdot v^2 \)
   - \( \rho \) = density at 1000ft altitude
   - \( v \) = velocity
   - \( \rho = 0.4135 \text{kg/m}^3 \)
   - \( v = 32 \text{kmph} \)
   - \( = 8.889 \text{m/s} \)
   - Dynamic pressure \( q = 16.33 \text{kg/m-s}^2 = 0.3411 \text{ lb/ft}^2 \)

4. Taper ratio for vertical tail
   - Taper ratio \( \lambda = C_{\text{tip}} / C_{\text{root}} \)
   - \( C_{\text{tip}} \) = tip chord length
   - \( C_{\text{root}} \) = root chord length
   - Taper ratio \( \lambda = 0.4 / 0.6 \)
   - Taper ratio \( \lambda_{\text{vt}} = 0.66 \)

5. Taper ratio for horizontal tail
   - Taper ratio \( \lambda_{\text{ht}} = 1 \)

6. Ultimate load factor \( N_2 = 6 \)

7. thickness to chord
   - for horizontal stabilizer
t/c - NACA 4412 = 14.65%
   - for elevator
t/c - NACA 0012 = 15.55%
   - for rudder
t/c - NACA 0012 = 10.55% (TIP)

8. \( W_{\text{dg}} \) = design gross weight = \( \text{mass} \cdot \text{g} = \text{density} \cdot \text{volume} \cdot \text{g} \)

When aluminium is considered,
\( W_{\text{dg}} \) (horizontal tail) = 198.582N (437.798 lb)
\( W_{\text{dg}} \) (vertical tail) = 51.935N (114.497 lb)

When Carbon fiber is considered,
\( W_{\text{dg}} \) (horizontal tail) = 124.7349N (274.9933 lb)
\( W_{\text{dg}} \) (vertical tail) = 32.6232N (71.9218 lb)

5 CONCLUSIONS
In the competitive environment of aircraft industries it becomes absolutely necessary to improve the efficiency, performance of the aircrafts to reduce the development and operating costs considerably, in order to capitalize the market. An important contribution to improve the efficiency and performance can be achieved by decreasing the aircraft weight through considerable usage of composite materials in primary aircraft structures. Based on above study, it is concluded that metallic and composite skin panel structures have their own advantages in various factors. Metallic (Aluminium) structure is partially superior to composite (Carbon Fibre) in strength and cost aspects. Composite (Carbon Fibre) structure is superior to metallic (Aluminium) structure in weight aspect which will influence in airplane performance.

ACKNOWLEDGEMENT
Behind the successful completion of our research, there’s a big hand of the faculty Prof Yagya Dwivedi whom we express our deep gratitude. We’re also highly indebted to those who inspired us to carry out this research and helped us a lot.

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