COB-2023-1908 APPLICATION OF MICHAEL ASHBY’S METHODOLOGY FOR MATERIAL SELECTION OF AN SAE AERODESIGN LANDING GEAR

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Abstract. The SAE Brazil Aerodesign competition is aimed at engineering students who wish to enhance their knowledge in the field of aerodesign by undertaking the theoretical and practical design of a radio-controlled aircraft. Therefore, as in various other areas, it is crucial that materials are selected appropriately in Aerodesign, making the project as optimized as possible. The method developed by Michael F. Ashby was used in conjunction with simulations using the finite element method in the Ansys software to validate the application of composite materials made from natural fibers (such as jute and Curauá fibers) to construct the aircraft’s landing gear by the team. Evaluating aspects such as mechanical strength and the weight-to-strength ratio of the tested materials compared to the same parameters offered by higher-cost materials, such as carbon fiber or glass fiber, used by the team in previous projects. With the applied methodology, it was found that the selected materials were able to meet the mechanical demands imposed by the project, as well as provided cost savings in the final product, validating their applicability in the design.

Keywords: Material Selection, Aerodesign, Landing Gear, Mechanical Properties

1. INTRODUCTION

The development of aeronautical design techniques by engineering students is the basis for the SAE Brasil AeroDesign competition, which proposes the detailed design of a radio-controlled aircraft in which the main objective concerns the design of an airplane with the lowest empty weight and capable of carrying the highest possible load.

Material Selection (MS) is a critical step in the design of any engineering product (Parate and Gupta, 2011). This criticality is even more pronounced in the context of the SAE Brazil AeroDesign competition, as the materials used in aircraft construction must exhibit an ideal synergy between strength and weight, to withstand multiple loads during operation while maintaining a reduced weight of the aircraft. MS directly enhances the capacity and payload value that the airplane can carry.

In this regard, one way to determine the materials employed in a project is through the Ashby Methodology, which involves the development of a systematic and scientific procedure for material and manufacturing process selection (Ashby et al., 2005). Developed by the British engineer Michael F. Ashby, the approach starts with questions such as ‘What is the component’s function in the design?’, ‘What objectives must be optimized?’ and ‘What constraints must be satisfied?’ Parate and Gupta (2011). The advantage of this approach lies in its systematic and impartial nature, as it focuses on the product’s objectives.

Jute and Curauá fibers come from the northern region of Brazil, making their use considerably less common than carbon fibers or glass fibers. Therefore, the main objective of this study is to apply Michael Ashby’s material selection method to validate the use of natural fibers in designing a main landing gear (MLG) for the Uirapuru Aerodesign team for
the 25th SAE Brazil AeroDesign competition. Additionally, the structural integrity of the designed MLG will be evaluated under critical loads through “finite element static analyses”.

2. THEORETICAL BACKGROUND

The Ashby procedure consists of four different steps, as shown in Fig. 1.

2.1 Translate design requirements

The first step is the translation of design requirements for a component, which define its functions and constraints, into a material specification. Engineering components serve a specific purpose, whether to support a load, withstand pressure, or transfer heat, among others. However, these functions must be performed within certain constraints, such as dimensional restrictions, the ability to withstand loads or pressures without failure, insulation or conductivity requirements, and operating within a specific temperature and environment range (Ashby et al., 2005).

During the design process, the engineer has specific objectives, such as reducing costs, minimizing weight, ensuring safety, or finding an optimal combination of these properties. Some parameters can be adjusted to achieve these objectives, such as dimensions not constrained by the design requirements. Additionally, the engineer can choose the material to be used in the component, which is considered a free variable in this context.

The component’s function, imposed constraints, intended objectives, and free variables (such as dimensions and material) are essential elements that define the conditions and limits for selecting the appropriate material. A clear statement of these aspects is the first step in relating the design requirements to the material properties and establishing criteria for selecting the most suitable material (Ashby et al., 2005).
2.2 Screen using constraints

During the screening stage, candidates unsuitable for the application are eliminated because one or more of their attributes fall outside the limits established by the constraints. For instance, requirements like "the component must withstand high temperatures" or "the component must have high tensile strength" impose clear limits on attributes, such as maximum operating temperature and mechanical strength, that successful candidates must meet. These imposed limits on attributes are called "attribute limits." During the screening process, materials are evaluated against these limits to identify those that possess the necessary attributes to perform the desired function adequately in the specific application (Ashby et al., 2005).

2.3 Rank using objective

The attribute limits are not sufficient to rank the remaining candidates. Optimization criteria found in later-developed material indices are necessary to perform this ranking. These indices measure how well a candidate that passes the screening can perform the required function. In some cases, performance is limited by a single property, while in others, it is a combination of properties. For example, the best materials for a lightweight and robust structure may be determined by the combination of high mechanical strength and low density. In contrast, for an efficient thermal insulator, the choice may be based on a combination of low thermal conductivity and high heat resistance.

However, it is more common for performance to be limited by a combination of properties. For example, for a component that requires high corrosion resistance and good machinability, the choice of the ideal material may depend on a combination of corrosion resistance, ductility, and machinability. A material index is the property or group of properties that maximize performance for a particular design. Several material indices are associated with maximizing a specific performance aspect. These indices provide criteria of excellence that allow materials to be ranked based on their ability to perform well in the specific application.

Precisely, the screening isolates the candidates capable of fulfilling the required function, while the ranking identifies, among these candidates, those that can perform the function most efficiently (Ashby et al., 2005). The material indices assist in selecting the most suitable material, considering combinations of properties that optimize performance to meet the project requirements.

2.4 Seek supporting information

The result of the previous steps is a reduced and organized list of candidates that meet the established constraints and maximize or minimize the required excellence criterion. Although it is possible to consider simply the top-ranked candidate, it is important to evaluate possible hidden flaws. This is accomplished by assessing the track record of this material when used in other projects and products, discovering its ‘reputation’ and reliability. This is especially crucial when dealing with composites, as choosing a high-modulus fiber alone does not account for all the properties of the resulting material. For example, a laminate with fiberglass will exhibit different mechanical properties depending on the resin matrix used in its composition (Rangaswamy and Vijayrangan, 2005).

Documentation significantly differs from structured property data used during screening. Typically, it consists of descriptions, graphs, or images, such as case studies of previous material usage, failure analyses (FEMEA and FEMAP), corrosion-related details, and information on availability and price, among other relevant aspects. This information can be found in manuals, manufacturer data sheets, and case studies. Documentation is crucial in narrowing down the shortlist of candidates to the final selection by providing detailed information that aids in decision-making (Ashby et al., 2005).

2.5 Indexes and diagrams

The Ashby methodology involves constructing two-dimensional graphs that relate two relevant material properties on a logarithmic scale. Ashby et al. (2005), these properties can be mechanical, physical, thermal, or any other important property for the specific application. These parameters are measured through indices that relate them in a way that facilitates the reading and comparison of properties for their defined function during the translation step. Table 1 presents some of the indices to which they relate.

The most commonly used graph in the Ashby methodology is the "property chart." The horizontal axis represents one property, such as tensile strength, and the vertical axis represents another property, such as density. Materials are represented as points on the chart, where each point corresponds to a specific material.

Furthermore, the Ashby methodology uses "performance lines" to indicate specific performance requirements. These lines are drawn on the property chart, and help visualize which materials meet the necessary performance criteria for a specific application.
Table 1. Table of Indices. Source: Ashby et al. (2005).

<table>
<thead>
<tr>
<th>Item</th>
<th>Function, objective, and constraints</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tie</td>
<td>minimum weight, stiffness prescribed</td>
<td>(E/\rho)</td>
</tr>
<tr>
<td>Beam</td>
<td>minimum weight, stiffness prescribed</td>
<td>(E^{1/2}/\rho)</td>
</tr>
<tr>
<td>Beam</td>
<td>minimum weight, strength prescribed</td>
<td>(\sigma_{y}^{2/3}/\rho)</td>
</tr>
<tr>
<td>Beam</td>
<td>minimum cost, stiffness prescribed</td>
<td>(E^{1/2}/C_{\mu}\rho)</td>
</tr>
<tr>
<td>Beam</td>
<td>minimum cost, strength prescribed</td>
<td>(\sigma_{y}^{2/3}/C_{\mu}\rho)</td>
</tr>
<tr>
<td>Column</td>
<td>minimum cost, buckling load prescribed</td>
<td>(E^{1/2}/C_{\mu}\rho)</td>
</tr>
<tr>
<td>Spring</td>
<td>minimum weight for given energy storage</td>
<td>(\sigma_{y}^{2}/E\rho)</td>
</tr>
<tr>
<td>Thermal Insulation</td>
<td>minimum cost, heat flux prescribed</td>
<td>(I/\kappa C_{p}\rho)</td>
</tr>
<tr>
<td>Electromagnet</td>
<td>, maximum field, temperature rise prescribed</td>
<td>(C_{p}\rho/\rho_{e})</td>
</tr>
</tbody>
</table>

2.6 The landing Gear

Components are named according to their structural function, describing how they are loaded. Tie rods support tensile loads, while beams and panels are designed to withstand bending moments. The Shafts transmit torques, while the columns must bear axial compression loads. The landing gear of an aircraft needs to be able to withstand compression caused by the vehicle’s weight and the impact with the ground during landing while remaining as lightweight as possible to avoid becoming an impediment to take-off and flight of the airplane.

2.7 The Finite Element Method (FEM)

The central idea of the FEM is to divide the problem domain into small finite subdomains, called elements, which are interconnected at specific points called nodes. These elements can have different shapes and sizes, forming a mesh or grid that represents the system under analysis. In this way, mathematical equations that describe the physical or mechanical behavior of the system can be discretized within each element. Based on the boundary conditions and material properties, the method solves these equations for each element and then combines their solutions to obtain an approximate solution for the entire system.

The FEM is a powerful tool for solving partial differential equations that describe the mechanical behavior of solid structures under different loading and constraint conditions. Solid mechanics studies how external forces applied to a deformable solid affect its shape, stress, and deformation state. This includes analyses of stresses, strains, temperature fluctuations, fracture analysis, and fatigue, among others (Mendonça and Fancello, 2019).

3. METHODOLOGY

The four steps of Michael Ashby’s methodology were applied to appropriately select the material for the design of the main landing gear. Initially, the main requirements were translated into objectives, mapping, and understanding the critical project needs, which can be visualized in Tab. 2.

Table 2. The first step of Michael B. Ashby methodology. Source: Ashby et al. (2005).

<table>
<thead>
<tr>
<th>Sorting</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>Assist in the landing process</td>
</tr>
<tr>
<td>Objective</td>
<td>Minimize the density</td>
</tr>
<tr>
<td>Main restrictions</td>
<td>Withstand the landing loads</td>
</tr>
<tr>
<td>Negotiable restriction</td>
<td>Material</td>
</tr>
</tbody>
</table>

The screening and elimination process began from this initial stage and the definition of requirements for the Uirapuru Aerodesign team’s landing gear project. In this phase, the previously selected materials were ranked according to their compliance with certain limits (Tab. 3), simplifying the range of materials available for the application.

Table 3. The second step of Michael B. Ashby methodology. Source: Ashby et al. (2005).

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Resistance</td>
<td>Maximize</td>
</tr>
<tr>
<td>Density</td>
<td>Minimize</td>
</tr>
</tbody>
</table>
After that, the ranking process began, identifying the materials that best perform the product’s primary function. For this purpose, criteria of excellence were introduced, maximizing fundamental properties. For this study, mechanical strength was maximized while density was minimized.

A database was consulted to obtain information about materials applicable to the current use. The Ashby chart was plotted with strength on the y-axis and density on the x-axis. Based on the project’s constraints and requirements, a desired performance region was determined on the Ashby chart (Fig. 2), marking the limits of properties defined in the screening step and using material indices. Finally, it was possible to identify a search area, which narrowed down the number of candidates for the documentation process.

The previous steps were responsible for selecting materials capable of meeting the project requirements and ranking those that best fulfill these functions, thereby reducing the necessary database for documentation. Additionally, local conditions such as suppliers, knowledge about the material, and available manufacturing processes were essential factors in the selection process.

The Ashby diagram presents a search area in which the limits were defined for a material with a minimum mechanical strength of $200\text{ MPa}$ and a maximum density of $2000\text{ Kg/m}^3$ based on the constraints of the other sub-teams of the Aerodesign project. Additionally, the material index considered was for a beam with minimum weight and prescribed strength, as shown in Tab. 1.

After plotting the graph, it was observed that the materials that best met the requirements would be composite (Fig. 3). Glass fibers and carbon fibers were selected as they are widely used composites in the SAE Aerodesign competition and easily obtainable from suppliers. Two other selected composites were natural fibers of Jute and Curauá, which have been studied in the country’s North region due to their excellent weight-to-strength ratio (Oliveira, 2015), fitting within the proposed limits for the method.
3.1 Computer Simulation

For the performance analysis of the selected materials, static simulations were conducted using the Finite Element Method through the software Ansys (Ansys Workbench 2020). The mechanical properties of carbon and glass fibers were obtained from the Ansys materials database. The properties of Jute and Curauá fibers were obtained from the work of De Araujo Alves Lima et al. (2020) and Filho and Dias (1997). Table 4 shows the properties of the selected materials. The composite materials used have an Epoxy resin matrix.

Table 4. Analytical results for mechanical properties. Source: The Autor.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm^3)</th>
<th>Strength MPa</th>
<th>Young’s modulus GPa</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curauá</td>
<td>1.33</td>
<td>1929.8</td>
<td>87.23</td>
<td>0.25</td>
</tr>
<tr>
<td>Jute</td>
<td>1.15</td>
<td>254.46</td>
<td>22.33</td>
<td>0.25</td>
</tr>
<tr>
<td>Carbon fiber</td>
<td>1.57</td>
<td>300.00</td>
<td>135.0</td>
<td>0.45</td>
</tr>
<tr>
<td>Glass fiber</td>
<td>1.86</td>
<td>250.50</td>
<td>21.410</td>
<td>0.3145</td>
</tr>
</tbody>
</table>

The materials were registered in the software’s database, and using the geometry of the main landing gear of the Uirapuru Aerodesign team’s project, boundary conditions were determined for the most critical case, which is landing on a single wheel (Fig. 4).

Figure 4. Boundary conditions for the single wheel landing case. Source: The Autor.

A mesh used for the simulation was generated, consisting of 819,653 nodes and 527,908 elements, and the only function used was refinement, as exemplified in Fig. 5.

Figure 5. Mesh used in the simulation. Source: The Autor.

The following flowchart was elaborated to illustrate the steps of this work (Fig. 6).
4. RESULTS

The results of the numerical simulations for the materials in Tab. 4 are illustrated in Fig. 7, 8, 9, and 10.

The safety factor is calculated as the ratio of the material’s failure stress to the maximum equivalent stress obtained using the Von Mises criterion. The fiberglass has a safety factor of 1.85, which is higher than the value of 1.5 used in Aerodesign (Fig. 7).

For carbon fiber, the safety factor was 2.53 (Fig. 8), which is above the value used in the competition’s regulations, justifying why it is widely used in Aerodesign.
The simulation for the natural fiber Jute, illustrated in Fig. 9, shows that it reached an acceptable safety factor value (1.76), which is close to the limit of 1.5.

![Figure 9. Safety factor of Jute. Source: The Autor.](image)

For the natural fiber Curauá, a value much higher than that used in Aerodesign was found for the safety factor (13.4), as shown in Fig. 10.

![Figure 10. Safety factor of Curauá. Source: The Autor.](image)

Table 5 illustrates all the simulation results for the selected materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Safety Factor</th>
<th>Eq. Stress (Von-Mises)</th>
<th>Max. Principal Stress</th>
<th>Deformation</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fiber</td>
<td>1.85</td>
<td>135.43 MPa</td>
<td>204.48 MPa</td>
<td>1.273 mm</td>
<td>0.045 Kg</td>
</tr>
<tr>
<td>Carbon fiber</td>
<td>2.53</td>
<td>118.46 MPa</td>
<td>265.02 MPa</td>
<td>0.197 mm</td>
<td>0.038 Kg</td>
</tr>
<tr>
<td>Jute fiber</td>
<td>1.76</td>
<td>144.15 MPa</td>
<td>190.17 Mpa</td>
<td>1.231 mm</td>
<td>0.028 Kg</td>
</tr>
<tr>
<td>Curauá fiber</td>
<td>13.4</td>
<td>144.15 MPa</td>
<td>190.17 Mpa</td>
<td>0.315 mm</td>
<td>0.032 Kg</td>
</tr>
</tbody>
</table>

In the obtained results, it was observed that compared to fiberglass, natural Jute fiber performs relatively better, as its safety factors are close to and above 1.5, while Jute fiber has a significantly lower density. Therefore, jute fiber could serve as a substitute for fiberglass if the safety limit is not reached.

Natural Jute fiber has a significantly lower safety factor than carbon fiber, but its mass for the landing gear is also lower. Therefore, in a project, the decision of which material to use will be determined based on the primary requirement defined by the team in the initial steps of the methodology, namely, whether to prioritize reducing mass with decreased strength or increasing the safety factor, even if it results in heavier landing gear.

The natural Curauá fiber outperforms all other fibers regarding safety factors, with values significantly higher than necessary for the competition. The landing gear constructed with this fiber would be lighter than the one made with carbon and glass fibers but slightly heavier than the one made with Jute fiber. However, Curauá fiber requires a lengthy manual cleaning treatment before its lamination process, which can hinder teams due to the time constraints of the SAE Aerodesign competition.
Despite the excellent results regarding safety factors and weight for Curauá and Jute fibers, they are not yet sold on a large industrial scale, making it challenging to acquire them even for teams located in the North region due to the scarcity of suppliers. For this reason, Carbon and glass fibers are more commonly used by Aerodesign teams.

5. CONCLUSION

By following the steps suggested by Ashby et al. (2005), the selection process started with many materials available in the market and narrowed down to a small group that was ranked and documented. This process helped to identify the materials that best meet the requirements of the Uirapuru Aerodesign team’s project.

The fibers proved to be compatible with the project’s limitations, as they passed all the selection phases defined by the method and simulations. Furthermore, they fulfill the competition’s objective of encouraging future engineers to train their skills and seek innovative solutions, proving to be suitable choices.

Jute and Curauá fibers showed excellent results compared to traditional carbon and glass fibers, despite facing challenges due to the scarcity of suppliers. In this regard, it is evident that there is a potential market to be explored if more companies invest in their research and commercialization, as these fibers could become suitable substitutes.

Finally, a possible aspect to be explored would be the variation in the percentages and sizes of the natural fibers used, as these factors can significantly affect the mechanical properties of fibers like jute (Barbosa et al. 2020). Different fibers could also be combined to create composites with intermediate properties. This approach opens further research and optimization possibilities to tailor the materials to specific applications and requirements.

6. ACKNOWLEDGEMENTS

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7. REFERENCES


8. RESPONSIBILITY NOTICE

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