

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

**Helner Mascarenhas dos Santos<sup>1</sup>**  
helner.santos@itec.ufpa.br

**Leonardo Tavares<sup>1</sup>**  
Leonardo.Tavares@itec.ufpa.br

**Felipe Diniz da Silva<sup>1</sup>**  
felipe.diniz.silva@itec.ufpa.br

**Sávio de Oliveira Moreira<sup>1</sup>**  
savio.moreira@itec.ufpa.br

**Arthur Wylson Cecim Negrão<sup>1</sup>**  
arthur.negrao@itec.ufpa.br

**Ana Paula Mattos<sup>1</sup>**  
anapmattos@ufpa.br

<sup>1</sup>Federal University of Pará, R. Augusto Corrêa, Belém-Pa, 66075-110

**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 building steps of a radio-controlled aircraft. Therefore, as in various other areas, it is crucial that materials are properly selected, making the project as optimized as possible. The method developed by 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 composites, 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 the design applicability.*

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

## 1. INTRODUCTION

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

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 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. Therefore, 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. This fibers are lighter than the synthetic, however, their strength limit is lower. 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 at 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.

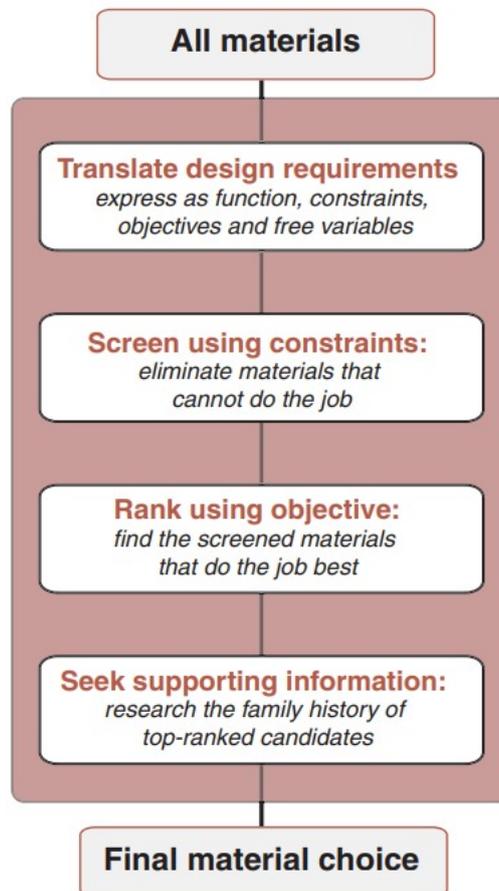


Figure 1. Stages of selection using the Ashby method. Source: Ashby *et al.* (2005).

Each step plays a solid role in consolidating the material selection, which will be explained below.

### 2.1 Translate design requirements

The first step is the translation of design requirements for a component, defining its functions and constraints into a material specification. Engineering components serve a specific purpose, whether to support a load, withstand pressure, or transfer heat. However, these functions must be performed within certain conditions, 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, like dimensions not constrained by the design requirements. Additionally, the engineer can choose the material to be used in the component, what is considered a free variable in this context.

The component's function, imposed constraints, intended objectives, and free variables are essential elements that define the conditions and limits for selecting the best 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 resist

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 correctly 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 task. 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, in others, it is a combination of properties. For example, the best material 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 a specific application.

### 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, as well as 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. 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.

Table 1. Table of Indices. Source: Ashby *et al.* (2005).

Item	Function, objective, and constraints	Index
Tie	minimum weight, stiffness prescribed	$E/\rho$
Beam	minimum weight, stiffness prescribed	$E^{1/2}/\rho$
Beam	minimum weight, strength prescribed	$\sigma_y^{2/3}/\rho$
Beam	minimum cost, stiffness prescribed	$E^{1/2}/C_m\rho$
Beam	minimum cost, strength prescribed	$\sigma_y^{2/3}/C_m\rho$
Column	minimum cost, buckling load prescribed	$E^{1/2}/C_m\rho$
Spring	minimum weight for given energy storage	$\sigma_y^2/E\rho$
Thermal Insulation	minimum cost, heat flux prescribed	$I/\lambda C_p\rho$
Electromagnet	, maximum field, temperature rise prescribed	$C_p\rho/\rho_e$

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 a region composed of materials that meet the necessary performance criteria for a specific application.

## 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 resist 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, in this study, a critical condition of landing with only one wheel will be analysed.

## 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. (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).

Sorting	Details
Function	Assist in the landing process
Objective	Minimize the density
Main restrictions	Withstand the landing loads
Negotiable restriction	Material

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).

Requirements	Details
Mechanical Resistance	Maximize
Density	Minimize

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.

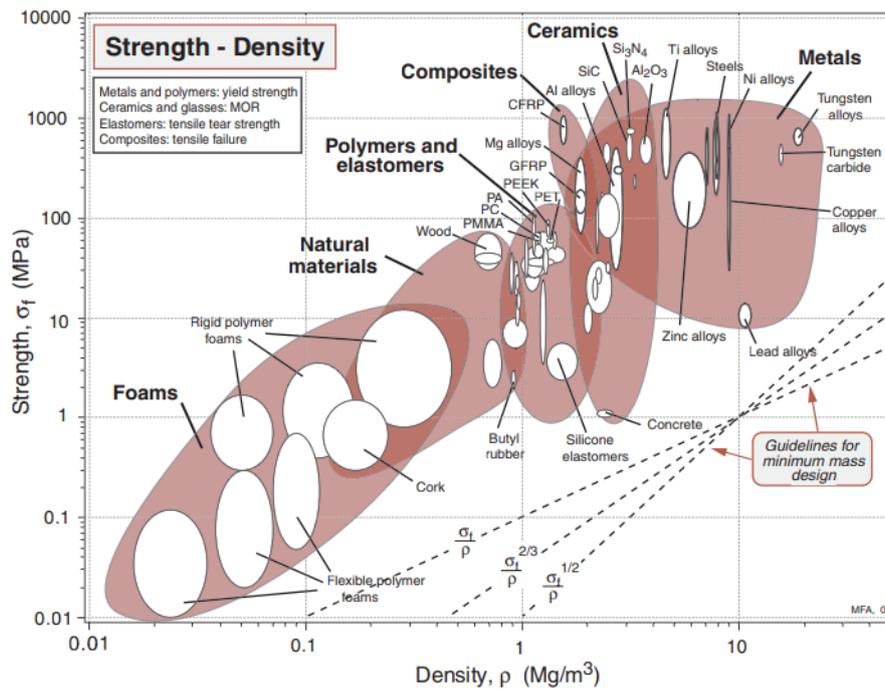


Figure 2. The strength–density chart. Source: Ashby *et al.* (2005).

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 with limits 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, those two 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.

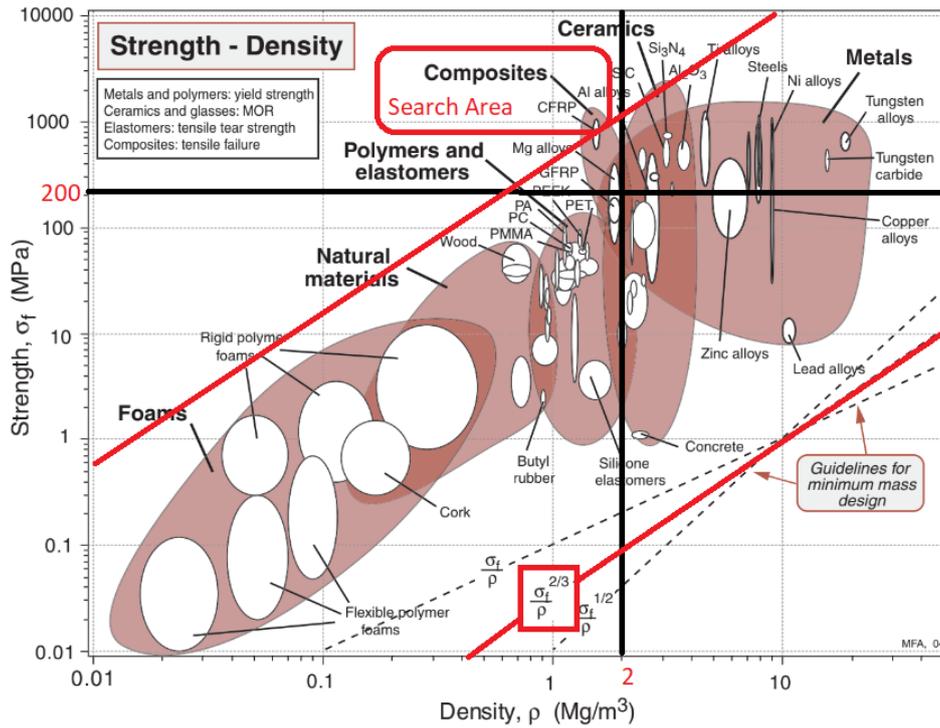


Figure 3. Results of the Search area. Source: Modified from Ashby *et al.* (2005).

### 3.1 Numerical 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 Rocha (2015) and Almeida *et al.* (2017) respectively. Table 4 shows the properties of the selected materials. The Jute composite was made with five layers of polyester resin in parallel mode and molding with compression. The Curauá composite was made with epoxy resin with continuous fibers aligned at 0° molding with compression.

Table 4. Analytical results for mechanical properties.

Material	Density $g/cm^3$	Strength MPa	Young's modulus GPa	Poisson's	References
Curauá fiber	1.168	78.98	44.54	0.25	Rocha (2015)
Jute fiber	1.17	70.61	1.33	0.25	Almeida <i>et al.</i> (2020)
Carbon fiber	1.57	540.20	46.16	0.337	Ansys Engineering Data (2020)
Glass fiber	1.86	250.50	21.410	0.3145	Ansys Engineering Data (2020)

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).

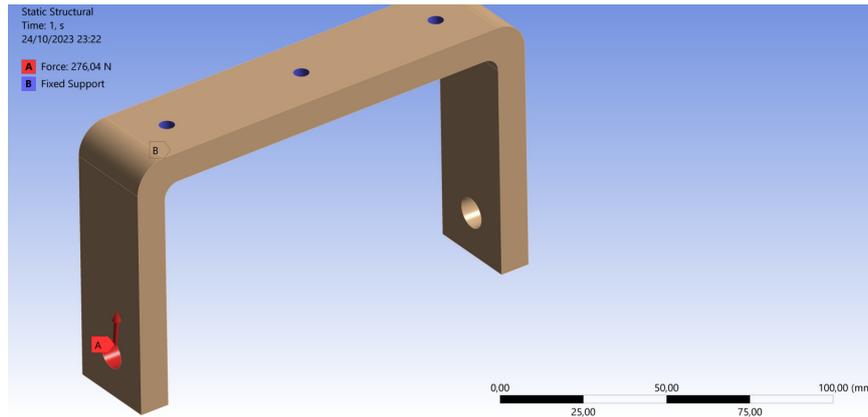


Figure 4. Boundary conditions for the single wheel landing case.

A mesh used for the simulation was generated, consisting of 337040 nodes and 194486 elements, as exemplified in Fig. 5.

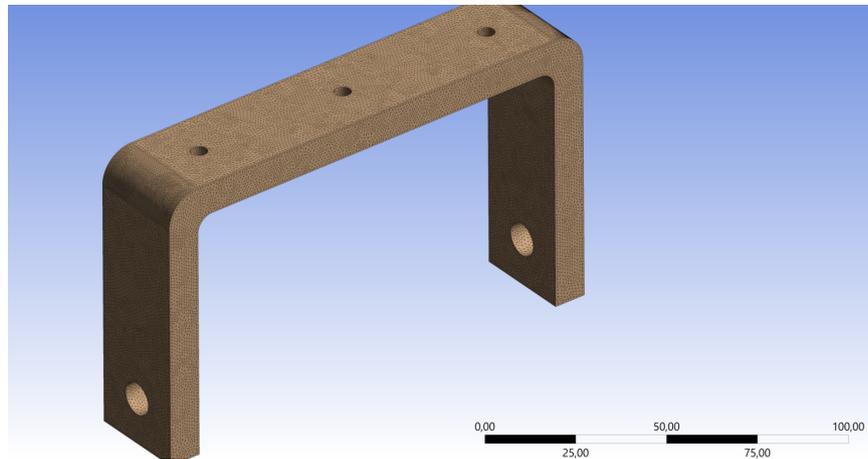


Figure 5. Mesh used in the simulation.

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

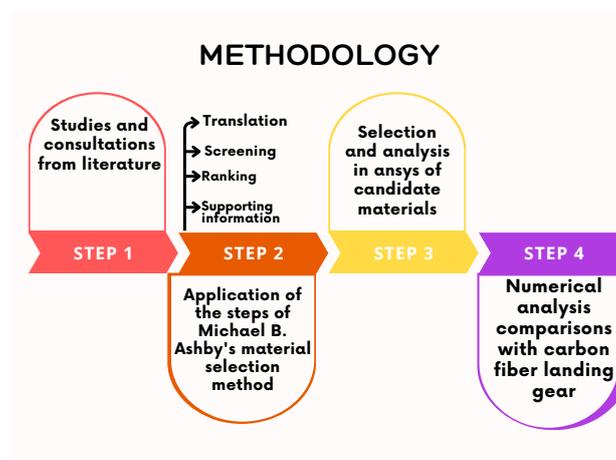


Figure 6. Methodology applied in the project.

#### 4. RESULTS

The results of the numerical simulations for the materials in Tab. 4 are illustrated in Fig. 7.

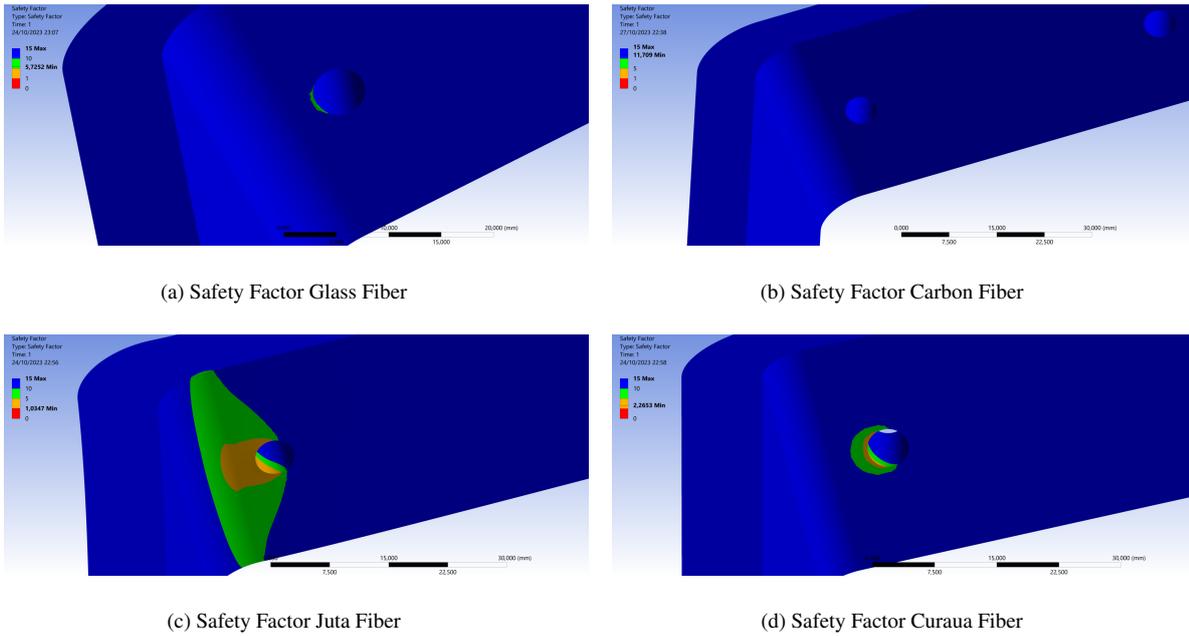


Figure 7. Numerical result of the Safety Factor for different fibers

The safety factor is calculated as the ratio of the material's failure stress to the maximum principal stress obtained using the max tensile stress criterion. The Glass composite has a safety factor of 5.72, which is much higher than the value of 1.5 used in Aerodesign (Fig. 7). For carbon fiber, the safety factor was 11.71 (Fig. 7), which is above the value used in the aeronautical industry, justifying why it is widely in this market.

However, for the Natural composite the safety factor where smaller. The simulation for the natural Composite Jute, illustrated in Fig. 7, shows that it reached a not acceptable safety factor value (1.03), because is too close to the limit of failure. But, for the natural composite Curauá, a value a little higher than that used in Aerodesign was found for the safety factor (2.26), as shown in Fig. 7.

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

Table 5. Numerical results.

Material	Safety Factor	Max. Principal Stress	Deformation	Mass
Glass Composite	5.72	43.754 MPa	0.018 mm	0.160 Kg
Carbon Composite	11.71	46.135 MPa	0.008 mm	0.136Kg
Jute Composite	1.03	68.24 Mpa	2.594 mm	0.101 Kg
Curauá Composite	2.26	34,86 Mpa	0.009 mm	0.101 Kg

In the obtained results, it was observed that compared to Glass and Carbon composite, natural Jute composite performs poorly and didn't reached the SAE standard, as its safety factors are close to 1. However, Jute composite has a lower density, making a 27% lighter Gear than Carbon composite and 38% than Glass composite. Jute fiber could serve as a substitute for Glass and Carbon composite if the safety limit is not reached, when is necessary to lower the weight. Jute fiber has a significantly lower safety factor than Curaua fiber, but its mass for the landing gear is the same.

The natural Curauá composite outperforms the Jute composite, with safety factor value higher than necessary for the competition. The landing gear constructed with this composite would be lighter than the one made with carbon and glass composite. 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.

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.

Despite the good results regarding safety factors and weight for Curauá fibers and not so good for Jute, 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 and others reason, Carbon and glass fibers are more commonly used by Aerodesign teams.

## 5. CONCLUSION

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.

Curauá fibers showed good results compared to traditional carbon and glass fibers that has much higher safety factor but are more heavy, despite facing challenges due to the scarcity of suppliers. Despite the limitations, Curauá and Jute fiber has a lot of potential and researchers invest in two types of alternatives: Physical and chemical treatment of fibers and the creation of hybrid composites. 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 (De Araujo Alves Lima *et al.* (2020).

## 6. ACKNOWLEDGEMENTS

We want to thank Msc. Igor dos Santos Gomes for his contributions to this paper by providing theoretical and practical background of using natural fiber composites for engineering projects.

## 7. REFERENCES

- Almeida, L., Branco, C., Filho, E., Sousa, F., Gomes, I., Magalhães, J., Fujiyama, R., Silva, D., Silva, F., Kuwahara, M. and Barbosa, F., 2017. "Compósitos poliméricos híbridos com fibras naturais e sintéticas contínuas e alinhadas." doi:10.26678/ABCM.COBEF2017.COF2017-1098.
- Ashby, M.F., Boston, A., London, H., Oxford, Y., San, P., San, D., Singapore, F. and Tokyo, S., 2005. *Materials Selection in Mechanical Design*. ISBN 1865843830. URL <http://books.elsevier.com>.
- De Araujo Alves Lima, R., Kawasaki Cavalcanti, D., de Souza e Silva Neto, J., Meneses da Costa, H. and Banea, M.D., 2020. "Effect of surface treatments on interfacial properties of natural intralaminar hybrid composites". *Polymer Composites*, Vol. 41, No. 1, pp. 314–325.
- Mendonça, P.T.R. and Fancello, E.A., 2019. *The method of finite elements applied to mechanics of solids (in Portuguese)*. Editora Orsa Maggiore, Florianópolis.
- Oliveira, F.H.D., 2015. *AValiação Comparativa de Compósitos Unidirecionais de Poliéster com Fibras de Vidro ou de Curauá*. Master's thesis, UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL, Escola de Engenharia, Programa de Pós-Graduação em Engenharia de Minas, Metalúrgica e de Materiais, Porto Alegre, Brasil.
- Parate, O. and Gupta, N., 2011. "Material selection for electrostatic microactuators using ashby approach". *Materials and Design*, Vol. 32, pp. 1577–1581. ISSN 02641275. doi:10.1016/j.matdes.2010.09.012.
- Rangaswamy, T. and Vijayrangan, S., 2005. "Optimal sizing and stacking sequence of composite drive shafts". *Materials science*, Vol. 11, No. 2, pp. 133–139.
- Rocha, I.G.d., 2015. *Influência do retardante de chamas nas propriedades mecânicas e flamabilidade em compósitos poliméricos de epóxi/fibra de curauá*. Master's thesis, Universidade Federal do Rio Grande do Norte.

## 8. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.