A Systematic Procedure for Design and Structural Mechanical Analysis: A Case Study for Construction of a Buggy

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***Abstract*—Our research aims to develop an efficient framework for machine design in response to the growing industry demand for optimization. We utilize Design Thinking (DT) combined with Shigley's Methodology (SM) to address ill-defined problems and promote human-centric problem-solving. SM's iterative process consisting of six phases facilitates effective planning and innovation. We conducted a case study focusing on the design and analysis of a buggy-type vehicle with specific dimensions. Various analyses, including static, fatigue, structure resonance, thermal, aerodynamic, and impact analysis, were performed using MATLAB and Solid-work's software. The structural analysis indicated values below the yielding stress, with a safety factor of approximately 3. The aerodynamic and impact studies were crucial in understanding the effects of airflow and assessing the structure's resistance to impacts at different speeds. The obtained results validated the design in terms of safety coefficient, structure resonance, heat dissipation, impact resistance, and aerodynamic performance. Additionally, the cost of the designed prototype was found to be 48% lower compared to a similar model.**

***Keywords*—design methodology, design thinking, static analysis, dynamic analysis, impact analysis, resonance analysis and aerodynamic analysis**

I. Introduction

Buggy, is the name of the vehicle designed and manufactured by hand to cross different types of terrain, the first vehicles manufactured of this type were inspired by and used the Volkswagen Beetle as a base. Due to its great versatility, the success of these vehicles has been such that it is currently used both for racing and for military use. In 1964, Bruce F. Meyers saw a disemboweled Beetle crossing the dunes on the beach. He was fascinated about what he saw and led him to build his own Buggy. Bruce wanted the shape of the vehicle to have the appearance of a wave, this series of events would result in the birth of the buggy's as we know them today [1–3]. The first designs had a series of problems related to the maneuverability, efficiency and weight of the vehicle that were solved over the years. Currently there is a wide variety of buggies on the market, these can be classified by the number of passengers, type of frame or structure and type of terrain that travels. This classification has a considerable influence on the design of the vehicle, in the case of a buggy that travels through sand dunes, a low centre of gravity, a frame and a resistant bodywork in the form of a helmet must be determined to protect passengers in the event of an accident. Overturning, for flat terrain a lighter design with greater stability at high speeds is sough [4–6]. The first step to make the prototype of the buggy is to make the sketch of the structure, sizing and establishing the number of bars that it will have to give rigidity and consistency to the design, then the type of material and the profile of the bars are selected. In most cases, tubular profiles are used due to their behaviour against normal and shear forces. There are three manufacturing methods that have been handled over the years: a) reuse an existing structure, b) completely design the frame, c) the third is the combination of both methods [7]. The designed structure allows establishing the appropriate measures for the parts that will be integrated into the vehicle, among the most important systems that must be designed are the steering, the differential, the gearbox and the brakes; the first 3 have sets of gears that allow them to perform their functions, for their design it is essential to select the type of gear, module and pressure angle that ensures the maximum power transmitted. The selection of the appropriate material that is capable of withstanding the loads both static and cyclic [8]. The brake design is focused on the brushes and the effects caused by friction, therefore heat dissipation in the disc must be foreseen to avoid failures due to overheating [9].

To validate the design process, several methods have been developed since the creation of the first car, mainly tests using a real prototype, however, with the advancement of technology, this practice is less common.

Manuscript received October 9, 2022; revised February 22, 2023; accepted May 25, 2023.

doi: 10.18178/ijmerr.12.6.362-377

The software Solid-works allows you to carry out the analysis piece by piece, of parts designed by simulation through finite element analysis, in this way results are obtained with greater precision and avoiding expenses in prototypes for tests [10–12]. The static analysis allows us to know the behaviour of the material, the fatigue`s study provides information on the life and the damage that the part will suffer under cyclic loads, the factors that modify the modulus of elasticity must be considered to obtain more real results. The resonance study, the software uses the analysis modal to determine the frequency of parts being subjected to vibration, clamping points and material selection are essential to obtain representative results. For thermodynamic analysis, exclusive of brakes, the material and the friction forces that generate heat are considered. The friction values used were standard, due to the complexity of their calculation, however, the error it represents is less than 2%, which is permissible [1, 10, 12].

The objective of this article is devoted to developed a basic framework for efficiently and systematic machine design. The object study was a buggy-type vehicle and its validation through various analyses carried out by the Solid-works design software. It was used to performs each of the studies through Finite Element Analysis (FEA). This method consists of dividing the geometry of the object of study into a limited number of parts, in such way that the results approximate a real behaviour associated with parameters through characteristic points in the geometry (nodes) [5]. The design procedure, starts, with the design methodology according to Design Thinking [6] and Shigley [7]. Design thinking which consists, identifying the problem based on the bibliography studied, establishing the design needs and the most appropriate improvements. Performing a preliminary design establishing the bases of the project. To validate the finished prototype, the pertinent studies are carried out based on the needs identified for each piece and finally the evaluation of the buggy's design car [7]. To conclude with the design process, impact and aerodynamic studies are carried out, in order to obtain a safe vehicle that has a favourable design at high speeds. During the study, weak points were detected in the structure when hitting a wall at 80 km/h. Therefore, structural parts were added to ensure passenger safety. Regarding the design, areas of resistance were identified that were dissipated through modifications to the bodywork. The article meets the objective of providing a design guide for a buggy-type vehicle, emphasizing the stages and analyses that must be carried out to meet the established requirements, thus achieving an efficient design that allows it to be manufactured in the future.

II. Methods and Procedure

To design is to formulate a plan for the target of a special requirement. If the requirement results in the creation of machine elements, the product must be safe, competitive, manufacture, functional and usable. Design is a highly creative process, furthermore it is also a decision-making process. In the following sections will be discussing the Design Thinking methodology, Shigley methodology, FEM analysis, Static, Fatigue, Resonance, Aerodynamic and Impact analysis respectively.

A. Design Thinking Methodology

Design thinking is a methodology for innovative problem resolving. It is exceptionally useful dealing problems that are ill-defined or unspecified, by re-outlining the problem in human centrist ways. In Principle, the DT process is iterative, flexible and focused on collaboration between designers and users, with an emphasis on bringing ideas to life based on how real users think, feel and behave. DT challenges complex problems by: Testing and Developing a prototype/solution to the problem. DT is a non-linear, iterative process that teams use to understand users, challenge assumptions, redefine problems and create innovative solutions to prototype and test. To develop innovative products are particularly complex, and there are no assurances for success, either, in DT. However, when you get it right, there's an option you could make happen. If the DT process was learned how to apply in a systematic way, the chances are great for success. The above methodology involves five phases [6, 13]: Empathize, Define, Ideate, Prototype and Test

Empathize: It is the first phase of Design Thinking, this part means putting ourselves in the shoes of the customers, this stage allows us to understand what is truly relevant to the user, so that based on that information, we can make smart design decisions and find the best solutions connected to their needs. It is important to stress out, our point of view of reality to see the situation with a broader perspective through the eyes of the user. [13]

Define: The challenges are contemplated when making a new product, process, technology, etc. The challenges are divided into three parts: a) challenge of known cause, b) Causes of possible causes of the problem, and c) Root of the unknown problem. In the final part of this stage, the challenges to establish the most relevant user needs and problems are defined, which will be of the utmost importance to obtain a more innovative and efficient result [6].

Ideate: The main objective of this stage is to generate an endless number of solution options to the problem established in Empathize and Define process. The activities that favor expansive thinking must be carried out to obtain unusual ideas that could lead to generating visionary solutions. The brainstorming is one of the most important exercises. This consists of collecting unfiltered/new creative ideas and sharing knowledge to solve technical problems. In this way, generate a creative, innovative and adequate solution in a collaborative way based on the ideas previously collected [13].

Prototype: The ideas selected from the idealization process could be the outcome, in low-cost, smaller-scale tangible elements focused on the most relevant aspects of the possible prototype. With the above information, this allows us to enhance other possible solutions and identify new errors and aspects that can be improved in the design. A prototype could necessary to modified, reassessed and even recreated as many times as necessary until reaching an appropriate result that meets the customers' requirements, then the prototypes must undergo tests to validate their quality [6, 13].

Test: Finally, the final phase of the Design Thinking methodology. The main objective is to analyze the solution alternatives through tests that allow determining which prototype meets the customers' requirements of the project and overcomes the challenges posed at the beginning of the investigation. During this stage, the weak points of the project could be detected, therefore the necessary changes must be made, this process becomes iterative until an adequate design that meets the defined requirements is reached [6, 13].

B. Shigley's Design Methodology

This methodology is well known and widely used for design engineers. Shigley's definition for mechanical design means design of components and systems of mechanical systems–Machines, structures products, devices and instruments. The concept is based on: Identification of need, definition of the problem, Synthesis, analysis and optimization, evaluation and presentation [7].

- **Identification of need**: This is about to establish a final purpose of the project. It can be done by some general statement of the client's dissatisfaction with the current situation.
- **Definition of the problem:** There is an iteration between the definition of the problem and the recognition of need. In this stage, it has to include all the specifications of the project and it is important to write a formal problem statement which expresses what the design has to accomplish.
- **Synthesis:** This is the first and most important step in synthesis task. There are several schemes proposes, investigated and quantified.
- **Analysis and optimization step**: It can be noticed that design is iterative, involving multiple steps ,result evaluation and potential revisiting of prior phases Thus, the system can be synthesized several components, analyse and optimize them.
- **Evaluation and presentation**: This stage is the final prove of the success of the project, which involves the testing of the prototype in Laboratory. Finally, the presentation has to be done to the clients.

In order to obtain an optimal and structured results during the design process. DT and Shigley's methodologies were combined, in order to obtain an adequate design procedure for a successful structured design process, see Fig. 1.

As it could be observed in the proposed flowchart, the first step is the definition to identify the problem through empathy, a tool proposed in DT to determine an appropriate and precise way the needs of the user currently facing the problem. An extensive literature review has to be carried out, in order to identify scientific articles, focus exclusively on design methodology and automotive/machine design.

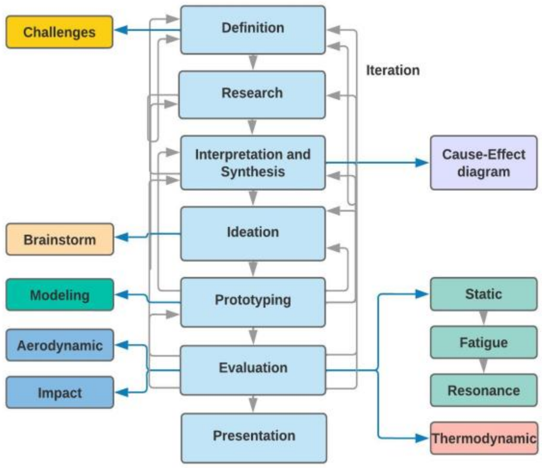

Figure 1. The proposed flowchart of the design procedure combined with design thinking and Shigley's methodologies.

The first challenge is to establish the methodology that must be followed to carry out a mechanical design, the second is related to the elements present in each model system. The third challenge is the analysis tools that must be used to validate the prototype. The challenges can be outlined to formulate the objectives of the research and its research problem to be solved. In our case, we have to deal with a contraction of a buggy-type vehicle, applying methodology design and machine structural analysis. The idea is to integrated design methodology of Design Thinking with Shigley methodology, and FEM analysis, respectively.

Based on the bibliography searched, which corresponds to the second stage of the proposed methodology. It is defined as the process of collecting reliable information that provides theoretical support to our research work, the sources must be highly reliable as articles and scientific journals. The characteristics of the most relevant elements in a vehicle were described, such as, main frame vehicle structure, the types of gears of the vehicle. The structural analysis will start with the structural static analysis, follow by selection of the preliminary materials of each element. Thereafter, there is the fatigue analysis to determine the severity of the propagation of the cracks due to cyclic loading. Then, it was performed the FEM for resonance analysis, to define the mode shapes, natural frequencies and the damping factor of the structure. In order to avoid faults due to resonance in the machine. The thermal analysis for the brakes was carried out to prevent/define failures due to the increase in temperature in the disc during the braking stage. The aerodynamic analysis was performed to see the buggy resistance to a crash at speed of 80 km/h. Finally, the finite element method was used for above structure analysis

Steps three and four are closely related to each other. They worked together and interactively to complete them successfully. The interpretation and synthesis refer to the added value assigned to the product, that is, to the set of features or benefits. As it was mentioned before, the main target of this research work is the design of a buggy using computational design tools. This paper has the author's own design procedure combining two design methodologies not only, to speed up the design process, but also to build up a frame design work for engineers. The aspects that were taken into account: aerodynamic design, low center of gravity and cage-type structure; each one allows to obtain a more optimal and better-quality design focused on the safety and stability of the vehicle. With the benefits related to the added value of the project, the idealization continues, a fundamental step to establish the design ideas related to both the added value and the elements of the vehicle, brainstorming was used. To collect the greatest number of ideas. that allows to obtain results with a greater degree of creativity and speed, within this process we can highlight the following solutions: reduction of the angle of inclination of the hood and the windshield, implementation of a spoiler in the rear part of the buggy, increase the distance between the wheels and design a bumper that reduces lift and drag, engine location, and different structural designs. Subsequently, the ideas passed through a filter to determine which were the most recommended to apply to the prototypes that were going to be made, this process was carried out three times to collect the largest number of ideas.

The creation of the prototype is constituted as the fifth procedure step of this design process. The Solid-works design software was used to carry out the static stress analysis, fatigue, impact and aerodynamic analysis of the buggy structure, respectively. First, the structure's sketches were created that will allow the parts that constitute the vehicle to be adequately modeled. Thereafter, the gear systems which act on the buggy, the transmission system, the steering and the differential, were designed. The disc brakes were also modeled and finally the main frame structure, such as, the bodywork, seats, lights, bumpers and wheels were also designed. The final designed model was modified on several occasions based on the criteria previously determined as well as on the results obtained from the various analyzes carried out in the evaluation stage.

The evaluation stage procedure is the most important phase when designing any element, since it allows rejecting or validating. This stage is closely related to the prototyping stage, considering that the results obtained will determine if the model should be modified or maintained. Therefore, it began with the static analysis of all the pieces that make up the buggy, establishing fixed loads on each one of them depending on the work they perform and the weight they must resist. The outcome obtained are the safety factor and the deformation that both are produced in each element depending on the selected material. In the first instance it was established that the safety factor must be greater than 1.5 in order to avoid future mismatch. Thereafter the fatigue analysis was performed, using the Soderberg's criterion and the Marin factors were applied to obtain results with greater accuracy. The software simulates cyclic loads on the pieces, to obtain the recommended number of cycles.

One important procedure is the resonance analysis which was applied to all the elements. It allows us to compare the natural frequencies of the parts with respect to the source, in our case the motor. In case the natural frequencies coincide with the motor nominal frequency, the system enters into resonance and a fault could be developed in the system. For the brakes, the thermal analysis was applied, it reveals the increase in temperature due to the activation of the brake, therefore these values must be correctly interpreted in order to avoid overheating of any element in the brake. Thereafter, the impact test and the aerodynamic study are carried out, the first simulates a crash of the vehicle against a surface at a certain speed, the results certify the degree of safety that the vehicle possesses. The aerodynamic study determines the effect it causes the air flow over the buggy, mainly the lift and resistance forces that prevent the car from moving correctly, this analysis mainly evaluates the design of the buggy. Designing with good aerodynamic enhances car's capacity to accelerate easily, with efficiently fuel economy.

Finally, the project will be presented to the users, showing the process and the results obtained that support the realization of the project, the benefits and the impact that it intends to cause must be clearly established.

III. BASICS OF FINITE ELEMENT METHOD (FEM)

The FEM is numerical procedure, analysis of mechanical structures to solve a wide variety of engineering problems. Initially, in order to have a full understanding, the Kattan's book [14] was used for the basics of FEM's procedure Therefore, we applied FEM with Matlab to introduce the structure basic analysis, the formulation of the rigid matrix of a beam element. It starts with a flat beam which resist a bending moment and traverse shear stresses. The element characteristics matrix, has different names in different research areas. In structural mechanics it is called stiffness matrix. The analysis procedure is to determine the nodal displacement to nodal forces. The calculation selected to solve the elements of the design made is the one belonging to chapter 7 of Kattan's book, referring to the beam element as a two-dimensional finite element where both local and global coordinates coincide. This type of element has a limit of elasticity, moment of inertia and length, the number of nodes depends on the accuracy to be obtained and the rigidity matrix is given as follows given by 4 ° of freedom. Fig. 2 (a, b) denote a uniform bar showing nodal displacements. Fig.2(c–f) are associated with bending moments. Quadratic interpolations functions (*N_1, N_2, N_3 and N_4*) can be applied to obtain the stiffness matrix (k).

Eq. (1) is generated based on the four Functional equations describe in Fig. 2.

$$v = [N_1 N_2 N_3 N_4] \begin{Bmatrix} V_{1y} \\ \phi_1 \\ V_{2y} \\ \phi_2 \end{Bmatrix} = Nd \quad (1)$$

Where vector N is the quadratic functions, vector d is the nodal displacement, V_{1y} is the vertical nodal displacement, $\acute{Ø}_2$ is the node beam angle.

$$\frac{\partial^2 v}{\partial x^2} = [\frac{\partial^2}{\partial x^2} N]d$$

$$[-\frac{6}{L^2} + \frac{12x}{L^3} - \frac{4}{L} + \frac{6x}{L^2} - \frac{12x}{L^3} - \frac{2}{L} + \frac{6x}{L^2}]d = Bd \tag{2}$$

where B represent the second derivative of the functions.

$$k = \int_0^L B^T EIBdx = \frac{EI}{L^3} \begin{pmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^3 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{pmatrix} \tag{3}$$

Finally, the rigid matrix k, with displacement, angles, forces and moments can be seen in Eq. (4):

$$\frac{EI}{L^3} \begin{pmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^3 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{pmatrix} \begin{Bmatrix} V_{1y} \\ \phi_1 \\ V_{2y} \\ \phi_2 \end{Bmatrix} = \begin{Bmatrix} F_{1y} \\ M_1 \\ F_{2y} \\ M_2 \end{Bmatrix} \tag{4}$$

where E is the module elasticity, V is the displacement, ϕ is the angle of the beam, I is the cross-section moment of inertia, and L is the length of the bar. F is the shear force, and M is the bending moment, respectively. The matrix 4×4 is called the stiffness matrix (K). Once the stiffness matrix k is obtained, the following equation must be followed to obtain the pending values, where V is the displacement vector and F the force vector, both global Eq. (5), both vectors determine the boundary conditions allowing the matrix to be solved above by partition and Gaussian elimination, obtaining the displacement values and unknown reactions that allow determining the nodal force vector as follows:

$$[K]\{V\} = \{F\} \tag{5}$$

The results obtained with the last equation are related to the transverse and rotational displacements of each node, as well as the forces that appear in each one of them [14]. Some obtained stress results from Eq. (5), will be used to compare the results with a standard FEM software.

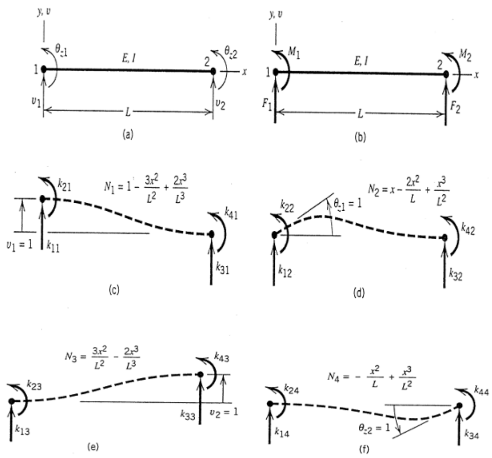

Figure 2. Formulation of the rigid matrix of a beam element, with four degree of freedom [14]. Nodal displacements (a,b) and bending moments (c,d,e, f).

IV. SPUR, BEVEL AND HELICOIDAL GEAR DESIGN

This section is an attempt to apply that principle of gear design by presenting information about the details for gear design. For a correct design of the gear systems to the buggy, including the differential system, gearbox and steering, a study of the geometry, the kinematic relationships and the forces transmitted by the different types of gears that exist must be carried out. The Spur bevel gears transmit movement between parallel axes. However, The helical gears transmit movement between parallel and non-parallel shafts, subject to radial and axial forces. In order to define gear's characteristics the following data must be established: Diametric pitch, module, number of teeth, pitch diameter, addendum, dedendum and crest [7]. Fig. 3 illustrates a free- body diagram of the forces and moments acting on the system.

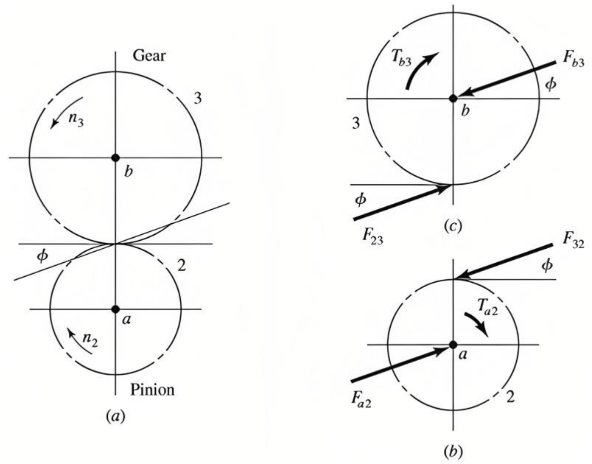

Figure 3. Free-body diagram with forces and moments acting on the spur gears [7].

The following formulas are used to determine the main parameters of the gears and then perform the calculation of forces as we already know [15].

$$V = \frac{\pi dn}{12} \tag{6}$$

$$W_t = 33000 \frac{H}{V} \quad \text{(English system)} \tag{7}$$

$$W_t = 60000 \frac{H}{\pi dn} \tag{8}$$

where V is the pitch-line velocity, d is gear diameter, n is the gear speed, W_t transmitted load, H is the power (HP).

For bevel gears, a couple of formulas must be increased to have the forces acting on each component fully defined (radial and axial forces).

$$W_t = \frac{T}{\tau_{av}} \tag{9}$$

$$W_r = W_t \tan\theta \cos\gamma \tag{10}$$

$$W_a = W_t \tan\theta \sin\gamma \tag{11}$$

where W_t is the transmission force, W_a is the axial force, W_r is the radial force. The readers are referring to bibliography to complete the set of equations used in the paper [9]. Fig. 4a) illustrates a bevel gear, the forces acting at the centre of the tooth. The tooth forces acting on a heliciodal gear can be sen in Fig.4b).

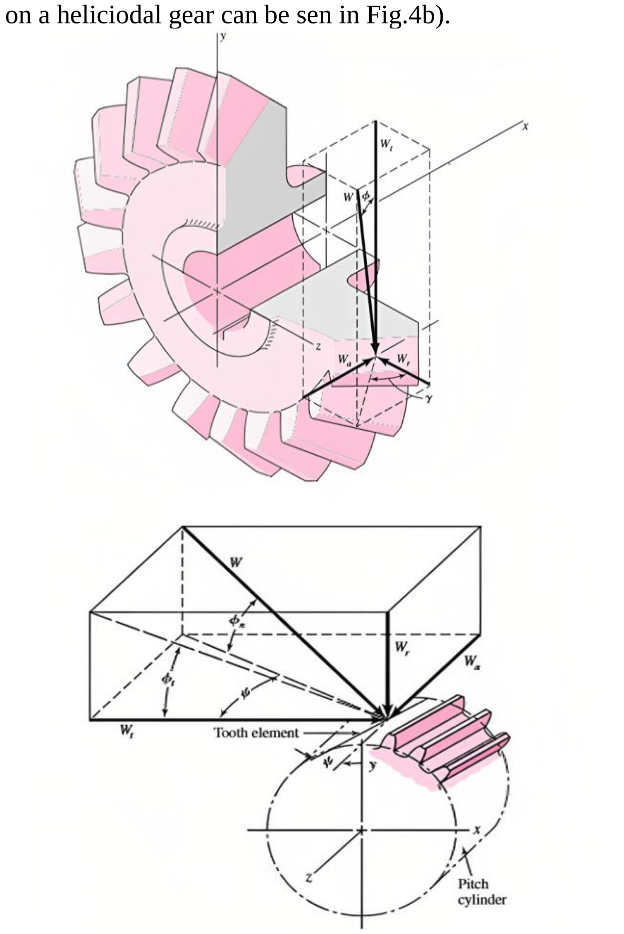

Figure 4. Tooth mesh forces, a) Bevel gear tooth forces and b) Tooth forces acting on a helicoidal gear [15].

In summary, the following equations from (16) to (26) are applied to determine buggy's system mechanical behavior. The stress analysis, fatigue analysis, finite element methods, impact analysis, resonance analysis, and aerodynamic analysis are all essential tools for understanding and analyzing structures and systems. Their combined application enables engineers to design and optimize structures that can withstand external forces, dynamic events, and fluid interactions while ensuring reliability, durability, and safety.

TABLE I. REFERENCE SAFETY FACTOR VALUES [15].

Knowledge of loads	Knowledge of effort	Knowledge of environment	Knowledge of material	Safety Factor
1. Precise Determination	Precise Determination	Controllable conditions	Well-known	1.25–1.5
2. Easily Determinable	Easily determined	Reasonable constant	Well-known	1.5–2.0
3. Determinable	Determinable	Ordinary	Average	2.0–2.5
4. Average	Average	Average	Least tested	2.5–3.0
5. Average	Average	Average	Not tested	3.0–4.0
6. Uncertain	Uncertain	Uncertain Average	Well-known	3.0–4.0

A. Stress Analysis

Stress and strain analysis is an engineering field which determines the stresses and strains in structures subjected to forces and moments. This tool is essential to determine the behaviour of the elements that are part of a design, this analysis allows the understanding of the nature of the forces and how the components of a machine transmit forces and movement from one point to another. This analysis defines if it fails or not the design structure, are necessary design modifications to solve the possible problems. The forces are distributed along different surfaces lead us directly to the concepts of stress, its transformations and its components. Taking into account these aspects for the development of the systems that are part of the buggy design. The analyses were carried out by the Finite Element Method (FEM), based on the Von Mises equation, which allows us to determine the main stresses in the elements. For the stress-strain, modal analysis, aerodynamic and impact analysis the Solid-works's software was used. The general von Mises equation is Eq. (12):

$$VonMises = \sqrt{\sigma_x + \sigma_y + \sigma_z + \tau_{xy} + \tau_{yz} + \tau_{xz}} \tag{12}$$

where σ_x is the stress in x-direction, σ_y is the stress in y-direction, σ_z is the stress in z-direction, τ_{xy} is torsional xy-stresses, τ_{yz} is torsional yz-stresses, and τ_{xz} is torsional xz-stresses, respectively. One important value in stress analysis is the safety factor which allows us to know the resistance of our designed element. It is the ratio of an ultimate (load/strength) divided by allowable load (Stress), see the Eq. (13). In order to perform the design validation process of each piece, the design factor is fundamental, the environment and the material of the piece are taken into account, for controllable conditions and an accurate determination of the efforts, a safety factor between 1.25–1.5 are recommended. If the case is an uncertain work environment for designed pieces the safe factor is recommended between 3 and 4, therefore values between 2 and 3 will be sought for vehicle parts [16].

$$SF = \frac{S_y}{\sigma_{VM}} \tag{13}$$

where S_y is ultimate tensile long/strength, σ_{VM} is allowable load.

B. Fatigue Analysis (FA) for a Buggy

The structural analysis of failure tendency, the initiation of cracks' propagation in the structure due to cyclic loading is also called fatigue. Fatigue failure analysis emphasizes fluctuating or alternating stresses that are repeated many times on certain elements [7]. FA is important to predict the durability of components under its operating stages. The above failures are extremely dangerous because they are sudden and therefore dangerous. To classified the cracks' propagation can be identified three stages: micro cracks, this is the initiation stage; crack propagation to a critical size, and finally the rupture of the material [17].

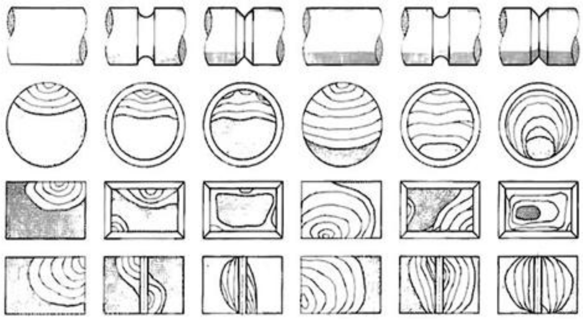

Figure 5. Scheme of fracture surfaces [17].

In order to achieve accurate results in the fatigue study, the factors that modify the resistance limit of the material must be considered, known as Marin factors, which quantify the effects caused on the surface, size, load, temperature, reliability and those caused by difficult-to-quantify effects such as residual stresses and corrosion Eq. (14).

$$S_e = K_a K_b K_c K_d K_e S_e^{'} \tag{14}$$

where k_a is surface condition modification factor, k_b is the size modification factor, k_c is loading modification factor, k_d is temperature modification factor, k_e reliability factor, S_e is endurance limit at the critical location of a machine and $S_e´$ rotary-beam endurance limit, respectively. Obtaining a value close to the real one of the resistance limits, the failure criterion under which the analysis will be carried out must be chosen. The Söderberg criterion is broadly used for fluctuating loads to define the failures in pieces. It is based on the stress values medium and alternating within an analysed point; establishes that at that point the piece will resist as long as it complies with Eq. (15):

$$\frac{\sigma_m}{S_y} + \frac{\sigma_a}{S_e} \leq 1 \tag{15}$$

where σ_m is mean stress component, σ_a is the alternating component, S_y is tensile strength, S_e is the fatigue limit and n value medium of the factor of safety.

$$\frac{\sigma_m}{S_y} + \frac{\sigma_a}{S_e} = \frac{1}{n} \tag{16}$$

The criterion is represented by a straight line within the plot of mean versus alternating stress, also called the Söderberg line, indicating the failure boundary. As can be seen, any combination of average and alternating stresses to the left of the line will resist, while if it is to the right of the line, it will fail according to the criterion [18].

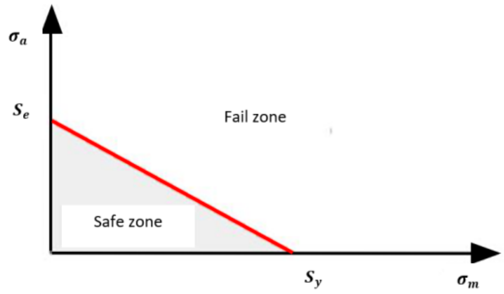

Figure 6. Söderberg's criterion [15].

C. Finite Element Method for Resonance Analysis (FEMRA)

Modal analysis is also called Resonance Analysis. It has a major importance the structure dynamic analysis for design, manufacturing and maintenance. Therefore, in recent years, it has been considerable interest of Finite Element Method for Resonance Analysis (FEMRA). Modal parameters identification plays and important role in structural health monitoring and fault detection. It is considered a technique for the dynamic analysis of structures, which estimates the dynamic properties of the interacting elements, among the most important are structure fundamental frequencies, mode shapes and damping. These properties depend entirely on the material and the boundary conditions, in addition to the degrees of freedom presented [19]. The modal analysis is carried out based on structural tests and simulation under finite element analysis in specialized programs, the results obtained allow us to know the response of the element to stimuli caused by vibration and detection of damage caused by it [20].

This phenomenon occurs when a piece or structure has the same frequency or period of vibration as that of an excitation element that occurs at a certain speed, which can cause resonance failures that cause considerable damage or even structural collapse. That are caused by intense levels of vibration that originate vibratory forces that damage the apparatus of the object studied. For this situation, the objective is to prevent our parts from having the same frequency as the structural natural frequency [21].

D. Thermodynamic Analysis of Disc Brakes

The brake's system of a vehicle is extremely important to protect the safety of passengers, since it allows the car to be partially or totally stopped. In general, 70% of the kinetic energy produced is absorbed by the front brakes and the rest by the rear brakes. This system is based on the friction exerted by the pressure of the pads on the disc to stop the movement, as a consequence heat is produced in the device, which must be dissipated by convection through the disc blades, [22, 23]. To correctly carry out the thermodynamic analysis in Solid-works, it is essential to calculate the pressure and the force exerted by the pads on the disc.

$$p_a = \frac{T}{\Delta\theta \times p_a \times r_i \times (r_o - r_i)} \tag{17}$$

$$F = \Delta\theta \times p_a \times r_i \times (r_o - r_i) \quad (18)$$

where T is the temperature, $\Delta\theta$ is the angle, Pa is the pressure, r_o and r_i are outer and inner radius respectively, the data previously obtained, the calculation of heat dissipated by convection in the periphery of the brake is made, and in this way include the appropriate values in the software, this will allow us to know if the selected material is suitable for this function and if the geometry made does not generate heat concentrates [24].

$$Q = h \times As \times (T_s - T_\infty) \quad (19)$$

where h is heating coefficient A is the area, T_s is surface temperature, T_∞ is surrounding temperature.

V. Impact Analysis

Impact tests allow knowing the behaviour of a system under extreme conditions, it is extremely important because the current trend is focused on consumption efficiency, which is achieved by reducing the weight of the bodywork and parts that compose it. The selection of materials must protect the safety of the population [25, 26]. In the case of a vehicle, that of its passengers, this analysis can be carried out using the Solid-works design software, which performs a mesh of the part in question and subsequently the conditions of the test, speed and acceleration are established, finally adds the direction and sense of movement. The results simulated by the program show us the behaviour of the object of study over time and if any fracture occurs when it collides with a rigid barrier under the given conditions [27]. The New Vehicle Assessment Program for Latin America and the Caribbean (Latin NCAP) performs these tests under internationally known methods, which provide a rating from 0 to 5 stars based on four aspects: adult occupant protection, child occupant protection, protection for pedestrians and vulnerable road users and driving assistance technologies. It should be noted that these tests are carried out under controlled environments with vehicles already manufactured [28]. The equations that allow determining the behaviour of a material during an impact test are those that determine the toughness of an element. Charpy's pendulum is a clear example of the use of energy conservation equations and energy that is absorbed during the impact [29].

$$E = \frac{1}{2}mV^2 + \frac{1}{2}mg + \frac{1}{2}kx^2 \quad (20)$$

$$\tau = mg(h - h') \quad (21)$$

$$\tau = Pl(\cos\beta - \cos\alpha)g \quad (22)$$

where E is mechanical energy, m is the mass, V is the lineal velocity, k is the spring stiffness, x is the lineal variable in X- coordinates. The gravitational energy is τ, P is the pressure and l is the width of the disc.

VI. Aerodinamic Analysis of the Buggy Using Solid-works

The buggy's aerodynamics properties play and important function in the performance of the vehicle, but also in the safety and the comfortless for the passengers. The effect of the high speed in the aerodynamic properties reduces the vehicle performance because of the lift and drag forces developed. Therefore, an extensive aerodynamic analysis carried out in the wind tunnel can be necessary. However, due to difficulties to have access a proper and expensive laboratory, the software's for simulation aerodynamically process can be a good option.

This branch of fluid mechanics allows studying the effects that occur on solid bodies when there is relative movement between them and the fluid dynamics. As it was mentioned before, it's essential to determine the lift and drag forces for automobile design. A proper feature aerodynamic design allows reaching high speeds in less time, increasing efficiency and improving the vehicle's grip during curves [30]. Solid-works allows this analysis to be carried out, with initial conditions must be established, such as: type, speed and direction of the fluid. The determine software will perform a meshing of the design in question as well as than the previous analyses, with the difference that it creates a volume of fluid around the object of study in such a way as to create the aerodynamic map and calculate the lift and drag forces that are produced, in order to determine the effects that are generated on vehicle surface.

The air that circulates around the vehicle that generates aerodynamic forces to be analyzed is modeled as an in-compressible, isotherm and Newtonian flow. The equations that govern its behaviour are the Naiver-Stokes equations. Composed of the conservation of mass and conservation of momentum equations [31].

$$\nabla \times v = 0 \quad (23)$$

$$\rho(\frac{dv}{dt} + (v \times \nabla)v) = \nabla \times (v\nabla) - p\nabla \quad (24)$$

where v is speed of fluid, ρ is density, ∇ is fluid divergence and p is pressure. It is also important to define the equations of the coefficients of drag (C_d) and lift (C_l).

$$C_d = \frac{2F_d}{p_\infty |v|_\infty^2 A} \quad (25)$$

$$C_l = \frac{2F_l}{p_\infty |v|_\infty^2 A} \quad (26)$$

where F_d is resistance force, F_l lift force and A is the vehicle front section area.

VII. Results and Discussion

Mechanical Design Methodology (DM) is most regularly described as creative decision making to fulfil a stated need. The function of MD is to made more effective to achieve systematic procedures for machine designing. The MD's is highly documented for machine design procedure, however there is still a lack to fully use the MD as a framework for a systematic procedure for machine design. The design procedure started with two design methodologies, Design Thinking (DT) and Shigley's methodology, respectively. Both methods embrace our project to construction of a Buggy. Based on the DT, it was performed an extensive outlining of the project's requirements and needs. Design thinking is dealing problems that are ill-defined or unspecified, by re-outlining the problem in human centrist ways. In Principle, the DT process is iterative, flexible and focused on collaboration between designers and users, with an emphasis on bringing ideas to life based on how real users think, feel and behave.

The basics of the FEM was applied with MATLAB, to introduce a new scholar how the Finite Element Methods works. Furthermore, in order to be it applicable and it could be interesting, some results will be compared with the standard software outcomes. All the structure analysis was carried out by the software, Solid-works. This software is an integrated design tool to aid simulate physical behaviour, such as, temperatures, kinematics, dynamics stress, deflection, vibration which can be used for all type of design.

The design's requirements for the buggy's main frame were length 3 m, and wide 2 m, and height of 1.8 m, respectively. The buggy will be designed to carry about a weight of 150 kg. The total drive torque that has to apply on the buggy to make it move, it has to count force to push up a gradient, force to overcome the rolling resistance of the wheels, force to overcome aerodynamic drag and force. Based on the above data the power needed is about 30 HP Based on the initial analysis of reaction forces and deformations. The engine will be located in the rear of the buggy, so there is a configuration of two support bars to mount the engine, since it was supported by two bars, the force produced by the weight of the motor was divided by two and a uniform distribution was assumed. Fig. 7 shows the bar to be analyzed. The results of the reactions in the system are:

F_1=0.3680 [KN] M_1=0.0569 [KN-m]

F_4=0.3680 j[KN] M_4=−0.0569 [KN-m]

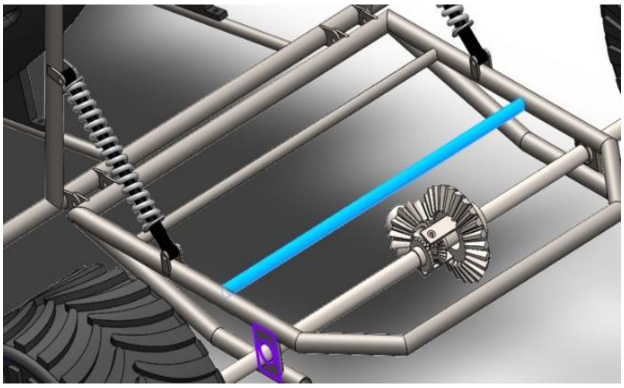

Figure 7. Engine support bar.

The piece to be analyzed is a "Y" frame whose purpose is to serve as a union between the main part of the structure, the tires and the front and rear shock absorbents. Fig. 8 illustrates the static analysis performed. Fig. 8(a) is the principal stresses analysis, the maximum stress is 112.21 MPa, applied a load of 2000 N both in the vertical and horizontal directions. The obtained values are below the elastic limit reference of the material (ASTM A36) which is 250 MPa, so it can be concluded that the deformations that occur in the piece will not exceed the elastic zone of the stress-strain curve of the piece. On the other hand, results in Fig. 8(b) the deformations are in millimeters, where the maximum deformation is in the middle part of the piece, the result of the analysis is considered correct because the deformation produced is almost imperceptible. Fig. 8(c) represents the obtaining result of the safety factor analysis, which is 2.2. It can be which is considered a successful result due to the importance of the part in terms of safety and operation within the vehicle design.

The fatigue analysis was carried out for all the elements of the buggy's structure. Fig. 9 shows a typical fatigue analysis of the planetary gear. It will be illustrated the fatigue analysis which is the largest planetary present in the differential. This element is essential for the movement and correct operation of the vehicle's wheels, which allows the wheels to turn tires at different speeds in order to maintain proper stability on the buggy. Based on the literature review (Shigley), the material selected for this piece was 1023 steel, which has a modulus of elasticity of 2.05×1011 N/m^2. It has 25 teeth, a modulus of 7 mm and a pressure angle equal to 35 °.

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The obtained results for fatigue analysis can be define that there will be no fatigue failures in the main planetary which belongs to the vehicle's differential. The percentage of damage caused by cyclic loads is 0.0001%, which indicates insignificant effects on the integrity of the piece. On the other hand, we have the gear life span, which is greater than a trillion cycles, an appropriate value taking into account that it is an element that will be constantly subjected to cyclic loads during its useful life. As was mentioned before, to obtain the results closest to reality, the factors of Marin to obtain the new value of the modulus of elasticity equal to 1.7×1011 N/m^2, it is also worth mentioning that the Söderberg criterion was selected as the basis of the analysis in Solid-works.

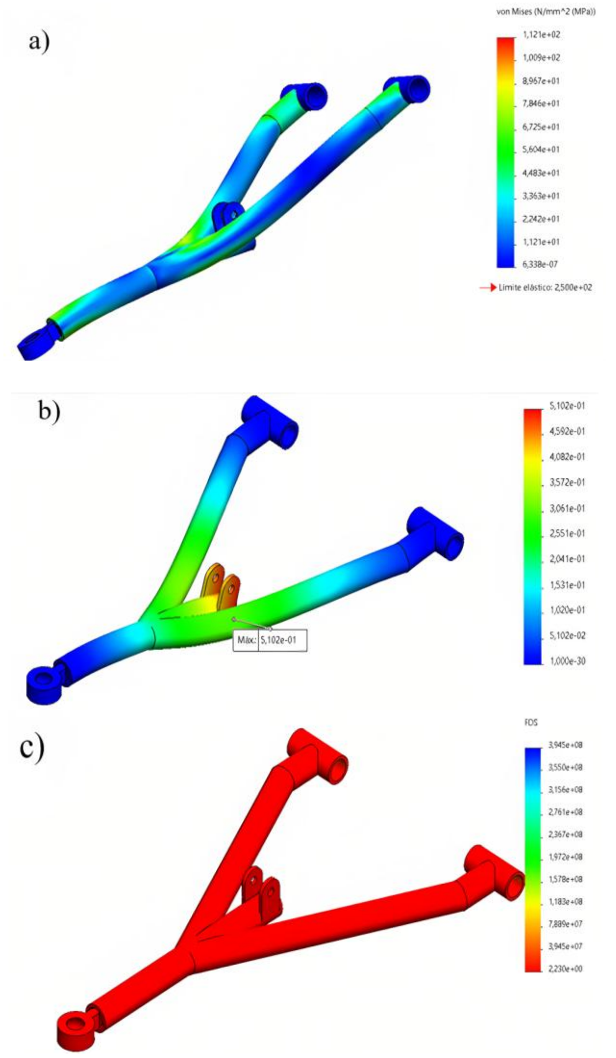


Figure 8. Static analysis of support Y frame. a)Principal stress analysis with forces applied in vertical and horizontal direcctions ,(b) Results of the structure`s deformations, (c) Results of the safaty factors analysis.

Due to the importance of the Tresca's criterion to define the maximum shear. It was included in the calculation of the structures [15]. Table II shows the total obtained results of the static analysis of the buggy's structure. It can be stressed out that all the elements are below the reference values.

TABLE II. STATIC ANALYSIS`S RESULTS

No		Von Mises	Displacements	Safety Factor	Safety Factor (Tresca´s Criterion)
		[Mpa]	[mm]		
Structure					
1	Main Frame	103.9	1.774	2.41	2.05
Gearbox					
2	Input Shaft	14.53	0.002412	1.9	1.62
3	2th input shaft	92.97	0.0022	3.3	2.81
4	E2 Up (Gear 2th Speed)	111.3	0.018	2.54	2.16
5	E2 Down (Gear 2th Speed)	78.96	0.016	3.6	3.06
6	E3 Up (Gear 3th Speed)	66.35	0.1653	4.3	3.66
7	E3 Down (Gear 3th Speed)	73.64	0.015	3.84	3.26
8	ER (Reverse Gear)	92.97	0.0069	3	2.55
9	Ee Down	81.37	0.163	3.5	2.98
10	Output Shaft	20.2	0.0017	1.4	1.19
11	2th Output Shaft	93.7	0.002876	3.7	3.15
12	ER Down	96.59	0.91	2.93	2.49
13	ER Up	26.53	0.006323	1.1	0.94
14	Sleeve gear	52.43	0.00141	5.25	4.46
15	Secondary Shaft	15.53	0.014	1.8	1.53
16	E2 Up	198.4	0.01,83	1.42	1.21
17	Ee Up	143.1	0.024	1.98	1.68
Differential					
18	Main Gear	85.56	0.017	4.1	3.49
19	Little Piñon	39.93	0.0044	7.2	6.12
20	Transmission Pinion	349.7	0.016	1.5	1.28
21	Pinion	811.97	0.0069	3.462	2.94
Steering					
22	Rack Gear	10.11	0.0000087	2.11E+11	1,7935E+11
23	Pinion shaft	677	1	4.2	3.57
24	Pinion	48.75	0.0065	5	4.25

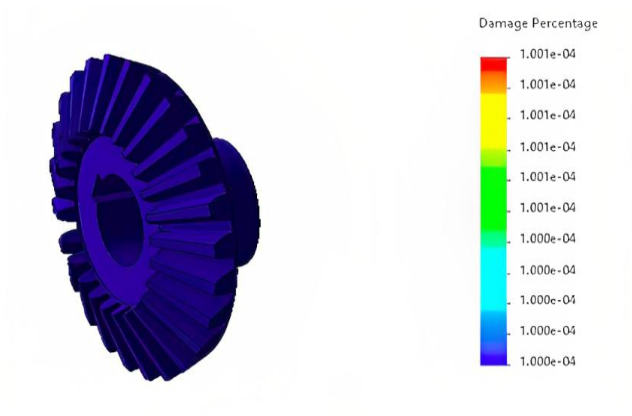


Figure 9. Planetary gear's fatigue analysis.

Table III summaries of the fatigue results for all buggy's element, all the elements fulfil the requirements.

TABLE III. RESULTS OF FATIGUE ANALYSIS

Elements	Fatigue	Damage
	#Cycles	%
Main Structure	1.00E+06	0.1054
Gear box		
Input Shaft	1.00E+08	2.086
ER (Reverse Gear)	1.00E+06	1.001E-04
E3 Up (Gear 3th speed)	1.00E+06	1.001E-04
E3 Down (Gear 3th speed)	1.00E+06	1.001E-04
Ee Down	1.00E+06	3.023E-02
2th Input Shaft	1.00E+06	4.034E-02
Output Shaft	1.00E+06	1.001E-04
ER Down	1.00E+06	1.017E-04
ER Up	1.00E+06	1.001E-04
Manga	1.00E+06	0.8043
2th Output Shaft	1.79E+05	0.01424
Secondary Shaft	1.00E+08	0.0042
E5 Up (Gear 5th speed)	1.00E+06	1.001E-04

Differential		
Main Pinion	1.00E+11	1.003
Secondary Pinion	1.00E+06	0.1433
Transmission Pinion	3.36E+04	2.3533
Steering		
Rack Gear	1.00E+06	0.00313
Pinion Shaft	1.71E+03	0.413
Pinion	1.00E+06	1.0434

Fig. 10 is the result of the structure resonance analysis of the minor input shaft belongs to the gearbox with a diameter equal to 19.05 mm and a height of 50.80 mm. For this study, the piece should not have the same structural natural frequency as the motor, in this case 50 Hz. The procedure to carry out this analysis consists of indicating the operating conditions of the element and its material. The Burst Random signal was used, as excitation source for the analysis. For this case, the material steel was chosen as ASTM A36. As it can be seen, the results of the 4 main frequencies of the piece when it is excited are found to be 5015.5 Hz, 5044.2 Hz, and 12939 Hz, respectively. To conclude that the piece will not enter into resonance during its operation condition and therefore there will be no faults, at least due to the structure resonance effects.

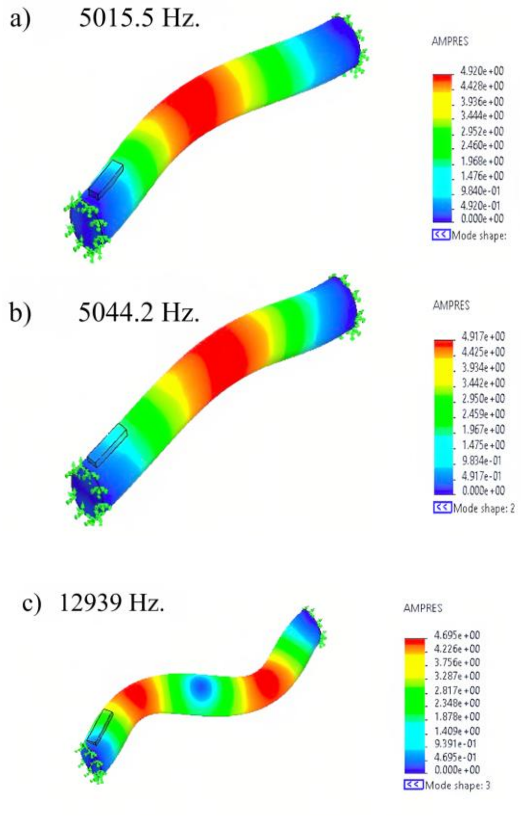


Figure 10. Structure resonance analysis of the minor input shaft,(a) Resonance at 5015.5 Hz,(b) Resonance at 5044.2 Hz, and (c) Resonance at 12939 Hz, respectively.

Structure resonance analysis is crucial for understanding and mitigating risks related to resonance effects. By identifying natural frequencies and designing structures to avoid resonance conditions, engineers can improve system integrity and reliability, minimizing failure risks from dynamic excitation's. Table IV denotes the results summering of the structure resonance analysis.

TABLE IV. RESULTS OF STRUCTURE RESONANCE ANALYSIS

Elements	Structure Resonance Frequency [Hz]			
	1	2	3	4
Main Structure	63.305	67.972	101.18	110.69
Gear box				
Input Shaft	10.574	8.9593	8.9528	1.1899E+5
RG (reverse gear)	3440.3	4934.2	5316.8	7655.1
E3 Up (Gear 3th speed)	5908.8	5913.2	6813.4	7941.6
E3 Down (Gear 3th speed)	3838.9	4139.3	4148.6	5042.2
Ee Down	5910.7	5912.9	6806.1	6812.6
2th Input Shaft	8.8004	30313	60575	90757
Output Shaft	0.002931	11353	22.431	34770
ER Down	42094	44998	45053	49061
ER Up	3142.8	3144.2	3779.8	3924
Arm	61690	61935	62094	62471
2th Output Shaft	0.00166	146.86	147.02	1502.7
Secondary Shaft	0.001144	8650	17281	25875
E5 Up (Gear 5th speed)	8889.3	10618	10620	12220
Differential				
Main Pinion	193.84	4942.1	5386.9	5595.2
Secondary Pinion	38048	58424	59479	62605
Transmission Pinion	0.000775	25414	25527	26059
Steering				
Rack Gear				
Shaft Pinion	25500	26348	26909	34457
Pinion				

The brake's thermal analysis was performed with the forces that are exerted on the disc, by using the theory exposed in the book of Design in Mechanical Engineering of Shigley [15], Chapter 13, in addition the theory of energy conservation was used to find the heat produced by friction.

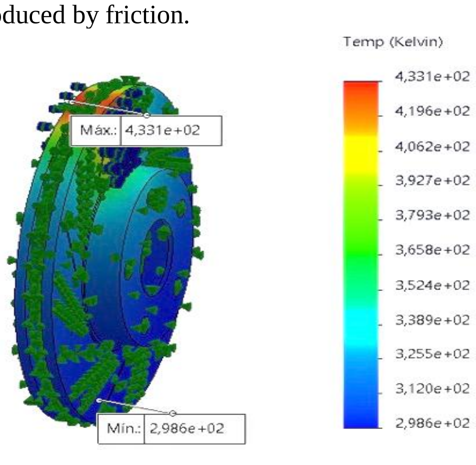


Figure 11. Disc brake's thermal analysis.

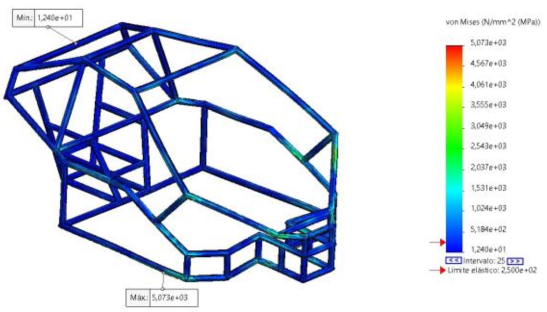
The measurements of the footings are taken as design data, with the external radius measuring 118.9 mm, the internal radius 79.5 mm and comprising a total of 28.92 °. In addition to above data, the torque that is applied is needed. It was found that this has an average magnitude of 360 [Nm]. It was also taken into account that it is a uniform wear process. The material to be used is gray nodular lamellar graphite cast iron with a friction of 0.35. With this data we calculate the pressure of 3,286.2 KPa and the force exerted on the disc of 1,750 N.

The disc's thermal analysis was carried out based on the studies belonging to Solid-works. It was necessary to calculate the heat produced by the friction between the contact of the pad and the disc, managing to find an average heat during the brake in the area of 100 Watts. Due to the speed with which the buggy moves, a convective heat transfer coefficient of 80 (W/m^2 K) is obtained. As can be seen in the following image, a maximum temperature of 433K was obtained in the area where braking occurs, this for a speed decrease from 60 km/h to 0 km/h in a time of 1.5s.

The same analysis is repeated for the other three-disc brakes, obtaining similar results.

The results of the three previous studies allow us to carry out the aerodynamic analysis of the vehicle body, based on the theoretical support stated in the document. The main objective of this study is to know the effects of the lift and drag forces generated by a fluid, in this case the air. Solid-works gives us the possibility to carry out this analysis in a simple way, the first step was to select the system of units that the analysis will use. In this case it was the international system, thereafter the air was chosen as the fluid that will interact with the design structure. Finally, a speed of 80 km/h was established for the air, considering an average speed of movement of the vehicle. The software produces a mesh around the body before performing the analysis, ensuring that the object of analysis does not have interior spaces that could affect the results.

The impact analysis presents the same analysis variables as the static with Von Mises, deformation and displacement analysis. However, for this analysis it is only necessary to establish the speed, acceleration, the impact direction, since the simulation consists of impacting the structure against a solid wall generated by the software. Fig. 12 shows the main frame impact analysis. The analysis was performed at different impact speeds, 140 km/h, 100 km/h, 60 km/h and 40 km/h, respectively. The obtained results can be determined that the structure will have a maximum deformation of 8 cm in the impact at a higher speed, which causes fracture in it. In addition to the fact that in all cases the maximum stresses are above the yield limit, however at 60 km/h and 40 km/h it only deforms, since it enters the plastic zone of the material, which means adequate values considering the impact speed. Table V summaries the obtained results of the impact analysis.



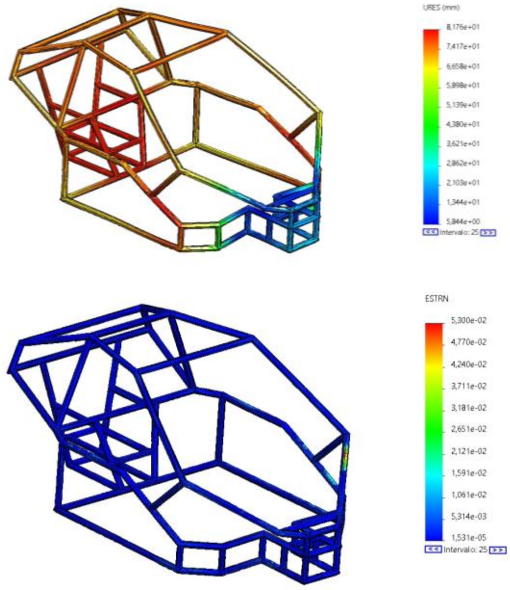


Figure 12. Results of the main frame's impact analysis.

TABLE V. IMPACT ANALYSIS RESULTS

Speed	Von Mises (MPa)	Displacements (mm)	Deformation
140	5,073	81.76	0.175
100	3,405	57.27	0.132
60	2,042	34.8	0.0817
40	1,298	22.76	0.053

The gear systems designed through software can be seen in Fig. 13, specifying the design process used to make each of the pieces. The first system made is the differential, an essential mechanism to control the rotation of the rear wheels during its displacement in curves. It is necessary to select the type of gear and enter the pressure angle, number of teeth and module data. All the gears used in this mechanism are conical with a pressure angle of 14.5° and the chosen material was 1,023 steel. The gear that transmits the power from the engine to the differential (#21) has 12 teeth with a module of 7 mm, the crown has 25 teeth and a module equal to the previous one (#18), the satellites have 12 teeth with a module of 2.5 mm (#19) and the planets have 25 teeth with a module of 2.5 mm (#20), respectively.

The gearbox was performed in the same way as the differential, this mechanism allows to modify the output torque or change the engine speed. It should be emphasized that the lower the torque, the higher the speed, the design consists of 5 speeds and reverse. Helical gears were used for the speeds in order to reduce noise and straight for reverse. The output speeds depend directly on the conversion factor calculated through the data of the gears used for each change, a speed of 1000 rpm was taken. In the secondary axis to carry out the calculations, the helix angle of the gears is 36.87° with a pressure angle of 20° and a diametrical pitch of 10 teeth per inch, the values of the teeth and factors are summarized in the following table.

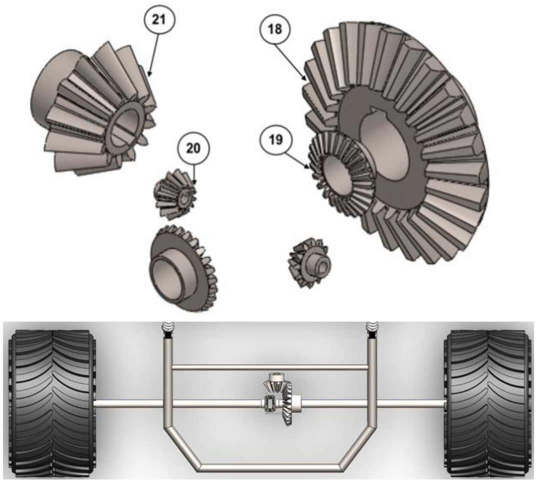


Figure 13. Gear box`s differential system

TABLE VI. GEARBOX DATA

No. Speed	Secondary shaft teeth	Output shaft teeth	Factor
First	12	42	0.29
Second	15	39	0.38
Third	20	34	0.59
Fourth	There is none because motor shaft is connected to output shaft for this speed.		1
Fifth	29	25	1.16

Fig. 14 represents the assembly of the vehicle's gearbox, as well as the differential, the elements are listed according to the order of the previous tables. The material used for the gears was an ANSI 1050 steel considering its resistance and toughness, for the sleeves and transmission shafts, aluminium and copper alloy was selected since they are the pieces that have major load.

The last gear mechanism designed was the steering system, Fig. 15, which allows the movement of the tires to perform maneuver in motion. It consists of a rack and a straight pinion, both have a pitch of 8 teeth per inch, however the number of teeth varies in each piece, the rack consists of 50 teeth unlike the pinion of 30, the ends of the rack are attached to bars that transmit movement to the wheels.

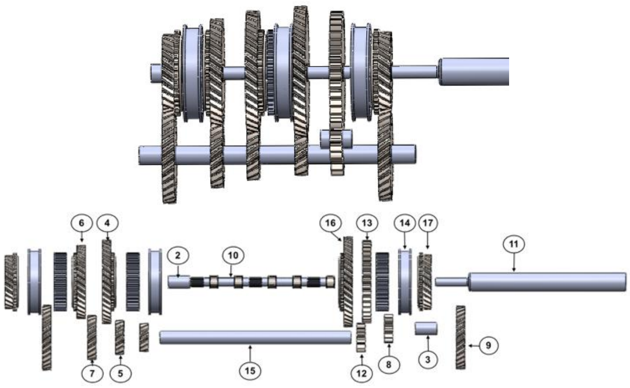


Figure 14. Gearbox.

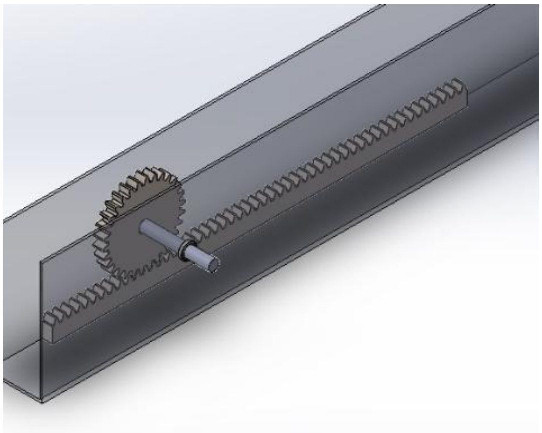


Figure 15. Steering system.

Finally, the assembly of all the pieces designed was carried out to obtain a vehicle with high specifications and that provides safety to the passengers, as can be seen in the following image, the vehicle has an aluminium body, PVC fenders and designed seats. The tires and shock absorbents were selected based on commercial catalogue; these elements were chosen based on design criteria in order to contribute positively to the designed model. The designed buggy, see Fig. 16, consists of a 30 HP electric motor, which allows it to move at a speed of 60 km/h, the vehicle has the following dimensions: 1.8 meters high, 2 meters wide, 3 meters long and a free height to the ground of 15 cm.

The most outstanding aspects of the design made are the presence of shock absorbents on all four tires to provide greater comfort while driving, space for a spare tire in the structure, aerodynamic design and low centre of gravity in order to provide stability to the vehicle.

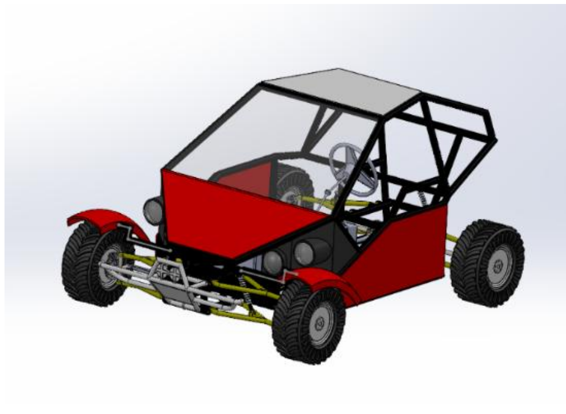
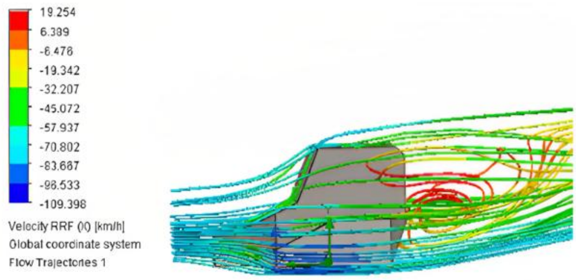
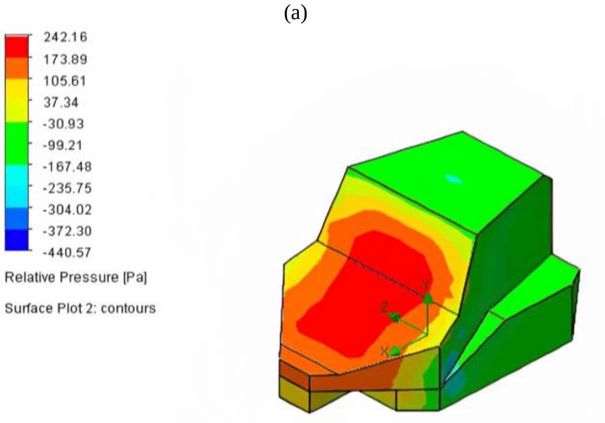


Figure 16. Final prototype of the designed Buggy.

The aerodynamic study has been carried out by iterations, constantly improving the design until obtaining the most appropriate based on the results obtained throughout the simulations, the evolution obtained by the 3 designs carried out is shown in Fig. 17, vehicle at a speed of 80 km/h. The images show the behaviour of the air and on the right side the relative pressure that the air exerts on the vehicle. The first design presents a certain angle of inclination of the windshield with respect to the hood, the presence of turbulence can be observed in the rear part of the vehicle in addition to high pressures on the bodywork. It produces drag forces that affect the performance of the buggy in movement. For the second design, the angle between the windshield and the hood was reduced, considerably reducing the presence of turbulence. However, the relative pressure values remain high. The modifications made for the final design are evident, since the hood is aligned with the windshield, in addition the sides were modified in order to dissipate the air and not generate turbulence, the pressure exerted by the air on the vehicle decreased without affecting the stability of the same generated by the lift forces obtained. Therefore, it can be considered that the final design is the most appropriate. It is important that there is an adequate amount of pressure to maintain the stability and maneuverability of the vehicle, both studies are complementary each other and ensure an effective design in terms of aerodynamics. The aerodynamic factor encompasses various characteristics that affect the aerodynamic behavior of an object or fluid flow, while the Naiver-Stokes equation provides a mathematical representation of fluid flow dynamics.



(a)



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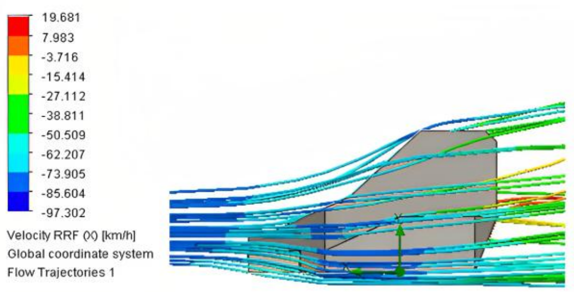
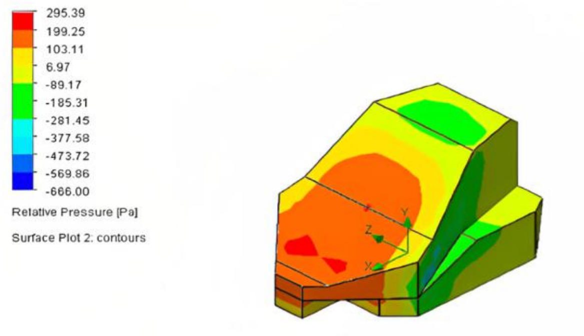
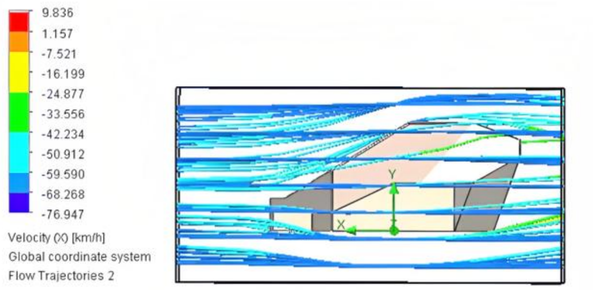


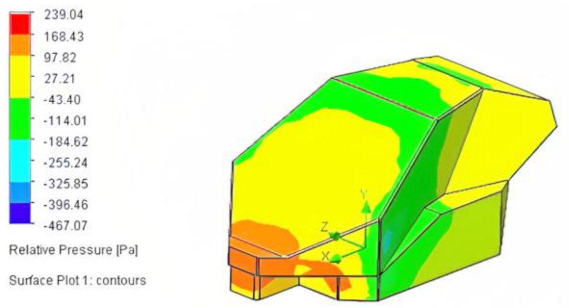
(c)



(d)



(e)



(f)

Figure 17. Aerodynamic analysis of the Buggy's structure.at 80 km/h, with three different models. (a,b) Initial model for analysis , (c,d) Reduced inclination of the hood respect to the windshield. (e,f) Final design, the hood and the windshield has the same angle

VIII. DISCUSSIONS

In this section, we discuss the obtained results of our research work, and we present practical implications of our work for researchers and design engineers. The complications that occurred throughout the work will be pointed out and recommendations will be established for the realization of future related projects, considering the aspects of design methodology, analysis and interpretation of the obtained data. The input data for each of the studies is essential since they determine the results obtained and their degree of reliability. For each analysis, various data must be entered, for example, for the static analysis, the forces and forces must be considered. The initial conditions have to be considered, while for the analysis a number of cycles must be established and the analysis criteria that the software will use. It should be emphasized that the studies are iterative processes since they depend strictly on the material of the machine element in question. Therefore, it is advisable to make a list of the most common materials based on their applications before carrying out the analyses.

Solid-works performs various analyses using the FEM module to facilitate the calculation. It was divided the buggy's structural analysis in several parts, in order to facilitate the analysis procedure. It performs a mesh with a number of variable nodes based on the precision sought, the greater the number of nodes, the greater the precision as well such as the simulation time and the resources of the equipment used. It was recommended that the number of nodes be slightly varied from that established by the software, in order to avoid very high simulation times. it must be avoided that there are interference in the model and a very low number of nodes since for these reasons the creation of the mesh fails.

Mainly for static and resonance analysis it is necessary to correctly establish points and types of fasteners, otherwise Solid-works will consider the model as unstable and the analysis will not be performed. In the same way it happens when auxiliary elements are present in the model.

The advantages of adopting a systematic approach to machine design, including reduced design time, improved accuracy, enhanced manufacture, and optimized performance. By following a structured methodology, engineers can streamline the design process, minimize errors, and deliver high-quality machines that meet customer requirements efficiently.

IX. Conclusions

The intention of this paper is to capture and bridge the gap among the methodology designing and the material structure analysis. In order to investigate and evaluate the usefulness of the proposed methodology a case study has been applied with the construction of a buggy. The Design Thinking and a Shigley Design methodology were implemented for creative problem solving. The design methodology used in this work allowed carrying out a great reliability in the results, thanks to the stipulated sequence of steps. It can be using as a framework for real-world mechanical design projects.

According to the results obtained, the most relevant findings of the investigation are presented below:

- The design requirements for the buggy's main frame where length is 3m, wide is 2m. and height of 1.8m, respectively. The buggy will be designed to carry about a weight of 150 kg.
- It was performed an extensive analysis of static, fatigue, structure resonance, thermal, aerodynamically and impact analysis, respectively. The obtained results were below the material reference values.
- Matlab and Solid-works were applied in a didactic way to introduce Finite Element Method (FEM).
- The total drive torque that has to apply on the buggy to make it move, it has to count force to push up a gradient, force to overcome the rolling resistance of the wheels, force to overcome aerodynamic drag and force. Based on the above data the power needed is about 30 hp.
- The cost of the designed prototype was found to be 48% lower compared to a similar model.

The advantages of adopting a systematic approach to machine design, including reduced design time, improved accuracy, enhanced manufacture ability, and optimized performance. By following a structured methodology, engineers can streamline the design process, minimize errors, and deliver high-quality machines that meet customer requirements efficiently.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Ruben Vasquez, Juan Rene, and Sebastián Paniagua conducted the structure analysis of all elements, and the initial writing of the paper; Grover Zurita designed and wrote the major part of the paper; all authors had approved the final version.

Acknowledgements

The authors want to express their gratitude for the support of the "Bolivian Private University".

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