Design and Torsional Rigidity Analysis on Frame of Formula Garuda 17 Based on Student Formula Japan 2017 Rules

Z Arifin¹, I N Yoga¹ and J F Zain²

¹Department of Automotive Engineering Education, Universitas Negeri Yogyakarta, Indonesia
²Department of English, Faculty of Arts and Language, Universitas Negeri Yogyakarta, Indonesia

E-mail: zainal_arifin@uny.ac.id

Abstract. The objective of this study are to: (1) Produce the design of the Formula Garuda 17 car that complies with Student Formula Japan 2017. (2) Produce the frame design of the Formula Garuda 17 car that has a torsional rigidity that can withstand bending and twisting loads. The type of research used is research and development, also known as R & D, and the development model of the Formula Garuda 17 car frame, which is a model for developing Analysis, Design, Development, Implementation, and Evaluation (ADDIE). The results showed that the frame design was in accordance with Student Formula Japan 2017 regulation, and the torsional rigidity value met the target of 1,026.7NM / degree while the Factor of safety value in the bending force was 3.3 so that this frame was categorized as safe for the race.

1. Introduction

Student Formula Japan is a student class formula car competition where participants are not only required to make the fastest car, but also pay attention to the aspects of vehicle design that are contested in the Design Presentation, the manufacturing process and the financial prices that are contested in the Cost & Manufacture Event, as well as the marketing business. the car which will be contested in the Business Presentation. Apart from the three Static Events above, there are also Dynamic events that include Acceleration, Skid pad, Autocross, Endurance & Efficiency. Before the vehicle is manufactured, the Team must send the Structure Equivalency Spreadsheet (SES) and Impact Attenuator Data (IAD) documents and these documents must be approved and declared passed by the committee, which will be the approval document from the committee used as a condition for participating in a technical inspection. To be able to participate in a series of dynamic events, a car must first pass various tests, namely the Technical inspection, Tilt test, Weight test, Noise test, and Brake test.

In the initial design aspect of the Formula Garuda 17 (FG17) vehicle, it must pay attention to various aspects, especially regarding compliance with regulations in the competition, this is very important to ensure the concept of the framework design in the form of a Structure Equivalency Sheet (SES) report can be approved by the committee as a series of stages. Technical Inspection. In addition, the analytical aspect in the design is also very necessary to minimize failure part after the component is produced. Based on the 2017 Student Formula Japan regulations, one of the components the committee pays attention to is vehicle frame. The team that chooses to use the Steel Space Frame must have a main frame structure which includes Main roll hoop, Front roll hoop, Front bulkhead, Roll hoop bracing and support, Front bulkhead bracing and support, and Side impact structure [1].
Figure 1. Regulation frame Student Formula Japan 2017.

The FG 17 frame design is designed to pass the Technical Inspection smoothly and to reduce weight but still ensure that the torsional rigidity of the frame can withstand bending and twisting forces, and the frame torsional rigidity significantly affects vehicle behaviour and handling [2] So it is necessary to do an analysis in designing the framework. Increasing torsional rigidity is an important goal in automotive design, a more practical measurement serves to involve torsional rigidity and vehicle mass to ensure an increase in torsional rigidity will not add to the weight of the vehicle [3]. The software used to design and analyse the frame on the Garuda Formula car 17 is Solid works 2018 with Finite Element Analysis to determine the strength of the frame.

The development procedure for the Formula Garuda 17 car frame according to the ADDIE development model can be seen in the following explanation:

1.1. Analysis
The analytical activities in this study include a study of the regulations that apply to the 2017 Student Formula Japan competition related to vehicle frames, then continued with literacy studies regarding vehicle frames, especially for racing needs, as well as an analysis of the Garuda Formula 16 car frame. At this stage the FG 17 concept was developed in accordance with the results of the analysis of FG 16 in accordance with applicable regulations. In addition, through this stage the researcher is able to determine the target of the frame to be made both in terms of frame weight and from the required torsional rigidity value.

1.2. Design
The design stage is carried out after the researcher knows the results of the performance analysis of the Garuda Formula 16 frame and understands the regulations of Student Formula Japan 2017, especially those related to the vehicle frame and has determined the target of the vehicle frame, both the target regarding the frame weight and the value of the desired torsional rigidity. There are several stages in this design activity, the first is making a 3-dimensional design using Solid works 2018 software where all measurements regarding length, distance, dimensions and thickness of the pipe, as well as the angles formed by the frame structure have been adjusted to the applicable regulations.

Next is a product analysis regarding the torsional rigidity of the frame using the Finite Element Analysis at Solid Works 2018 where the results will show how much deformation is at the load point in millimetres (mm) and then these results are entered into the formula to calculate the torsional rigidity value of the frame. If at this stage the results of the torsional rigidity analysis have not met the target, then a re-design and re-analyse can be done until the specified target can be achieved.
Then after the design and targets have been achieved, a Structural Equivalency Spreadsheet (SES) document is prepared which will then be uploaded to the committee website before the frame design is manufactured.

1.3. Development
The development carried out is the answer to several problems that have been described on the background of the problem, namely design changes to ensure the framework meets regulations and there are no major repairs during a technical inspection. Then the target of SES collection also corrects previous mistakes where revisions must be made 2 times, in addition to reducing the weight of the frame with a target of reaching 2Kg is also one of the developments carried out.

1.4. Implementation
Then at this stage it is an application of the design made in the form of a Garuda 17 Formula car frame product. Making the Garuda 17 Formula car frame refers to the SES report that has been approved by the committee so that it can pass the technical inspection stage.

1.5. Evaluation
Evaluation is carried out to find out several things including the accuracy of the vehicle frame weight target, then evaluation from the committee through the answers from the SES sent and also during the technical inspection will evaluate whether the frame has passed the regulations or not, if it passes it will be marked with a pass sticker by the committee [4].

2. Methodology
Data collection techniques in this study include taking vehicle weight data with the SolidWorks 2018 software and weighing the original test. Then data regarding the torsional rigidity value of the frame can be obtained through the results of the Finite Element Analysis simulation, which is then entered into the formula to calculate the value of torsional rigidity with the equation below [5].

\[
\text{Torsional Rigidity} = \frac{\text{Torque Load}}{\text{Angular Deflection}}
\]

3. Result and Discussion
From the results of the research conducted, there are several results obtained, including:

3.1. Structural Equivalency Spreadsheet
The results of the corrections from the committee stated that the design of the Garuda 17 Formula frame was OK even though there was a calculation error regarding the number of pipes in the Main hoop brace support which should have been counted as 2 pipes, but the jury accepted it and the SES that had been submitted was still declared passed. The SES that was sent received approval from the committee because of the total 13 entry sheets sent to the committee, all designs were in accordance with the applicable regulations.
3.2. Torsional Rigidity

Vehicles traveling at high speed and in turning conditions will produce a rolling effect on the vehicle frame which affects the driving stability effect, therefore the rolling effect that occurs on the vehicle is minimized so that the vehicle remains stable even though it turns at high speed. From the analysis of the first case study regarding torsional rigidity, the displacement maximum/angular deformation was obtained 0.84426mm. To determine the angle formed, the angular deformation distance must be divided by the centre distance, which is 500mm.

\[ \psi = \frac{0.84426\text{mm}}{500\text{mm}} = 0.0017\text{rad} \]

The angular displacement results were obtained 0.0017rad or 0.0974°. Next, to calculate the torsional rigidity value, is to enter the data into the formula

\[
\text{Torsional Rigidity} = \frac{\text{Torque Load}}{\text{Angular Deflection}}
\]

\[
\text{Torsional Rigidity} = \frac{100\text{Nm}}{0.0974\degree} = 1026.7\text{Nm/degree}
\]

Torsional rigidity is how big the frame is will flex when under load and one front wheel rises and the other front wheel drops while the rear of the frame is held, this condition occurs especially when the vehicle is in the cornering position. If the torsional rigidity value reaches or exceeds the set target, the vehicle will remain stable even though it is in the cornering position at high speed, but if the torsional rigidity value does not reach the desired target, there will be a rolling effect on the vehicle when cornering, causing reduced driving stability.

The torsional rigidity target is 834Nm/degree, while the analysis result reached 1,026.7Nm/degree. From these results, it can be concluded that the torsional rigidity value of the Garuda 17 Formula frame design has reached the predetermined target so that when the vehicle is driving at high speed and turning, the stability of the vehicle will be maintained because the resulting rolling effect is able to withstand the...
torsional rigidity value of order. Then to find out whether the weight of the frame has reached the target of 2kg reduction from the weight of the previous frame, measurements were taken through software and the result was the weight of the Garuda 17 Formula frame design. 31.11 kg, which means that the frame weight reduction has been successfully carried out by 2.08 kg and has met the target.

![Figure 3](image1.png)

**Figure 3.** Displacement torsional rigidity.

### 3.3. Bending Force

All components whose loads are held by the frame will produce bending loads during both static and dynamic conditions. This load will affect the strength of the vehicle frame, therefore the vehicle frame must have sufficient strength to withstand this bending load so that the frame remains safe for use in competitions. From the analysis of the second case study regarding bending force, the maximum displacement of the driver seat is 0.877mm with a maximum stress value of 50.068Mpa, but this load is still categorized as safe because the minimum factor of safety is 9.19. While the load on the engine results in a maximum displacement of 2.23mm with a maximum stress value of 137,527Mpa and the minimum value of the factor of safety is 3.34 so it is still categorized as safe. By considering the results of the analysis in the second case study, it can be concluded that the design of the Garuda 17 Formula frame is able to withstand bending forces caused by other components so that the frame is safe to use for competitions.

![Figure 4](image2.png)

**Figure 4.** Factor of safety bending force.
3.4. Technical Inspection Results
After the SES was approved, the Garuda 17 Formula frame was manufactured as approved by the committee. After all the manufacturing processes have been completed, then during the 2017 Japan Student Formula competition, the Garuda UNY Team participated in a series of Technical Inspections which were held on Tuesday, September 5, 2017 at ECOPA Stadium, Shizuoka, Japan. In the Technical Inspection that was carried out, there were about 102 items that were checked, and the result was that most of the items checked were in accordance with regulations, including vehicle frames that did not experience problems, but there were 2 minor errors, namely the safety wire pattern on the wheel hub nut and the distance of the brake hose. with a double A-arm that is too close, however this can be resolved by the team immediately so that the Team can immediately pass the Technical Inspection on the first day and get a pass sticker from the jury as evidence.

4. Conclusion
Based on the research that has been done, as well as a description of the research results and the discussion that has been done, it can be concluded that (a) the design of the Formula Garuda 17 car frame is in accordance with the applicable regulations in Student Formula Japan 2017, this is evidenced by the results of the Structural Equivalency Spreadsheet which was declared OK by the committee and the success of the Garuda Formula car to pass the Technical Inspection stage as evidenced by the obtaining of a pass sticker from the committee; (b) the set torsional rigidity target value that is above 834Nm/degree has been achieved through the results of the analysis using Solid works where the results show the torsional rigidity value of the Garuda 17 Formula frame design is 1,026.7Nm/degree and the frame weight reduction target of 2Kg has also been achieved because of the weight of the Formula frame. Garuda 16 of 33.19Kg reduced to 31.11Kg on the Garuda 17 Formula frame, so the weight is reduced by 2.08Kg; and (c) the results of the frame strength analysis to withstand the bending force also reached the target because from the results of the analysis, the maximum displacement that occurred in the frame was only 2.76mm, then the maximum stress was 138.256MPa and the factor of safety which became a reference for safety or not also had a minimum value 3.33 which is categorized this frame is safe and able to withstand bending forces.

5. References
[1] SAE International 2017 2017-18 Formula SAE Rules [Online] https://www.fsaeonline.com/
[2] Velie H D 2016 Chassis Torsional Rigidity Analysis for a Formula SAE Racecar (Michigan: University of Michigan)
[3] Tebby S, Esmailzadeh E and Barari A 2011 Methods to Determine Torsion Stiffness in an Automotive Chassis (Ontario: University of Ontario Institute of Technology)
[4] Branch R M 2009 *Instructional Design-The ADDIE Approach* (New York: Springer)

[5] Dassault S S 2011 *SAE Design and Analysis Project with SolidWorks Software* (USA: Concord)

[6] JSAE 2017 *Student Formula Japan 2017* [Online] https://tech.jsae.or.jp/formula/2017team_en/login.aspx.