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**Literature Review Matrix:**

**Research Question: How can I apply researched designs and studies on formula vehicle frames to the further develop the SAE Formula team?**

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|  | **Source/Evidence/ Data #1** | **Source #2** | **Source #3** | **Source #4** | **Source #5** |
| **Citation** | Abdullah, Mansor, Mohd Tahir, Kudus, Ikhwan, Hassan, and Igadiman, 2012 | Abrams et al., 2008 | Jawad and Polega, 2002 | Bullen and Karri, 2002 | George and Riley, 2002 |
| **Purpose** | 1.) Explains the design of the Space frame chassis used widely in formula vehicles.  2.) The design and alternations made to the design during the process of physical assembly give important footsteps for the SAE Formula Project.  3.) The design is joined with other aspects of the project to analyze the vehicle as a whole. | 1.) To evaluate the stiffness of a chassis when using the engine as a part of the frame.  2.) To decrease deformation and deflection along the beams of the chassis when providing proper support near the engine block.  3.) Properly simulate the design and analyze the results of incorporating the engine into the chassis supports. | 1.) Explain important components of formula suspension design, and what designs provide ideal durability and performance.  2.) To reduce the cost while designing the suspension system, reduce the weight of the design, and increase the strength of the design by careful material selection.  3.) To explain the importance of each component role in the suspension of the formula vehicle. | 1.) To develop skills of project management geared towards the SAE formula project.  2.) To apply knowledge of engineering discipline and learn management skills and the design process.  3.) Expanding and applying research knowledge in the professional field of engineering. | 1.) The study identifies different factors taken in when designing a frame for an SAE formula vehicle. The model design for the chassis examines torsional force effects acting on the frame of the vehicle using finite elemental analysis.  2.) Compares the simulation of torsional stress on the frame versus a physical frame test against torsional stresses. |
| **Why is the study necessary?** | 1.)The article integrates all aspects of the vehicle for testing and evaluation, which shows all aspects in the design process.  2.) The study shows the importance of an effective and operational frame for a formula vehicle.  3.) Shows importance of the integration of design software and simulation. | 3.) Deformation due to stresses and vibration are a high factor in failure of a frame or chassis for a performance vehicle.  2.) If the frame deflects, other parts in the formula vehicle can also be severely damaged besides the frame itself.  3.) Any reduction of deformation can help further the design for the SAE Formula project. | 1.) The budget of the project and overall performance of the design is the main tradeoff when designing the suspension system for the SAE formula project.  2.) Basic designs in mechanics are shown in the suspension design and evaluated through testing, which help further the overall success of the vehicle. | 1.) The study helps develop skills in management, applying the design process in projects, and to utilize the skills learned in mechanical engineering.  2.) It incorporates all aspects of engineering, and calls for branching outside of the field to incorporate different aspects of project management. | 1.) The ability to distribute forces effectively along the frame of the vehicle is a very important factor in helping to avoid load concentrations.  2.) The ability to properly compute through simulation with close approximations are useful to designing the frame because the effectiveness of the simulation compared to experimental results will save time and money.  3.) Torsional stresses can severely affect the handling of the formula vehicle. |
| **Methods** | The chassis is first designed using a Solidworks software.  The chassis is loaded past the maximum weight experienced by the motor, driver, suspension, and transmission to evaluate stress along the frame.  2.) Different strains including torsional stress and bending stress are computed to help identify where key weak points lie along the frame.  3.) The frame is tested about different forces experienced from acceleration, deceleration, and variable loading.  4.) The design is then altered and tested along the same environment as the first.  5.) The two designs were welded using the square steel rods proposed in the simulations. | 1.) The article identifies which kinds of stiffness are be ideal for different forces acting on the frame.  2.) The chassis is evaluated with supports along the engine and then without supports to measure the different frequencies of vibration experienced throughout the supports.  3.) The ideal frequencies are intended to minimize strain energy throughout the frame.  4.) The study uses a mesh beam when simulating the forces acting on the frame to ensure the most ideal results when analyzing the data.  5.) The design was tested in free space representation, to show all degrees of freedom for bending and rotation.  6.) The designs were simulated through 3 elastic modes in vibration to help analyze what frequencies were experienced during different modes. | 1. The control arms are selected to ensure roll stability of the vehicle. The control arms help unify the suspension and chassis, and also are adjusted for different roads for competitions. 2. The type of steel used for the control arms are determined through stress analysis simulations. 3. The uprights for the ball joints are then selected based on weight-ratios. To ensure the selected material for the uprights, several materials were tested for durability along deceleration and sharp turning. 4. The wheel hubs are then chosen for wheel and tire rotation. The main factor taken into consideration is weight and friction. The hubs use bearing that are pressed in them to reduce friction, and clover geometry to reduce weight. 5. Rockers are implemented into the design to connect to the suspension shocks. The rockers help keep the shocks inside the frame to protect them from deformation and damage. The material selected for the rockers is evaluated through finite elemental analysis, to ensure weight and strength tradeoffs. | 1.) The article identified which design aspects were needed to begin the formulation of the vehicle.  2.) The frame requires computer aided designs to determine the appropriate materials, and also eliminates different materials by using finite elemental analysis.  3.) The study split the project group into different roles for designing the frame and engine of the vehicle. Splitting the groups requires communication between the different groups in order to manage time, budget, and an expected completion date. | 1.) The different stresses are broken down into different parameters.  Bending stresses occur due to weight from the driver and the engine act normal to the frame, causing bending in the frame. Lateral stresses are due to the layout of the road and sharp turning causing stress acting parallel to the frame.  Stresses acting when the rear and front wheels force in opposite directions.  2.) Strain gauges are used to compute these forces over a period of time, the time frame is converted to frequency to evaluate vibrational effects.  3.) A model is created using solid works, breaking the frame into its components and nodes.  The ideal chassis has an infinitely rigid structure.  4.) The engine is then integrated into the frame to ensure all aspects contributing to stresses.  5.) The dynamic effects are also taken into consideration included with the static analysis of the structure. The stiffness is evaluated based on the torsional forces acting while the vehicle corners, this causes the frame to deflect to an angle.  6.) The frame is measured from the difference of the spring deflection in the suspension. |
| **Results** | 1.) The alternative design showed an increased safety factor along all aspects except for torsional forces.  2.) The two designs had sufficient safety factors for physical fabrication.  3.) The assemblies showed reasonable tolerances for the simulated forces acting on them. | 1.) The results showed the first design, which did not support the engine with the chassis, experienced lower natural frequencies than the design with supports.  2.) The lower natural frequencies indicate that the frame is more likely to deform and experience torsional deformation.  3.) The simulation shows diagrams of different stages in the elastic modes when the frame is deflecting and deforming.  5.) The deformations for both designs were evaluated in a static analysis. | 1.) The materials were evaluated through simulation based on the weights ratio compared to the materials strength.  2.) The assembly showed no signs of failure, and was used in the SAE Formula Competition.  3.) There were no failures when competing with the suspension design used. | 1.) the group completed the project for the competition.  2.) All departments of engineering were involved and inter-disciplined with one another.  3.) the group learned valuable skills about communication and project management which helps prepare the group for the professional field. | 1.) The results are compared to an experimental torsional test while the frame and suspension is lifted onto jacks.  2.) The results of the values obtained from the simulation are compared to the experimental test on the frame. The percent differences are off by the highest of 7% on the front of the frame. This shows the elemental analysis of the computer design is an acceptable means of experimentation. |
| **Discussion/Conclusion** | 1.) The assemblies showed reasonable tolerances for the simulated forces acting on them.  2.) The road testing for both designs worked well with the project, and the frame simulation has been used since. | 1.) The simulation helps show where and why certain deformations occur in a chassis when subjected to different forces.  2.) The design with supports along the engine showed a large increase in resistance to bending and torsion.  3.) The design is being further researched to decrease cost and weight, while trying to maintain the stiffness resulted. | 1.) The article explains how each component was tested thoroughly using finite elemental analysis before implementing it into the design.  2.) Each component needed to meet various requirements to ensure safety of the driver and the vehicle itself. | 1.) The aspects of computer design is a major way to reduce the budget cost of the formula project.  2.) Using computer design to simulate and analyze is a great alternative to calculate materials needed and the stresses that are experienced during operation.  3.) It helps demonstrate the design process and helps apply the aspects of project management. | 1.) The design analysis can only fully be determined by both experimentation and simulation.  2.) Comparing the results give multiple views of how the vehicle should act versus what physically occurs. This is mainly due to assumptions made about the complete rigidity of the elemental design.  3.) The simulation helps save money from repeating physical experimentation, and can be a quick way to analyze a possible flaw in the frame design. |
| **How can this help my senior project?** | The force simulations provide data for where problems may occur when fabricating a frame.  The methods of identifying which forces are important to test for when building a frame provide a solid foundation for planning and analyzing a design. | The article points out which stages of elastic deformation due to vibrations are dominant when applying forces to the chassis of a formula vehicle.  The design and stress analysis are contributed by weight, beam design, support location, and material selection, which can help further understanding of frame design. | The article shows how using finite elemental analysis to determine suitable materials, based upon weight and strength, is a very important and useful tool for designing the formula vehicle.  The simulation saves money and helps understand what key factors may affect the overall performance of the vehicle. | The study helps break down the importance of communication between the project group and all departments of engineering and sciences.  The computer aided design is a great aspect to apply to the Formula project to help manage time and budget of the project. | The article helps show how to compare the experimental data to that of the simulated data. The two experimentations can help save time and save money on the project budget. The amount of detail given about the design process and stress analysis helps give a direction on where to start when designing a frame. |

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[1] M. A. Abdullah, M. R. Mansor, M. Mohd Tahir, A. Kudus, S. Ikhwan, M. Z. Hassan*, et al.*, "Design, Analysis and Fabrication of Chassis Frame for UTeM Formula VarsityTM Race Car," 2012.

[2] R. Abrams, "Formula sae race car analysis: simulation & testing of the engine as a structural member," in *FISITA 2008 World Automotive Congress, Munich, Germany*, 2008.

[3] B. A. Jawad and B. D. Polega, "Design of Formula SAE Suspension Components," SAE Technical Paper2002.

[4] F. Bullen and V. Karri, "Design and construction of a Formula SAE racecar in a teaching and research framework," *Quality conversations: Research and development in higher education,* vol. 25, pp. 74-82, 2002.

[5] W. B. Riley and A. R. George, "Design, analysis and testing of a formula SAE car chassis," SAE Technical Paper2002.