Introduction
The Central Michigan University (CMU) Formula team requires a torsional rigidity test stand to experimentally determine the torsional rigidity of the Formula vehicle's frame. The team also requires a simulation involving Finite Element Analysis (FEA) to predict what the torsional rigidity of the vehicle's frame would be before the team approves the final design of the frame. The FEA simulation will also be used as a reference to determine the accuracy of the torsional rigidity test performed on the vehicle. These two values, the simulation and the experimental data, are opportunities for improvement for the SAE Formula team during their competitions. This will provide the customer with the ability to optimize the design of the frame, by reducing weight and increasing rigidity, leading to a faster, safer, and more successful race car.

Testing Process Design
The function of the test stand is to determine the strength and rigidity of the CMU Formula team’s vehicle chassis through torsional analysis. The torsion rack is designed to twist the frame of the vehicle by applying load at one of the wheel uprights. This applied load is resisted by the overall stiffness and strength of the chassis. The chassis’s response to the load is directly related to the material and geometry of the chassis. Through the applied load, parts of the chassis will flex and twist creating a rotational displacement on the front mounting beam. The rotational displacement of the front beam is captured by an accelerometer sensor that detects the change of angle in 3D space. The RasPad is connected to a touchscreen tablet to allow for mobility and ease of use for the Formula team. The Graphical User Interface (GUI) is also designed to take any guess work in the experimental method and prompt the user to properly utilize this test stand. This experimental test, combined with a Finite Element Analysis simulation performed on the chassis can identify areas of improvement or overbuild for the SAE Formula team to improve the overall design of the car.

FEA Testing
The FEA simulation was conducted to verify the experimental results of the test stand, and to allow the Formula team to run simulations on different frame designs for the future before having to actually construct the vehicle frame. Figure 2 below depicts the deformed vehicle frame of the Formula team’s most current car. Under the applied load of 100 lbs located 21.8 inches away from the center of the vehicle the torsional rigidity was recorded at 14,592.8 in*lbs/deg having a maximum rotational displacement of 0.1494 degrees.

Front Beam Stability
Due to the large torque applied to the system as part of the overall design, careful calculations had to be made into whether the applied torque would cause the test stand to tip over while in operation. The test stand’s versatility allows for a wide range of adjustment and length. This calculation required statics analysis to ensure there would be no concern with the test stand tipping over for any size chassis. The front concrete block is being put in the middle of the front beam and will not be offset towards the opposite side of where the load will be applied for total equilibrium. Previously, the front concrete block was offset in order for the applied load to be in complete equilibrium. This was due to the Middle Third Rule, which states no tension is developed in a foundation if the resultant force lies within the middle third of the structure. This theory is based on a civil engineering concept, so the location of the pivot will be placed in the middle of the front beam, and the front concrete block will be in the middle as well. The design of this concept is rigid enough any tipping will not be of concern based on where the center of gravity lies on the front beam. The resultant force from the front beam lies within the middle third of the beam which means that stability will be ensured. The center of gravity lies at 3.03 feet mark alongside the beam from all the moments caused by the front beam, front concrete block and the applied load which satisfies the Middle Third Rule, meaning that stability will be satisfactory for the location of the pivot and the size of the front concrete block for the testing at the center. The concrete blocks weigh enough to prevent any rolling or tipping of the test stand when the vehicle frame is on the stand with the applied load.

Manufacturing
All manufacturing of the test stand was conducted within the CMU machine shop. The bulk of the work was completed on the plasma cutter for cutting slots and holes in both the rear and front beams using drawings created on CAM software. Slots in the front beam allow the test stand to adapt to different size chassis, as regulations are subject change every year. Holes for the hub mounts were drilled and the pivot plate was hole punched and welded. Concrete was mixed and poured in custom built forms to ensure proper dimensions of concrete blocks.

Measurement
A 3 axis accelerometer is used detect the acceleration of gravity in the x,y and z axes. The 3 components vectors result in a single directional vector. By comparing the reference vector and the resultant vector, an angle change is calculated with the vector algebra rule:

\[ \cos(\theta) = \frac{V_x \cdot V_{ref}}{|V_x| |V_{ref}|} \]

The dot product of the reference and resultant vectors divided by the magnitude of the reference and resultant angle. The angle change of the front beam shows how much the chassis twists. Using the amount of torque applied by the front beam with the force of the weights, torsional rigidity is calculated as shown here.

\[ K = \frac{T}{\Delta} \]

Where K is the torsional rigidity, T is the torque applied and \( \Delta \) is the angle change. Figure 5 shows the accelerometer used, while figure 6 is an image of the touchscreen tablet used.

Conclusion
The concept of utilizing an accelerometer to measure torsional rigidity of a formula car chassis has been shown to be both technically and economically feasible. The portability, ease of use and reliability of the torsional rigidity test stand will ensure that the CMU Formula team will use it for years to come. The FEA analysis of two different iterations of the Formula chassis provides adequate information to calculate the accuracy of the accelerometer measurements and prove that the calculated deflection is within the sensor’s capabilities. The beam deflection analysis and the test stand stability analysis both concur that this project as designed will be safe to operate and all major areas of error in the test stand have been identified and mitigated. In the near future, we plan to update the measuring algorithm to improve accuracy and speed. Further analysis will be performed to accurately measure the torsional rigidity by comparing the measurements to the FEA estimates.

Graphical User Interface
To streamline the operation of the torsional rigidity test stand, a Graphical User Interface (GUI) was developed. The GUI is designed to be user friendly and practical. The interface gives the user simple instructions to assist in the measuring process. A series of buttons are used in the interface to take measurements and export the data to a desired location. The user simply presses these buttons and follows the prompts in order to complete the testing procedure. A prototype of the GUI is shown below in figure 7:

This GUI is installed onto the RasPad touch pad for great mobility and for further utility in future projects the CMU SAE Formula team will have. The RasPad will export a .CSV file which can be easily converted into an Excel sheet. This data will be compared with the FEA data for verification.

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