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Dynamic Simulation and Analysis of FSAE Racer for Development of Stability Control System

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Acknowledgements:

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Keywords:

Adams/Car; FSAE; Roll; Yaw; Pitch

Introduction:

As the automotive industry continues to progress, much research has gone into the protection of the consumers, while also drastically increasing vehicle stability and efficiency. One system that has captured interests lately is the vehicle's suspension, as it plays a key role in the vehicle's safety and performance. Maintaining optimum tire contact with the road ensures maximum stability, traction and performance; minimizing slippage and maximizing handling. Modern suspension systems in full-sized vehicles come in a variety of designs, however, they all generally allow for each wheel of the vehicle to move up or down independently of each other, hence the term independent suspension. This project focuses on the dual control arm suspension design, a simple and widely used independent suspension system. This suspension assembly increases rider comfort by making for a more stable ride while also minimizing unnecessary vehicle movement during driving events. One way to improve the standard dual control arm suspension system that has recently gone under much review is the active or semi-active suspension system.

An active suspension system will collect dynamic vehicle data and, with this collected data, alert the driver of unsafe conditions and adjust the vehicle's suspension parameters to maximize vehicle stability and maintain traction. The ultimate goal of this ongoing research is to develop a simple and inexpensive active or semi-active suspension system for Georgia Southern Eagle Motor Sports. Each year, a collegiate level event is held where student teams design and build a formula style racer with which to compete at a national scale. These vehicles undergo a variety of test including acceleration, high speed cornering, and on-track racing. This suspension system would ensure driver safety while drastically increasing the vehicle's performance on the track.

In order to aid in the development of such a system, a computer model of the vehicle, capable of simulating dynamic vehicle movements, must be created. To accomplish this task, Adams/Car by MSC software was employed. This software is capable of providing in–depth analysis of vehicle reaction to dynamic events such as acceleration, braking, cornering, speedbumps, etc. With each simulation run, data is presented to the user for analysis. This data is used for the benefit of the driver of the physical car, as well as for the development of improvements to the vehicle. The Figure below serves to explain roll, yaw and pitch of the vehicle as these terms will be used throughout the results.

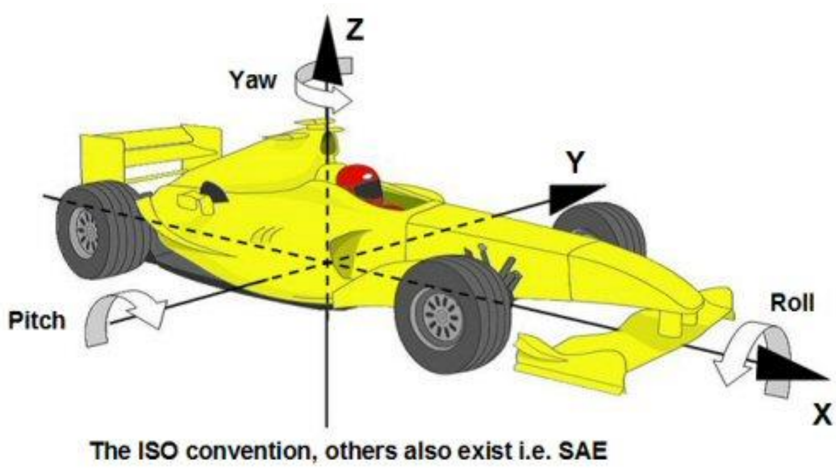

Figure 1- Roll, Yaw, and Pitch Diagram

Model Preparation:

To create the 2016 model for the FSAE car, a template of a generic FSAE racer was downloaded from the MSC database and opened in Adams/Car software. Each hardpoint of this 2012 model was updated to reflect the current 2016 car design taken from Eagle

Motor Sport's models created in both SolidWorks and Optimum Kinematics. This was done by manually inputting Cartesian coordinates of the connection points of each component of the vehicle. These connection points are known as hardpoints and they denote the location where two vehicle components meet, such as the location where the strut mounts to the chassis of the vehicle. After setting each of these hardpoints, the configurations of the vehicle's front and rear suspension systems were in the correct arrangement, however, they were not located in the correct areas with respect to each other, i.e. the front and rear subsystems were on top of one another. To correct this, the vehicle's wheelbase and track widths were input into the model to inform the software how far each of the four wheels should be from each other.

The mass properties of the vehicle then needed to be set. In order to find the location of the physical vehicle's center of mass, a scale was placed under each wheel and, using a standardized procedure, the location of the vehicle's mass center was determined. This coordinate, along with the weight of the full vehicle including driver was transferred to the software to create a more accurate model of the 2016 FSAE car. Completed front and rear dual control arm suspensions created in Adams/Car, as well as the full vehicle model are seen below in Figures 2, 3, and 4.

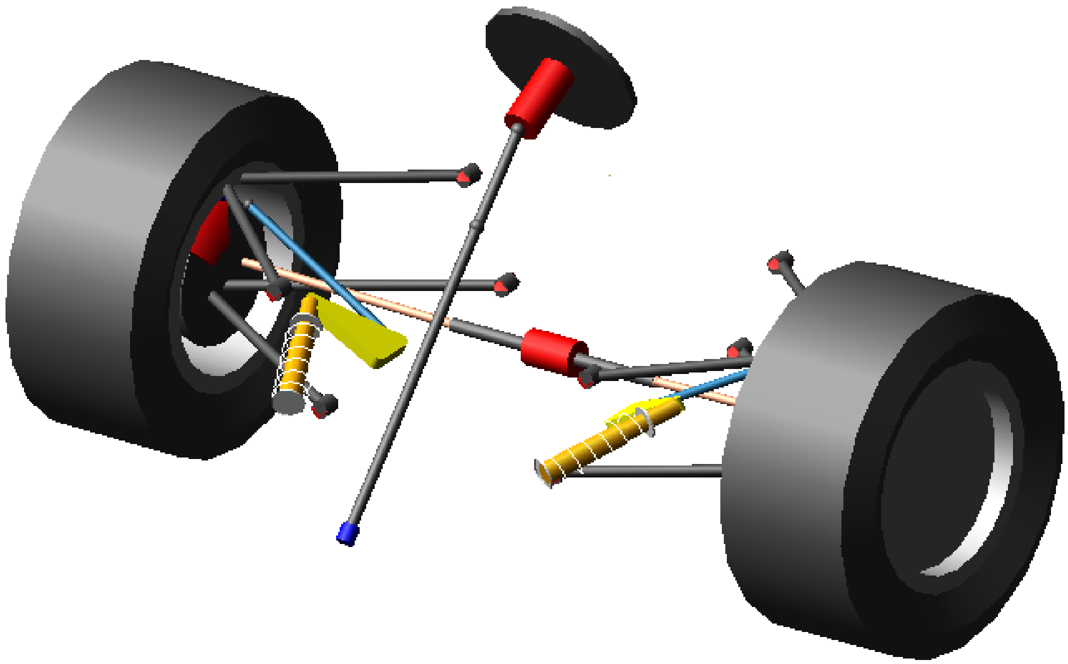

Figure 2 – Front Suspension Assembly, compete with steering subassembly and brakes

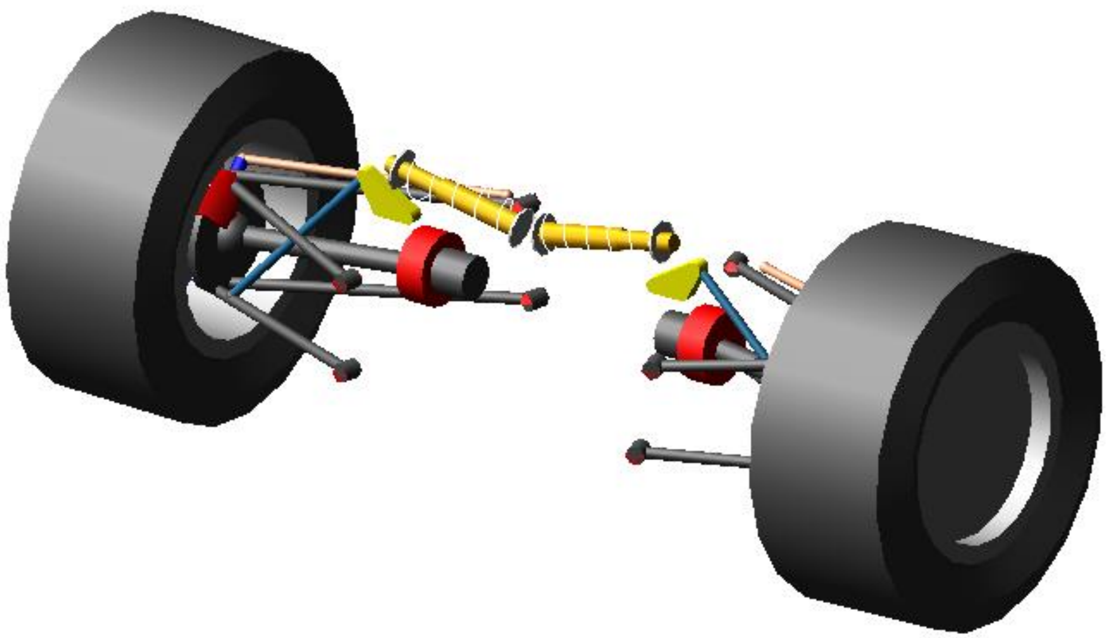

Figure 3 – Rear Suspension Assembly, complete with powertrain and brakes.

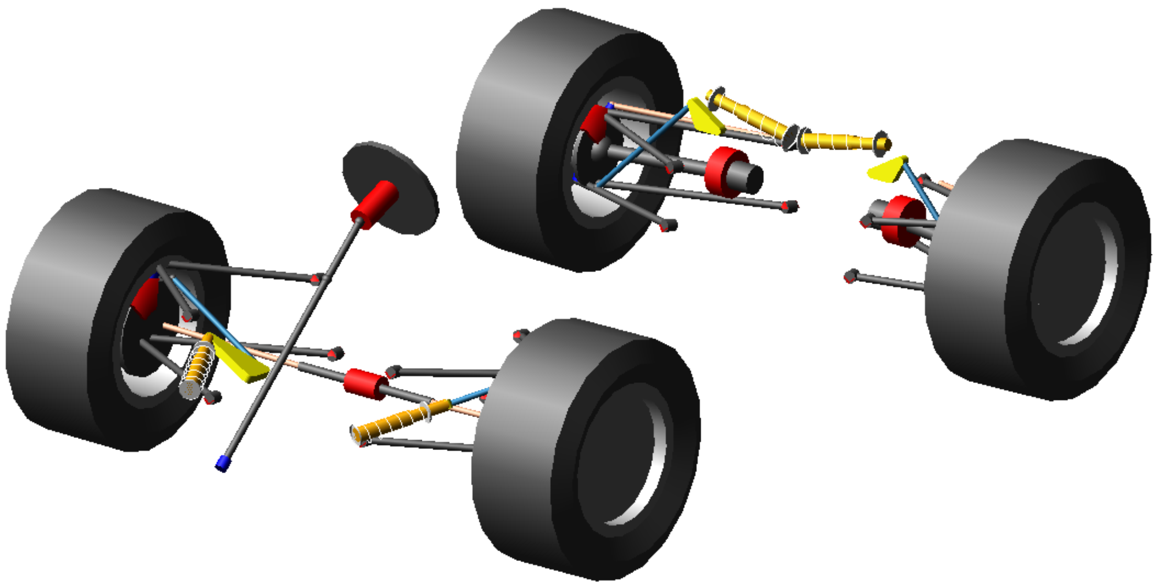

Figure 4 – Full Vehicle Assembly modeled using Adams/Car software.

Simulation Results:

Several results of constant radius cornering simulations and straight line acceleration events are graphed below. Figures 5-8 are concerned with constant radius cornering events and examine the roll angle, pitch angle, steering wheel angle, throttle demand and side slip angle of the vehicle during the test run under a specific set of radius and velocity parameters. The simulation results displayed are from a 30 second long, constant 20 m radius turn at a constant speed of 20 km/hr.

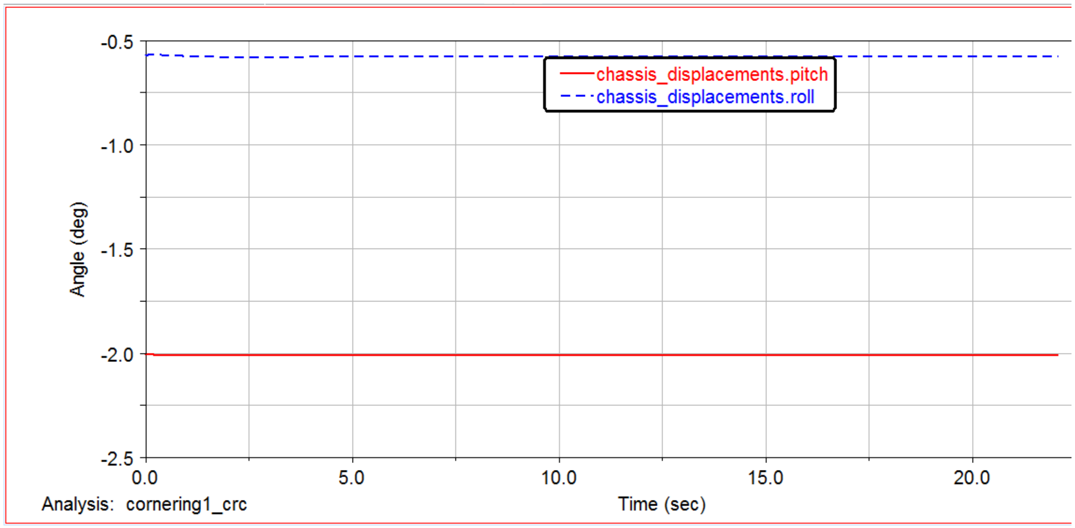

Figure 5 – Roll and Pitch Angle v. Time (Constant Radius Cornering, 20m radius, 20km/hr)

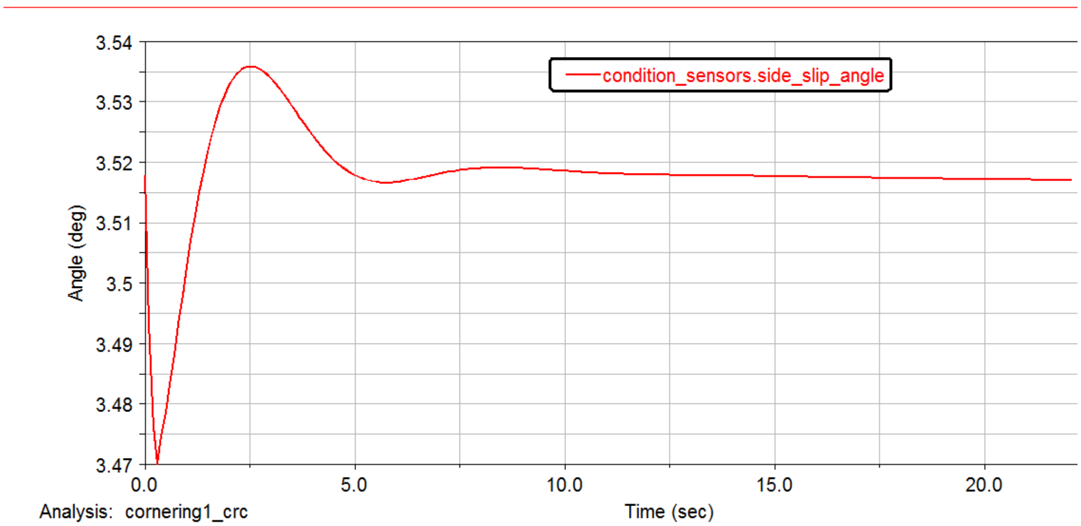

Figure 6 – Side Slip Angle v. Time (Constant Radius Cornering, 20m radius, 20km/hr)

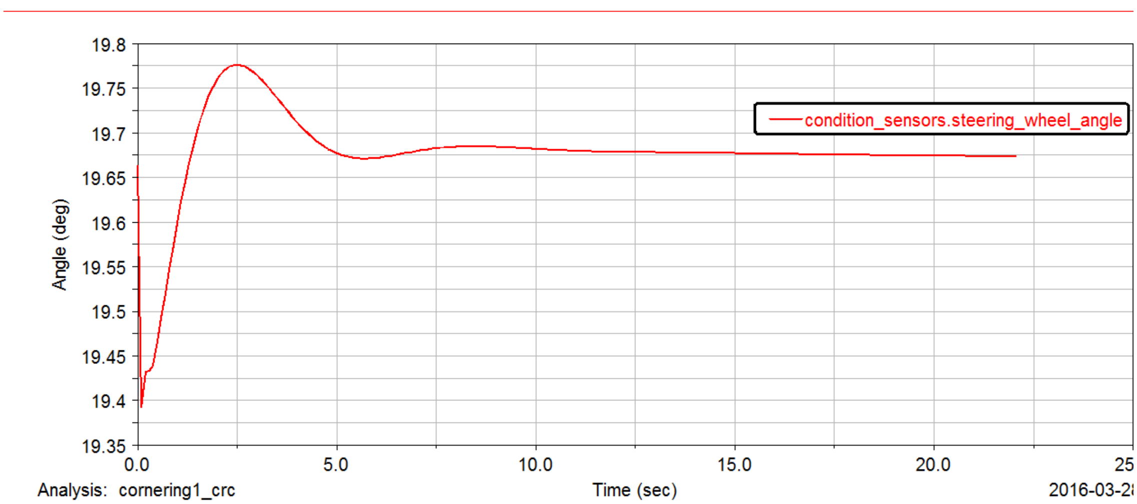

Figure 7 – Steering Wheel Angle v. Time (Constant Radius Cornering, 20m radius, 20km/hr)

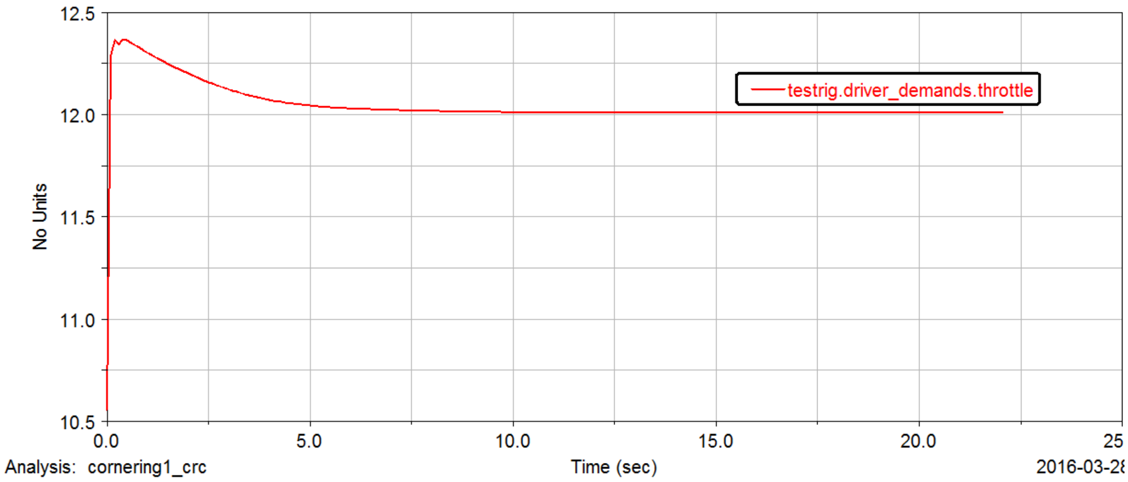

Figure 8 – Throttle Demand v. Time (Constant Radius Cornering, 20m radius, 20km/hr)

Figures 9-17, shown below, are results from a straight line acceleration run from 10 km/hr to the vehicle's top speed over a period of 60 seconds. Velocity angle vs time, pitch angle, side slip angle, wheel slippage, and rear shock data results are all displayed below. In addition to the numerical data, driver demand results such as throttle position and steering wheel angle results are displayed as well.

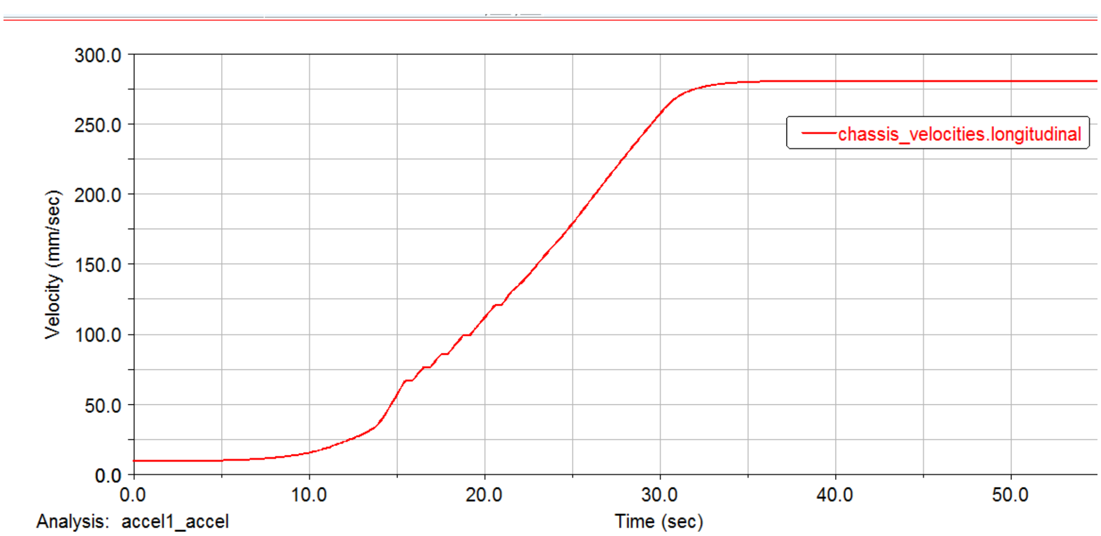

Figure 9 – Velocity v. Time (Straight Line Acceleration)

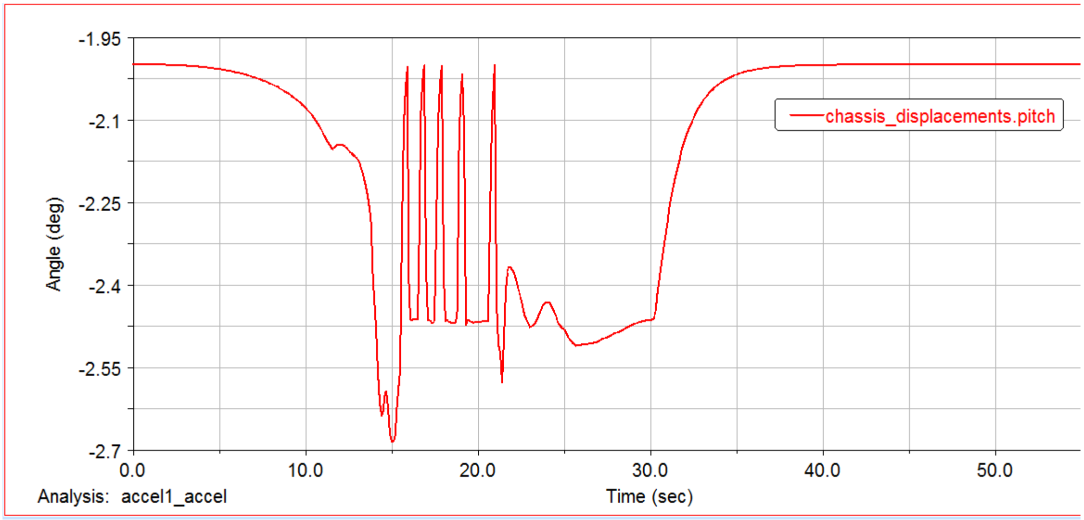

Figure 10 – Pitch angle v. Time (Straight Line Acceleration)

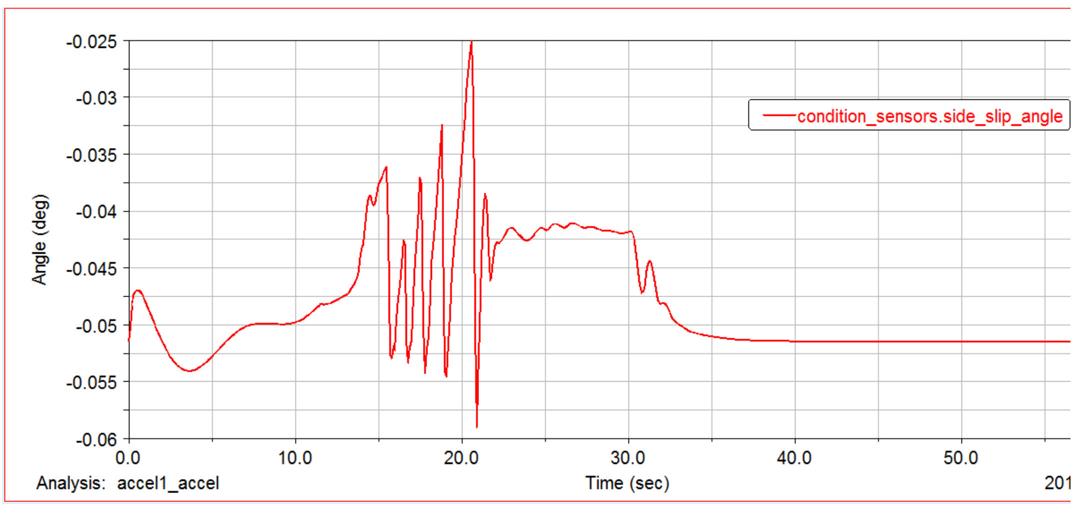

Figure 11 – Side Slip Angle v. Time (Straight Line Acceleration)

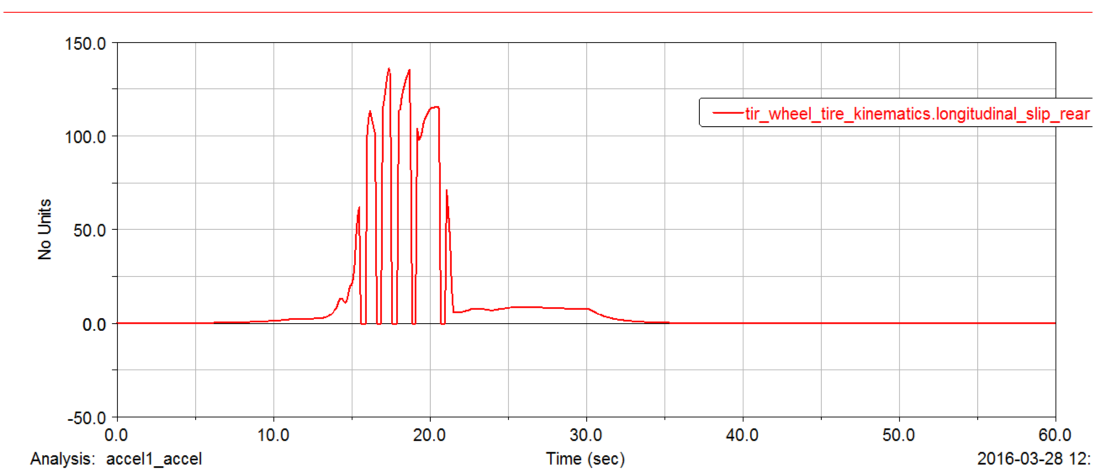

Figure 12 – Rear Wheel Slippage v. Time (Straight Line Acceleration)

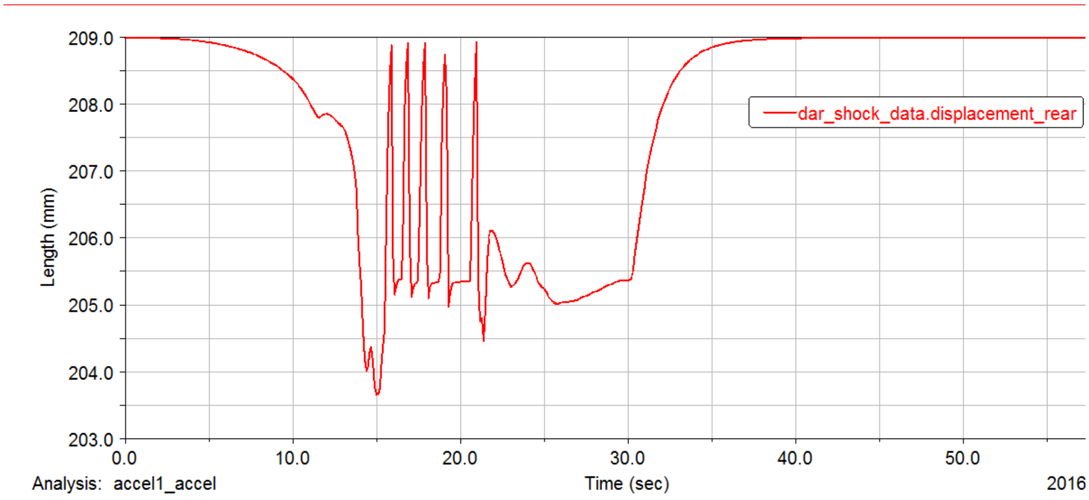

Figure 13 – Rear Shock Displacement v. Time (Straight Line Acceleration)

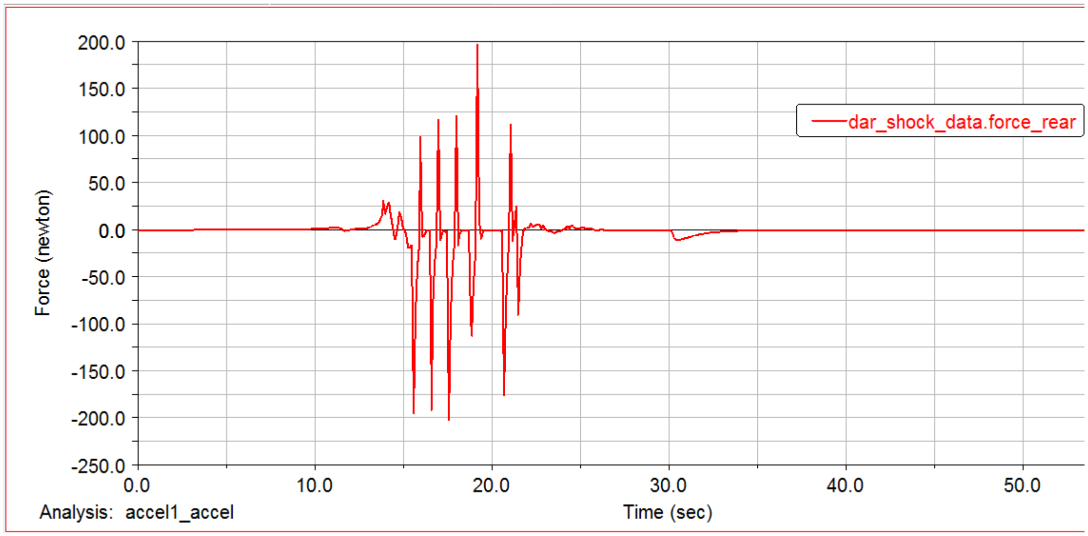

Figure 14 – Rear Shock Force v. Time (Straight Line Acceleration)

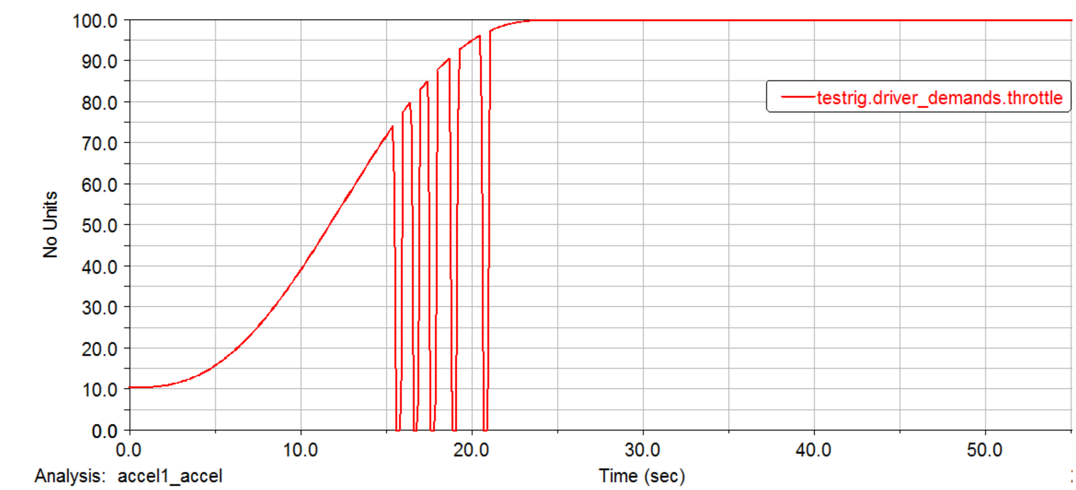

Figure 15 – Throttle Demand v. Time (Straight Line Acceleration)

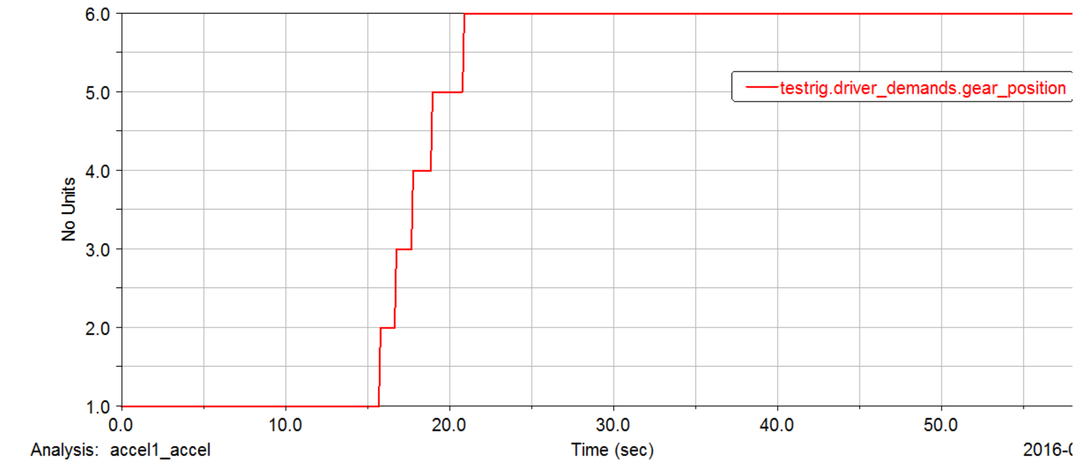

Figure 16 – Gear Position v. Time (Straight Line Acceleration)

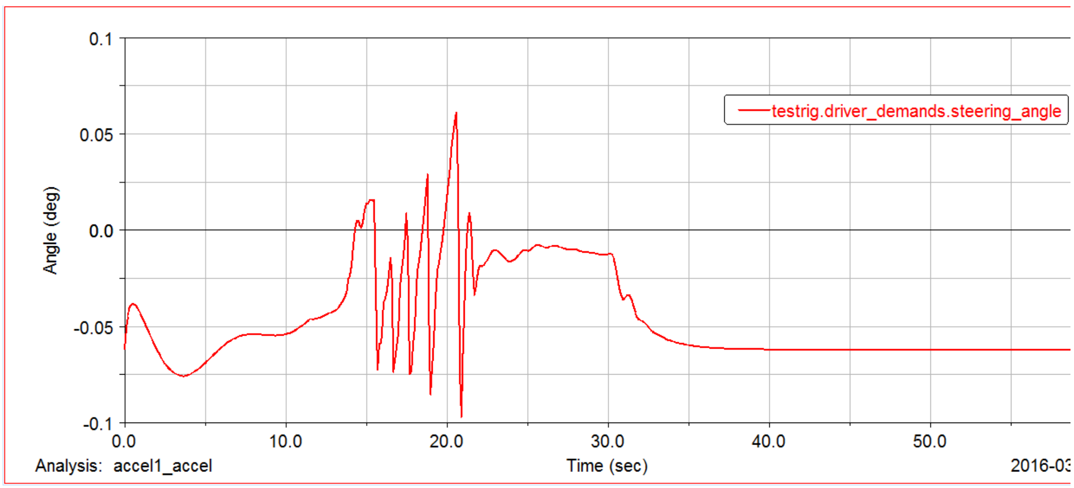

Figure 17 – Steering Wheel Angle v. Time (Straight Line Acceleration)

In addition to straight line and cornering events, Adams/Car is capable of simulating dynamic suspension analysis. These types of tests simulate the vehicle driving over an obstacle, such as a speedbump or pothole. The figures below display some of the results of this type of test. The simulation run was of the vehicle driving at 50 km/hr over a 10 cm bump in the road. Data results taken from this simulation are vertical chassis displacements, pitch angle, front and rear shock forces, and loaded tire radius.

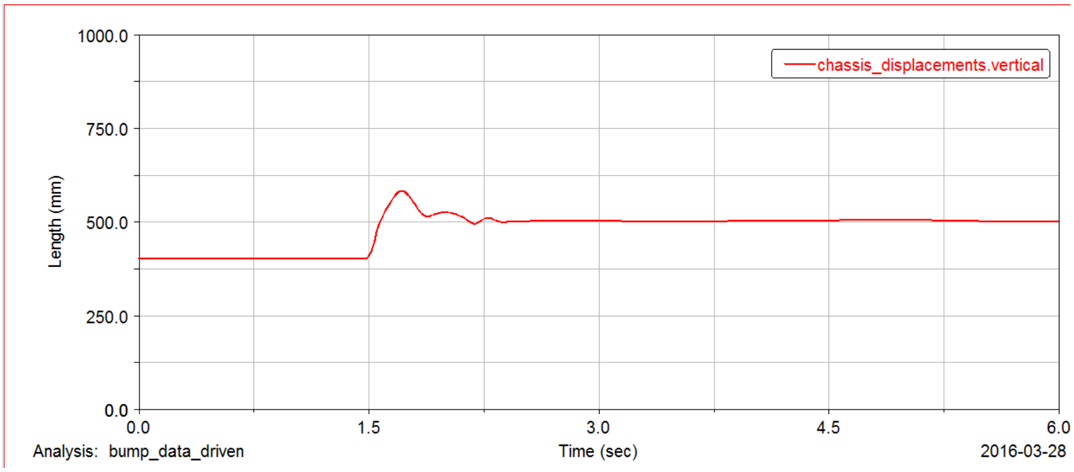

Figure 18 – Vertical Chassis Displacements (10 cm Road Bump)

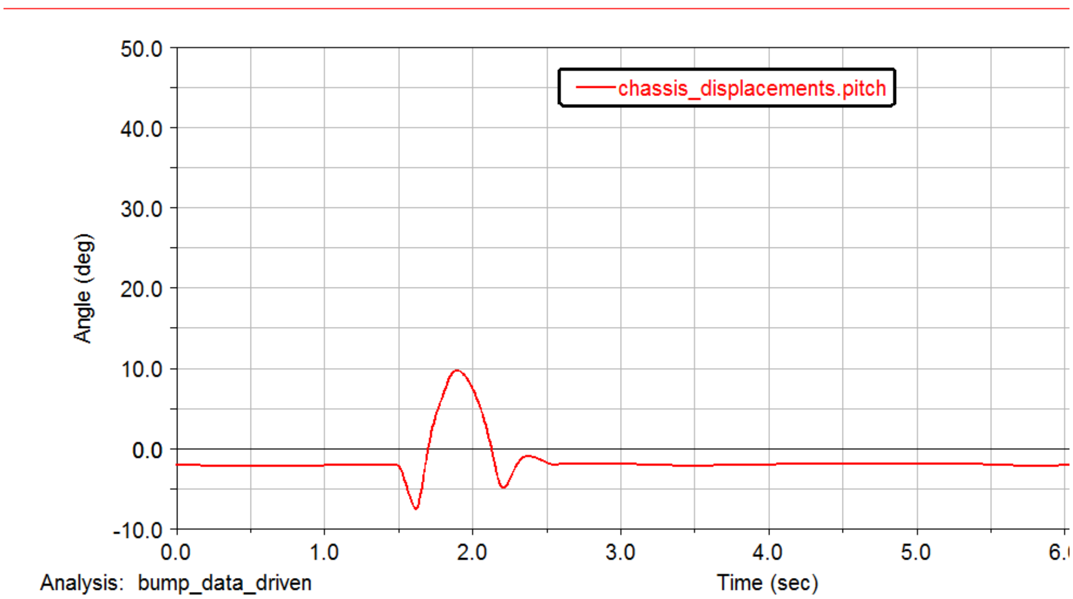

Figure 19 – Chassis Pitch Angle (10 cm Road Bump)

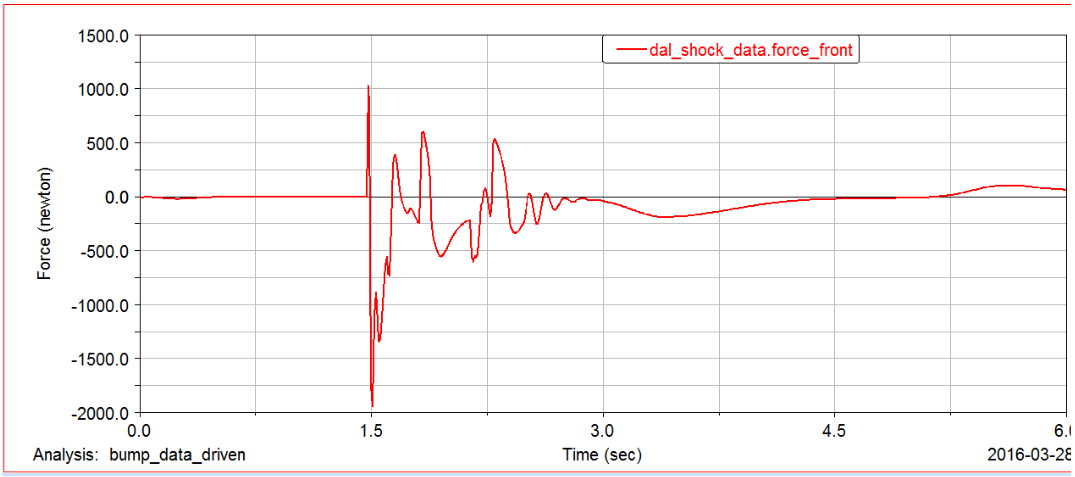

Figure 20 – Front Shock Force (10 cm Road Bump)

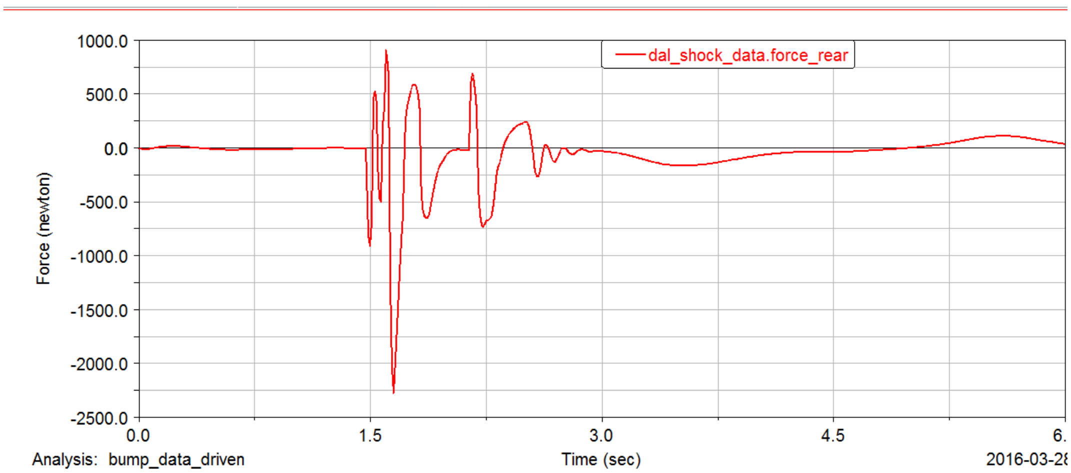

Figure 21 – Rear Shock Force (10 cm Road Bump)

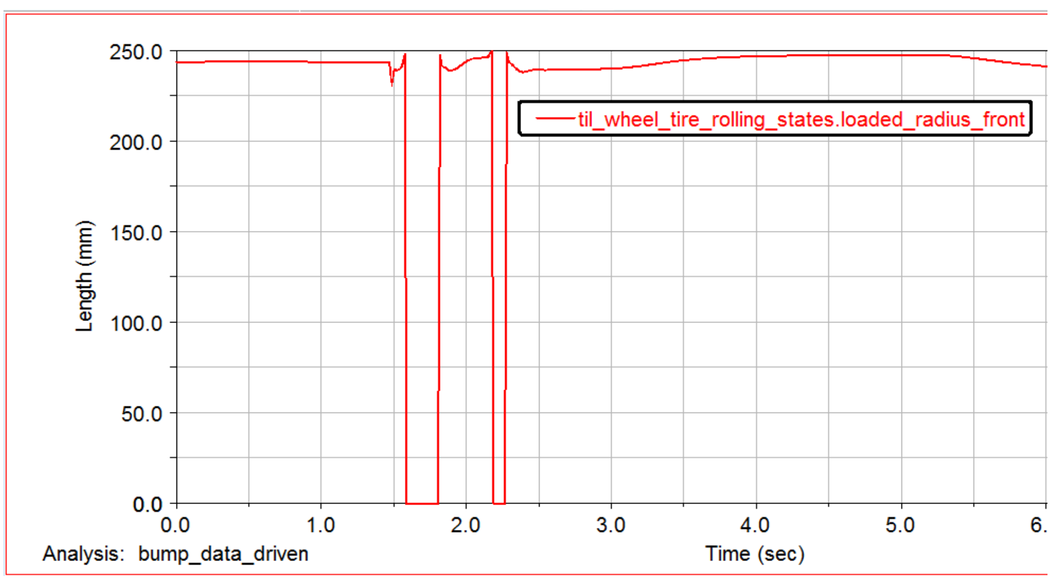

Figure 22 – Front Tire Loaded Radius (Straight Line Acceleration)

Cornering Simulation Discussion:

From these constant radius cornering simulation results, Figures 5-8, many observations can be made. At this moderately low speed, 20 km/hr, the roll of the vehicle does not play a large factor in stability. As seen in figure 5, the vehicle's roll maintained a consistent 0.6 degrees while the angle of roll for a vehicle of this stature is fully capable of handling 10 degrees of roll [1]. These results are beneficial in that the driver will know that when performing a test run at this speed and radius, he will be safe from rollover. Sideslip angle is the angle difference between the direction the vehicle is moving and the direction the vehicle is facing. A high level of sideslip angle is evidence of a larger amount of wheel deformation during a turn. A high sideslip angle may lead to a loss of traction if corrections are not made. As seen in Figure 6 in the results, the maximum sideslip angle achieved in this maneuver was calculated to be about 3.535 degrees, a safe amount for this maneuver. This important data has applications in the development of an active suspension system. Understanding the dynamics of a vehicle taking a turn like this will aid in the development of this control system. Provided an instantaneous roll angle, the system will be able to communicate with the suspension system, deciding how to react. If roll angles are deemed dangerous, a warning will be displayed to the driver and the suspension will be modified to prevent rollover and loss of traction. One method of maintaining vehicle stability that has recently undergone research is the application of a hydraulic actuator to stiffen the antiroll bar [1]. Adams/Car's application in this development is deciding what are dangerous values for roll and sideslip angle. Provided this data, the safety parameters of a stability control system can be set.

In addition to these data driven results, the driver demand results also prove important. These types of results are mainly beneficial to the driver of the vehicle during physical tests as they can theoretically teach the driver how to drive the vehicle on a given course. The steering wheel angle to maintain, Figure 7, and the throttle demand, Figure 8, are both given for this type of maneuver. Employing driver demand results from the simulation will lead to more efficient and safer driving by knowing how to properly maneuver the vehicle.

Straight Line Acceleration Discussion:

As seen in Figure 9, during the straight line acceleration simulation, the FSAE racecar accelerates from 10 km/hr to a high speed of 100.8 km/hr. It is important to note the shift points during the acceleration process. These can be found by observing the "steps" in the otherwise smooth velocity v. time curve. These points are important because of their result on the stability of the vehicle. These shift points cause the car to pitch forward as the vehicle momentarily pauses and reaccelerates as observed in Figure 10. This shifting of gears also cause the racecar to have an erratic sideslip angle, noticeable in Figure 11. Shifting gears seems to impose lateral forces on the wheels, causing elastic deformation in the tires. It should also be noted that at each shift point, the rear wheels do lose traction as seen in Figure 12. This loss of traction is undesirable as it lowers overall acceleration and can be dangerous at high speeds or during certain maneuvers. To counteract this, a traction control system can be designed for the vehicle to note when traction is lost. This system can be based on data derived from Adams/Car simulations as the cause and effects of this traction loss can easily be seen. With this knowledge, the traction control system to be designed will be able to more easily regain traction in the event of wheel slippage.

The result of the pitch angle imposed on the vehicle during acceleration and shifting is seen in Figures 13 and 14. These two data sets display the resulting force and displacement on the rear struts as the vehicle pitches back and forth during the simulation. As the chassis pitches backwards, the rear struts compress, slowing the movement of the chassis. A stiff suspension will result in a jarring movement during shifts, while a soft suspension will result in being rocked back and forth continually. Data such as this is crucial to the active suspension system as this strut data will inform the control system how to react. The control system will command the suspension system to stiffen or loosen the struts based on vibration data as well as force and displacement data from the struts. This will result in a much smoother ride for the driver and a much more efficient run for the vehicle.

As was shown earlier for the cornering runs, straight line acceleration simulation can also output driver demand results. As seen in Figures 15, 16 and 17, the throttle demand, gear position and steering wheel angle are all available to teach the driver of the car how to most effectively maneuver this vehicle on a similar course.

Road Bump/ Pothole Discussion:

In the conducted road bump simulation, the vehicle drove over a 10 cm high bump at 50 km/hr. This imposed massive shock on the vehicle as seen in Figures 18-22. Figure 18 displays the vertical movement of the chassis as the vehicle drives over the bump in the road. As seen at 1.5 seconds, the front tires make contact with the bump. It should be noted that the chassis moves upwards about 15 cm and then back down to its new baseline 10 cm higher that before the bump. This quick upwards and downward motion is uncomfortable for the driver as the vehicle rocks up and down. In addition to creating a bumpy ride, this up and down movement also causes the vehicle to lose traction as seen in Figure 22. It can be observed in this figure that in two instances during the 6 second run, the front tires lose effective contact with the ground, resulting in a loss of traction. This may be counteracted by a suspension control system by softening the suspension on contact, and then stiffening to help maintain chassis stability. As seen in Figure 19, the pitch angle is very large. By minimizing chassis movement, the car can be made much safer and more efficient. Front and rear shock forces are also observable in Figures 20 and 21. This data was collected for aid in the development of the stability control system as it will help in understanding the effects of chassis pitch on the struts, the primary component in combating chassis pitch displacement.

Conclusion:

Upon modeling and simulating the 2016 FSAE racecar fabricated by Georgia Southern Eagle Motorsports, the importance of simulations have made themselves evident. These simulations have proven valuable to the team as it aids them in designing and even driving the vehicle. They have made themselves a prime source of data for the creation of a stability control system for an active suspension system. Understanding vehicle reactions to dynamic situations is necessary to make any progress in a self-adjusting suspension system, and this understanding comes from running simulations in software such as Adams/Car. This research will not only benefit Georgia southern Eagle Motorsports, but can be useful on a global scale to improve worldwide automotive industries.

References:

[1] Aykent, B. “Effects of Sway Acceleration Control on Rollover Propensity and Assessment of Lateral Specific Forces” (No. 2010-01-132.5). Society of Automotive Engineers Technical Papers (2010).
[2] “Heave, Pitch, Roll, Warp, and Yaw.” White-Smoke (2007).