Estimation of Dynamic Behavior and Performance Characteristics of a Vehicle Suspension System using ADAMS

A.MD.Zameer Hussain basha[1], S.Mahaboob Basha[2]

[1]PG student,department of mechanical engineering,Chiranjeevi Reddy Institute of Engineering and Technology,Anantapur,AP-515001

[2]Head of the department of mechanical engineering, Chiranjeevi Reddy Institute of Engineering and Technology,Anantapur,AP-515001

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Abstract - *This work proposes a methodology to estimate tire side slips angles in front-wheel steered, rear-wheel driven four wheeled vehicles. A three degree-of-freedom model with slip angle, yaw rate and roll angle as degrees of freedom was constructed to capture the coupling between steering and roll dynamics of such vehicles. An open-loop estimator was designed based on this model to estimate the side slips angles of tires using available real-time measurements which include steering angle, steering torque and suspension positions. The model incorporates all sources of compliance, stiffness and damping, all with non-linear characteristics. The vehicle model is created in ADAMS (automatic dynamic analysis of mechanical systems) formulation. The model is used for the purpose of vehicle handling analysis. The estimator was validated by comparing its predictions with that of an ADAMS model. The paper presents a comparative analysis between different half-car models for the suspension system of the rear axle of the motor vehicles, the difference between models consisting of how the equilibrium of the car body is assured.*

Key Words: FEA, lugs, pin, margin of safety, Vonmises stress, ANSYS.

1. INTRODUCTION

1.1 Suspension system: The suspension system of an automobile helps to support the car body, engine and passengers, and at the same time absorbs shocks received from the ground while vehicle moves on rough roads and un even roads. The dynamic model of the suspension and steering system of the motor vehicles includes the kinematic elements - bodies (car body, axle, wheel carrier, guiding links), as well as the elastic and damping elements (ex. springs, dampers, bushings, antiroll bar, bumper and rebound elements) are very important to understand the behavior of the vehicle.. The increasingly growing demand for more comfortable passenger car imposes new models of the guiding systems, close to real systems on the vehicle. Suspension systems serve a dual purpose — contributing to the vehicle's road holding/handling and braking for good active safety and driving pleasure, and keeping vehicle occupants comfortable and a ride quality reasonably well isolated from road noise, bumps, and vibrations. A typical suspension system is shown in the figure 1.
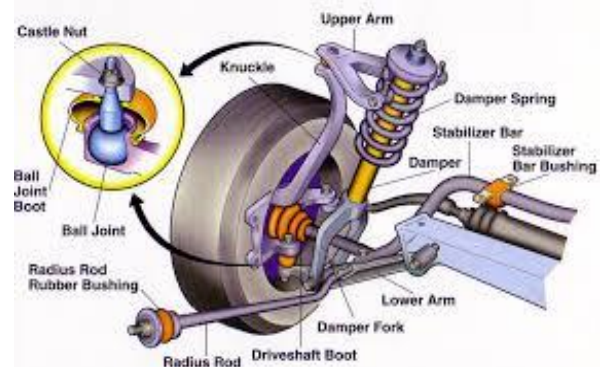

Figure 1: Suspension terminology

1.2 Steering system

Steering system is used to control the vehicle directions when it is moving on road. Many modern vehicles use rack and pinion steering mechanisms, where the steering wheel turns the pinion gear; the pinion moves the rack, which is a linear gear that meshes with the pinion, i.e. for some rotation of steering angle rack moves some distance to produce angle to wheels. In simple way it is nothing but converting circular motion into linear motion along the transverse axis of the car (side to side motion).Figure 2 shows the assembly of steering and suspension system.
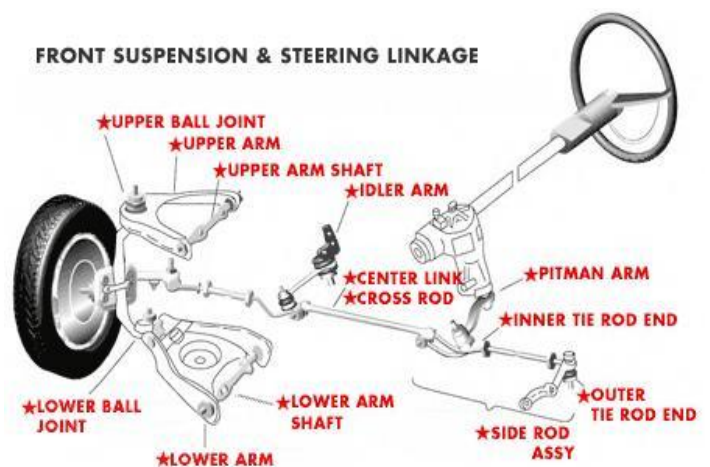

Figure 2: Suspension with steering

1.3: Steady-state handling characteristics

- Steady-state handling performance is concerned with the directional behavior of a vehicle during a turn under non-time-varying conditions.

- An example of a steady-state turn is a vehicle negotiating a curve with constant radius at constant forward speed. In the analysis of steady-state handling behavior, the inertia properties of the vehicle are not involved.

When a vehicle is negotiating a turn at moderate or high, speeds, the effect of the centrifugal force acting at the center of gravity can no longer be neglected. To balance the centrifugal force the tires must develop appropriate cornering forces. A side force acting on a tire produces a side slip angle.

Slip angle α

Slip angle α is the angle formed between the direction of wheel travel and the line of intersection of the wheel plane with the road surface.

Tire cornering (lateral) stiffness C_α

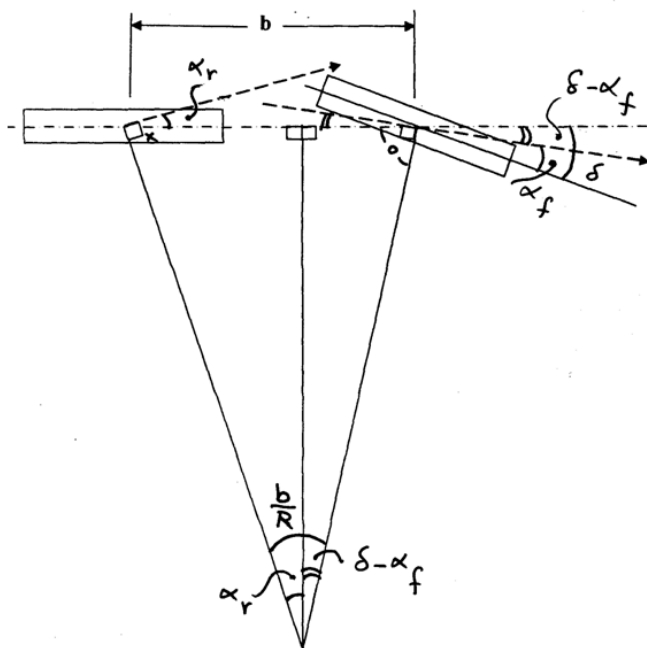The cornering stiffness C_α is used to compare the cornering behavior of different tires.

Figure 3: Ackerman Steering Geometry

1.3.1: Neutral Steer

When the under steer coefficient Kus = 0, which is equivalent to the slip angles of the front and rear tires bring equal (i.e., αf = αr and wf /Cαf = wr/Cαr), the steer angle δ required to negotiate a given curve is independent of forward speed and is given by δ = b / R

1.3.2: Under Steer

When the understeer coefficient $K_{us} > 0$, which is equivalent to the slip angle of the front tire of being greater than that of the rear tire, (i.e., $\alpha_f > \alpha_r$ and $w_f /C_{\alpha f} > w_r/C_{\alpha r}$), the steer angle required to negotiate a given curve increases with the square of vehicle forward speed.

1.3.3: Over Steer

When the under steer coefficient K_{us} which is equivalent to the slip angle of the front tire α_f being less than that of the rear tire α_r (i.e., $\alpha_f < \alpha_r$, and $w_f /C_{\alpha f} < w_r /C_{\alpha r}$), the steer angle required to negotiate a given curve decreases with the increase of vehicle forward speed.
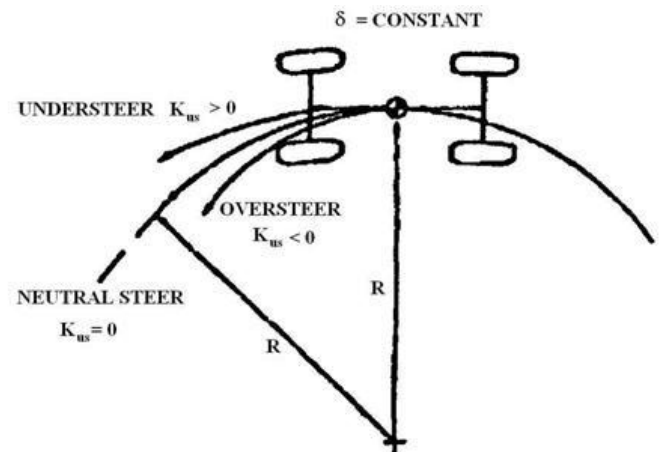

Figure 4: Steering effects

1.4 Suspension Outputs

There are more than 70 outputs we will get from suspension analysis. Basic outputs are described below.

Toe: The difference in distance between the front and rear of the tires, when the tires are closer together at the front than at the rear, the wheels are said to be **toed in**, and if they are farther apart at the front, they are **toed out**. Toe-in is also called **positive** and toe-out **negative**.

Camber: The inward or outward lean of the top of the wheel. If the top of the wheel tilts outward from true vertical, it has positive camber, and if it tilts inward at the top, it has negative camber.

Caster Angle: Forward or rearward tilt of the steering knuckle away from true vertical. Viewed from the side, a line drawn through the upper and lower ball joints (SLA) describes the caster angle.

Steering Axis Inclination (SAI): The angle, away from true vertical, formed by a line drawn through the ball joints (or the lower ball joint and the upper strut mount on MacPherson strut systems). The SAI is always an inward tilt.

Slip angle: Understanding tire slip angle is fundamental to understanding how to go faster on four wheels.

Tire slip angle creates a force that is known as "cornering force". It is cornering force that makes a vehicle able to turn a corner. The more cornering force you have available the less you have to slow down for corners.

In the case of a racing vehicle, the less you have to slow down, the quicker you can do a lap/complete the stage/get up the hill etc ...

Scrub Radius: The distance between where the SAI line meets the road and the centerline of the tire. It is the turning pivot area for the tire's contact patch on the road. If the scrub area is inboard of the centerline, it is said to be a positive scrub radius, and if it is outside of the centerline, it is said to be a negative scrub radius.
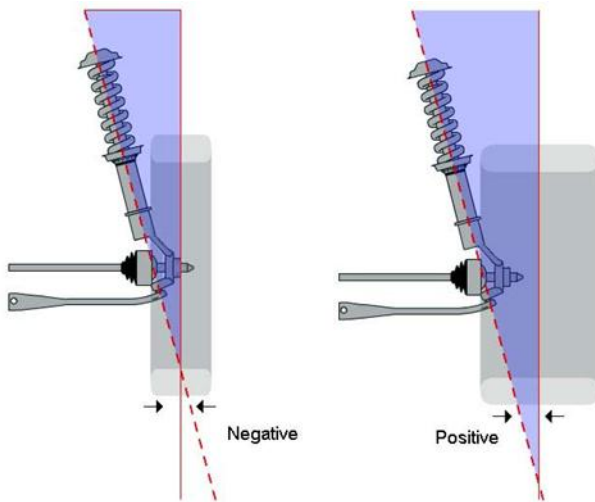

Figure 5: Scrub radius

Coordinate system: The below figure shows the representation of a vehicle in coordinate system i.e pitch, yaw & roll.
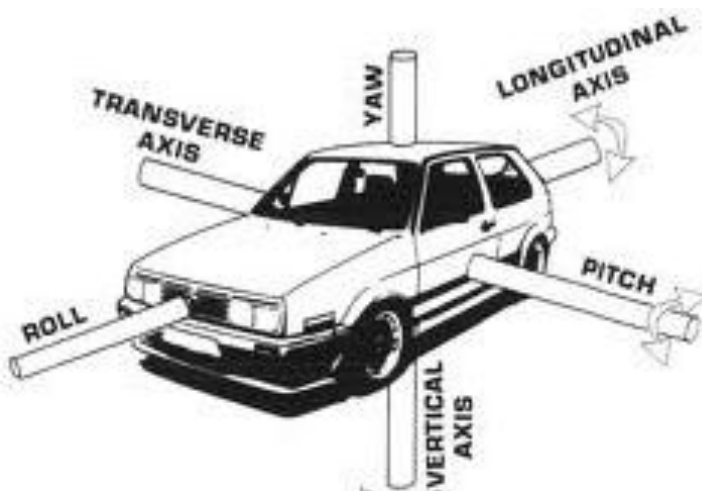

Figure 6: Standard vehicle coordinate system

2. ABOUT ADAMS

ADAMS is a multi-body dynamics simulation tool developed by MSC software. It also called as mechanical system simulation tool. The abbreviation of ADAMS is automatic dynamic analysis of mechanical systems. In this paper we used ADAMS car template to build the suspension system. Adams/Car, part of the Adams 2013.1® suite of software, is a specialized environment for modeling vehicles. It allows you to create virtual prototypes of vehicle subsystems and analyze the virtual prototypes much like you would analyze the physical prototypes. You create assemblies in Adams/Car by defining vehicle subsystems, such as front and rear suspensions, steering gears, anti-roll bars, and bodies. You base these subsystems on their corresponding standard Adams/Car templates. For example, Adams/Car includes templates for double-wishbone suspension, MacPherson strut suspension, rack-and-pinion steering, and so on. When you analyze an assembly, Adams/Car applies the analysis inputs that you specify. For example, for a suspension analysis you can specify inputs to:

- Move the wheels through bump-rebound travel and measure the toe, camber, wheel rate, roll rate, and side-view swing arm length.
- Apply lateral load and aligning torque at the tire contact path and measure the toe change and lateral deflection of the wheel.
- Rotate the steering wheel from lock to lock and measure the steer angles of the wheels and the amount of Ackerman, that is, the difference between the left and right wheel-steer angles.

Once you complete the analysis of your model, you can share your work with others. You can also print plots of the suspension characteristics and vehicle dynamic responses. In addition, you can access other users' models without overwriting their data.

- Euler-Lagrange method to create equations of motion
- Predictor-corrector methods to solve equations
- Integrated animation and plotting
- Powerful parametric, scripting and post-processing abilities

Applications:

- The general purpose graphical user interface is Adams/View
  - Model building, simulation submission, animation
- Equations are built and integrated with Adams/Solver
  - Solver is a standalone application, but typically used seamlessly from within Adams/View
- Plotting and animation done with Adams/PostProcessor
  - Tightly integrated with Adams/View
- Industry verticals (e.g., Adams/Car) for model templates

3. Multi body simulations of suspension system

It contains how to modify and analyze a double-wishbone suspension system. The Adams basic model is taken from Adams template builder and analyzed with the multiple inputs. Mainly two types of analysis are considered to check the performance characteristics.

1) Quasi static suspension analysis
2) Dynamic suspension analysis

To perform the analysis, you must first create a double-wishbone suspension and steering subsystem from standard Adams/Car templates and subsystems. Adams/Car templates define a subsystem's topology and specify how one subsystem connects to another. Templates also contain default parameters, such as locations, part masses, and inertias. The following figure 7 shows the Adams template.
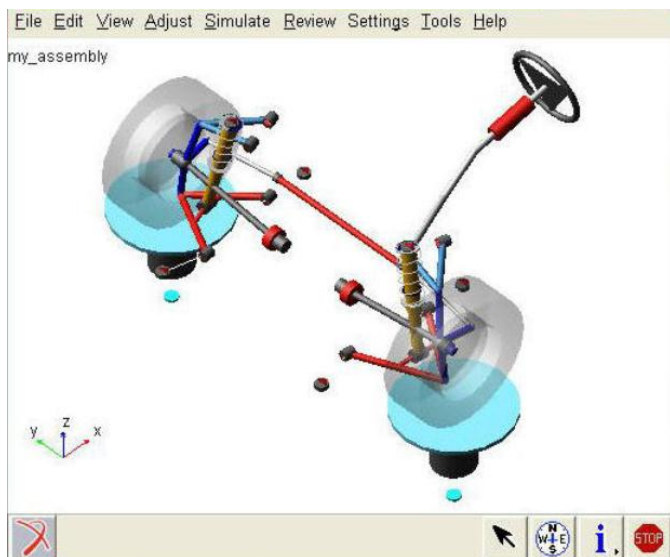
Figure 7: Double wishbone suspension with steering system

3.1 Create suspension model in ADAMS

In this section, work carried with a suspension and steering assembly from two subsystems: a suspension subsystem and a steering subsystem. You create the suspension subsystem using the standard double wishbone template. We don't need to create the steering subsystem. Instead, we can open an existing subsystem that provided by Adams car template.

To create the front suspension subsystem:

1. Start Adams/Car Standard Interface as described in Starting Adams/Car Standard Interface.
2. From the File menu, point to New, and then select Subsystem.
3. In the Subsystem Name text box, enter UAN_FRT_SUSP.

4. Set Minor Role to front. A minor role defines the subsystem's function and its placement in the assembly (for example, front or rear). In this case, you select front because you are creating a front suspension.
5. Right-click the Template Name text box, point to Search, and then select shared_car_database.
6. Select templates.tbl and double-click _double_ wishbone.tpl.
7. Verify that Translate from default position is not selected.

Adams/Car creates the suspension subsystem using the default data contained in the template and displays it as shown in figure 8.
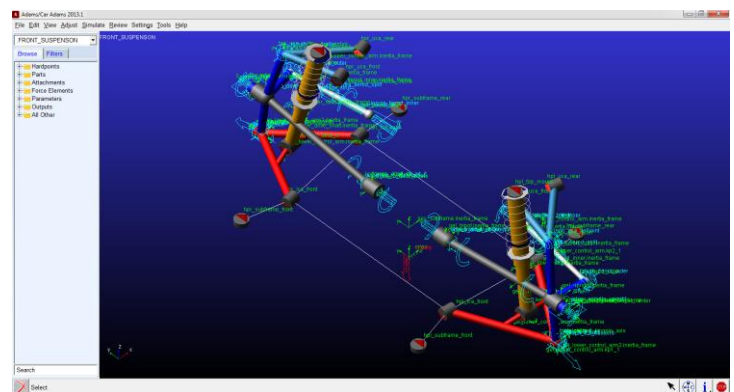
**Figure 8:** Double wishbone suspension template

This suspension system has joints, constraints and locations of assembly hard points which created according to the suspension data in Adams car template. It also contains flexible elements like springs and buses to control the vibrations.

3.2 Creating suspension assembly

After successfully creating suspension template we have to assemble proper steering assembly and test rig to conduct different tests on the suspension system.

1. From the File menu, point to New, and then select Suspension Assembly.

2. In the Assembly Name text box, enter my_assembly.

3. Click the folder icon next to Suspension Subsystem.

The name of the suspension subsystem you just created appears.

4. Select Steering Subsystem.

5. Right-click the Steering Subsystem text box, point to Search, and then select the shared_car_database.

6. Select subsystems.tbl and double-click MDI_FRONT_STEERING.sub. The Steering Subsystem text box now contains MDI_FRONT_STEERING.sub and an alias to its directory path.

Note that by default Adams/Car selects a test rig for the assembly,__MDI_SUSPENSION_TESTRIG.
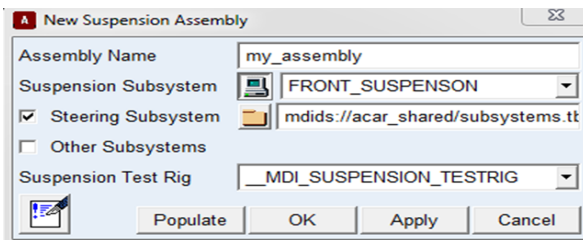
Now preparing the model for test is completed. Figure 9 shows the assembly of suspension system, steering system and test rig.
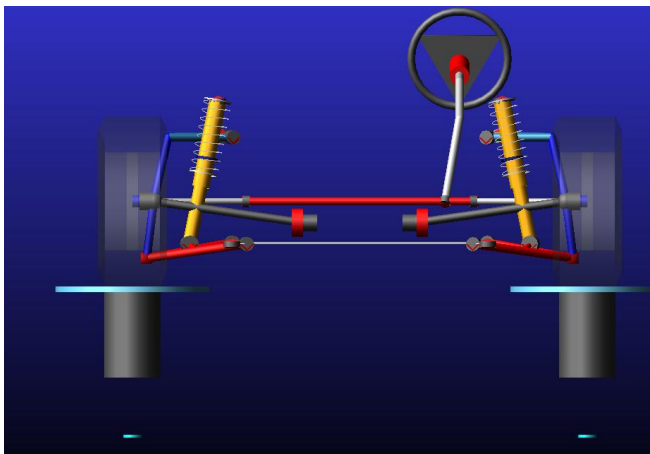

Figure 9: Adams suspension assembly model

3.3 Performing a Baseline Parallel Wheel Travel Analysis(Quasi-static analysis)

In this session a parallel wheel travel analysis on the suspension and steering assembly need to be perform, then plot and view the results. The following steps performed on assembly.

• Defining Vehicle Parameters
• Performing the Analysis
• Animating the Results
• Plotting the Results

3.3.1 Defining Vehicle Parameters

Before performing a suspension analysis, you must specify several parameters about the vehicle in which you intend to use the suspension and steering subsystems. These parameters include the vehicle's wheel base and sprung mass, whether or not the suspension is front- or rear-wheel drive, and the braking ratio. For this analysis, you enter the parameters to indicate front-wheel drive and a brake ratio of 64% front and 36% rear. To define vehicle parameters: From the Simulate menu, point to Suspension Analysis, and then select Set Suspension Parameters. The following assumptions are considered for this analysis.

• All driving force is applied to the front wheels.
• The brake ratio value indicates the % of braking force that is applied to the front brakes.

Figure 10 shows the all considered suspension parameters.

3.3.2 Performing the Analysis

During the analysis, the test rig applies forces or displacements, or both, to the assembly, as defined in a load case file. For this analysis, Adams/Car generates a temporary load case file based on the inputs you specify.

This parallel wheel travel analysis moves the wheel centers from -100 mm to +100 mm relative to their input position, while holding the steering fixed. During the wheel motion, Adams/Car calculates many suspension characteristics, such as camber and toe angle, wheel rate, and roll center height.
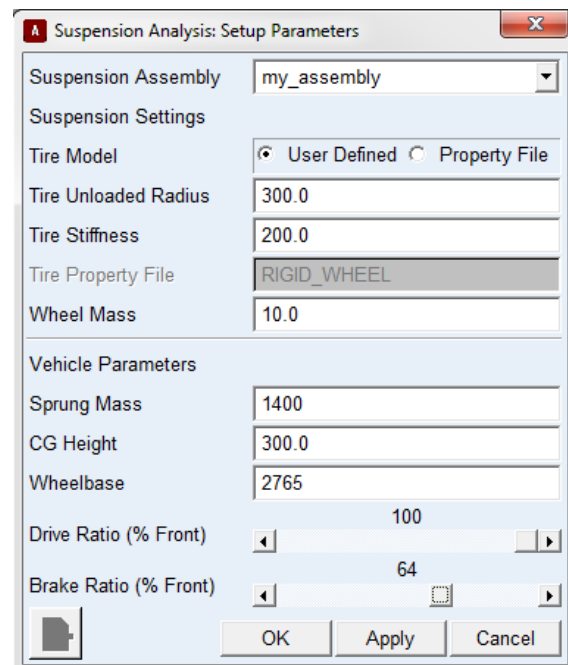

Figure 10: Adams suspension parameters

1. From the Simulate menu, point to Suspension Analysis, and then select Parallel Wheel Travel.

2. Set up the analysis as follows:

• Suspension Assembly: my_assembly
• Output Prefix: baseline
• Number of Steps: 100
• Mode of Simulation: interactive
• Bump Travel: 100
• Rebound Travel: -100
• Travel Relative To: Wheel Center
• Steering Input: Angle

3. Select OK. The following data shows inputs for analysis
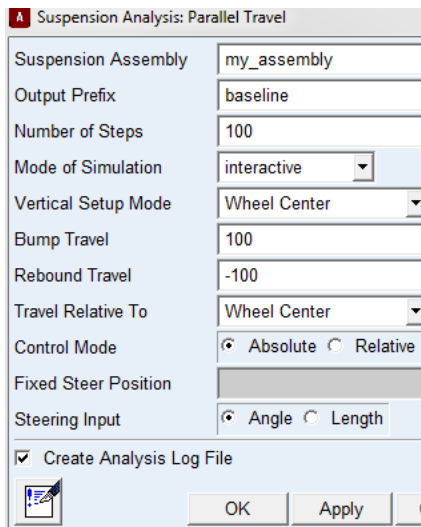
3.3.3 Animating the Results

        In this section, you view the analysis you just ran. Adams/Car has already loaded the animation and graphic files for animating representation of results.

To animate the results:

1. From the Review menu, select Animation Controls.
2. Select the Play tool.

Adams/Car animates the motion of the suspension analysis. Notice that the suspension moves from rebound (down), to bump (up), and that the steering wheel does not rotate.

 The following figure 11 shows the results from baseline analysis. It shows the reaction forces and moments.
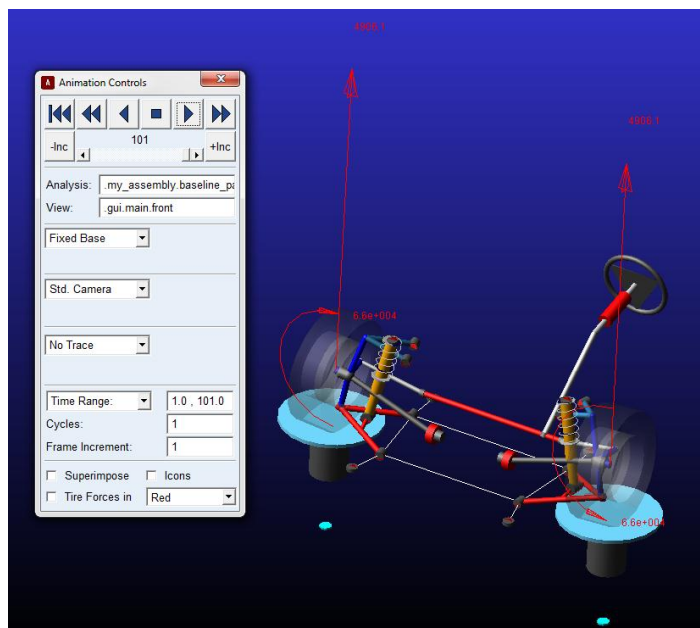
Figure 11: Reaction solution

3.3.4 Plotting the Results

Adams provides post processor tool where we can compare and take the plots for different characteristics of suspension system.

The following plots are some of the characteristic plots from base line parallel wheel travel analysis.
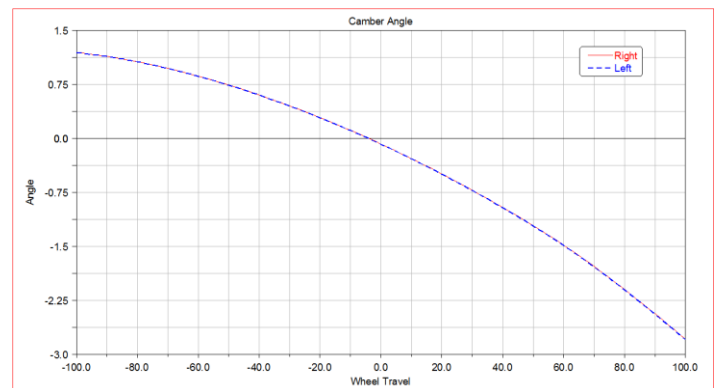
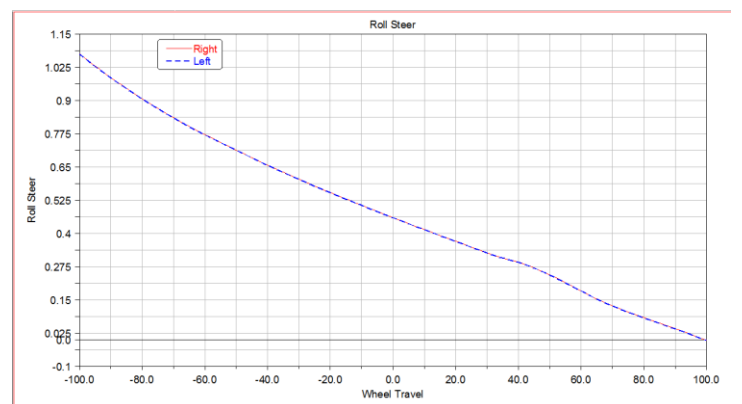**Figure 12:** Caster angle
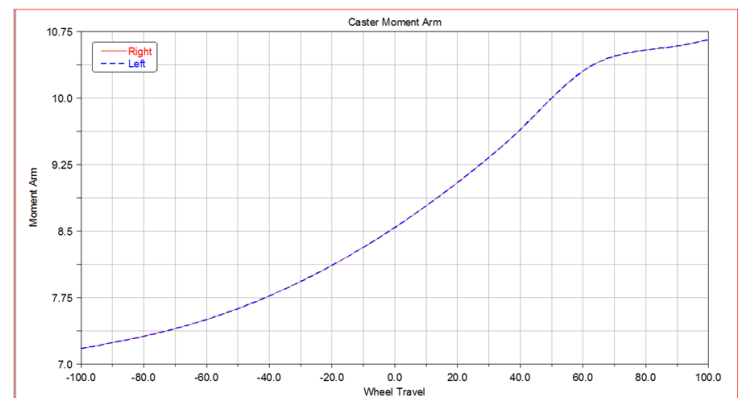
Figure 13: Caster moment arm
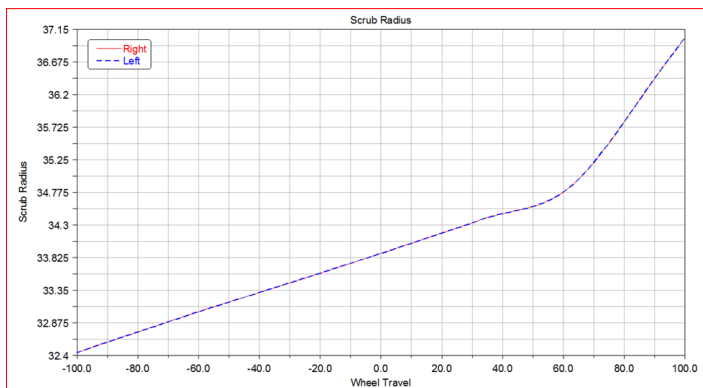

Figure 14: Roll steer
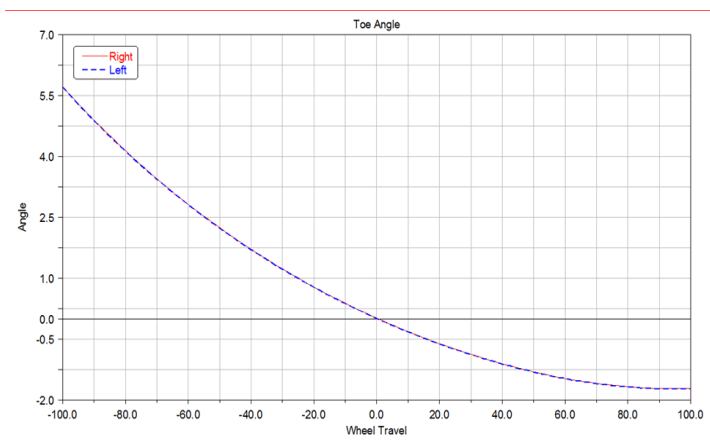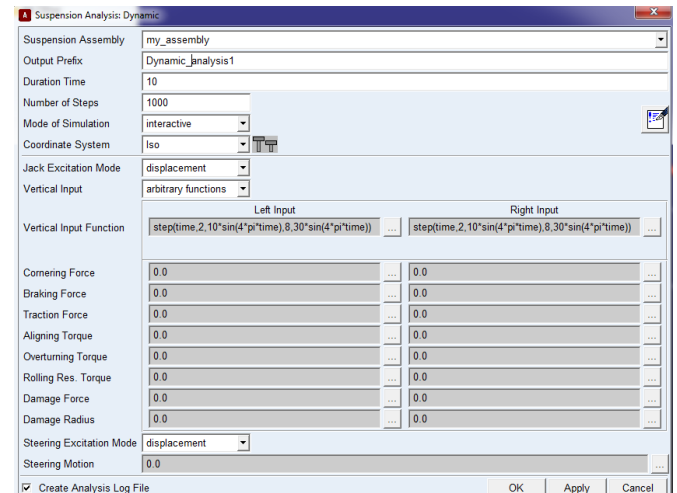
Figure 15: Scrub Radius

Figure 16: Toe Angle

3.4 Dynamic suspension analysis

A Suspension Assembly consisting of a double wishbone suspension and a rack and pinion steering system. The dynamic suspension analysis is carried out to actuate the wheel pads across a range of frequencies.

- To simulate using the *Dynamic Solver Statements*, go to **Simulate** –> **Suspension Analysis** –> **Dynamic**

- You will use **View Functions** to define the vertical displacement of the Jack. The function below steps up the amplitude from 10 mm in bounce and rebound to 30 mm respectively with a frequency of 4 Hz.

- Insert step(time,2,10*sin(4*pi*time),8,30*sin (4*pi*time)) into both the left and right Vertical Input Function fields. Assuming other effects are zero.

Figure 17: Dynamic inputs

3.4.1 Results

Plot the bushing force in the lca_front bushing:

- Hit the F8 key in Adams/Car to switch to Adams/PostProcessor

- Locate the bkl_lca_front_force and bkr_lca_front_force REQUEST under user-defined REQUESTs:

- The **fz_front** component corresponds to magnitude of the force in the Z direction. Plot this quantity to obtain a figure18 similar to the one below:
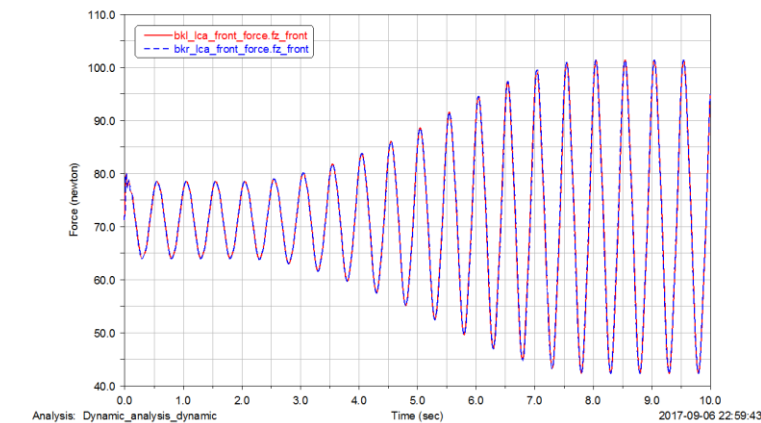

Figure 18: force output

4. CONCLUSIONS

Quasi-static analysis and dynamic analysis of double wish bone suspension system is carried using multi-body dynamics simulation software. Various vehicle characteristic plots studied and analyzed in static and dynamic behavior under 4Hz frequency repose. Since equal amount of frequency response is considered in both left and right side wheels the response of the system also giving same fore on

both sides of the wheels. Hence the suspension model is perfect and does not have any disturbances in force sharing. The maximum force is observed in static for 100mm bounce and re-bound is 4096N and the moment is 66000N-mm.

ACKNOWLEDGEMENT

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