STUDY OF THE ACTIVE SUSPENSION IMPACT IN COMPACT/SPORTY VEHICLE PERFORMANCE

TESIS
PRESENTADA COMO REQUISITO PARCIAL PARA OBTENER EL GRADO ACADÉMICO DE MAESTRO EN CIENCIAS ESPECIALIDAD EN SISTEMAS DE MANUFACTURA

POR
JOSÉ ALFONSO MARTÍNEZ QUIROZ

MONTERREY, N. L.  DICIEMBRE DE 2003
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Study of the active suspensions impact in compact/sportive vehicles performance

Por

José Alfonso Martínez Quiroz

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Abstract

This research compared the characteristics of a full vehicle model, representing a Mustang 2003 using passive, semiactive and active suspension systems. For this, ADAMS/Car simulation software was used. The passive model was separated in four models, with and without antiroll bars; the semiactive models include Skyhook logic which varies the coefficient of viscous damping to simulated the semiactive suspension; the active model have forces in each damper to simulated the actuators and the controller was simulate with the ADAMS/Control tools kit.

In first instant the research was based on discovering stabilizer bars influences in the vehicle's behavior, after that the active and semiactive suspension systems was included in the analysis.

Some characteristics of the vehicle model response were analyzed, including the pitch and roll displacement and chassis acceleration of the vehicle body. The vertical displacement and acceleration of the body mass were used to represent the ride comfort of the vehicle, while the roll displacement of the body and the lateral velocities of the body were used to evaluate the vehicle safety.

The results of the study show that the antiroll bars help some of the vehicles characteristics but nevertheless when helping one of them it harms others having mixed them to reach an intermediate behavior.

The active and semiactive suspension improve the vehicle behavior in similar way, the results for this kind of suspension have similar performance, since both systems feedback the relative velocity of the body to control the dynamic responses.

Both models have better performance, having better handling and greater comfort that the passives systems. The velocity in turns was increased by the active and semiactive suspensions systems having better safety. Chassis accelerations are smooth in the active and semiactive suspension systems having better comfort.
Dedicatory

A las dos personas a quien debo lo que soy... a mis padres

A ti madre, por creer en mi, por apoyarme en todos los aspectos en que se puede apoyar a alguien y por depositar toda su fe y amor en mi.

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Chapter 1

Introduction

The automotive market is characterized by a highly dynamic development focused on customers’ needs. Especially security and comfort have been prioritized during the last years, more remarkably at the luxury level. These kinds of cars are the first in using certain high performance element (comfort or security elements) which are expensive for the compact cars.

In this time, some manufacturers have presented products that share a same purpose, the search of special characteristics in diverse matters as design, personality, exclusive features, sportsmanship, dynamism and technological innovation. Different manufacturers from automotive technology have insisted on developing new systems of electric brakes and active suspensions that improve the behavior and the security of their cars, as well as evolved transmissions to facilitate the drive.

Nevertheless the uses of these technologies continue becoming attached as I mentioned in the beginning, only to luxury cars, while compact and sportive cars exhibit a delay in its use.

1.1 Background.

In the last decades an impressive development in the automotive industry has occurred based on new developed technologies. Global position system (GPS), advanced audio systems, alarm computer systems, electronic communication system with the user, voice recognition systems as well as many innovating controls are clear examples of the present developments, even computers for checking status of the battery’s load are used.

Security systems have even been developed to avoid that the driver fall asleep when he drive tired or at night, by means of muscle relaxation sensors located in the vehicle steering wheel, a controller determines if the driver begins to fall asleep and simultaneously turn on an alarm signal that makes him react immediately.

The fuel injection system is one of the systems that have revolutionized the automotive industry, by means of a controller, it can check the combustible-air relation and even adjust it according to the motor and atmosphere temperature, causing greater fuel efficiency and polluting agents to be near 0 emissions.

Another very important system which use feedback and computer adjusting is the braking system (called ABS), in which, by using computers, it allows stability in the vehicle when is driven in abrupt zones, this stability collaborate to accidents’ reduction.
With respect to the suspension's parts, some technologies that allow a better comfort to the system have been developed. Suspensions systems controlled by computer have been introduced like electronic air bags with weight sensors (ride control), that allow greater and faster suspension system stability when finding irregularities in the traveled road.

In some analyses made previously within the ITESM, tendencies have been identified towards suspensions dimensions reduction, which also are determined by the dimensions reduction in the vehicle structure, which denotes a general tendency. Nowadays the efforts directed towards the weight reduction in all the cars begin to be evident with the micro car's manufacturing. The market is in constant search to be able to build new cars that spend and cost less.

Dimension reductions that have been studied in previous thesis were focused on passive suspensions (computer does not take part in checking and regulating it), in these works, simulations in ADAMS/View and ADAMS/Car was used, developed by the MSC-Software company.

This software was used at the Center for Product Design and Innovation (CDIP) of Instituto Tecnológico y de Estudios Superiores de Monterrey. In the present time there are diverse software that allows making the mechanical system simulation, in two or three dimensions, such as Working model 2d, working model 3d and ADAMS (Car, View, Engine, Etc).

1.2 Problem definition.

The conventional suspensions and, in particular, the antiroll bar function, perform the task of maintaining horizontally the car when it is driven in curves.

But these bars also produce negative effects in the suspension behavior, as a higher global hardness. These bars also are the cause of the wheels to bounce in the pockets zones (on asphalt or in the field), after that, instability conditions are created with the consequent potential danger that this entails.

This is solved with the active suspension system, but as has been mentioned previously, only luxury cars have these privileges nowadays, while compact cars are far to have this kind of systems.

Nevertheless as all new technology, in just a short time, these will propagate or will be found within the reach of the small vehicles.

1.3 Goal of the thesis.

By means of software ADAMS/Car, to analyze the differences between active and passive suspension systems, searching the different possibilities of introducing control to the vehicle's dynamic performance.
1.4 Hypothesis

It is possible to simulate in ADAMS-View and ADAMS-Car the dynamic performance improvement achievable by using active suspensions in compact/sportive cars and, based on the simulations, to identify the required actuators for designing a new generation of compact/sportive cars with improved dynamic performance.

1.5 Methodology

![Diagram of the Methodology]

Figure 1.1 Sequences of activities
Chapter 2

Suspensions

2.1 Car suspensions evolution

First transport (load carriers) was probably introduced around 3500 B.C., which did not require a high comfort.

In the middle of the 16th century was the first springing development, it was a loaf spring that can still be seen on load trucks.

The primary function of suspension at this time was to allow the four wheels to keep contact at all time with an uneven road surface and any increase in the comfort of the passengers was a bonus.

The springs had changed to an elliptical shape and were bolted between the axle and the chassis when powered and faster vehicles appeared.

2.2 Principles of suspension systems

Actually the main suspension objectives are:-

1) To provide independent shock absorption to individual wheels.

2) To have adequate body roll. [1] [5]

3) To maintain the wheels in the proper steer and camber attitudes to the road surface. [1]

4) To keep the tires in contact with the road with minimal load variations. [1] [5]

Perfect suspension system would be just hard enough to suppress body roll, and just soft enough to clamber over any bump. But actually the road surfaces are varied and suspension setting becomes a compromise between comfort and handling. [26]

The present technological accomplishment allows respond to the different suspension system demands by means of the implantation of three different types of suspensions [8]

- Passive suspension.
- Semi active suspension.
- Active suspension.
2.3 Passive suspension

Passive suspension systems are constituted by smooth springs for comfort and hard springs for better performance in cornering.

The suspension and damping must compensate the non wished vehicle movements, caused by the pavement and driving maneuvers. These must care that the tires always have contact with the pavement, so that the forces transmitted between the vehicle and the pavement are minimal. These kinds of suspensions with conventional shock absorbers are used predominantly. [11]

2.4 Adaptive suspension

It represents an evolution to the conventional shock absorbers in passive suspensions. [23]

Adaptive suspension modifies the springs’ stiffness or the shock absorber coefficient by means of low power actuators, normally of discreet way based on different parameters previously measured by sensors.

![Diagram of Passive and Adaptive Suspension]

Figure 2.1 Passive (a) and Adaptive (b) suspension Scheme

CATS suspension (Computer Active Technology suspension) is a commercial example, installed in the Jaguar sport models like the XKR and the S-Type R, which uses adaptable electronic regulation technology to change smooth to hard adjustment, depending on the road and the dynamic driving conditions. It can vary the shock absorber hardness in two positions, automatic or manual. [23]

Another example is Volvo S60 R in which is mounted an adaptive suspension system denominated Monroe Four-C (Continuously Controlled Concept Chassis). It consists of variable hardness shock absorbers which are controlled by computer that receives information from different sensors.
2.5 Active and semi-active suspensions

Active suspension beginnings was in the 80’s, Formula 1 Lotus began to experiment with active suspensions in the Lotus T92, but was until the 90’s when it really was practice and viable. The reason, its high costs and the power consumption. The active and semi-active suspensions consist of closed-loop with feedback. [23]

In the fully active systems, there are not shock absorbers or springs. A hydraulic actuator generates forces to compensate the vehicle balance and pitching, whereas an electronic computer measures constantly (with diverse sensors) the profile of the race and sends electrical signals to the front and back suspensions. [14]
Passive suspension system works for high and low frequencies. Active suspension can control both ranks. But this system has high cost and need power to work (that is taken from the motor), the use of the high frequencies systems (active suspension) is reduced to the competition cars, although Lotus is developing a commercial system that will appear towards 2005. [23]

Outside the circuits, semi-active suspensions are been used, that control the lower forces with active elements and the higher with passives. These use conventional springs.

2.5.1 Semi active suspension.-

Semi active suspension uses regulated systems which allow varying the suspension and damping mechanisms to adapt them to sport use or comfort necessities. Semiactive suspension does not need external power. [5]

Magneto-rheological shock absorbers represent a particular case of this type of suspension and relatively recent advance. The first prototypes date from 90's beginning, General Motors presented this system in 1999, and now its second generation is used in models like Cadillac Seville and the Chevrolet Corvette. [23]

Magneto-rheological fluid is a magnetically soft particles suspension such as iron micro spheres in synthetic hydrocarbon base fluid. When this fluid is in "off" state, it is not magnetized, and the particles exhibit a random pattern. But in "on" or magnetized state the applied magnetic field aligns the metal particles into fibrous structures, changing the rheology fluid to near plastic state. Magneto-rheological fluid performs a critical active ride and handling function.

![Figure 2.4 Magneride fluid Magnetization](image)

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This variable damping follows the same operation principle that the electro valves: smooth when is possible and hard when is necessary. [23]

2.5.2 Active Suspension

"The electronics in the automobile can reach all those vehicle’s points that are susceptible to be controlled since they are subject to different requests”. [6]

One of these cases is the suspension. An ideal suspension would be hard in good pavements and high speed; normal, in mixed requirements, and soft, when the maximum comfort is desired. In addition it would maintain constant body height independently of load and it would even be able of in freeway and at high speeds (up to 100 km /hour) the body approached towards the ground to obtain an aerodynamic effect and less fuel consumption. [5]

Using active suspensions is possible to obtain improvements in comfort and vehicle direction performance. In order to provide flexible control, the active suspensions eliminate the trade-off between ride performance and comfort that is present in passive suspensions. [6].

• Active suspension’s components

A fully active suspension system uses hydraulic cylinders or an actuator as the major load carrying components; a variable output hydraulic pump with an output up to 4 gallons per minute; a series of sensors to detect each spring height as well as body motions in all directions; one or two microprocessors as system control units; a hydraulic flow control and pressure control valve for each wheel unit; one or more hydraulic accumulators; the necessary hydraulic lines to connect these parts; and a special silicone fluid that provides the proper flow characteristics under all temperature conditions. [3]

• Active suspension operation

When the sensors note the pressure increase and/or upward suspension motion of the wheel as it passes over a bump, the pressure in the actuator is decreased, which greatly reduces the harshness and the upward body motion. As the wheel passes over the bump or a dip in the road, fluid is pumped back into the actuator to stop a downward body motion. One system has the ability to bring the actuator pressure from zero to full pressure in one-tenth of a second. Each actuator is controlled separately for bump control. [3]
2.6 Suspension’s components evolution.

2.6.1 Sprung and unsprung weight

Unsprung weight of a car is the weight of the tires, brakes, suspension links and other components that are moved with the wheels. These components are on the roadway side of the springs and react to roadway irregularities. The rest of the weight is on the vehicle’s chassis side of the springs and comprises the sprung weight [22]. The ratio between sprung and unsprung weight is one of the most important components of vehicle ride and handling characteristics. [3]
The two main suspension’s components are springs and dampers.

Springs extend and contract depending on bumps in the road. They absorb energy of vertical wheel movement.

Dampers absorb springs’ energy. Without them the car would continue oscillating vertically similarly to simple harmonic motion.

Beneath is a timeline showing the suspension development in the last century.

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**Figure 2.7 The suspension development in the last century**

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2.6.2 Springs:

Springs have many shapes, but essentially work in the same way, they are deformed when stress is applied and returned to normal when stress is relieved. Over the years this deformation has been achieved by variety of methods. [23]

- **Spring evolution**

The leaf spring or wharves covered without problem the low performance cars necessities. Nevertheless, as motors specifications and speeds were increase, this type of springs was limiting the direction and handling capacities. [23]

- **Leaf springs.**

This kind of spring was the most commonly used spring. [3] These were popular on American cars until about 1985 and are still used on most heavy duty vehicles. [29]

They consist of leaves of metal held together at the ends by metal tight bands. The leaves on the top are longer and the ends of the top leaf are connected to the car. The axel or wheel is connected to the middle of the lowest leaf. [29]

![Figure 2.8 Leaf Springs.](image)

- **Torsion bars**

Torsion bars were patent by Ferdinand Porsche. This is used on VW Beetles and Peugeot 205's. [29] One end of the bar is held to the stationary at wheel axle and connects the other on the frame. [3]

Torsion bar suspension uses steel bar flexibility, twisting lengthwise to provide spring action.

Adjusting the torsion bars controls the height of the vehicle’s front. Adjusting bolts are located at the torsion bar anchors in the front cross member. The inner ends of the lower control arms are bolted to the cross member and pivot through a bushing. [30]
Coil Springs

The basic characteristic of the spring which makes them useful is the fact that they are springy. An uncompressed spring exerts no force as long as it is uncompressed, the more compress it is, the more it pushes back [2].

Coil springs are torsion bars coiled up. By pressing on the top of the spring a twisting is induced in the shaft, spread down the length of the coil. [29]

Air Springs

This kind of spring was invented in the 50's. In this each wheel has a hybrid piston, with its own reservoir. Pressure is provided by a high-pressure pump [29]. This system has the ability to stay at constant height, regardless of load and allows control this manually or automatically. It also allows the car rolled into a corner to cancel the roll induced by the lateral forces on the car. Air suspensions are complex and expensive. [3]

2.6.3 Shock Absorbers

When the vehicle is traveling and the wheels strike a bump, the spring is comprised and it will attempt to return to its normal loaded length. But it will rebound, causing the body of
the vehicle to be lifted. To control spring oscillation, a dampering device called shock absorber is used. [8]

Many types of shock absorbers have been used in the past.

In 1900, cars rode on carriage springs. The first vehicle's manufacturers were focused on the challenges of enhancing driver control and passenger comfort [31]. Modern vehicles use the telescoping Shock absorber [7].

![Figure 2.11 The first vehicles named “carriage”](image)

First shock absorbers were simply two arms connected by a bolt with a friction disk between them. Resistance was adjusted by tightening or loosening the bolt.

These shocks were not very durable, and the performance left much to be desired. Over the years, shock absorbers have evolved into more sophisticated designs. [32]

- **Friction dampers**

Emile Moors invented this kind of damper in 1899. This is a device with a leather washer clamped between two discs, connected to the chassis and the axle. [32]

![Figure 2.12 Friction dampers](image)
• Fluid Dampers

It kind of damper works against hydraulic fluid in the pressure tube. In this hydraulic fluid is forced through little orifices inside the piston. These orifices let small amount of fluid through the piston.

C.L. Horock invented the telescopic damper who tried exploit the resistance to piston’s movement (1901), fitted at its center with a one-way valve and immersed in a fluid. [32]

Figure 2.13 Horrock’s telescopic damper (1901)

Louis Renault designed (1905) a damper that provided resistance to motion with increasing travel with a double-ended piston moving in a cylinder. [32]

Figure 2.14 Louis Renault’s double ended piston hydraulic damper.

Telescopic fluid dampers have been universally accepted on cars. In this moment, the use of hydraulic shock absorbers has been prevailing in the industry, in which the damping force is an increasing function of the speed.
Figure 2.15 Twin tube and gas-pressurized monotube shock absorbers. [1]

2.6.4 Control Arms

A control arm is a bar with pivots at each end, used to attach suspension members to the chassis.

When coil springs are used in both front and rear suspension, three or four control arms are placed between the rear axle housing and the frame to carry driving and brake torque. The lower control arms pivot on the frame members and sometimes support the rear coil springs to provide up-and-down movement of the axle and wheel assembly.

Figure 2.16 Control Arms.

2.6.5 Suspension bushings

These are the rubber grommets which separate most of the suspension's parts from each other. This is one of those little parts which hardly anyone pays any attention to, but it's
vitaly important for car's handling, as well as safety. Rubber is a favored material because it requires no lubrication and will not transfer minor road vibrations. [3]

![Suspension Bushings](image1)

**Figure 2.17 Suspension Bushings.**

### 2.6.6 Joints:

Joints are elements that allow hinging the suspension elements, the most common joint is the sphere joint (trunnions and terminals)

![Ball joint](image2)

**Figure 2.18 Ball joint**

### 2.6.7 Antiroll bars

The anti-roll bar is usually connected to the lower control arm of the suspension, it passes through two pivot points under the chassis and is connected to the opposite suspension system. When the body attempts to tip to one side, one end of the bar bends down and the other end bends up. It helps to keep the vehicles level. [8]

![Antiroll bar function](image3)

*As this side moves vertically relative to the body*

*And this side is lifted a small amount, canceling some of the roll*

*The antiroll bar twists along its length*

**Figure 2.19 Antiroll bar function.**
Front and rear anti-roll bars are designed to reduce body-roll during turns. They work when are twisted, that is, when vertical movement on one side of the bar exceeds the vertical movement on the other side, as when only one wheel goes over a bump. In addition to reducing body-roll, antiroll bars also reduce the adhesion limits of wheels. By varying the antiroll stiffness is possible influence the oversteering or understeering characteristics of a car. An oversteering tendency will be reduced by locating the anti-roll bar at the front where it will reduce the cornering force and adhesion of the front tires. If the vehicle understeers, the anti-roll bar should be located at the rear. If an anti-roll bar is already at both ends of the vehicle, use an anti-roll bar of greater stiffness/diameter and use a less-stiff/smaller-diameter bar at the other end. [22]

Latest high tech anti-roll bar used computer to sense the roll of the car and adjusts the stiffness by pumping fluid in and out of a shock absorber. This system however is more expensive although it provides good road holding and comfort. [31]

2.6.8 Tires

"The most important items of the chassis are the tires" [2]. The ride and handling characteristics of an automobile are related on the characteristics of the tires. Tires are the vehicle's reaction point with the roadway. They manage the input of forces and disturbances from the road.

Tire characteristics are therefore a key factor in the effect the road has on the vehicle, and in the effectiveness of the output forces that control vehicle stability and cornering characteristics. [22]

2.7 Types of suspensions

The different styles of suspension fall into two general classifications, independent and nonindependent. [3]

These kinds of suspension will be briefly described following:

2.7.1 Nonindependent suspension

Until the 70's, most cars still used nonindependent suspensions, especially at the rear axle. Basically, it is a rigid axle fixed between left and right wheels. The car body is suspended by leaf springs or coil springs. When one wheel rides on a hump, the shock is transferred to another wheel. Besides, both wheels will be cambered, thus non-neutral steering is inevitable.

• Solid axle leaf spring

This was invented by M.E. Hertel in 1897; this system was very used in the last century because it is simple and cheap [30]. In this suspension system the wheels are mounted at either end of a rigid beam so that any movement of one wheel is transmitted to the opposite wheel causing them to steer and camber together. [1]
In this suspension, the rear axle housing is mounted on springs and is attached to a set of upper and lower control arms to provide proper rear axle housing alignment [13]. This system can be changed to take less space by separating the shock absorbers and springs. Figure 2.21 illustrates a typical suspension system utilizing coil springs.

Beam axle is only used in front wheel drive cars where the back axle is not driven. This is a relatively simple system where a beam runs across the car and the wheels are attached at either end. The ends also have springs and shock absorbers attached to them. [30]
2.7.2 Independent Suspensions

In independent suspension systems, each one of the wheels, are mounted on separated spindles and controls arm. Mounting the wheels separately allows them to travel up or down independently of the other wheel on the same axis [3].

- Swing axle suspension

The simplest type of independent suspension is the swing axle. [3] This is a very old independent suspension, used by some sports cars since the 50s, such as VW Beetle, Porsche 356. It disappeared for at least 2 decades because it has so much weakness. The only advantage is that it provides independent shock absorption. [30]
• **Double wishbones suspension**

Double wishbones (or "A-arms") are for many suspension designers, the most ideal suspension. It can be used in front and rear wheels, it is independent and has near perfect camber control. This is the first choice for racing cars, sports cars and demanding sedans. [30]

This kind of suspension consist of two transverse links (control arms) either side of the vehicle, which are mounted to rotate on the frame, suspension subframe or body and, in the case of the front axle are connected on the outside to the knuckle or swivel head via ball joint. [15]

Basically, double wishbones suspension always maintains the wheel perpendicular to the road surface, irrespective of the wheel's movement. This ensures good handling.

![Double wishbones suspension from Honda Prelude and accord.](image)

Figure 2.24 Double wishbones suspension from Honda Prelude and accord.

• **Short-long arm suspensions.**

This kind of suspension is the typical RWD Car's suspension, it consist of two control arms (a short upper arm and a longer lower arm), a steering knuckle with spindle, and the necessary bushings and ball joints. [3]

![Short-long arm suspensions from Ford motor company.](image)

Figure 2.25 Short-long arm suspensions from Ford motor company.
• **McPherson strut suspension**

Earl S. McPherson developed a suspension using strut configuration in 1940's [1]. It was introduced on 1951 Ford consul and Zephyr [3] and has since become one of the dominating suspension systems of the world because of its compactness and low cost. In this type of suspension, the telescopic shock absorber also serves as control arm. Besides, since the strut is vertically positioned, the whole suspension is very compact.

This simple design does not offer very good handling. Body roll and wheel's movement lead variations in camber.

![McPherson strut suspension](image)

Figure 2.26 McPherson strut suspension.

• **Trailing arm and Semi-trailing arm suspension**

It is one of the most simple and economical design of an independent front suspension. [1] These kinds of suspensions are rather old. It was commonly used in before multi-link rear suspension became popular in 1990s.

Trailing arm suspension are often used on more expensive and high performance car [1], this employs two trailing arms which are pivoted to the car body at the arm's front edge. The arm is relatively large compare with other suspensions' control arms because it is in single piece and the upper surface supports the coil spring. It is rigidly fixed to the wheel at the other end.

Semi-trailing has a disadvantage, when the wheel moves up and down, camber angle changes, unlike double wishbones suspension.

Most modern sedans replace it with multi-link or double wishbones suspension. Trailing arm and Semi-trailing is disappearing in the industry. [27]
• **Torsion beam suspension**

Most modern mini cars employ this kind of suspension as rear suspension. This needs little width of the car, thus enable greater rear seat room. Its shock absorbers are shorter and can be inclined steeply away from the vertical, thus engage less boot space. It is cheaper too. [30]
2.8 Mustang’s suspension

2.8.1 Front Suspension

The Mustang front suspension is a modified McPherson struts. The coil springs are inboard of the struts. This suspension is criticized because its geometry produces camber changes during vertical suspension movement and body roll that adversely affect handling. [17]

![Figure 2.29 Mustang front Suspension.](image)

2.8.2 Rear Suspension

The Mustang's rear suspension consists of a live rear axle held in position by 4-links (upper and lower control arms), coil springs, shock absorbers and an antiroll bar.

The upper and lower rear control arms constitute the four links in this rear suspension. When the car rolls in a turn, one side of the chassis moves upward relative to the rear axle, the other side moves downward, and these non-parallel control arms must twist and change length axially to allow the axle to articulate. [17]

![Figure 2.30 Mustang rear suspension [1](image)
2.8.3 Mustang Coil Springs

Calculating the stiffness or rate of a coil spring:

\[ K = \frac{Gd^4}{8D^3N} \]

- \( K \) = Spring rate in pounds per inch
- \( d \) = Diameter of the spring wire in inches
- \( G \) = 12,000,000 for steel springs (a constant)
- \( N \) = Number of active coils (number of coils that are free to move + 1/2 coil)
- \( D \) = Diameter of the coils measured to the center of the wire, in inches

Applying the formula to the springs’ stiffness on Mustangs: [2] [3] [11]

<table>
<thead>
<tr>
<th>Front Springs</th>
<th>W</th>
<th>N</th>
<th>D</th>
<th>K</th>
<th>Approximately</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.65&quot;</td>
<td>8.75</td>
<td>4.25&quot;</td>
<td>398.63</td>
<td>400 lb/in.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1 Springs’ stiffness of Mustang front suspensions.

<table>
<thead>
<tr>
<th>Rear Springs</th>
<th>W</th>
<th>N</th>
<th>D</th>
<th>K</th>
<th>Approximately</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.55&quot;</td>
<td>7.5</td>
<td>4.625&quot;</td>
<td>184.99</td>
<td>185 lb/in.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2 Springs’ stiffness of Mustang rear suspension.

2.8.4 Antiroll bars on Mustangs

Ford Mustang naturally is understeer because of its rear-wheel drive and front-end weight bias. A rear Antiroll bars is an easy way to add some stiffness to the rear suspension and reduce this understeer. It gives a more "precise" feel to the steering. It makes the car turn easier and feel more stable and the front tires wear longer. [17]

Adding a rear Antiroll bar not only reduces understeer, it also makes the car more likely to oversteer. That makes the car’s turn quicker, but also more dangerous because it could lead to a spin-out. To correct oversteer, the driver must stay off the brakes, add power, and turn the steering wheel in the direction of the slide.

Figure 2.31 Mustang rear antiroll bar
Chapter 3

Some important Suspensions’ characteristics

3.1 Camber angle

Camber is the angle that the plane of the tire makes with the vertical [2]. Ideally the tire should be as near vertical (zero camber) as possible under all driving conditions. However, some negative camber is desirable in hard turns to offset the tendency of the inside tire to roll under. Camber is measured with a specialized level called camber gage. [20]

![Camber Angle Diagram]

Figure 3.1 Camber Angle

3.1.1 Camber angle in mustangs

Mustang's McPherson strut suspension doesn't do a very good job of producing negative camber in turns. Ford recommends ½ degree negative camber on the 2000 Mustang. Camber is adjusted by moving the top of the front strut toward the center of the car (negative camber) or toward the outside of the car (positive camber). [17]

![Camber Types Diagram]

Figure 3.2 Types of Cambers.
3.2 Caster angle

Caster angle is the angle (in degrees) between the steering axis and true vertical. When the car is moving this generates a self centering force, which causes the steering wheel to return to straight-ahead when the user release it after a turn. [20]

![Caster Angle Diagram]

Figure 3.3 Caster Angle

3.2.1 Caster angle in mustangs

2000 Mustangs come from the factory with caster angle at about 3.2 degrees. This can be increased by moving the top of the strut toward the rear of the car. At 4 degrees caster or less, the car will gain positive camber when the wheel is turned (not good). More than 4 degrees of caster will produce negative camber gain when the wheel is turned (good). Five or six degrees of caster are optimal on a street-driven Mustang. [17]

![Caster and Camber Adjustment Diagrams]

Figure 3.4 Camber and caster Mustangs adjust (a) and camber adjustment slots (b).

Mustang's strut towers do not have slots to permit caster adjustment. If it is wanted to change the factory caster setting, it is needed to replace the stock plates on the top of the strut towers with aftermarket caster/camber plates that permit adjustment in two directions.
3.3 Kingpin inclination angle

The kingpin inclination angle is the angle in the front elevation between the steer axis (the kingpin axis) and the vehicle’s vertical axis. It is positive when the steer axis is inclined upward and inward. [20]

3.4 Roll camber coefficient

Roll camber coefficient is the rate of change in wheel inclination angle with respect to vehicle roll angle. Positive roll camber coefficient indicates an increase in camber angle per degree of vehicle roll. [20]
3.5 Roll center location

Roll center location is the point on the body where the moment of the lateral and vertical forces exerted by the suspension links on the body disappears. Every vehicle has a front roll center and rear roll center. They are independent from each other and are determined by suspension geometry. [20]

![Figure 3.8 Roll Center Location (Front View)](image)

3.5.1 Mustang roll center location

The front roll center height of a car with the Mustang's McPherson strut suspension can be found as follows:

- Drawing a line at an angle of 90 degrees from the top of the front strut.
- Drawing a second line through the lower control arm. The point where these lines intersect is the instantaneous center.
- Drawing a third line from the instantaneous center to the tire centerline. The point where this third line crosses the car's centerline at the roll center.[17]

![Figure 3.9 Mustang front roll center height](image)
The rear roll center height of a car with Mustang's non-parallel four-link rear suspension can be found as follows:

- Finding point A by drawing lines through the non-parallel upper links.
- Finding point B by drawing lines through the non-parallel lower links.
- The roll center is the point where line A-B crosses a vertical plane through the axle centerline.[17]

![Diagram of Mustang rear roll center height](image)

**Figure 3.10 Mustang rear roll center height**

The roll axis of a mustang can be found by drawing a line that connects the front and rear roll centers. [17]

![Diagram of Mustang Roll axis](image)

**Figure 3.11 Mustang Roll axis.**

### 3.6 Suspension roll rate

Suspension roll rate is the torque, applied as vertical forces at the tire patches, per degree of roll, measured through the wheel centers.
3.7 Toe angle

Toe angle is the angle between the longitudinal axis of the vehicle and the line of intersection of the wheel plane and the vehicle’s XY plane. [20]

Toe-in keeps the car going straight, improving high-speed stability, and toe-out produces wandering and high-speed instability. Too much of either one will cause excessive tire wear. When the car is in motion, drag forces create a natural tendency for tires to toe-out.

3.7.1 Toe angle in mustangs

Ford recommends 1/4 degree of toe-in on 2000 Mustangs. Adjustment is made by changing the length of the front wheel spindle tie-rods. [17]

3.8 Steering system characteristics

3.8.1 Ackerman

Ackerman is the difference between the left and right wheel steer angles. A positive Ackerman indicates that the right wheel is being steered more to the right than to the left. [20]
Chapter 3

Some important suspensions’ characteristics

3.8.2 Ackerman angle

Ackerman angle is the angle whose tangent is the wheel base divided by the turn radius. Ackerman angle is positive for right turns. [20]

3.8.3 Caster moment arm

Caster moment arm is the distance from the intersection of the steer axis and the road plane to the tire contact patch measured along the intersection of the wheel plane and road plane. Caster moment arm is positive when the intersection of the steer axis and road plane is forward of the tire contact patch. [20]
3.8.4 Ideal steer angle

Ideal steer angle is the steer angle in radians that gives Ackerman steer geometry or 100% Ackerman. For Ackerman steer geometry, the wheel center axes for all four wheels pass through the turn center. [20]

The ideal steer angle and the steer angle are equal for the inside wheel. When making a left turn, the left wheel is the inside wheel. Conversely, when making a right turn, the right wheel is the inside wheel. A positive steer angle indicates a steer to the right.

3.8.5 Outside turn diameter

Outside turn diameter is the diameter of the circle defined by a vehicle’s outside front tire when the vehicle turns at low speeds.

For a left turn, the right front wheel is the outside wheel. For a right turn, the left front wheel is the outside wheel. [20]

3.8.6 Turn Radius

The turn radius is the distance measured in the ground plane from the vehicle center line to the turn center along the y-axis. Turn radius is positive for right turns and negative for left turns. [20]

3.9 Dynamics characteristics

3.9.1 Pitch

It is the vehicle’s rotational movement about y axis, it happen from front to rear and vice versa. [7]

3.9.2 Roll

It is the vehicle’s rotational movement about x axis; it happen from left to right and vice versa. [7]

3.9.3 Yaw

It is the vehicle’s rotational movement about z axis. [7]

3.9.4 Bounce

It is the vehicle’s vertical translation movement about z axis.[7]
3.10 Understeer and oversteer

Understeer is when a vehicle doesn't turn as quickly as the angle of the front wheels would suggest. This is because the front tires have a greater slip angle than the rear tires. [3] [2]

Oversteer, is when the vehicle turn too far, with the back end sliding around and, in extreme cases, trying to pass the front.

A car is said to have neutral steering capabilities if the tire slip angle are the same at the front and the rear. [3]

The causes for under or oversteer; can be a lot, the presence or absence of anti-roll bars, and even the size and type of tires.

Most cars are constructed with understeer because understeer is easier to cope for the average driver. The instinctual reaction for a driver in a sliding car is to lift off the throttle and hit the brakes, which will transfer weight to the front end and increase traction there, helping an understeering car to recover control. Doing the same thing in a car that's oversteering will usually make the situation worse by unloading the rear tires and further reducing their traction.

It's possible for a vehicle to have both understeer and oversteer at different times. One example is the first-generation Porsche 911 Turbo.
3.11 Cornering dynamics

A moving body will continue moving in a straight line until it is acted upon by a disturbing force (Newton's First Law). The balance that exists between the disturbing force and the reaction of the moving body (Newton's second Law) is present in the automobile, the cornering forces produced by tires, the force causing the turn and the force resisting the turn will always be in balance [22].

A car Driven to constant speed at the moment to pass through a constant radio curve has the influence of a constant force that acts away of the curve center. This is the centrifuges force, and this change with the speed and the curve radius. The centrifuges force cause the car inclination, and does that the car slip if the adhesion limits is exceeded. The centrifuges force represents the car inertia or its resistance to the movement in the curve trajectory [22].
In order to calculate the centrifugal force in the car, it is necessary to know the car weight, the speed, and the curve radius. Then the formula is: [9]

\[ F_{cent} = \frac{m \cdot V^2}{14.97 \cdot r} \]

Where

- \( F_{cent} \) = centrifugal Force, lb
- \( m \) = Vehicle mass, lb
- \( V \) = Vehicle velocity, mph
- \( r \) = path radius, ft

The lateral acceleration is calculated by: [9]

\[ \text{Lateral acceleration} = \frac{V^2}{14.97 \cdot r} \]

3.12 The Criteria for Good Handling of Vehicles:

The desirable characteristics are the following:

1) Shorter time delay in the yaw rate and lateral acceleration responses of the vehicle to steering input [10].

2) Good compromise between the requirements of sufficiently high damping of yaw rate and margin of stability and the responsiveness of the vehicle to steering input. [12]


4) Increasing response immunity to external disturbances. [13]

5) Reduction of the variation in the steering response with increasing vehicle speed. [13]

7) Reducing the roll response [12].
Chapter 4

Control

In this time, control has a very important role in the automotive technology, in suspension study case, automotive suspension designs have compromise between comfort and handling. Good ride comfort requires a soft suspension, whereas insensitivity to applied loads requires hard suspension. Good handling requires a suspension setting somewhere between the two.

The damping coefficient of the damper determines both the stability of the vehicle and the comfort of the travelers, as shown in Figure 4.1 a high damper provides good stability, keeping the tires in contact with the road and preventing jackknifing and other problems, but will transfer much of the road input to the passenger, causing an uncomfortable ride. Conversely, a soft damper will disturb the travelers less, but it lowers the stability of the vehicle. [24]

![Figure 4.1 Damping Compromise.](image)

An active suspension system has the ability to store, dissipate and to introduce energy to the system. It may vary its parameters depending upon operating conditions and can have knowledge other than the strut deflection the passive system is limited to.

Another system that minimizes the vibration of the suspended body and gives a good “Active” control of the car is the semi active system, which changing the size of the orifice through which the hydraulic fluid passes or changing the properties of the fluid itself produce variable damping. [24]

Passive and semiactive dampers have a similitude; in each of these dampers, the magnitude of damping is dependent on the relative velocity across the damper. The force
versus velocity curves of each type of damper, however, is not identical. The typical curves for a passive and a semiactive damper are shown in Figure 4.2 [25]

![Figure 4.2 Passive and Semiactive Damper Curves](image)

In passive dampers, the magnitude and direction of the force exerted by the damper depend only on the relative velocity across the damper. In semiactive dampers, however, although the direction of the force exerted by the damper still depends on the relative velocity across the damper, the magnitude of the damping force is adjustable.[25]

A semiactive damping systems that suggest placing a damper between the suspended body and some inertial frame of reference is the named “Skyhook”. This system use two accelerometers at each wheel, one on the axle to measure the acceleration of the axle, and other on the car frame directly above the axle to measure the acceleration of the body. Then accelerations are integrated to provide absolute velocity. [25]

In on-off skyhook control, the damper is controlled by two damping values.

Skyhook logic is:

- Damper “hard” (damper ON) when \((V2-V1)\times V2 >0\)
- Damper “soft” (damper OFF) when \((V2-V1)\times V2 <0\)

V2 – sprung mass velocity
V1 – unsprung mass velocity (wheel)

4.1 High bandwidth systems

High bandwidth or fully active suspension system considers an actuator connected between the sprung and unsprung masses of the vehicle. A fully active system aims to control the suspension over the full bandwidth of the system. In particular this means that is aimed to improve the suspension response around middle frequency (10-12 Hz) and low frequency (3-4Hz). A fully active system will consume a significant amount of power and will require actuators with a relatively wide bandwidth. These have been successfully implemented in Formula One cars and by, for example, Lotus [4]
4.2 Low bandwidth systems

Low bandwidth systems are slow-active systems. In this type the actuator will be placed in series with a road spring and/or damper. Low bandwidth system aims to control the suspension over the lower frequency range. At higher frequencies the actuator effectively locks and hence the wheel movement is controlled passively. With these systems is possible achieve a significant reduction in body roll and pitch during maneuvers such as cornering and braking, with lower energy consumption than a high bandwidth system.

Low bandwidth semiactive policies require only sensing and actuation at the bandwidth of the sprung mass, whereas a policy such as skyhook requires sensing of the relative velocity, which requires a higher bandwidth.

4.3 Current Technology

Active suspension systems that have been successfully implemented include the high profile examples found on Formula One racing cars. Formula one car represents the extreme of active suspension implementation, being fully active systems using high bandwidth aerospace specification components [4]. For wide spread commercial use much cheaper actuators and control valves must be used, and so semi-active or low bandwidth systems are the norm here.
Chapter 5

ADAMS/Car

ADAMS/Car, Mechanical Dynamics (MDI) virtual prototyping software is powerful Software, which make possible to create and to analyze suspension and vehicle assemblies, it is a specialized environment for modeling vehicles. It allows to create virtual prototypes of vehicles, and analyze these much like if would analyze the physical prototypes.

5.1 Benefits to use ADAMS/Car.

ADAMS/Car enables to work faster and smarter, letting have more time to study and understand how design changes affect vehicle performance. Using ADAMS/Car is possible:

- Explore the performance of the design before building and testing a physical prototype.
- Analyze design changes faster and at lower cost than physical prototype testing would require.
- Vary the kinds of analyses faster and more easily than if we had to modify instrumentation, test fixtures, and test procedures.
- Run analyses without the dangers associated with physical testing.

5.2 ADAMS/Car hierarchy

ADAMS/Car hierarchy is comprised of the following components:

5.2.1 Templates.

Models built in the "Template Builder" by users who have expert privileges. Templates are parameterized and topological representations of vehicle subsystems, which can include front suspensions, brakes, chassis, and so on. [19]

Figure 5.1. Mustang front (a) and rear (b) suspensions templates.
5.2.2 Subsystems

Subsystems are based on templates and allow standard users to change the parametric data of the template. For example, it is possible to change the location of hard points, modify parameter variables, and so on. [19]

Figure 5.2 Architecture of front suspension Assembly with direction system

5.2.3 Assemblies

Are comprised of subsystems that can be grouped together to form suspension assemblies, full-vehicle assemblies, and so on. [19]

Figure 5.3 Mustang Front suspension Assemblies with (a) and without (b) steering system.
5.3 ADAMS/Car interfaces:

5.3.1 Standard Interface

It is used when working with existing templates to create and analyze assemblies of suspensions and full vehicles. Both standard users and expert users can use standard interface.[19]

5.3.2 Template Builder interface.

Template builder is used to create new templates for use in standard interface, it needs expert user privileges.[19]

5.4 Configuration to obtain expert privileges

To obtain the expert privileges user it is required to do a little change in the configuration file .acar.cfg (distinguishing it of another called file acar.cfg). This file is located in the user home directory and defines the personal adjustments like user modes, personal database and tables, predetermined properties archives, etc. The change that must be made is the one that is in the following figure, in ENVIRONMENT MDI_ACAR_USER_MODE becomes the change of standard to expert. The file must be opened like text file and save with the made changes.

```
[acar.cfg - Notepad]
%ADAMS/car Configuration File
%
---
- List of personal environment variables

Desired user mode (standard/expert)
ENVIRONMENT MDI_ACAR_USERMODE expert
---
- List of personal database directories

Example database entry:
DATABASE proto_2000 /usr/people/gabriel/prototype.cdb
```

Figure 5.4 Configuration files to work with expert privileges.
5.5 Configuration to obtain ADAMS/View interface

It is possible also to have the A/View interface when working with subsystems and assemblies, thus to be able to use the A/View tool, it allow for example using the main toolbox for a easy handling of the model. For this it must also add the A/View atmosphere in the configuration file .acar.cfg

![acar.cfg - Notepad](image)

Figure 5.5 Configuration file to work with A/View tools environment.

5.6 ADAMS/Car analyses [20]

Using ADAMS/Car to analyze a virtual prototype is like testing a physical prototype. To do this it is needed specify the following:

- The virtual prototype to be tested.
- The kind of analysis to be performed.
- The analysis inputs to be used.

The inputs to the analysis are specified by typing them directly into an analysis dialog box. After specifying the prototype assembly and its analysis, the inputs that are specified are applies and the results are records. To understand how the prototype behaved during the analysis is possible plot the results.

Each kind of analysis that is performed requires a minimum set of subsystems, full-vehicle analysis requires front and rear suspension subsystems, front and rear wheel subsystems, one steering subsystem, and one body subsystem.
5.6.1 Types of analyses

There are two types of analyses: suspension analyses and full-vehicle analyses.

5.6.2 Suspension analyses

ADAMS/Car lets analyze and view virtual prototypes of suspensions and steering subsystems.

For a suspension analysis, it is possible specify inputs to:

- Move the wheels through bump-rebound travel and measure toe, camber, wheel rate and other characteristics.
- Apply lateral load to measure the toe change and lateral deflection of the wheel.
- Rotate the steering wheel to measure the steer angles.
- Based on this kind of results, it is possible alter the suspension geometry or spring rates and analyze the suspension again to evaluate the effects of the alterations.

A suspension analysis is performed to learn how a suspension controls the wheel motions and transmits load from the wheels to the chassis. To perform a suspension analysis, first we create or open a suspension assembly that contains the selected subsystems and the test rig. We then specify ranges of vertical wheel travel, steering travel, and static tire contact patch loads and the number of solution steps.

Figure 5.6 Suspension analysis process (A suspension analysis in ADAMS/Car is a quasi-static equilibrium analysis).
5.6.3 Types of suspension analyses

![Figure 5.7 Types of suspension analyses.](image)

Possible types of suspension analyses are:

- **Wheel travel analyses**

  This analysis allows looking at how the characteristics of a suspension change throughout the vertical range of motion of the suspension. It is possible to perform three types of wheel travel analyses.

  - **Parallel wheel travel analysis**

    This analysis keeps the left wheel and right wheel heights equal while moving the wheels through the specified bump and rebound travel.

  - **Opposite wheel travel analysis**

    This kind of analysis moves the left and right wheel through equal, but opposite, vertical amounts of travel to simulate body roll.

  - **Single wheel travel analysis**

    This analysis moves one wheel, either the right or left, through a rebound travel while holding the opposite wheel fixed in a specified position.

- **Roll and vertical force analysis**

  A roll and vertical force analysis sweeps the roll angle while holding the total vertical force constant.
• **Steering analysis**

A steering analysis steers the wheels over the specified steering wheel angle or rack travel displacement from the upper to the lower bound.

• **Static load analysis**

Depending on the type of load of input, the static load analysis applies static loads to the spindle and the tire patches between the specified upper and lower load limits.

• **External file analysis**

There are two types of external-file analyses: load case and wheel-envelope analysis.

• **Load case analysis**

This analysis reads the analysis inputs from one or more existing load case files, performs one analysis for each load case file.

• **Wheel envelope analysis**

A wheel-envelope analysis generates wheel center positions and orientations for use in packaging the wheel/tire within the wheel well (fender). The analysis sweeps the wheels through their vertical and steering travel in fixed increments based on information stored in a wheel-envelope input file (.wen). The positions and orientations for the left and right wheel centers are output to a wheel-envelope output file (.wev) for import into computer aided design (CAD) packages.

5.6.4 **Full vehicle analyses**

ADAMS/Car lets analyze virtual prototypes of full vehicles.

It is possible to take created suspension subsystems and integrates them with other subsystems to create a full-vehicle assembly to perform various analyses on the vehicle.

[Figure 5.8 Full-Vehicle Analysis Process]
It is possible perform several types of full-vehicle analyses using ADAMS/Car. All of the analyses, except for the data-driven analyses, use the .MDI.SDI.TESTRIG, and are therefore based on the Driving Machine.

![Figure 5.9 Types of full vehicles analyses.](image)

- **Open-loop steering analyses**

  ADAMS/Car provides a wide range of open-loop steering analyses.

  The open-loop steering analyses include:

  - **Drift**
    In Drift analysis, the vehicle reaches a steady-state condition in the first ten seconds.

  - **Fish-Hook**
    This analysis is to evaluate dynamic roll-over vehicle stability.

  - **Impulse steer**
    The purpose of the test is to characterize the transient response behavior in the frequency domain. Typical metrics are: lateral acceleration and vehicle roll and yaw rate, both in time and frequency domain.

  - **Ramp steer**
    This analysis is used to obtain time-domain transient response metrics.

  - **Single lane-change analysis**
    During a single lane-change analysis, the steering input goes through a complete sinusoidal cycle over the specified length of time.

  - **Step steer**
    The purpose of this analysis is to obtain time-domain transient response metrics. The most important quantities to be measured are: steering wheel angle, yaw angle speed, vehicle speed and lateral acceleration.
• Swept-sine steer
The most important factors for this evaluation are: steering wheel angle, lateral acceleration, yaw speed, and roll angle.

• Cornering Analyses

Driving Machine cornering analyses are used to evaluate vehicle’s handling and dynamic response. Cornering analyses combine open and closed loop controllers of the steering, throttle, brake, gear, and clutch signals to perform complex analyses on the vehicle.

The cornering analyses include:

• Braking in a turn

This is one of the most critical analyses encountered in everyday driving. The purpose of this analysis is to examine path and directional deviations caused by sudden braking during cornering. Typical results collected from the braking-in-turn test include lateral acceleration, variations in turn radius, and yaw angle as a function of longitudinal deceleration.

• Constant radius cornering

For constant radius cornering analysis, the Driving Machine drives the full vehicle down a straight road, turns onto a skid pad, and then gradually increases velocity to build up lateral acceleration.

One common use for a constant radius cornering analysis is to determine the understeer characteristics of the full vehicle.

• Cornering with steer release

The vehicle performs a dynamic constant-radius cornering to achieve the prescribed conditions (radius and longitudinal velocity or longitudinal velocity and lateral acceleration).

• Lift-off turn-in

The purpose of this analysis is to examine path and directional deviations caused by suddenly lifting the throttle pedal during cornering and applying an additional ramp steering input.

• Power-off during cornering

This analysis allows determine the power-off effect on course holding and directional behavior of a vehicle whose steady-state circular path is disturbed by throttle power-off. Typical results collected from the power-off cornering
analysis include variations in the heading direction and longitudinal deceleration, as well as sideslip angle, yaw angle and gradient.

- **Straight-Line-Behavior Analyses.**

The analyses based on the Driving Machine focus on the longitudinal dynamics of the vehicle.

The straight-line-behavior analyses include:

- **Acceleration test.**

  An acceleration test analysis helps you study the anti-lift and anti-squat properties of a vehicle.

- **Braking**

  The braking test analysis helps to study the brake-pull anti-lift and anti-dive properties of a vehicle.

- **Power-off straight line**

  This analysis allows examine operating behavior and directional deviations caused by suddenly lifting off the throttle pedal during a straight-line analysis. Typical results collected from the power off straight-line analysis include variations in heading direction and longitudinal deceleration.

- **Course event analyses**

  This kind of analysis is of a course-following type, such as ISO-lane change. In an ISO-lane change analysis, the Driving Machine drives the full vehicle through a lane change course as specified in ISO-3888: Double Lane Change. The analysis stops after the vehicle travels 250 meters; therefore, the time to complete the lane change depends on the speed input.

- **Driver-control-file-driven analysis**

  This analysis lets run an analysis described in an existing driver control file (.dcf). Having direct access to .dcf files allows easily perform nonstandard analyses on the full-vehicle assembly because all we have to do, is to generate a new .dcf file describing the analysis.
• **Quasi-Static Analysis**

Quasi-static analyses find dynamic equilibrium solutions for the full vehicle at increasing, successive values of lateral acceleration. Quasi-static analyses, in contrast to open-loop and closed-loop analyses, do not include transient effects and solve very quickly. For example, in a quasi-static analysis, a change in lateral acceleration from 0.1g to 0.5g does not show the lateral acceleration or yaw rate overshoot that a similar open loop and closed-loop analysis might show. Quasi-static analyses use either the .MDI_DRIVER_TESTRIG or the .MDI_SD1_TESTRIG.

- Constant-Radius Cornering Analysis.
- Constant-Velocity Cornering Analysis.
- Force-Moment Analysis.

• **Data-Driven Analysis**

This is the only analysis that requires the .MDI_DRIVER_TESTRIG and is based on a load case file. For this analysis is necessary to define the inputs for a data-driven analysis in a driver load case file (dri.). The driver load case file contains the time/distance open-loop signals for steering, throttle, brake, clutch, and gear.

• **ADAMS/Driver Analyses**

ADAMS/Driver enables to add the control actions of a human driver to the full vehicle simulations. This analysis can extend the set of full-vehicle events available in ADAMS/Car. It simulates the vehicle on a user-defined track representing a road.

ADAMS/Driver analyses use the .MDI.Driver_TESTRIG or the .MDI_SD1.TESTRIG.

5.6.5 **The Driving Machine**

The Driving Machine drives the virtual vehicle according to user instructions much like a test driver would drive an actual vehicle. The Driving Machine steers the vehicle, applies the throttle and brake, and shifts gears using open-loop or closed-loop controllers.

- Using open-loop control, the Driving Machine can, for example, input a swept sinusoid to the steering or play back recorded steering, throttle, brake, gear, and clutch signals as input to your virtual vehicle.

- Using closed-loop control, the Driving Machine can steer a vehicle around a skid-pad, while gradually increasing speed.
• What is possible do with the Driving Machine?

Using the Driving Machine it is possible:

- Input the vehicle path and speed, and use closed-loop.
- Input a variety of open-loop functions.
- Input recorded steering, throttle, brake, gear, and clutch signal to the model.
- Stop a simulation, switch controllers, and change output step size based on reaching a target lateral acceleration, longitudinal velocity, or distance traveled.

• Limitations to Driving Machine Analyses

The Driving Machine limitations are:

- It can only accurately steer a vehicle when positive steer inputs steer the vehicle to the left.
- It cannot control low velocities.

5.6.6 Testrigs

A Testrig consists of the tires and a representation of the ground. In the wheels are including the forces (complex) between this wheels and the ground like the union of the tire with the member of the corresponding suspension.

Therefore when suspension template is constructed, becomes without tire or ground, only have the parts of the suspension and the corresponding connectors. When template of a Testrig is made, the ground and the tires are constructed (normally the Testrigs already are made, only require different Testrig when is wanted to modify details like placing 4 tires in an axis, to put a traction control special, etc.)

When working in ADAMS/Car is possible use two Testrigs:

- _MDI_SUSPENSION_TESTRIG – To analyze suspensions assemblies.
- _MDI_SDI_TESTRIG – To analyze Full vehicles assemblies.

• Suspension Testrig

ADAMS/Car uses the suspension test rig, named _MDI_SUSPENSION_TESTRIG, in all suspension analyses. When is created a suspension assembly, ADAMS/Car assembles
the suspension test rig with the selected suspension and steering subsystems. The suspension test rig inputs excitation as motions and forces to the suspension and steering subsystems. The excitations are made up of one or more of the following:

- **Displacement** for wheel bumps and rebound vertical travel.
- **Roll and vertical force**.
- **Steering travel** at the steering wheel or rack.
- **Forces or torques** at the steering wheel or rack.
- **Forces and torques** at the contact patch and the hub.

**Driving Machine Test Rig**

ADAMS/Car uses the driving machine test rig, .MDI_SD1_TESTRIG, to perform open-loop and closed-loop full-vehicle analyses.

The driving machine test rig supplies a series of driving signals to the vehicle subsystems or to actuators to perform a desired maneuver. These signals include:

- **Steering**

Generally, steering is an angle and typically in degrees. It depends, however, on how the user set up the units in the ADAMS/Car session.

- **Throttle**

The throttle has no units, but is specified on a range from 0 to 100. Where 100 is full throttle and 0 is closed throttle.

- **Brake**

The units for brake are pressure (force/area).

- **Clutch**

No units. The clutch is specified on the range from 0 to 1, where 1 is clutch pedal fully depressed and 0 is opposite.

- **Transmission**

No units; just 1, 2, 3, 4, and so on.
Chapter 6

Modeling

6.1 Design Process with ADAMS

Figure 6.1 Entire design Process with using ADAMS
6.2 Vehicle Modeling [19] [21]

This section describes the building process for Mustang front suspension template and subsystem.

Building a template means defining parts, how they connect to each other, and how the template communicates information to other and to test rigs. At template level, it is not crucial to correctly define the parts, assign force characteristics, and assign mass properties, because it is possible to modify these values at subsystem level. It is very important, however, to correctly define part connectivity and exchange of information, because it is not possible to modify them at the subsystem level.

6.2.1 Principals steps to build a template

- Creating hardpoints.

  Hardpoints define all key locations in the model. They are the most elementary building blocks that permit to parameterize locations and orientations for higher-level entities.

- Creating parts.

  There are two types of parts: general parts and mount parts. General parts are rigid parts which have location, orientation, mass, inertia, and center of gravity. Mount parts are parts that attach to other parts.

- Creating attachments.

  Attachments (joints or bushings) are parameters which tell how the parts react in relation to one another. It is possible to define attachments for the compliant and kinematics analysis modes. The compliant mode uses bushings, while the kinematics mode uses joints.

6.2.2 Description of how Mustang front suspension template was made:

- Start Adams/car template builder. After modifying the .acar.cfg to have expert privileges, the following options appear: (Select the template builder option to start to work).

![Figure 6.2 Options to start Adams/car](image)

Figure 6.2 Options to start Adams/car
✓ From the File menu, select New and enter the suspension name. After select OK.

![Image of New Template dialog box]

![Image of Gravity icon displayed to start building templates.]

✓ Defining the hardpoints for the lower control arm.

![Image of Create Hardpoint dialog box]

Note. When a hardpoint is defined, ADAMS/Car automatically creates a symmetrical pair about the central longitudinal axis.

<table>
<thead>
<tr>
<th>Hardpoint Name</th>
<th>Location:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point1</td>
<td>67,-450,105</td>
</tr>
<tr>
<td>Point2</td>
<td>467,-450,105</td>
</tr>
<tr>
<td>Point3</td>
<td>267,-680,105</td>
</tr>
</tbody>
</table>

Table 6.1 Lower control arm Hardpoints

![Image of lower control arm hardpoints.]

Figure 6.3 Gravity icon displayed to start building templates.

Figure 6.4 Lower control arm hardpoints.
✓ Creating the lower control arm part:

Note. ADAMS/Car creates a part coordinate system, also referred to as local part reference frame, at the specified location, but it doesn’t create geometry.

✓ Creating the lower control arm geometry:

Select calculate mass properties of general part since Adams calculate the mass of the arm.
✓ Creating the Wheel Carrier

To create the wheel carrier, four hardpoints are created that define its location. Then wheel carrier part is defined using these hardpoint locations. Next, wheel carrier link geometry is added.

<table>
<thead>
<tr>
<th>Hardpoint Name</th>
<th>Location:</th>
</tr>
</thead>
<tbody>
<tr>
<td>wheel center</td>
<td>267.0, 800.0, 255.0</td>
</tr>
<tr>
<td>Masa</td>
<td>267.0, 725.0, 255.0</td>
</tr>
<tr>
<td>L.ca outer</td>
<td>267.0, 680.0, 105.0</td>
</tr>
<tr>
<td>Tierod outer</td>
<td>100.0, 750.0, 255.0</td>
</tr>
</tbody>
</table>

Table 6.2. Wheel Carrier Hardpoints

✓ Creating the Strut

The strut is created similar to the control arm; the location, orientation, and mass properties for the strut part are entered. Because the strut geometry would not be visible from inside the damper, it doesn’t need any geometry.
✓ Creating the damper

Before building the spring, a mount part must be created in the upper spring location.

To change spring stiffness is necessary open the properties files and change this value.
$--------------------------------------$
MDI_HEADER
[MDI_HEADER]
FILE_TYPE = 'lsf'
FILE_VERSION = 4.0
FILE_FORMAT = 'ASC11'
$--------------------------------------$

---UNITS
[UNITS]
LENGTH = 'mm'
ANGLE = 'degrees'
FORCE = 'Newton'
MASS = 'kg'
TIME = 'second'
$--------------------------------------$

SPRING_DATA
[SPRING_DATA]
STIFFNESS = 400.0
FREE_LENGTH = 200.0

✓ Creating the Tie Rod

First a hardpoint is created and then it is used to define the tie rod part.

![Figure 6.11 Model with tie rods.](image)

✓ Creating the Toe and Camber Variables

![Set Toe & Camber Values](image)

Note: When ADAMS/Car creates the toe and camber values, it also creates output communicators of the same name.

✓ Creating the Hub
Before creating the hub, it is necessary to create a construction frame. Construction frames are elements that are used whenever an entity requires specifying an orientation in addition to a location. The hub is created based on the construction frame.

![Figure 6.12 Figure with hubs.](image)

When all parts, springs, and dampers are created, attachments and parameters are defined.
✓ Defining the translational joint

Figure 6.13 Model with translational joint.

✓ Defining control arm attachments

Before bushings and joints for the control arm are created, it is necessary to create the mount parts that will connect to the body or subframe during assembly.

When mount parts are created, input communicators of class mount are created automatically. The input communicator requests the part name to which the mount part should connect. If ADAMS/Car finds a matching communicator during assembly, it replaces the mount part with the part that the output communicator indicates.
✓ Creating the mount parts:

![Create Mount Part](image)

- **Mount Name**: Subframe_to_body
- **Coordinate Reference**: Mustang_front_suspension ground hrs_point1
- **Inherit**: [Choose option]

![Create Mount Part](image)

✓ Creating the front bushing control arm:

![Create Bushing Attachment](image)

- **Bushing Name**: Arm_front
- **Part**: Mustang_front_suspension ground hrs_point1
- **J Part**: Mustang_front_suspension ground hrs_point1
- **Type**: left
- **Preload**: 0.0
- **Torsion**: 0.0
- **Offset**: 0.0
- **Rake**: 0.0
- **Geometry Length**: 20
- **Geometry Radius**: 20
- **Property File**: midas mongoose/AIS.bush/0001.bush
- **Location Dependency**: Delta location from coordinate
- **Coordinate Reference**: Mustang_front_suspension ground hrs_point1
- **Location**: 0.0
- **Orientation Dependency**: Origin axis along line
- **Coordinate Reference 1**: Mustang_front_suspension ground hrs_point1
- **Coordinate Reference 2**: Mustang_front_suspension ground hrs_point1
- **Axis**: Z

Figure 6.14 Model with bushing control arm.
✓ Creating the rear bushing control arm:

![Creating the rear bushing control arm](image1)

✓ Creating the control arm revolute joint:

![Creating the control arm revolute joint](image2)

So that this joint is active in kinematic mode active option is setting. A kinematic analysis uses constraints, such as translational and revolute joints, to define the attachments between the parts. During a compliant analysis, ADAMS/Car replaces these joints with bushings.
✓ Creating the control arm spherical joint:

![Screenshot of the control arm spherical joint creation process]

Figure 6.17 Model with Lower control arm spherical joint.

✓ Defining the strut attachment

Before defining the strut attachments to the vehicle body, it is needed define a mount part for the strut. Then a bushing for the strut is created. Next, a spherical joint to replace the strut mount bushing during kinematic analyses is created.

![Screenshot of the strut attachment creation process]
Figure 6.18 The strut attachments.

✓ Defining Wheel Carrier Attachments

Spherical joint between the wheel carrier and the tie rod is defined. Then the mount part that connects the suspension to the steering rack during assembly is created. Finally a convol joint between the tie rod and the steering rack is created.

✓ Creating a spherical joint:

Figure 6.19 Model with tie rod spherical joint.
✓ Creating a mount part for the convel:

![Create Mount Part](image)

- Mount Name: Tie rod to steering
- Coordinate Reference: Mustang_front_suspension_ground_tie_rail_tie
- From Mirrored: Wheel

✓ Creating a convel joint:

![Convel Joint](image)

- Joint Name: Tie rod Nexus
- Type: Left, Right, Angle
- Joint Type: Convel

✓ Defining the hub attachment:

![Hub Attachment](image)

- Joint Name: Hub Nexus
- Type: Left, Right, Angle
- Joint Type: Convel

Figure 6.20 Model with tie rod convel joint.

Figure 6.21 Model with hub revolute.
✓ Defining Suspension Parameters

ADAMS/Car calculates the steer axis by passing a line through two non-coincident hardpoints located on the steer axis. It is necessary identifying the part(s) and two hardpoints that fix the steer axis.

✓ Creating a steer axis:

![Diagram of steer axis creation]

Figure 6.22 Finished front suspension template.

6.2.3 Assembling the Model for Analysis

ADAMS/Car uses communicators to correctly assemble the model for analysis.

Communicators are the elements that allow the subsystems and test rigs to exchange information about the topological data, array and parameter variables and locations, orientations, and so on.

If ADAMS/Car finds no matching output communicator, it replaces the mount part with the ground part.
6.2.4 Defining Communicators.

To define how the suspension is to be connected to the suspension test rig, it is necessary defining the communicators that attach the hub to the suspension test rig at the wheel center, as follows:

To tell the suspension test rig to which part it needs to be connected, an output communicator of type mount is defined. This communicator accomplishes two tasks:

- Communicates the part to which the Testrig is being connected.
- Defines the i part of the static lock actuator. Because when the suspension is analyzed in static mode, it is necessary lock the hub to the wheel carrier. If the hub is not lock to the wheel carrier, the assembly will have a rotational degree of freedom that prevents the analysis from converging to a solution.

6.2.3 To display information about communicators:

The information window lists the mount input communicators.
✓ Creating the output communicators:

ADAMS/Car selects the hub as the part to which the test rig connects.

✓ Testing Communicators:

To verify that the input and output communicators were correctly specified, it is possible to test communication in the template.

✓ To test the communicators:
The Information window appears as shown next:

The Information window lists which communicators are matched, and which are not.

6.2.4 Saving the template

6.2.5 Creating a subsystem:
6.2.6 Creating an assembly:

<table>
<thead>
<tr>
<th>ADAMS/Car 12.0.0</th>
<th>New Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subsystem Name</strong></td>
<td>Mustang_front_suspension</td>
</tr>
<tr>
<td><strong>Main Role</strong></td>
<td>Front</td>
</tr>
<tr>
<td><strong>Template Name</strong></td>
<td></td>
</tr>
</tbody>
</table>
✓ To create the full vehicle assembly:
For more information of how to build a full vehicle, I recommend the following guides and tutorials.

Getting started using ADAMS/Car, pages 11 to 46.
ADAMS/Car Templates, pages 5 to 98.
Building templates, pages 5 to 39.

The documentation can be downloading from ADAMS help online, it must be installing similar to the ADAMS patches, the name of this Service Pack is APN-120-203, this service pack contains many improvements to the documentation, and provides documentation to support the new products available in other service packs.

When the service pack is installed in your computer, you can access to the information opening from ADAMS/Car window like the following figure.-

The following guides are available for ADAMS/Car

User's Guides
ADAMS/Car Components
ADAMS/Car Templates
Running Analyses in ADAMS/Car
Conceptual Suspension Modeling
Getting Started
Template-Based Guides
Component Descriptions
Building Templates
Managing Plots
Configuring
Customizing

The web page to download the service pack is:
http://www.mscsoftware.com/support/prod_support/adams/?Q=135&Z=144&Y=174

Click in product updates.
For a better understanding of the suspension kinematic an Adams/view model was constructed.

Figure 6.26 Finished Mustang model in ADAMS/View.

For the study of the antiroll bars impact in the vehicle performance 4 models were made.

- Without stabilizer bars.
- With rear stabilizer bar.
- With front stabilizer bar.
- With both stabilizer bars.

Figure 6.27 Mustang rear suspension assemblies with and without antiroll bars
Figure 6.28 Mustang full assembly with and without antiroll bars

6.3 Control modeling

6.3.1 Active suspension modeling.

To simulate the active suspension, the Adams Control tools kit was used. The following diagram block was simulated in this.

\[ \dot{x} = Ax + B_1u + B_2w \]
\[ y = Cx + Du \]

Figure 6.29 Control closed loop for the active suspension.

For the close loop the velocity of the body was feedback by mean of input functions. In this case, the input functions are the relative velocity between sprung and unsprung mass, velocity functions return a requested magnitude or component of the translational or rotational velocity vector between two markers. It is possible to use the velocity functions during a simulation to obtain from Adams the velocity measurements of an object. Velocity functions provide measurements that can be useful in creating equations that depend on the velocity of an object.
- **Velocity along Z axis (VZ) function.**

It returns a z component of the difference between the velocity vectors of two coordinate system markers.

- **Format**

VZ (To Marker, From Marker, Along Marker, Reference Frame)

Where

To Marker (required) is the coordinate system marker whose velocity is being measured.

From Marker (optional) is the coordinate system marker whose velocity is subtracted off. If not specified, this argument defaults to the global origin.

Along Marker (optional) is the coordinate system marker along whose y-axis the velocity is measured. If not specified, this argument defaults to the global y-axis.

Reference Frame (optional) is the coordinate system marker in which the time derivatives are calculated. If not specified this argument, it defaults to the ground reference frame.

After defining the input function, a gain was created and in each damper was used a force to simulate the active actuator. In the force function is used the gain of the control loop.
6.3.3 Semiactive suspension modeling

To simulate the semiactive suspension a “Point Point” actuator was used in each damper. Inside them the Skyhook logic was used: “Damper hard when $(V_2-V_1)*V_2 > 0$ and Damper soft when $(V_2-V_1)*V_2 < 0$", then the force function is: $(\text{Coefficient of viscous damping})*(V_2-V_1)$. For the switching +/- sign conventions were used that change the coefficient of viscous damping from 0.4 to 0.6 to simulate the semiactive suspension. For this in needed to create the state variables where is collocated the criterion for the switch (skyhook logic) and the velocity measure of the unsprung and sprung mass.

The sign convention format for this case is (middle value + sign (0.1, change criterion Variable))

Figure 6.30 Used force to simulated the actuator.

Figure 6.31 Point point actuator to simulated the semiactive suspension.
Chapter 7

Results and conclusions

In first instant the investigation was based on discovering stabilizer bars influences in the vehicle’s behavior, for this, was used the constant radius cornering analysis to constant velocity of 75 km/h and 80 meters of radius, after that were compared the simulations’ results of the four models mentioned in previous chapter, the results were the following:

Figure 7.1. Comparison between models with and without antiroll bars on constant cornering analysis to 70-120 km/h

Figure 7.2 Slip angle to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

Figure 7.3 Chassis roll angle to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.
Figure 7.4 Chassis vertical displacements to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

Figure 7.5 Chassis vertical acceleration to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

Figure 7.6 Chassis roll acceleration to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

Figure 7.7 Steering displacements to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.
Figure 7.8 Front aligning torque to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

Figure 7.9 Rear aligning torque to 75 km/h at constant radius (80 meters) cornering analysis for models with and without antiroll bars.

7.1 Comparison of results for the four models with and without antiroll bars.

<table>
<thead>
<tr>
<th>Model</th>
<th>Side slip angle</th>
<th>Roll Angle Displacement</th>
<th>Vertical chassis acceleration</th>
<th>Roll chassis acceleration</th>
<th>Angle front Steering</th>
<th>Front aligning torque</th>
<th>Rear aligning torque</th>
<th>Steering demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without bars.</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>With bars.</td>
<td>❌</td>
<td>🟢</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
</tr>
<tr>
<td>With front bar.</td>
<td>🟢</td>
<td>❌</td>
<td>🟢</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>With rear bar.</td>
<td>❌</td>
<td>🟢</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>❌</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

- ✗ Best behavior
- ✗ No clear behavior
- ❌ Worse behavior

The both bar model lose control at 76 km/h while the others models to 75 km/h.
After the simulation of stabilizer bars influences, the active, semiactive and passive models was analyzed. For the passive model the both antiroll bar was taken because was the best passive behavior on the last analysis. To a better vision of the models behavior two analysis were made, one using the constant radius cornering and other using the iso lane change analysis.

Constant velocity of 75 km/h and constant radius of 80 meters were used for the constant radius cornering analysis for active, semiactive and passive models and 75 km/h (initial) for the Iso lane change analysis.

### 7.2 The results of Constant radius cornering analysis were the following:

**Figure 7.10** Dynamic drag torque to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

**Figure 7.11** Chassis vertical accelerations to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

**Figure 7.12** Chassis pitch to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

**Figure 7.13** Chassis longitudinal velocities to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.
Figure 7.14 Chassis lateral velocities to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.15 Chassis vertical velocities to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.16 Slip angle to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.17 Chassis vertical displacements to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.
Chapter 7  
Results and conclusions

Figure 7.18 Steering displacements to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.19 Front aligning torque to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.20 Rear aligning torque to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.

Figure 7.21 Chassis roll angle to 75 km/h at constant radius (80 meters) cornering analysis for active, semiactive and passive models.
7.3 The results of Iso lane change Analysis were the following:

Figure 7.22 Aerodynamic momentum to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.23 Chassis vertical accelerations to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.24 Chassis pitch to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.25 Chassis lateral velocities to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.
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Figure 7.26 Chassis vertical velocities to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.27 Slip angle to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.28 Chassis vertical displacements to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.29 Front aligning torque to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.
Chapter 7

Results and conclusions

Figure 7.30 Rear aligning torque to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.

Figure 7.31 Chassis roll angle to 75 km/h (initial) at Iso lane change analysis for active, semiactive and passive models.
Conclusions

In this research, the dynamics vehicle behavior was examined. Passive, active and semiactive suspensions were included in the study.

For the passive suspension 4 models were simulated to understand the stabilizer bars influences in the vehicle’s behavior. Using feedback of the relative velocity between sprung mass and unsprung mass the active suspension was simulated, in which, actuators are against the movements of the body to improve the vehicle performance. Using the skyhook logic, semi active suspension was simulated, in which the coefficient of viscous damping is varied to obtain improves in the vehicle behavior.

Some characteristics of the response of the vehicle model were analyzed, including the pitch and roll displacement and chassis acceleration of the vehicle body. The vertical displacement and acceleration of the body mass were used to represent the ride comfort of the vehicle, while the roll displacement of the body and the lateral velocities of the body were used to evaluate the vehicle safety.

For the antiroll bar study (passive) the results aim to improve the dynamic characteristics between the two stabilizer bars. These bars help some of the vehicles characteristics but nevertheless when helping one of them it harms others having mixed them to reach an intermediate behavior.

The active and semiactive suspension improve the vehicle behavior in similar way, the results for this kind of suspension have similar performance, since both systems feedback the relative velocity of the body to control the dynamic responses. Both models have better performance, having better handling and greater comfort that the passives systems.

At 80 meters turns, the velocity was increased by the active and semiactive suspensions from 75 to 83 km/h respect to the passives systems.

Chassis’ accelerations are smooth in the active and semiactive suspension systems having better comfort.
Appendix 1

Installing ADAMS/Car new databases

When we have a new entire works in another computer, and we want to pass this work to another computer, there are two options, one is copy each template, subsystems and assemblies an paste in the respective private database folder in the new computer, or open the entire new data base, to do this is needed to do the following.-

1. From the Database Management tools, select Add to Search.

![Database Management tools](image)

2. Specify location of Database

In the "database name" field, you MUST specify "person" for the new database. Right mouse click in the Database Path field, or left mouse click on the folder icon. A file browser will come up. Navigate through until you have located the directory in which all of the Database subdirectories are contained, as shown;
Once you've hit the "Open" button, your dialog box will appear like this:

Select "OK". ADAMS/Car will then ask if you wish to register the database and save the changes to your configuration file. You do. Select as shown below:
3. Confirm your actions

Check inside of your .acar.cfg file. This file will be located in your home directory. Note that because the filename has a leading "dot" it is considered an invisible file and you may not see it in your Windows Explorer. You can always open Notepad and open from within the Notepad file browser.

You should see a line which appears like:

DATABASE customized_name C:/New database/

It is possible to successfully register your database(s) by manipulating the .acar.cfg file and not doing it inside of ADAMS/Car.

You can also select "Database Info" from the Database Management area under the Tools menu.

4. Get to work

If you try to open an assembly or a subsystem, you should now be able to successfully browse the database you've just registered

Final comments - Default Writable Database

By default, your "private" database is where changes are stored if you save a new template, subsystem, or assembly. Using the "Default Writable Database" selection tool from the Database Management area under the Tools menu, you may select the New database to store your work, if you wish
Appendix 2

Parametric analysis

The parametric product analysis is a technique by means of which is analyzed the performance of analogous products on the basis of its main parameters. The accomplishment of parametric product analyses is an indispensable premise for the competitive product development.

In our case a parametric analysis of the actuators has been made that there are in the market to give us an idea of which of them fulfill the specifications that we needed for our active suspension.

Matrix parametric analysis

<table>
<thead>
<tr>
<th>Company</th>
<th>Model</th>
<th>Useful force (N)</th>
<th>Operating pressure (bars):</th>
<th>Strokes (mm)</th>
<th>Medium</th>
<th>Speed:</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norgreen</td>
<td>M/1525/320</td>
<td>3118 to 7 bars</td>
<td>2 to 10</td>
<td>300</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RT/57200/320</td>
<td>2493.8 to 8 bars</td>
<td>1 to 10</td>
<td>320</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/5546/4/M300</td>
<td>2573.6 to 8 bars</td>
<td>1 to 10</td>
<td>300</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/5548/1/M300</td>
<td>3518.6 to 7 bars</td>
<td>1 to 10</td>
<td>300</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/5541/1/M300</td>
<td>5498.8 to 7 bars</td>
<td>1 to 10</td>
<td>300</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/1920/63/MX100 (compact)</td>
<td>2493.8 to 8 bars</td>
<td>1 to 10</td>
<td>100</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/1920/80/MX100 (compact)</td>
<td>3518.6 to 7 bars</td>
<td>1 to 10</td>
<td>100</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/1920/100/MX100 (compact)</td>
<td>5498.8 to 7 bars</td>
<td>1 to 10</td>
<td>100</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>RM/1920/125/MX1</td>
<td>8590.3 to 7 bars</td>
<td>1 to 10</td>
<td>100</td>
<td>Air</td>
<td></td>
<td>Double acting</td>
</tr>
</tbody>
</table>
### Appendix 2

<table>
<thead>
<tr>
<th>Make</th>
<th>Model/Part Number</th>
<th>Pressure (bars)</th>
<th>Stroke (mm)</th>
<th>Force (N)</th>
<th>Fluid</th>
<th>Design Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norgreen</td>
<td>PRA/1810 80/M/100</td>
<td>2795 to 6</td>
<td>2 to 10</td>
<td>100</td>
<td>Air</td>
<td>Simple acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>PRA/1810 100/M/10</td>
<td>4492 to 6</td>
<td>2 to 10</td>
<td></td>
<td></td>
<td>Simple acting</td>
</tr>
<tr>
<td>Norgreen</td>
<td>PRA/2820 80/M (Smart cylinder)</td>
<td>3518 to 7</td>
<td>2 to 8</td>
<td>1000 max</td>
<td>Air</td>
<td>max 4.9 ft/s (1.5 m/s)</td>
</tr>
<tr>
<td>Norgreen</td>
<td>PRA/2820 100/M (Smart cylinder)</td>
<td>5500 to 7</td>
<td>2 to 8</td>
<td>1000 max</td>
<td>Air</td>
<td>max 3.2 ft/s (1.0 m/s)</td>
</tr>
<tr>
<td>Burden sales CO</td>
<td>1X8X1 SA HYD CYLINDER # 9-5981</td>
<td>6974</td>
<td>137 max</td>
<td>203 max</td>
<td>oil</td>
<td>Simple acting</td>
</tr>
<tr>
<td>FESTO</td>
<td>DNA 193385</td>
<td>2216 to 7</td>
<td>0.6 to 12</td>
<td>300</td>
<td>Air</td>
<td>Double acting</td>
</tr>
<tr>
<td>FESTO</td>
<td>DNA 193386</td>
<td>3746.5</td>
<td>0.6 to 12</td>
<td>300</td>
<td>Air</td>
<td>Double acting</td>
</tr>
<tr>
<td>FESTO</td>
<td>DKE-100-PPV-A</td>
<td>4712 to 6</td>
<td>1 to 10</td>
<td>300</td>
<td>Air</td>
<td>Double acting</td>
</tr>
<tr>
<td>PARKER</td>
<td>ISO 6431, VDMA 24562-63</td>
<td>3117 to 10</td>
<td>10 bars</td>
<td>300</td>
<td>Air</td>
<td>Simple acting</td>
</tr>
<tr>
<td>PARKER</td>
<td>ISO 6431, VDMA 24562-100</td>
<td>5026.54 to 10 bars</td>
<td>10 bars</td>
<td>300</td>
<td>Air</td>
<td>Simple acting</td>
</tr>
</tbody>
</table>

### Pneumatic technology

The technologies of pneumatic control do not replace the mechanical, electrical or electronic control systems, by contrary, complement these control technologies being obtained designs from simple to complicate, of easy assembly, maintenance and repair.

### Cylinders Calculates

The theoretical forces of push (stroke to +) and traction (stroke to -) of the cylinders, is calculated multiplying the effective surface of the piston by the pressure. The effective surface of the cylinder in push is the total surface of the piston, the effective surface of...
cylinder to traction is the total except the surface (section) of the piston rod. The piston diameters and the piston rod.

The diameter (d) and the diameter of the piston rod (d) is specified in millimeters and the work pressure (p) in bar. In the formula P is divided by 10 to express the pressure in Newton by square millimeter (1 bar = 0.1 N/mm²)

The theoretical force (f) comes given by:

\[ \text{Trust } F = \frac{\pi D^2 P}{40} \text{ Newtons} \]

\[ \text{Pull } F = \frac{\pi (D^2-d^2) P}{40} \text{ Newtons} \]

Where

D = Diameter of the cylinder in millimeters.
d = Diameter of the piston rod in millimeters.
P = Pressure in bar
F = Force in Newton

Example

\[ \text{Trust } F = \frac{\pi (60)^2 8}{40} = 2261 \text{ Newtons} \]

\[ \text{Pull } F = \frac{\pi ((60)^2-(30)^2) 8}{40} = 1696 \text{ Newtons} \]
Appendix 3

Errors without install patches

After build the mustang suspensions templates and assembly those to have the suspensions subassemblies (front and back), these subassemblies were verified separately, running without problems and having the waited results, after that, the full vehicle assembly was made, but nevertheless the simulation failed, this mark an errors series that little by little were being purified as is explain next.

Using ADAMS/Car as it works after the normal installation, in a simulation as for example of ISO LANE CHANGE, the simulation does not run and marks the following error.

---- ERROR ----

SDI960: Please see Driver Lite protocol file
ID = 960

---- ERROR ----

SDI960: Error evaluating lateral controller
ID = 960

Terminating ADAMS/Car usersubs...
ID = 1

Installing the service pack APN-120-180, this error is eliminated but nevertheless appears the following one in any modification to the model, with which the model does not run and the animation have heaves of the car but the car does not runs absolutely nothing.

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Time Step</th>
<th>Cumulative Iterations</th>
<th>Cumulative Steps Taken</th>
<th>Integrator Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000E+00</td>
<td>5.00000E-04</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5.00000E-04</td>
<td>5.00000E-04</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

---- WARNING ----
The corrector has not converged after 6 attempts. No. of iterations = 10.

---- ERROR ----
The system matrix has a zero pivot for column 874, which is associated with VARIABLE/4 Algb Var. Consequently, the matrix is numerically singular.
Appendix 3 Patches

The system has 79 kinematic degrees of freedom.

ERROR: Error detected on line number 34, character 85 of the macro '.ACAR.macros.mac_pos_ana_msg_chk'.
ERROR: "term_status" is not a known constant, function or variable
ERROR:

(eval(last(<term_status>>>(.ACAR.macros.mac_pos_ana_msg_chk.msgname[2]))))

ERROR: The command was not executed.
ERROR: +7>&>
i nteger=(eval(last(term_status(.ACAR.macros.mac_pos_ana_msg_chk.msgname[2])))))
ERROR: Error detected on line number 36, character 70 of the macro '.ACAR.macros.mac_pos_ana_msg_chk'.
ERROR: "term_stat" is neither a field in nor a child of
".ACAR.macros.mac_pos_ana_msg_chk"
ERROR: (.ACAR.macros.mac_pos_ana_msg_chk.<term_stat>> != -1)

ADAMS/Car 12.0 Service Pack APN-120-180

This service pack addresses a variety of issues identified in ADAMS/Car 12.0 after its release. The most important updates were made to: improve the robustness of the suspension Testrig, add a 3D road event, and to improve the integration between ADAMS/Car and ADAMS/Controls.

Services pack installation order:

The following service packs should be installed, prior to installing the ADAMS/Car service pack, in the following order:

- ADAMS/Solver
- ADAMS/View

ADAMS/Solver 12.0 Service Pack APN-120-176 (30297, 10087)

This service pack provides critical updates to ADAMS/Solver version 12.0. The changes include corrections to IC's for motions dependent on variables, reading .adm files that reference long file paths, program faults in some cases when using friction, eigenvalues not properly reported in GSE's, inaccuracies in linear analysis of models with contacts, incorrect time-stamp updates for internal Solver, crashes on IBM UNIX, and an error in cylinder-sphere contacts. Refer to the descriptions below for more information on these issues.
Installation Instructions

Installation Instructions for service pack APN_120_176. ADAMS/Solver 12.0

Prerequisite Service Pack(s):

Run Setup_APN_120_176.exe

**ADAMS/View 12.0 Service Pack APN-120-173**

This service pack provides several performance improvements and corrections to issues discovered in the months following the 12.0 release. Refer to the description below for more information on the specific items included in the service pack.

Note: We recommend that you use the PCL driver (not PS) when making hardcopies on HP LaserJet printers. The PCL driver is required to properly print view ports that contain tables and reports. The PCL driver has also been found to render ADAMS hardcopies at a much higher performance than the PS driver.

Prerequisites: ADAMS/Solver 12.0 Service Pack APN-120-176

**Note.**

Another important patch is Service Pack APN-120-203; this service pack contains many improvements to the documentation, and provides documentation to support the new products available in other service packs.

**Solved problem?**

Previously installing the ADAMS/Solver and ADAMS/View Service pack the model makes more iteration and is possible to visualize great part of this simulation in the animation. The error that marks then is the following.

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Time Step</th>
<th>Cumulative Iterations</th>
<th>Cumulative Steps Taken</th>
<th>Integrator Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00000E+00</td>
<td>5.00000E-04</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5.00000E-04</td>
<td>5.00000E-04</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

--- WARNING ---

The corrector has not converged after 6 attempts. No. of iterations = 10.

The system has 79 kinematic degrees of freedom.
At time 5.0E-04 and step 2, ADAMS is adjusting solver and integrator parameters to attempt an integration restart.

Generating the Jacobian matrix for the displacements and velocities.

### Jacobian Matrix Statistics for the Initial Conditions

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Time Step</th>
<th>Cumulative Iterations</th>
<th>Cumulative Steps Taken</th>
<th>Integrator Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00000E-04</td>
<td>5.00000E-04</td>
<td>95</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1.35000E+00</td>
<td>1.00000E-02</td>
<td>940</td>
<td>181</td>
<td>1</td>
</tr>
</tbody>
</table>

Generating the Jacobian matrix for the dynamics problem.

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Time Step</th>
<th>Cumulative Iterations</th>
<th>Cumulative Steps Taken</th>
<th>Integrator Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.70000E+00</td>
<td>1.00000E-02</td>
<td>2414</td>
<td>418</td>
<td>2</td>
</tr>
<tr>
<td>4.05000E+00</td>
<td>1.00000E-02</td>
<td>3309</td>
<td>553</td>
<td>3</td>
</tr>
<tr>
<td>5.40000E+00</td>
<td>1.00000E-02</td>
<td>4111</td>
<td>688</td>
<td>2</td>
</tr>
<tr>
<td>6.75000E+00</td>
<td>1.00000E-02</td>
<td>4918</td>
<td>823</td>
<td>3</td>
</tr>
<tr>
<td>8.10000E+00</td>
<td>1.66667E-03</td>
<td>6320</td>
<td>1068</td>
<td>4</td>
</tr>
</tbody>
</table>

--- WARNING ---
The corrector has not converged after 6 attempts. No. of iterations = 10.

The system has 79 kinematic degrees of freedom.

At time 8.3567 and step 1256, ADAMS is adjusting solver and integrator parameters to attempt an integration restart.

<table>
<thead>
<tr>
<th>Simulation Time</th>
<th>Time Step</th>
<th>Cumulative Iterations</th>
<th>Cumulative Steps Taken</th>
<th>Integrator Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.35667E+00</td>
<td>5.00000E-04</td>
<td>7467</td>
<td>1255</td>
<td>1</td>
</tr>
</tbody>
</table>

--- WARNING ---
The corrector has not converged after 6 attempts. No. of iterations = 10.

The system has 79 kinematic degrees of freedom.

Generating the Jacobian matrix for the accelerations and forces.

--- ERROR ---
The system matrix has a zero pivot for column 874, which is associated with VARIABLE/4 Algb Var. Consequently, the matrix is numerically singular.

The system has 79 kinematic degrees of freedom.
Terminating ADAMS/Car usersubs...

ID = 1

It has been discovered that making small modifications to the model, this no longer marks errors after installing all patches previous, but nevertheless when making small movements in dimensions or position the errors appear, even when changing of gear in the transmission at the time of running the model.

The answer to the problem was.-

CR 42478 Confirmation Opened: 7/23/03 2:00:00 PM

Product: Car Report Type: Bug
Category: Analysis--Full Vehicle Severity: Feature Doesn't Work
Subcategory: Priority:
Release: Version 12.0 Status: Received
Platform: Windows2000 Programmer:
Submitter: Alfonso Martinez # Files: 0
Sub Email: jamq1@hotmail.com RFA Number:
True Sub: Must Fix:
Interface: External Web Site Patch Req:

Overview

I have problems when i run my full assembly vehicle, the error say that the variable/4 (transmission demand) doesn't have pivot

Detailed Description

I have problems when I run my full assembly vehicle, the error say that the variable/4 (transmission demand) doesn't have pivot, but I see that sometimes with other model which became in ADAMS, some rare is that I have noticed that for example if I make some modifications of component position the error disappears, but since I have all my full assy the error continues appearing, another one of the things that I have noticed is that, for example in computers that I have not worked, it have different errors how check the handling protocol, but I install product update APN-120-180 that comes in the Adams page and then already it begins to mark to the error that of variable/4 and the others errors disappear, another one of the things that I do not like is that for example the model working well and only change a little the dimensions of the front control arms and already with that the error appears that then if variable 4 is the transmission demand not have so that to appears, also I have noticed that for example if to invert output direction from input direction (since my model has the control arms is on the front and needs to change that reducer) and although the car loses the control the error does not appear but if I change the reducer to that the error turns of correct way appears, also another one of the things is that when group of people the analysis in open-loop steering events in single
line change the error does not appear in many times. One of my questions is that if the APN-120-180 is only that I can take of the page of Adams or if others exist.

Thank you very much.

Alfonso Martinez

In addition to uploading your model (CR 42480), I'd also suggest you follow the crawl-walk-run approach also suggested earlier. That is, since your current model has problems, can you help identify exactly where the root cause is?

You may not think the issue is too confusing, but I believe you can help. The crawl-walk-run approach suggests that a user first take a model that runs correctly, and incrementally add in his own 'stuff' until things go wrong. So what you need to tell us is what you used to make your model. Did you start with the standard mdi_demo_vehicle model?

What 'shared' templates/subsystems are you referencing? If you have your own template, can you replace that with an equivalent 'shared' template and have the simulation work without these errors?

You may also find that Technical Support is better equipped to walk you through modeling issues, if it turns out to not be a 'coding' bug in ADAMS/Car.

Overview

How can I send you my model to be verified?

Response 94863 by Alfonso Martinez at 18:30:00 on 7/23/2003

Response 94850 by Brian Edwards at 11:31:10 on 7/25/2003

Response Template - Choose reply, then cut and paste the following text as the body of your message. Please make sure the ~end~ is the last entry on the page. Please attach any relevant files when you reply.

Response 94853 by Brian Edwards at 15:58:22 on 7/25/2003
Appendix 3

I looked at assy_alfonso.asy, and it seems you have three subsystems. Can you replace two of the subsystems with subsystems (that is, use a instead of) so that you only have a single subsystem in your assembly? Then you should be able to determine if the error occurs only when referencing /subsystems.tbl/suspension_delantera_22Julio.sub, or something similar. This is along the lines of crawl-walk-run, where you try and simplify things to get at the root of the problem.

This is work that you can do best, since you're familiar with your files. Once you have this info, then you can re-post and we can continue from there.

Response 94863 by Alfonso Martínez at 17:51:05 on 7/25/2003

If a run a simulation with only my rear suspension subsystem from private, the simulation run but with only some modification which I do, the simulation does not run.

If I run a simulation with only my front suspension from private, the simulation run but only whit a little modification, the simulation fail.

If I take my front suspension and rear suspension subsystems from private, the simulation fail.

Response 95090 by Mark Krueger at 11:11:25 on 7/30/2003

Alfonso,

I have seen this problem before. I believe that you're running an event using machine control (closed loop control).

And I believe too, that the issue is fixed for v2003, which is just being released to customers. If you could send us information about the the type of simulation that would be helpful to me to confirm the issue. While you can change your model slightly and in some cases the you no longer see the problem, I do not believe there is a problem with your model.

Also can you tell me from through which company or university you have access to ADAMS/Car. It would be best for us if we could upgrade your installation of ADAMS/Car to v2003 to resolve the problem. Would that work for you?

Best Regards,

Mark
Appendix 4

In the Adams forum

hi, I am trying to run a full vehicle analysis, but I have the follow error.-
---- ERROR ----
The system matrix has a zero pivot for column 921, which is associated with VARIABLE/4 Algb Var. Consequently, the matrix is numerically singular.
but I saw that the template _double_wishbone.tpl have the same error, but when I run the assembly MDI_Demo_Vehicle_lt.asy that use this same template the Simulation run very good.
then the question is, what did Adams/car for run the MDI_Demo_Vehicle_lt.asy and didn’t have this error, because the template that they use is double_wishbone.tpl that when I assembly it the error appears.
Thanks.

Alfonso Martinez

So the first question that comes to mind:
What is variable/4?
And how does it relate to the data you populated the subsystem with?
A template is only topology until you add realistic data and create a subsystem from it. (PS. How do you simulate a template by itself?)

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Jesper Slättengren
Consulting Manager, Automotive Dynamics
MSC.Software

Thanks Jesper, I take the template for shared data base, this template is double_wishbone.tpl, then I do a subsystem and after that I do the assembly, and when I do the simulation the error appears, but when I run the assembly MDI_Demo_Vehicle_lt.asy who has this same template, the error didn’t appears and the simulation runs good. the variable 4 is the transmission_demand.
thank again a I’m waiting for an answer

Alfonso Martinez

I think that the root of this problem is that the initial condition of the transmission_demand is set to zero in some full vehicle macros. This causes problems in the power train template where the transmission demand is used. If the transmission_demand IC is non-zero, the problem does not occur.

I think if the user modifies his problematic ADM and changes the transmission demand to be non-zero, the singularity will be fixed.

IMHO: The CR associated with this thread should remain open and the full vehicle macros should be modified appropriately.

Regards,
Griffin
Appendix 5

First models in ADAMS/View

In the beginning of the thesis, a Mustang II suspension was simulated.

In first instant a bump in the left wheel was simulated, after that an active suspension was adapted to the model. These simulations were the basis to using ADAMS/Car.

It is recommend first learn ADAMS/View and after that go to ADAMS/car.

Front Mustang suspension model in ADAMS/View.

Active and passive models in ADAMS/View.
The results for this analysis were the following.

Chassis vertical position

Chassis vertical velocity

Chassis vertical accelerations
References


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