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Role of Kinematic Analysis in tuning the Dynamic Behavior of a Formula Car

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***Abstract*--The tuning the dynamic behavior of a race cars requires the race engineer to make sense out of the ocean of data available with him. This paper explores how basing the judgment on the kinematic analysis can help the race engineer make quick decision on the setup of the car.**

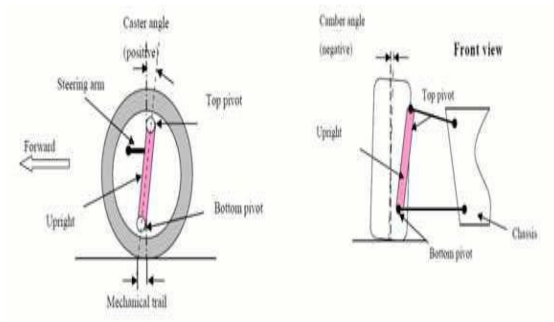
***Index Terms*--first term, second term, third term, fourth term, fifth term, sixth term**

I. INTRODUCTION

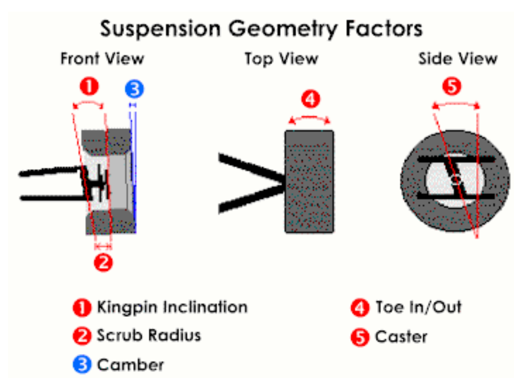
Modern Motorsport is an extremely competitive and cut throat event. Millions of dollar are spent on development of various systems on the car. The difference between the winning and losing team is only of a few fractions of a second. The responsibility of race engineer takes a herculean form. He has to take the final decision on the setup of the car and the amount of data available with him is staggering namely tire data, damper characteristics, bushing characteristics, aero maps , on track data and reading from the various onboard sensors. He has to take a momentary decision on the setup of car that will best work towards the dynamic behavior of car and extract every bit of performance from the car on the track. The paper explores how playing around with results of kinematic analysis of the suspension setup of the car can help him develop a clear picture of what might just be expected when flex , tire data ,aero maps , dampers and other dynamics forces starts to play around with the behavior of the car.

Basic vehicle dynamics terminology including suspension setup parameter:

1. Sprung Mass: Sprung mass of vehicle refers to the mass supported by the suspension spring like space frame, engine etc.
2. Unsprung Mass: Unsprung mass refers to the mass that is not supported by the spring for example wheel, hub, bearings etc.
3. Wheelbase: Wheelbase refers to the distance between centre of front axle and centre of rear axle. The wheelbase has a big effect on the longitudinal load transfer.
4. Trackwidth: Trackwidth is define as the distance between the between the right and left wheel centerlines.



Ans suspension geometry parameters are.



1. Slip Angle: Slip angle of a tyre is the angular deflection between the direction in which the tyre is pointing and the direction in which the tyre contact patch is travelling. The lateral force developed by the tyre is the function of slip angle
2. Camber Angle: It is the later al inclination of tyre in the transverse vertical plane as measured from the ground. It is necessary to have a small amount of negative camber in a suspension to induce camber thrust. Changes in the camber should be minimized to reduce the loss of camber thrust.

3. Steering Axis Inclination: SAI is the lateral inclination of steering axis in the transverse vertical plane as measured from the ground.
4. Scrub Radius: It is the distance between the treads centre of pressure and the intersection of steering axis with the ground. It acts as a moment arm which induces a torque about the steering axis during forward motion.
5. Caster Angle: It is the longitudinal inclination of the steering axis from vertical as measured from the ground. Positive caster induces a self correcting force which provides the straight line stability.
6. Toe Angle: It is the angle in the plane view which the tyre makes with the longitudinal axis. Static toe should be set such that the tyres do not become toe out during maximum bump and the roll.
7. Roll Center: Roll centre in SAE is defined as "the point in transverse vertical plane through any pair of wheel centers at which lateral forces may be applied to the sprung mass without producing suspension roll.

The Complexity of Setup Choices

Before we delve into the discussion of optimality or appropriateness of a setup choice or configuration for a given track and condition, it would very much to appreciate the number of choices available with the race engineer. Lets say there are only two adjustability options available with him i.e. on the front and rear anti roll bar and on each of them can either be put to three different stiffness values i.e. soft medium and stiff, it means total number of setup possibility with him is nine and that the race engineer should have exact knowledge of how the setup change influences the behavior of the car in all these nine configuration.

Now let's assume there are twenty four option available with the race engineer with three setup possibilities each. The setup parameter are ride height, caster , camber, toe, springs, damper low speed rebound, damper high speed rebound, damper low speed rebound, damper high speed rebound, damper piston, damper pressure, differential ramp angle braking, roll centre, pitch centre, bump steer, wing setting, gurney flaps, tire pressure, anti roll bars, anti roll bar blades, bump rubber gaps, brake bias setting. So, the total number of setup configuration are 3^(2*24) = 3^48 ~ 79 trillion. This is an extremely big figure even when we have made very rough estimation of the number of parameter and their setup choices.

Often the engineer has to rely more on his experience and intuition to take the decision on final setup choice.

II. KINEMATIC AND DYNAMIC ANALYSIS OVERVIEW

"Motion study" is a catch-all term for simulating and analyzing the movement of mechanical assemblies and mechanisms. Traditionally, motion studies have been divided into two categories: kinematics and dynamics. Kinematics is the study of motion without regard to forces that cause it; dynamics is the study of motions that result from forces. Other closely related terms for the same types of studies are multibody dynamics, mechanical system simulation, and even virtual prototyping.

Kinematic analysis is a simpler task than dynamic analysis and is adequate for many applications involving moving parts. Kinematic simulations show the physical positions of all the parts in an assembly with respect to the time as it goes through a cycle. This technology is useful for simulating steady-state motion (with no acceleration), as well as for evaluating motion for interference purposes, such as assembly sequences of complex mechanical system. Many basic kinematic packages, however, go a step further by providing "reaction forces," forces that result from the motion.

Dynamic simulation is more complex because the problem needs to be further defined and more data is needed to account for the forces. But dynamics are often required to accurately simulate the actual motion of a mechanical system. Generally, kinematic simulations help evaluate form, while dynamic simulations assists in analyzing function

Traditionally, kinematics and dynamics have followed the classic analysis software method of preprocessing (preparing the data), solving (running the solution algorithms, which involve the solution of simultaneous equations), and postprocessing (analyzing the results). Even though today's programs are much more interactive, most programs follow this basic process since it is a logical way to solve the problem. Most solvers are available as independent software programs.

One of the reasons for the popularity of solid modeling is that it sets the stage for many applications. You can practically create working drawings automatically, rendering models that closely resemble the real objects and generating physical models from rapid prototyping equipment. Similarly, studying the motion of moving mechanisms and assemblies is rapidly becoming almost a "free" byproduct of solid modeling, helping engineers to do the following:

- Simulate mechanisms to help develop workable designs
- View physically realistic animations to detect problems and to study aesthetics
- Find interferences among moving parts and fix them
- Verify an entire mechanical system with numerous, even unrelated, moving components
- Plot motion envelopes for designing housings and ensuring clearances.
- Create animations of assembly sequences to plan efficient manufacturing
- Generate accurate load information for improved structural analysis
- Calculate required specifications for motors, springs, actuators, etc. early in the design process
- Produce animations for output to video or for posting on web sites to show customers and clients how products will *actually* work—not just provide a set of pictures of how it *might* work

The basic output of motion studies are numerous, including animation, detecting interference, trace functions, basic motion data, and plots and graphs. Animated motions are the classic output of simple kinematic analyses. Initially, the designer uses simple animation as a visual evaluation of motion to see if it is what is desired. More sophisticated animations can show motion from critical angles or even inside of parts, a definite advantage over building and running a physical prototype.

The ability to detect and fix interferences without switching between software is one of the primary benefits of integrating motion simulation and CAD. Most systems provide color feedback, for example, by turning to red parts that experience interferences. More useful, however, are systems that turn the interference volume into a separate piece of geometry, which can then be used to modify the parts to eliminate the interference.

Trace functions provide additional information about motion. The motion of a joint or a particular point on a part can be plotted in 3D as a line or surface. Or, the system can leave copies of the geometry at specified intervals. Such functions can provide an envelope of movement that can be used to design housings or ensure clearances.

Motion data, such as forces, accelerations, velocities, and the exact locations of joints or points on geometry can usually be extracted, although such capabilities are more applicable to dynamic simulations rather than kinematic studies. Some systems allow users to attach instruments to their models to simplify specifying what results they want to see.

Most packages provide a plethora of plotting and graphing functions. Plots and graphs are most commonly used because values vary over time and are more meaningful than a single value at any given time. An especially useful capability for studying design alternatives is to plot the results of two different simulations on the same graph. Such data can also help designers determine the size of motors, actuators, springs, and other mechanism components.

Forces that result from motion are of particular interest because they can be used as loads (or, at least, to calculate them) for structural analysis of individual members. Typically, the highest load for a cycle is used to perform a linear static finite element analysis (FEA) of critical individual components of a mechanism. Integration of solid modeling, motion simulation, and FEA software can greatly streamline this process—especially important when studying design alternatives, where many analyses are required.

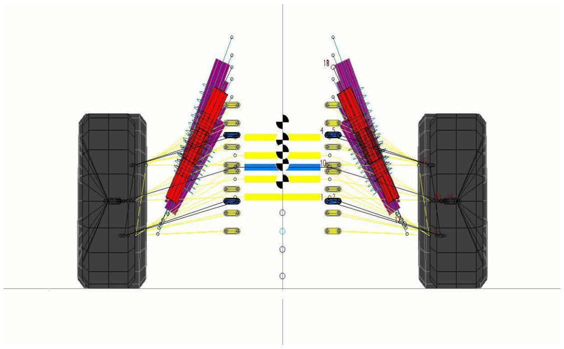
Engineers have used specialized software programs for performing various analyses for years in projects such as automobile suspension design. Doing all of the tasks in a single CAD program is becoming routine as solid modelers are being tightly linked to motion simulation softwares.

III. SETTING UP A KINEMATIC ANALYSIS

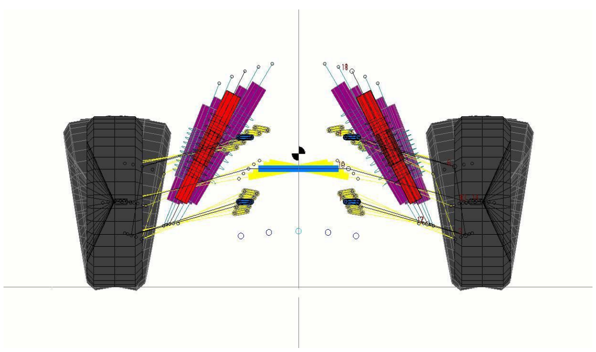
Though kinematic analysis is a thankless mathematical process we would limit our study to the solver setup and analysis of the result and how different dynamic factors like flex, compliances and aerodynamics affect the behaviour of pure kinematic and mathematical parameter like roll centre , pitch centre, roll axis etc and how they could give us an insight into the interdependence of all the parameter and the effect it has on the behavior of the vehicle.

The first step in setting up a analysis in any of these solver requires inputting of critical vehicle parameter like the wheelbase, track width, centre of gravity, moment of inertia, tires size and all major hard points on the suspension and steering system. On a multibody solver without any available template, the whole template has to be developed ground up where parts has to be defined, joints and constraints marked and the motion explained, but its not difficult to find a predefined template to which changes can be made. It is very important to understand the mathematical model used by the solver to solve the motions. Understanding the capabilities and constraints of the model used helps in interpreting the results with accuracy.

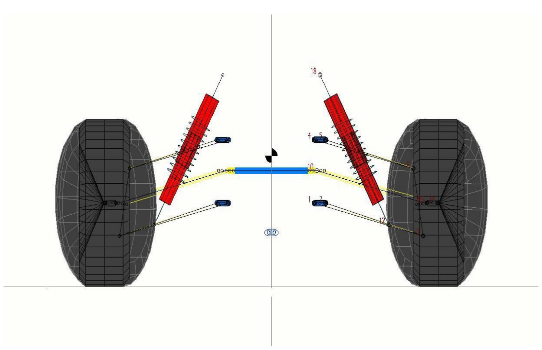
Once the model is setup the simulation for all the vehicular movements namely bump, roll, steer and pitch are carried out. Below we can see a animated results from the bump, steer and roll simulation.



Bump Travel Analysis

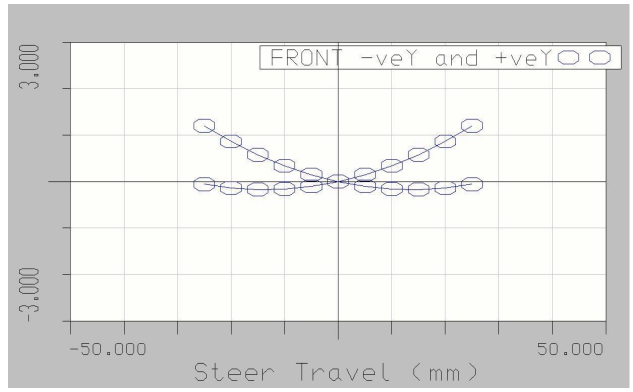


Roll analysis

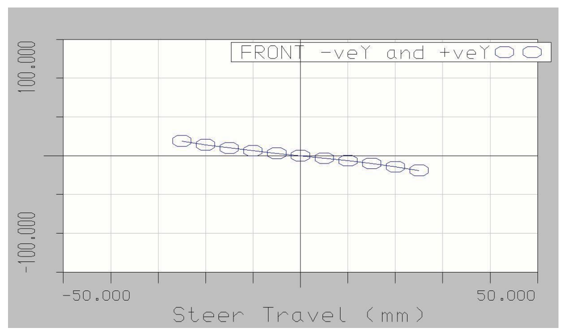


Steer Travel Analysis

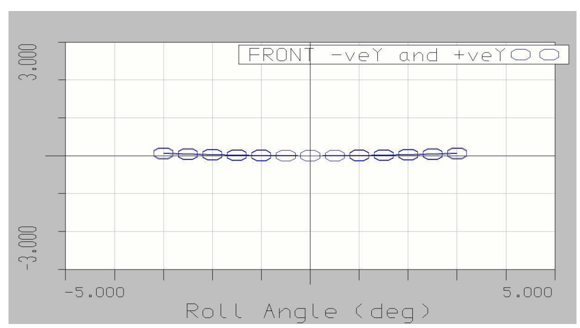
The results obtained are be tabulated and plotted along the whole range of travel in all the three basic motion



Steer Travel vs Roll Center change (horizontal dir)



Steer Travel vs Ackermann (%)



Roll Angle vs Roll center

Once the data and trends have been understood by the race engineer, a comparative study of the results should be done with the parameterized model of all the adjustable feature on the setup of the car. Now , regarding all the question on the change on the setup of car during the races can be traced back to the behaviour of critical mathematical points like roll centre pitch centre etc. A change in wishbone pickup points or a change in amount of anti dive can be always be traced to similar behaviour of these critical parameter which can easily be connected to the behaviour of the car on track. So an educated guess can be taken on whether to front roll centre should be raised up or not when car tends to understeer or the track condition has changed.Any desired change can be traced back to the behaviour of some the critical parameter which can be again retraced to the change in the vehicular setup.

It is not that Kinematic analysis can answer all the question that unpredictable racing environment throws up but when it comes to changing the setup of the car, putting the Kinematic Analysis in the centre and retracing all the forces around the results does simplify the job.

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