Shocks to the system

OptimumG's new series on springs and dampers begins with a look at why they're needed and the role they play in the suspension

By CLAUDE ROUELLE

A Formula 3 car on the limit at Pau. Selecting your damper settings is often a major concern, especially when it's raining and you have some aggressive kerbs to contend with

If you've been following OptimumG's articles in *Racecar* you have learnt some of the metrics taught at our Data Driven Performance Engineering seminars, which are used by our race engineers to analyse a car's performance. For this year, we've decided to tackle another very important topic in racing: springs and dampers.

This is because one of the most common questions we are asked at OptimumG is: how do we determine suspension spring rates and damping for a vehicle?

It is a difficult question to answer since it depends on many factors, and it's the engineer's responsibility to understand what the goals are: minimise body control, or improve the transient response? Since this topic is non-trivial, we will break it

When you are selecting the shock absorbers for your racecar you first need to define what the goals for the suspension system are

The decrease in friction factor corresponds to less lateral and longitudinal grip, the overall effect being slower lap times

down into several articles that will be published in the 2020 editions of *Racecar Engineering*. At the end of all these articles you should be able to understand why you need to have a suspension and a damping system; be able to calculate the required suspension stiffness values in a simplified method; calculate the coefficients required to dampen suspension movement; and provide the necessary equations to calculate the damping and stiffness.

Setting up

In this, the first of the series, we will start by understanding the need of a suspension. What are the goals and why for each situation it is necessary to have a different set-up.

For automotive applications a vehicle suspension allows controlled movement of the wheels relative to the vehicle body. In order to control it, passive, semi-active and/or active components are introduced. These enable the suspension system to adapt to various driving conditions. In most vehicles this is achieved with a passive compliant structure (suspension).

The vehicle suspension system consists of wishbones, springs, and shock absorbers to transmit and filter all forces between the body and road. If a vehicle has a passive suspension it will tend to oscillate under given inputs. To reduce the amount and duration of oscillation, some form of damping is required.

Suspension criteria

The automotive industry uses different kinds of suspension systems. The important criteria are the cost, the weight, performance, packaging, manufacturing, the kinematic properties and the compliance attributes. A suspension and damping system can serve multiple purposes, and some of the reasons for having them are described in **Table 1**.

In Table 1 we have presented the importance of having a suspension and a damping system. With that in mind the next step is to select our spring and damper. When choosing these a first common application is to define what are the goals for the suspension system. For example, are we trying to improve the tyre's mechanical grip or maintaining the vehicle's aerodynamic platform?

Table 2 summarises the three primary goals that we consider when selecting the spring and damper. Based on the scenario described in Table 2 (driver comfort, tyre comfort or body control) the suspension and dampers set-up will need to be different for each circuit and vehicle. If we are targeting driver comfort, then we want our suspension and dampers to minimise the acceleration of the sprung (chassis) mass; if our goal is tyre comfort then we want to minimise the TLV. Finally,

Table 1: Reasons to have a suspension

Purpose	Description
Improving driver and passenger comfort	The suspension acts as an interface between the vehicle body and the road, reducing the passenger accelerations and movements. The accelerations of the vehicle body are also dependent on the amount of damping in the system.
Reduce impulse forces	A compliant structure helps to reduce the peak forces in the vehicle structure due to external impacts. This helps to improve vehicle reliability and allows lighter structural designs.
Static load distribution	A suspension is a controlled compliant structure that can be used to distribute the normal load between the wheels.
Handling	The suspension can be used to influence the handling of the vehicle by changing the tyre's normal load distribution. This is achieved by adjusting the suspension stiffness distribution, the suspension geometry or by controlling the aerodynamic platform. The vehicle damping can also be used to influence the transient vehicle balance by changing the damping coefficients.
Improve mechanical grip	A suspension is compliant over bumps and impacts. This can help to reduce the tyre load variation (TLV) seen at the tyre-road interface. TLV has a large impact on grip due to the delayed response of the tyre to load variations and due to the load sensitivity of the tyre.
Aerodynamics	The balance and effect of the aerodynamics can be influenced on ride-height sensitive vehicles with a suspension system. The position and orientation of the vehicle body is also dependent on the amount of damping in the system.
Transient response	The vehicle heaves, pitches and rolls under inputs such as steering, throttle, brake application as well as large bumps and kerb strikes, etc. Dampers help to control the response of these inputs.
Forced vibration	The vehicle can be excited in heave, pitch, roll and single wheel vibrations. This occurs particularly near the system's resonance points and is due to the consistent unevenness/bumpiness in the track. Damping can help to reduce the magnitude of this response.

Table 2: Goals in selecting spring and damper combination

Scenario	Goal
Driver comfort	Driver comfort is important in motorsport as well as in passenger vehicles. An uncomfortable driver will fatigue quicker, have less concentration and be less consistent. If a driver is uncomfortable or cannot handle the level of discomfort, then the overall lap times will be slower.
Tyre comfort	Tyre comfort is important for mechanical grip. Mechanical grip refers to the efficiency (friction factor) of the tyre. Tyre comfort can be measured in terms of the TLV. If the normal load on the tyre varies then the tyre coefficient of friction will decrease overall. The decrease in friction is due to the tyre load sensitivity and the delayed response of the tyre to load changes. The decrease in friction factor corresponds to less lateral and longitudinal grip, the overall effect being slower lap times.
Body control	Body control is important for aerodynamic grip. Aerodynamic grip refers to the increase in tyre normal load due to the vehicle's aerodynamic devices. These devices commonly have an ideal position and orientation, optimised given the compromise between downforce and drag for the given circuit. The aerodynamic devices are often mounted to a vehicle that can pitch, roll and heave due to the suspension. If the devices are not kept in their ideal locations, then the car will have too much drag or too little downforce. The overall effect is slower lap times. Body control is also important for controlling the aerodynamic drag due to the aerodynamic devices.

Are we trying to improve the tyre's mechanical grip, or maintaining the aerodynamic platform?

If a race driver is uncomfortable, or cannot handle the level of discomfort, then the overall lap times will be slower

When a racecar has low or no downforce, as is the case with these Formula Fords, dampers should be selected to minimise the TLV in order to maximise the mechanical grip

if the vehicle is very aerodynamic dependent, all our focus is on maintaining the ride height which yields the optimum combination of downforce (coefficient and distribution) for each state (braking, accelerating and cornering).

In motorsport applications we are interested in all of these goals. Depending on the situation/track, some of these goals are more relevant than others. In **Table 3** we've summarised some typical goals for different scenarios.

Summing up

In this first article about springs and dampers we've looked at the advantages of having a suspension and damping system. What are the primary goals in selecting a spring and damper based on our goal (driver, tyre comfort or body control) and we have emphasised how for each different scenario you may want to have a different suspension and damping set-up.

In the next instalment (May's issue) we will be taking a more in-depth look at tyre comfort and why this is important to reduce the tyre load variation, and how the lateral force varies with the increase in tyre load variation.

Slip Angle is a summary of Claude Rouelle's OptimumG seminars.

OptimumG seminars are held worldwide throughout the year. The Data Driven Performance Engineering seminar presents several data acquisitions and analysis techniques which can be used by engineers when making decisions on how to improve vehicle performance. OptimumG engineers can also be found around the world working as consultants for top level teams.

Check out our seminar calendar on the website: optimumg.com/calendar

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Table 3: Suspension and damping goals for different scenarios

Scenario	Description
Smooth circuit	Minimal suspension travel or maximum stiffness is required due to the lack of unevenness or bumpiness in the track. Suspension can still be used to influence the handling and balance of the vehicle.
Off-road, rough surface	Significant suspension travel and softness is required. Suspension is used for driver comfort, reducing impact forces and the TLV over uneven surfaces.
Passenger vehicle	Reasonable suspension softness is required for driver comfort. The spring mass acceleration should be minimised.
High downforce	Control of the position and orientation of the aerodynamic devices (commonly attached to the sprung mass) relative to the ground is a priority for maximising the aerodynamic downforce and balance.
Low downforce	Suspension and dampers should be selected to minimise the TLV. This increases the mechanical grip of the vehicle, which is a priority when there is little aerodynamic contribution.

Depending on the situation and the track, some of these goals are more relevant than others