Suspension stiffness

Knowing your suspension goals is one thing, determining what stiffness values are required is another thing altogether

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As we have discussed in previous issues of *Racecar Engineering*, your suspension goals on a racecar will differ depending on application, so setting your goals early on in the design process is one of the key steps in ensuring a good design philosophy. Another important step to define is the desired amount of movement you want your suspension to have.

It is useful to describe the different ways a suspension can move. A conventional suspension has four degrees of freedom so we need four independent coordinates to uniquely describe the position of all four wheels with respect to the vehicle body. One common set of coordinates used to describe the various types of suspension movement are shown in **Figure 1**.

Heave motion describes all four wheels moving, an equal amount, vertically. Roll motion describes each pair of side wheels moving an equal but opposite amount. Pitch motion describes each pair of end wheels moving an equal but opposite amount. Warp motion describes each pair of diagonal wheels moving an equal but opposite amount.

These four coordinates are referred to as suspension modes. Typically, a vehicle does not move purely in any of these modes. For example, when the vehicle rolls in a corner it is usually accompanied with some amount of heave, and even some pitch, due to the difference in jacking effects at the front and rear of the vehicle. When a single wheel moves up, it can be thought of as a combination of heave, roll, pitch and warp movement in each of the different modes.

This concept is useful as we often want different amounts of movement in all four modes, and / or stiffness, due to each of the modes being caused by a different physical scenario. Heave is primarily due to vertical loading, including crests, troughs and downforce. Roll is primarily due to cornering. Pitch is primarily due to braking and accelerating. Warp is primarily due to road unevenness.

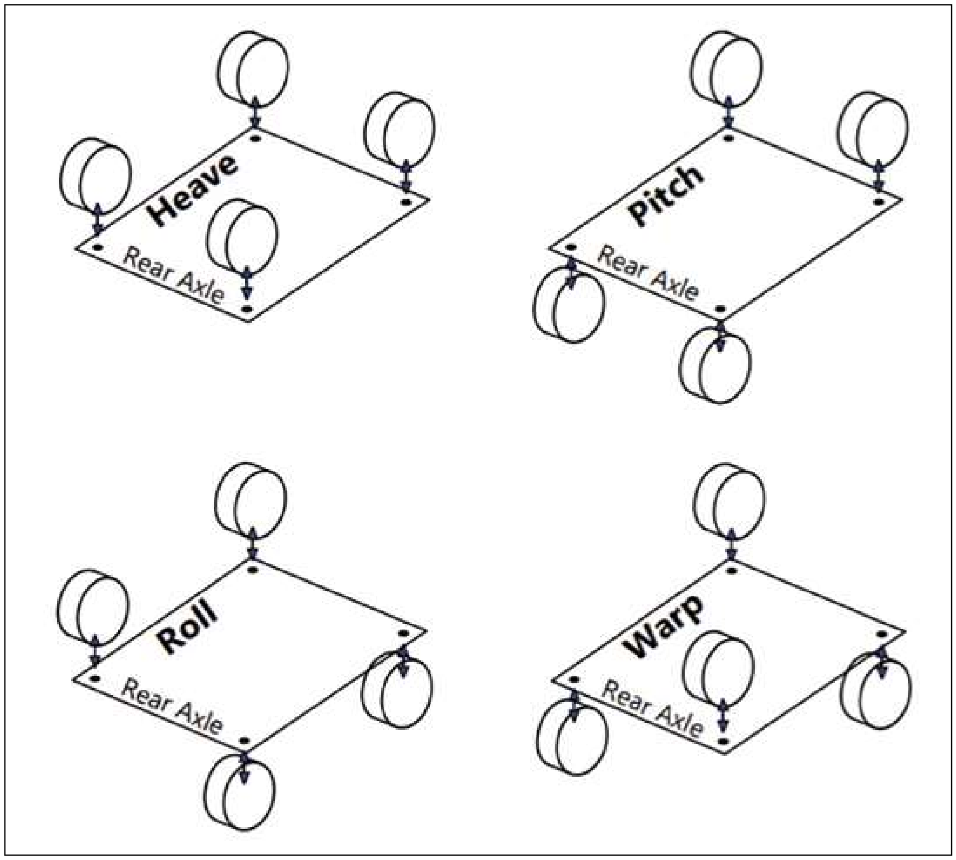

Figure 1: The four different modes of suspension motion

Table 1: Methodology to select spring stiffness

Method	Description
First method	Copy or approximate a similar vehicle suspension that run on similar tracks. Use the suspension and springing layout as an initial baseline and adjust through testing
Second method	Select a suspension type and the required spring stiffness to prevent unwanted movement under worst case loads
Third method	Select the desired suspension stiffness (eg heave, pitch, roll and warp) and choose the springing layout that best meets these requirements

Determining stiffness

When a suspension moves, there is some resistance to the movement. This is due to the various combinations of springs, anti-roll bars, dampers and compliance in the system. Determining what stiffness values are desired is not a simple task. **Table 1** summarises a few different ways this can be achieved.

The first and second methods described in **Table 1** are most useful when a vehicle already exists, or a particular layout is required. The third method is useful when the vehicle is still a concept, or we can freely change the suspension layout. It is a useful, high-level method as

A conventional suspension has four degrees of freedom

Many of these factors are difficult to evaluate quantitatively, hence many are determined from experience instead

we do not have to say exactly what springs are required, only to specify what the overall effect of the various spring combinations is going to be. You can decide on the specific implementation once you know what it is you want.

In general, there are many conflicting requirements that contribute to determining the desired suspension stiffness. Some factors that need to be considered are described in **Table 2**. It is important to note that many of these factors are difficult to evaluate quantitatively, hence many are determined from experience instead.

Key points

It is difficult to give generic advice for selecting stiffness values as the goals for different vehicles can vary drastically. The best thing to do is to decide what goals are most important for your particular case and how to meet them.

Once you know the requirements, then you can decide what combination of spring elements (corner springs, anti-roll bars, heave springs, four-wheel interconnection etc.) best meets the set requirements.

Table 2: Design stage

	Factors	Description	General trend
Design stage	Bumps and undulations	The amplitude and frequency of any bumps or undulations on the racing circuit	Large bumps require softer suspension
	Rules limitations	If the rules dictate a minimum or maximum suspension travel or stiffness, this will impact on suspension choices	This is a limit or boundary on the suspension design that must be adhered to
	Tyre	The tyre vertical stiffness can impact on spring selection. To have the same equivalent ride rate or suspension travel, different suspension stiffness is required	Softer tyre leads to a stiffer suspension
	Centre of mass (CM)	The height of the vehicle centre of mass is influenced by the amount of suspension travel. More travel requires a higher ride height and a higher CM	More travel = higher static CM
	Aerodynamic control	If the aerodynamics are attached to the vehicle body, then suspension movement can have a large impact on performance. Suspension travel can influence the position and orientation of aerodynamic devices	More travel = more spring mass movement
	Vehicle response	A stiffer vehicle tends to respond to inputs quicker	Quicker response = stiffer suspension
	Vehicle performance	A vehicle that can produce greater accelerations will produce more suspension movement given the same spring rate	Greater performance leads to a stiffer suspension

For example, if you decide that one of your goals is to have very little roll movement then you will need a very high stiffness in roll. You may set another goal that you want some pitch movement for driver comfort, but limit the movement to 5mm of travel at either wheel. Based on the load case that causes the most pitching, you can determine what your required pitch stiffness would need to be. Another goal may be to limit the heave movement to 100mm for aerodynamic concerns.

Finally, let's say you want the reaction loads on the tyres to vary as little as possible, so you decide to minimise the warp stiffness.

With these four requirements you have determined the required stiffness values in heave, pitch, roll and warp movement. The next step would be to pick a suspension layout that achieves this.

Choosing your suspension goals depends entirely on application, and to an extent how much comfort you want to afford your driver

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