Reference Manual

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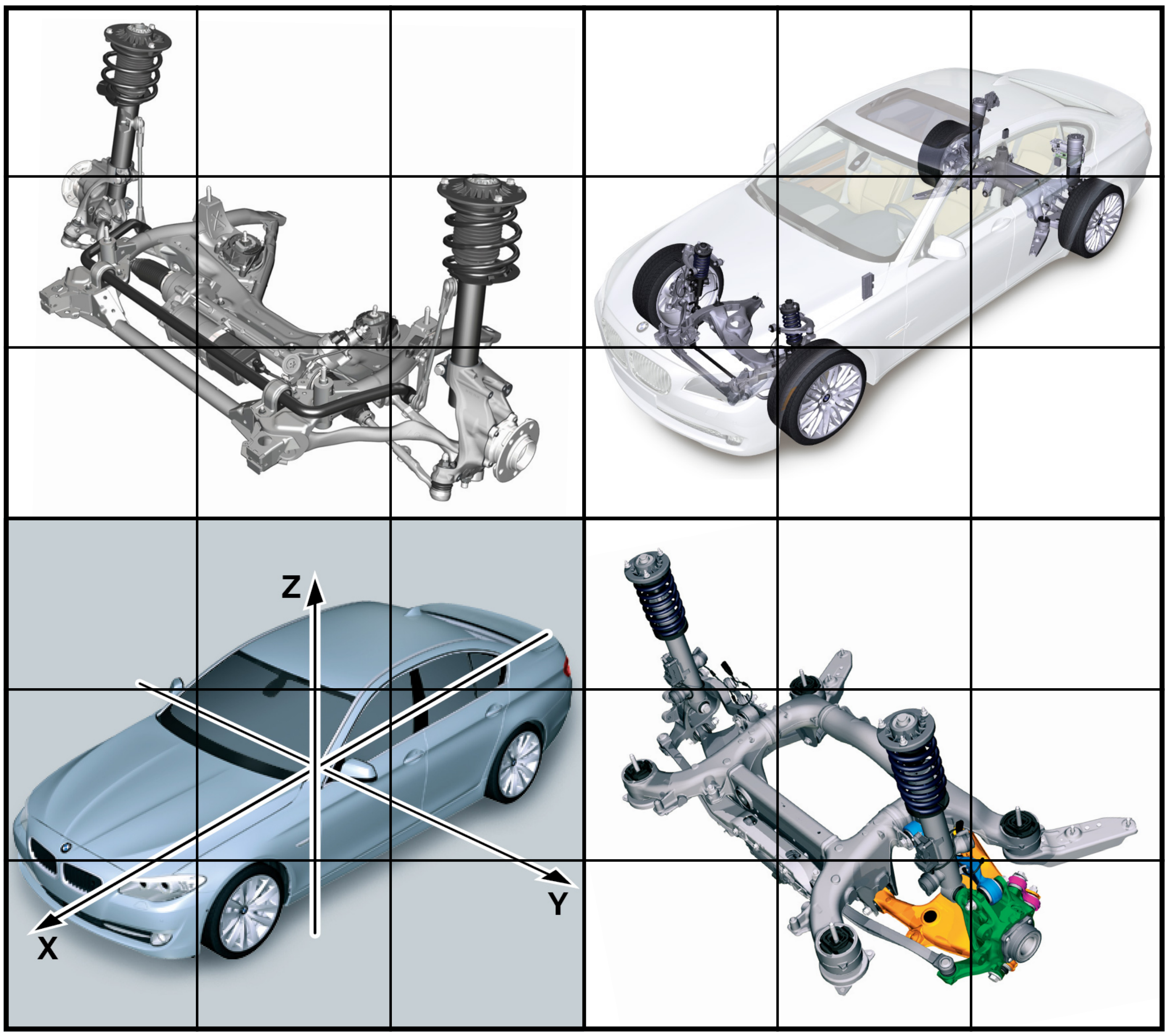
BMW
Technical Training

Chassis Dynamics



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Subject **Page**

Initial Print Date: 08/12 Revision Date:

Introduction to Chassis Dynamics

Model: All

Production: All

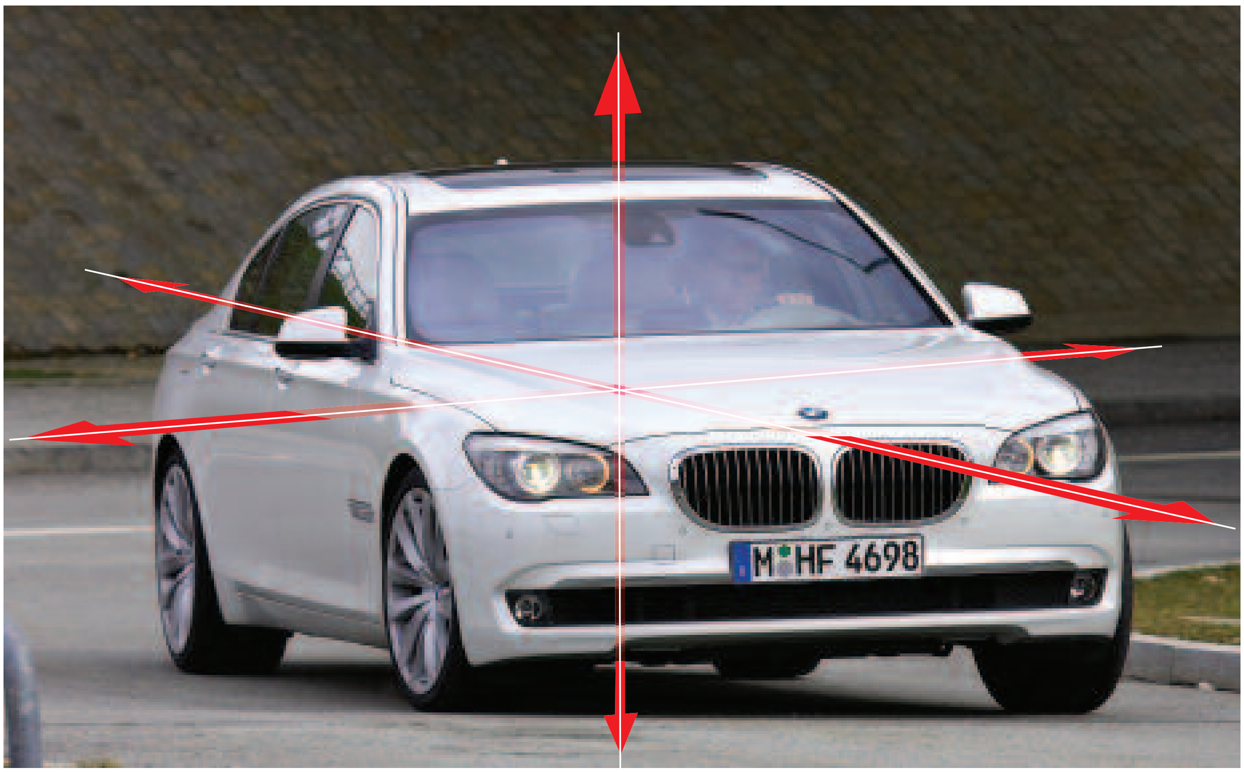
OBJECTIVES

After completion of this module you will be able to:

- Identify Chassis Dynamic Principles in BMW Vehicles
- Recognize Chassis Related Technology

Introduction to Chassis Dynamics

One of the trademark characteristics of a BMW is its ability to handle like a sports car and still provide a pleasing driver experience. To keep ahead of the competition, BMW has continually raised the bar from a performance standpoint. BMW engines are usually "Best in Class" in the premium segment. However, to remain a leader it is not only the engine which must outperform the rest of the pack. The chassis must allow for optimal comfort and safety as well as superior handing and braking.



This training module will help the technician understand the basics of vehicle dynamics. Terminology, as it applies to BMW chassis systems, will also be explained in this section. A thorough understanding of current chassis technology is needed to diagnose and perform service procedures of these vehicles.

The information in this training module will provide fundamental knowledge needed to understand such systems as Dynamic Stability Control, Active Steering and Active Roll Stabilization.

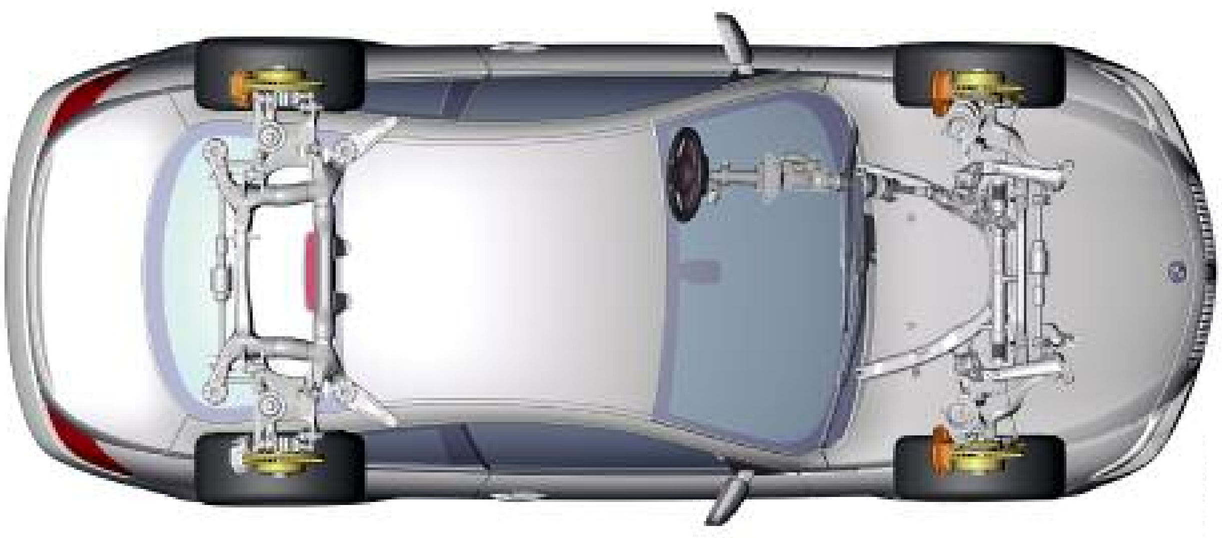
Vehicle Dynamics

A vehicle's cornering performance is also referred to as its self-steering properties. This handling performance is considerably influenced by the changing ratio of lateral force to wheel load on the front and rear axles. Lateral force increases as centrifugal force increases.

BMW vehicles are designed to have the best possible weight balance. A 50/50 weight ratio between the front and rear axles is always the intended design target.

The engineers at BMW always strive to achieve these goals during the design process. This effort can be seen by the use of lightweight components. New materials such as aluminum, magnesium and high-strength steel are used throughout various models. Even new materials, such as plastic, have been incorporated into the body.

For example, the E60 takes advantage of the lightweight front end technology (GRAV). On all modern BMW vehicles, the vehicle battery is installed in the rear of the vehicle for better weight balance.



Neutral Steer

In order for the vehicle to remain stable when driven through bends, the sum of the lateral forces on the wheels must counteract the total centrifugal force exerted on the vehicle.

The slip angles arising as a result of lateral force are the same on the front and rear axles. Neutral cornering facilitates the best use of lateral forces and thereby the highest limit cornering speeds.

However, it also reduces the subjective perception of how close the vehicle already is to the physical limit (the maximum transferable force or the sum of the forces). If this limit is exceeded, it is not possible for the driver to calculate in advance how the vehicle will react.

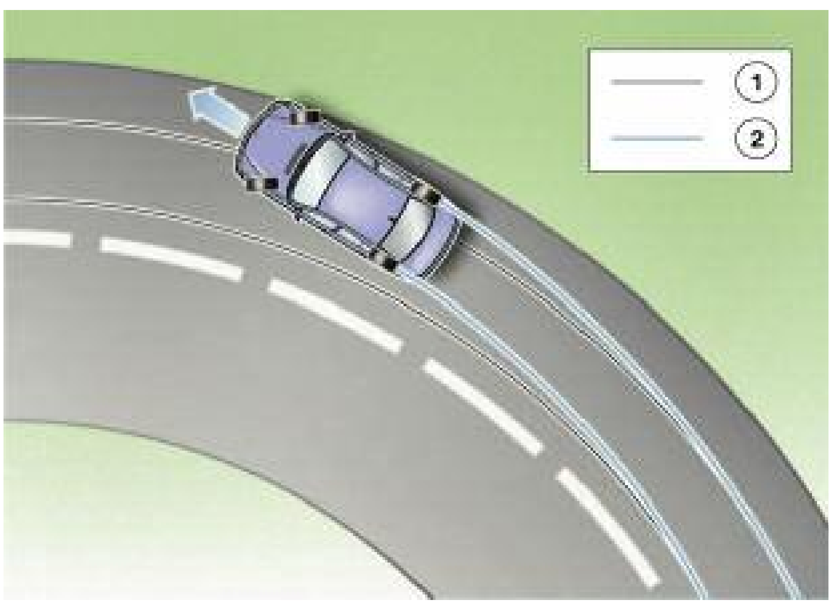
Whether the vehicle will:

- exit the curve at a tangent (neutral reaction),
- lose traction at front wheels and not follow the corner (understeer)
- lose traction at the rear axle and slide out of the corner (oversteer)

Understeer

The ratio of lateral force to wheel load is greater on the front axle than on the rear. The vehicle follows a larger cornering radius than that corresponding to the steering angle. It also slides to the outside of the turn via the front axle. When designing the chassis, this behavior is often the preferred option, because when the vehicle breaks away it can be returned to a straight line course which it is possible to calculate. Take, for example, a vehicle which begins to break away via the front axle while being driven to the limits; if the steering angle is then reduced, the vehicle will recover to assume a straightline course.

BMW chassis are designed so that they have slight understeer characteristics.

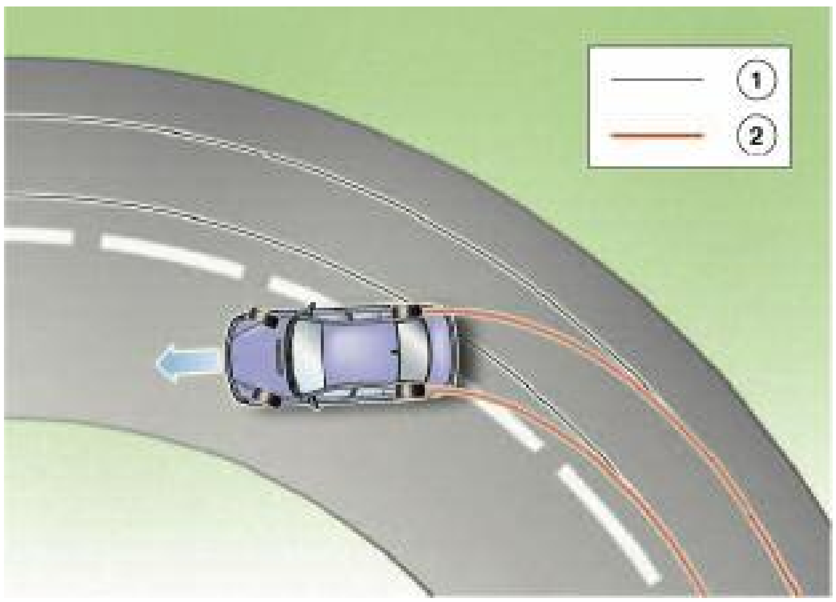


Index	Explanation
1	Line taken by a vehicle with neutral road behavior
2	Line taken by vehicle with understeer road behavior

Oversteer

The ratio of lateral force to wheel load is greater on the rear axle than on the front. The vehicle follows a smaller radius than that corresponding to the steering angle. The vehicle slides to the outside of the turn via the rear axle as the resulting force overcomes the grip of the tires.

In a RWD vehicle the driver can steer in the direction of the slide and back off the power which will reduce engine torque and shift the weight to the rear wheels in an attempt to regain traction and the control of the vehicle.



Index	Explanation
1	Line taken by a vehicle with neutral road behavior
2	Line taken by vehicle with understeer road behavior

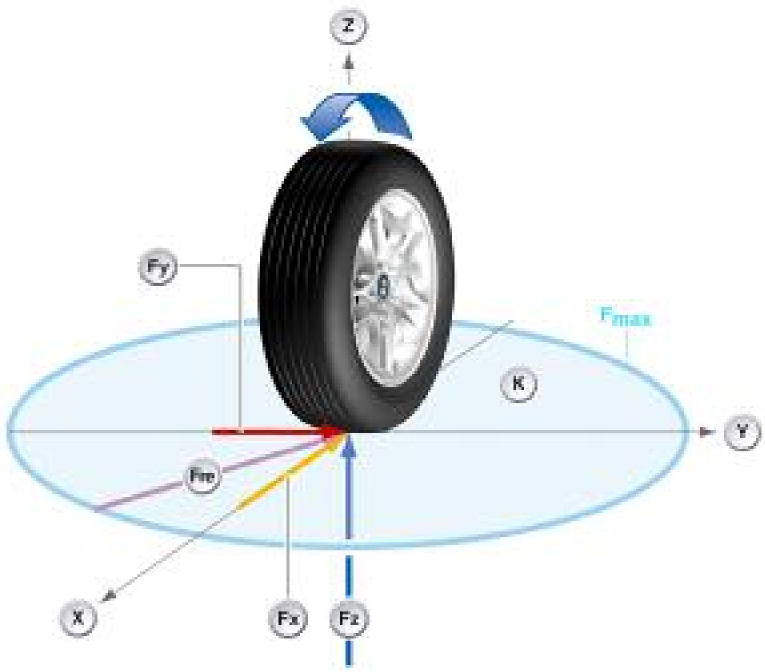
Due to inherit tendency of RWD vehicles to oversteer BMW chassis are designed so that they have slight understeer characteristics.

Chassis Forces

The chassis connects the vehicle with the road. Both force and drive torque are transferred to the road via the chassis. The chassis also has to absorb all cornering forces when the vehicle is cornering.

The chassis is therefore exposed to a huge number of forces and moments all of which act in different ways. It is essential that all these forces and moments can be transmitted in an optimum way via the tire contact areas.

As vehicles get more powerful and demands for ride comfort and driving safety rise, so the demands placed on the modern chassis increase considerably too.



Index	Explanation	Index	Explanation
Fx	Driving force	F_{re}	Resulting force
Fy	Cornering force	K	Maximum force area
Fz	Wheel contact force	X,Y,Z	Coordinate axes

Kinematics

From a physics point of view, kinematics are the laws which give rise to sequences of movements.

Where chassis engineering is concerned, kinematics is the sequence of movements at the wheels and wheel-guiding components. Kinematics therefore have a direct effect on the position of the wheel for the respective load conditions.

Co-ordinate Axes of Chassis Dynamics

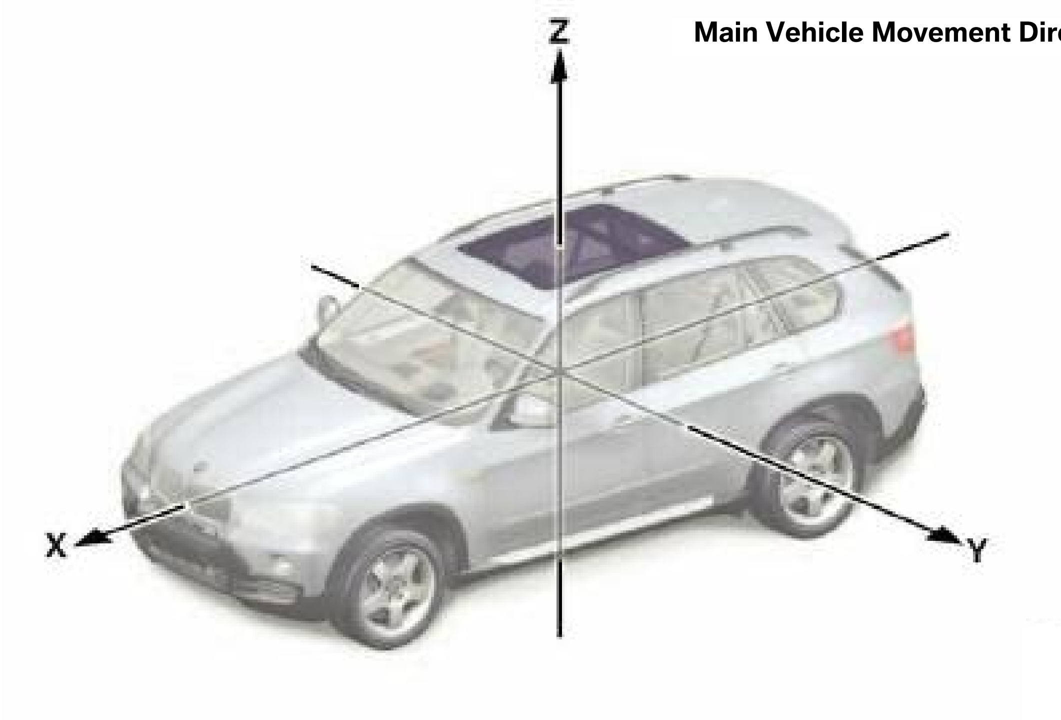
Forces are exerted on the chassis and therefore on the bodyshell when the vehicle is in motion. Certain dynamic influences cause movements in the vehicle body. These movements can be subdivided into and represented as three categories.

A coordinate system can be constructed for this with three spatial coordinate axes, which allows this degree of freedom to be defined.

Three main movement directions are derived from this system:

- Longitudinal dynamics
- Lateral dynamics
- Vertical dynamics

Main Vehicle Movement Directions



Index	Explanation	Index	Explanation
X	Longitudinal dynamics	Z	Vertical dynamics
Y	Lateral dynamics		

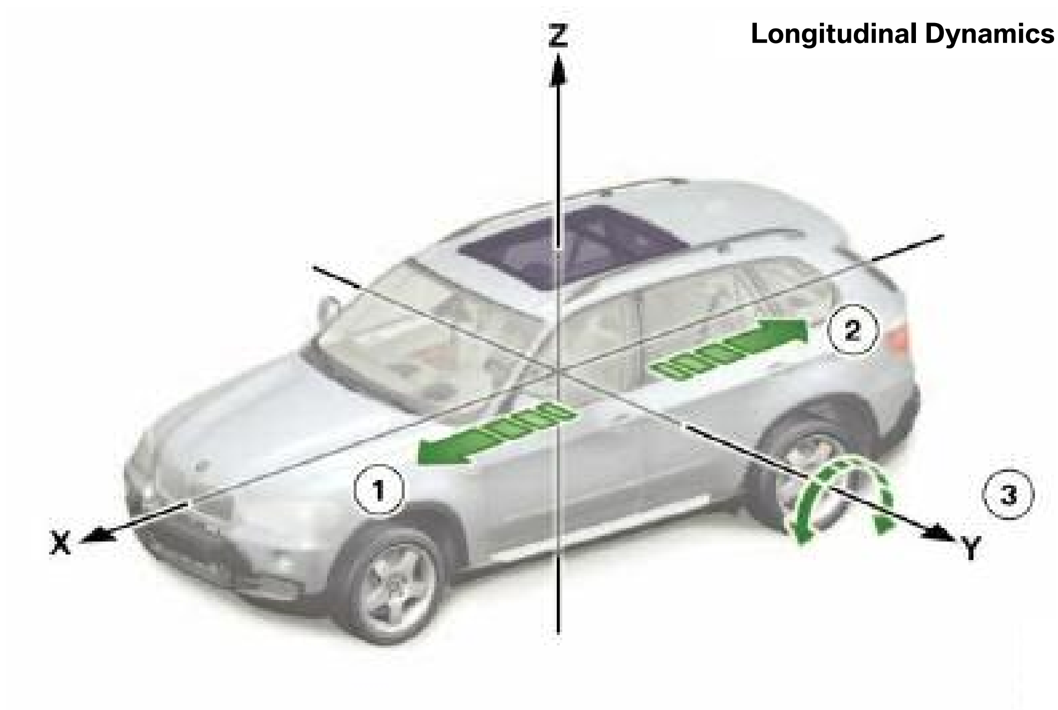
Longitudinal Dynamics (X Axis)

The main movement direction or direction of travel is defined by the x or longitudinal axis of the coordinate system.

These Longitudinal forces act along the centerline of the vehicle and are created by acceleration and braking. They are also refered to as “Pitch” due to the up or down movement that influences the hight of the front and rear of the vehicle.

Therefore driving situations involving longitudinal dynamics, such as accelerating or braking, also cause the vehicle to rotate about the y-axis.

Longitudinal Dynamics (Pitch)



Index	Explanation
1	Accelerating (longitudinal movement in positive x direction)
2	Decelerating (longitudinal movement in positive x direction)
3	Pitching (rotation about the y-axis)

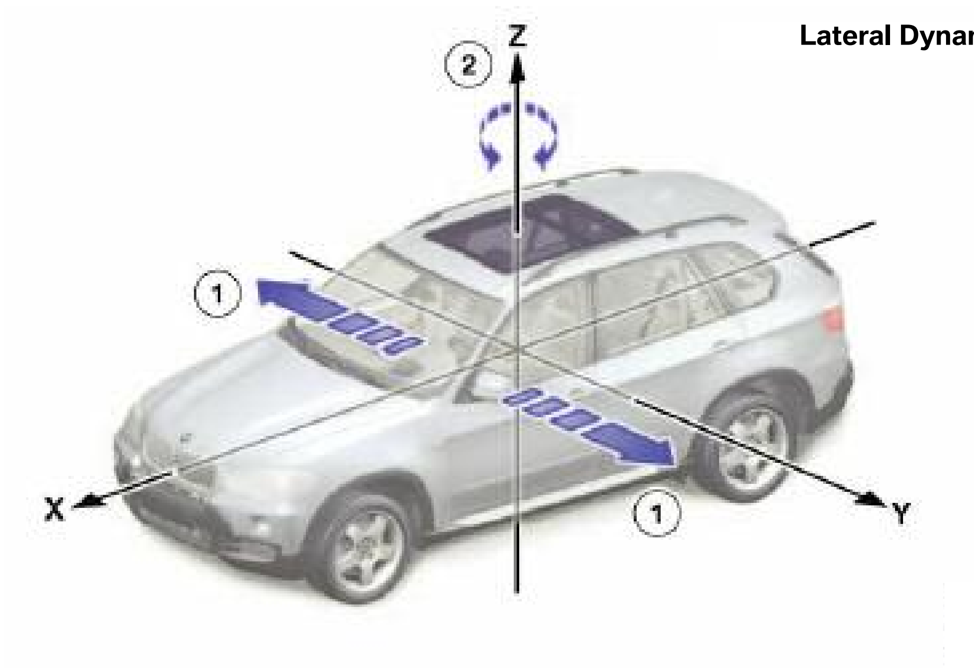
Lateral Dynamics (Y Axis)

Lateral forces are also known as transverse forces which act to deviate the vehicle along the Y axis. These forces are most prevalent during turns. Loss of traction, excessive steering angle and even crosswinds will contribute to increased lateral forces which will tend to veer the vehicle off its intended path.

This causes the vehicle to rotate about the vertical axis (z-axis). This rotating motion about the vertical axis is called "yaw".

As a side effect of the lateral movement, a rotating motion is also introduced about the x axis. This refered to as "roll", however, is described under vertical dynamics since, under these circumstances, the bodyshell moves in a vertical direction.

Lateral Dynamics (Yaw)



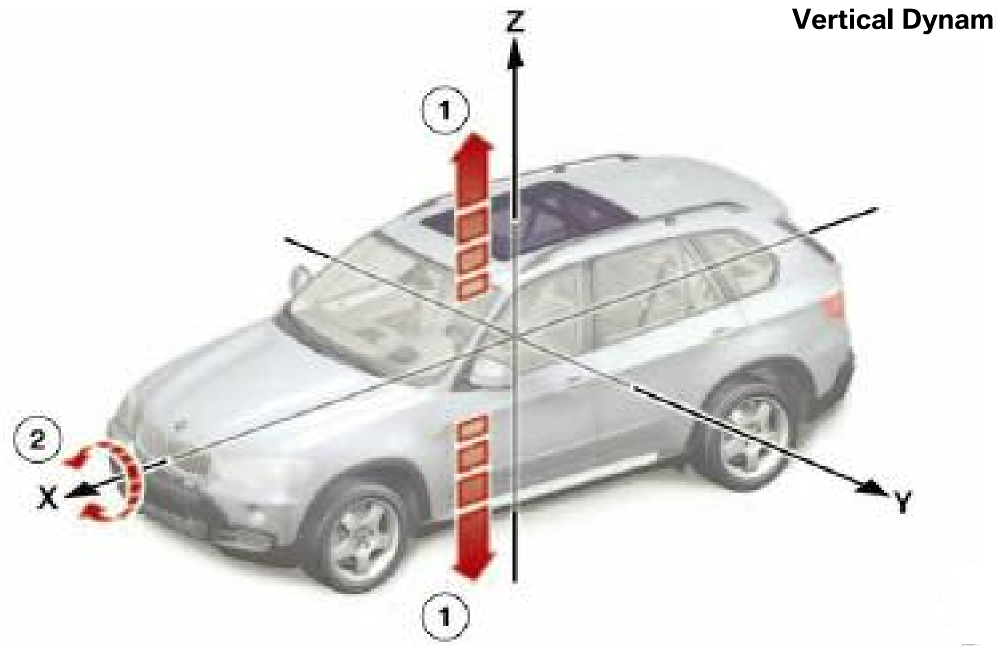
Index	Explanation
1	Movement in lateral direction (y direction) when cornering
2	Yawing (rotation about the z-axis)

Vertical Dynamics (Z Axis)

If the body moves along the z or vertical axis, we speak of vertical dynamics and describe oscillating up and down movements of the body as Kangarooing.

A rotating motion about the x-axis, or rolling, is also included in vertical dynamics. It is caused when the suspension of the left and right wheels is compressed to differing degrees. A triggering factor for this may area of unevenness along one side of the road only.

Vertical Dynamics (Roll)



Index	Explanation
1	Movement in vertical direction (z direction), also called kangarooing
2	Rolling (rotation about the x-axis)

But it may also occur on bends, where the centrifugal force created when cornering leads to a rolling movement of the bodyshell. The centrifugal force affects the vehicle's center of gravity thus creating a torque which rotates the bodyshell about the x-axis. The speed of this force indicates the degree of turning force.

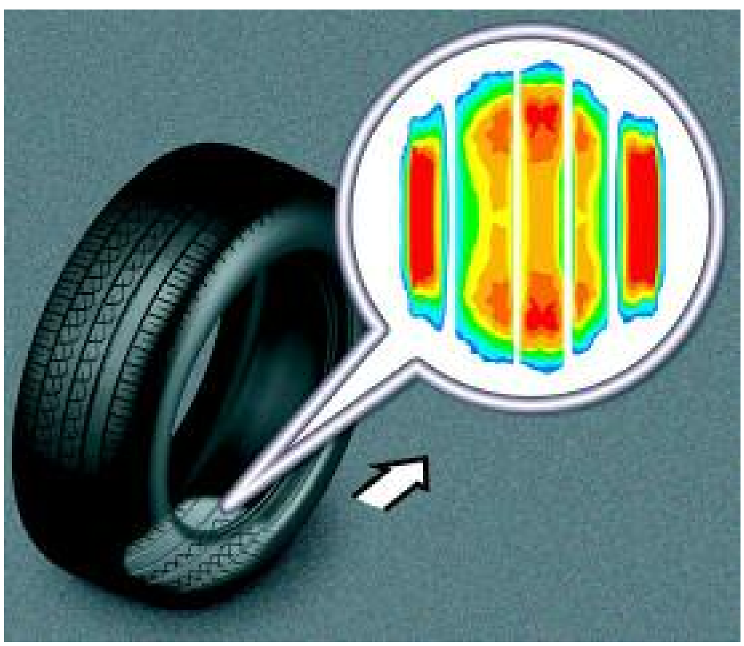
Index	Explanation
1	Vehicle center of gravity
2	Roll Axis
φ	Roll Angle
M	Rolling Moment
Fy	Lateral force
a_y	Lateral acceleration
h	Lever arm center of gravity height

Tire Contact Area

The tire contact area is the area which is covered by the wheel standing on the road.

Tire Contact Patch

The tire contact patch is the effective contact area of a tire in operation. It is therefore the tire contact area which is deformed by interfering forces (lateral forces, braking and acceleration forces) and by road surface quality.



The tire contact patch therefore describes the area of road which is touched by the tire when the vehicle is in operation.

BMW suspension systems are designed to allow for the optimum contact patch when the vehicle is in operation. For example, the “double-pivot” suspension is designed to keep the outside front tire as close to a zero camber angle on turns.

Pivot Axis

The pivot axis (red) is the effective axis about which the wheel being steered is turned. This does not actually have to correspond to the central axis of an axle component (e.g. a spring strut). It lies on the line connecting the upper and lower pivot points of the wheel suspension. The design dictates that the upper pivot point lies in the center of the spring strut support bearing. When determining the lower pivot point, the operating principle of the axle in question must be taken into account.

The illustration above shows an example of a single-pivot spring strut front suspension. In this case, the lower pivot point is situated in the outer ball joint of the control arm.

Pivot Axis (shown here using the single-pivot spring strut front suspension)

In the case of the double pivot spring strut front suspension shown below, the lower pivot point is not determined by an actual component. It must instead be constructed by extending the lines of action of the lower control arms (control arm and tension strut).

This axle design, in particular, allows the lower pivot point, and therefore the position of the pivot axle to change when the wheel is turned.

Double Pivot Spring Strut Front Suspension - Determining the Lower Pivot Point

BMW uses a variation of both of these suspension designs. (See BMW Suspension Systems section for more information)

Kinematics and Elastokinematics

The spatial arrangement of the pivot points or pivot axes of the arms and links of a suspension is known as kinematics. This term applies to components that are assumed to be non-deformable.

Elastokinematics takes into account the flexibility of the rubber-metal mounts, often of the ball joints and rarely of the components. It allows each wheel to move and flex individually without transfering loads and forces through the subframe to the opposing wheel.

Various arms define the horizontal plane of the rear axle wheel suspension at the axle carrier and the wheel carrier. These arms are mounted such that they can rotate about an approximately horizontal axis of rotation and therefore allow vertical movement of the wheel carrier.

Kinematics is primarily of significance in terms of vehicle handling. The kinematics is arranged such that defined camber and toe-in angles are achieved between the wheel and road surface in response to the suspension and steering.

Kinematics is superimposed by elastokinematic effects. These elastokinematic effects occur as the movement points and movement axes are spatially displaced by the effect of the forces at the wheel. This permits exact wheel control across significant spring travel, which is required for the desired driving properties. In addition, due to small effective lever arms, the rear axle barely reacts to interferences and ensures ride comfort.

Although all suspension system take into account the effects of elastokinematics, the "Integral Axle" multi-link rear suspension of the E31 was the first BMW to introduced a design that was exclusively built around this principle.

This design principle is still being applied today as subsequent variations of Integral III, IV and V axle design have been utilized on the 5, 6 and 7 series vehicles including the xDrive models.

Refer to the BMW Suspension Systems section for more information.