The Process of Vehicle Dynamics Development

Zhanglin Cai, Stephen Chan, Xiaofeng Tang and Jiang Xin

Abstract Automobile production in China is now ranked first in the world. As the market matures, vehicle users become more demanding on vehicle performance. Vehicle dynamics performance is directly related to drivers' ride and handling experience. The process of optimizing ride and handling has long been a challenge faced by chassis engineers. This article provides a comprehensive view of vehicle dynamics development for typical passenger vehicles. It focuses on the development work for suspension system before hardware is procured. The definition of vehicle dynamics is also explained in the first part of the article as background information.

Keywords Vehicle dynamics · Development process · Ride and handling · Simulation analysis · Suspension

Vehicle dynamics development is generally divided into three major phases:

- The first phase is to set the performance goals. Target setting is based on design experience of the vehicle development team as well as translating market requirements, or voice of the customers, into vehicle dynamics requirements. Typically vehicle dynamics specifications include ride, handling, and braking. During this phase of development, a lot of benchmark objective testing as well as subjective assessment are done to provide sufficient information for target setting.

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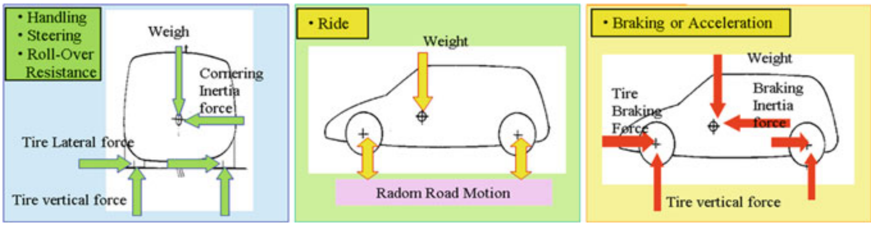


Fig. 1 Three aspects of vehicle dynamics

- The second phase is to develop the subsystem requirements from the vehicle dynamics specifications. The subsystem-level synthesis and performance tests are required in this stage to provide data to support subsystem target setting.
- The third phase is to transform the subsystem specification into component design parameters. This requires more precise simulation modelling tool for analysis in order to understand the design parameters of the key chassis components effect on overall vehicle dynamic performance. The result of this phase is to provide the component design requirements for the component level suppliers.

Once the hardware prototype is procured, in both vehicle level and component level, chassis tuning work begins. The goal is to refine the component specifications while balancing many chassis design parameters in order to meet the vehicle specifications. Although the second and third phases of the process are done early in the development, it is normal to iterate the process until an optimum design is completed. The specifications are occasionally modified as the vehicle program progresses, especially during the vehicle prototype phase of the development process. This can be caused by durability issues, simulation model discrepancy with actual performance, or marketing new trends.

In order to illustrate this process, roll dynamics is used as an example in this article. From determination of roll gradient to developing of front and rear roll stiffness, and roll stiffness to suspension component specifications.

1 What is Vehicle Dynamics?

Vehicle dynamics refers to the directional performance and dynamics of road vehicles, and typically vehicle dynamics is based on classical mechanics.

Vehicle motions are mostly due to the forces generated between the tires and road, and aerodynamics effects. In this article, the main focus is on suspension design and development, and aerodynamics effects are not considered. The tire forces can be divided into three directions: lateral, longitudinal, and vertical. Hence, vehicle dynamics performance can be divided into three aspects according to the force direction [1], see Fig. 1.

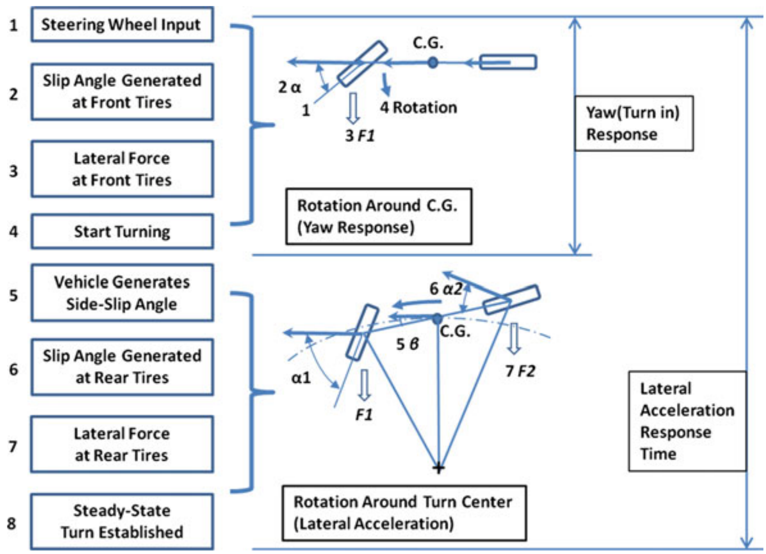


Fig. 2 Vehicle cornering sequence

- Lateral dynamics: examples are handling, steering response, and roll-over resistance.
- Longitudinal dynamics: examples are acceleration and braking performance.
- Vertical dynamics: examples are ride and pitch performance.

Take lateral dynamics as an example, the response sequence from a step steering input can be broken down into steps as shown in Fig. 2.

2 Vehicle Dynamics Development Process

Vehicle dynamics development process generally defined as the development work done before the prototype vehicle is produced. It is generally divided into three phases as shown in Fig. 3:

- Phase 1: VOC to VTS (Voice of Customers to Vehicle Technical Specifications) The first phase is to set the performance goals. Target setting is based on design experience of the vehicle development team as well as translating market requirements into vehicle dynamics requirements. Typically vehicle dynamics specifications include as ride, handling, and braking. This phase requires a lot of benchmark objective testing as well as subjective assessment to support target setting.
- Phase 2: VTS to SSTS (Vehicle Technical Specifications to Subsystem Technical Specifications)

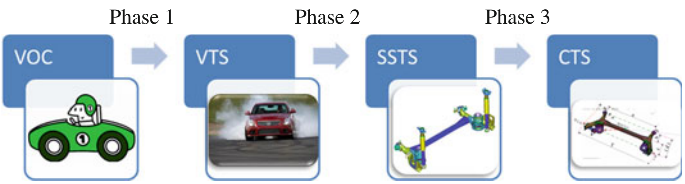


Fig. 3 Vehicle dynamics development process

The second phase is to develop the subsystem requirements from the vehicle dynamics specifications. The subsystem-level synthesis and performance tests are required in this stage to provide data to support subsystem target setting.

- Phase 3: SSTS to CTS (Subsystem Technical Specification to Component Technical Specifications)
  The third phase is to transform the subsystem specifications into component design parameters. This requires more precise simulation modelling tool for analysis in order to understand the design parameters of key chassis components effect on overall vehicle dynamic performance.

2.1 First Phase: From Voc to VTS

The first phase is the setting of performance goals. In addition to the development team visions and past experience on the vehicle performance targets, understanding of the voice of the customers and marketing trend are also key factors in setting vehicle performance targets. This is illustrated below in Table 1: VOC items regarding handling and ride are listed in the left column. VTS performance metrics are listed in the top row. Through the process of completing the Quality House table, the important VTS metrics can be identified.

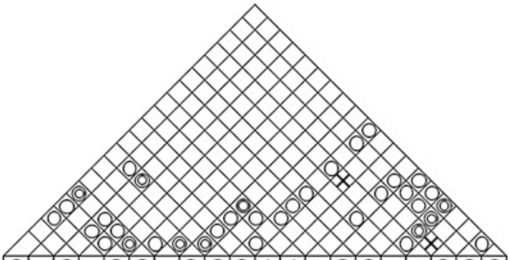
Based on the results above, some of the VTS metrics are more influential on VOC than others. However, it is important to select the representative VOC metrics and VTS metrics when using the Quality House analysis.

2.2 Second Phase: From VTS to SSTS

The second phase is to develop the subsystem requirements (SSTS) based on the vehicle dynamics specifications (VTS), see Fig. 4. The subsystem-level synthesis and performance tests are required in this stage to provide data to support subsystem target setting.

Roll gradient is used as an example here to illustrate the VTS flow down process.

Table 1 Quality house showing the relationship between VOC and VTS



Correlation between engineering requirements: ◎ Strong+; ○ +; × −; ※ Strong−

Improvement Direction: ▲ Larger is Better; ● Nominal is Better; ▼ Smaller is Better

Relationship Strength: ◎ Strong - 9; ○ Medium - 3; △ Weak - 1

	VOICE OF THE CUSTOMER	Item No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
	ENGINEERING REQUIREMENTS		Steering wheel torque at 0 g	Curb to curb turning radius	Steering sensitivity ratio	Static steering effort	Steering torque gradient ratio	Torque gradient at 0 g	Lateral acceleration response time	Understeer gradient	Steering sensitivity	Roll gradient	Maximum lateral acceleration	Yaw velovity damping	Pitch damping	Pitch gradient-acceleration	Pitch gradient-braking	Single bump disturbance	Impact isolation	Vertical damping	Front ride frequency	Ride frequency ratio
	Improvement Direction		●	▼	●	▼	●	●	▼	●	●	●	▲	▲	▲	●	●	▼	▲	●	●	●
Handling	Car feels heavy and sturdy	1	◎			○	○	◎	○	○	○	△	○	○	○	○	○	△		○	△	△
Handling	Car's handling allows for fast cornering	2			○				◎	◎	◎	◎	◎	◎						○	○	○
Handling	Car has good handling and stability at highway speeds	3	◎		◎	△	○	◎	◎	○	◎	◎		○	△	△	△			○	△	△
Handling	Car handles well over poor roads	4					△		○	○	○	◎		○	○	○	○	◎			◎	◎
Handling	Car handles well during all weather conditions	5		△	○		○		◎	◎	◎	○	◎	◎	◎	○	○	◎	◎	○	○	○
Handling	Car maneuvers in and out of traffic with ease	6		○		△	◎	○	△		◎											
Handling	Car's handling provides a total feel of the road	7	○		◎		◎	◎	◎	○		○	○								△	△
Handling	Car responds well to steering wheel movement	8	○		◎	○	○	◎	◎	○	◎	○										
Handling	Car is easy to park	9	◎	◎	○	◎					△											
Handling	Car comes to a smooth stop	10													◎		◎			◎		
Ride	Car has smooth ride over bumpy roads	11													○		○	◎	◎	○	◎	◎
Ride	Car does not shake or vibrate over bumpy roads	12										○						◎	◎	○	◎	◎
Ride	Car feels soft over speed bump	13																	◎		○	○
Ride	Car can isolate the uneven road input	14																	○	◎	○	○

Based on input from benchmarking study and development team input, the VTS roll gradient target for a new compact passenger vehicle is ≤5 deg/g.

The roll gradient is contributed by the front and rear suspension roll stiffness. While achieving the roll gradient of ≤5 deg/g, the limit handling performance requirement has to be met. The stability at the limit handling condition (typically greater than 0.6 g lateral acceleration) is an important factor in vehicle handling. The front roll stiffness and rear roll stiffness have to be balanced correctly. This is typically done by selecting a Tire Lateral Load Transfer Distribution (TLLTD). In this case the TLLTD is selected to be 60 % to ensure stable cornering at the limit.

In this case, the basic vehicle information is listed below:

Mass	1,040 kg
Mass Distribution	61 % Front
Roll-Center Height	Front 55 mm, Rear 150 mm
TLLTD Requirement	60 %
Roll Gradient	≤5 deg/g

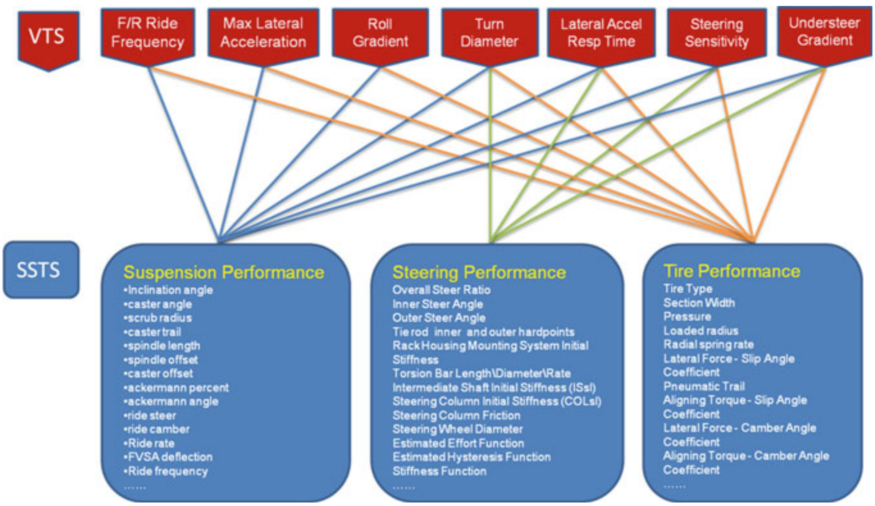


Fig. 4 Flow down from VTS to SSTS

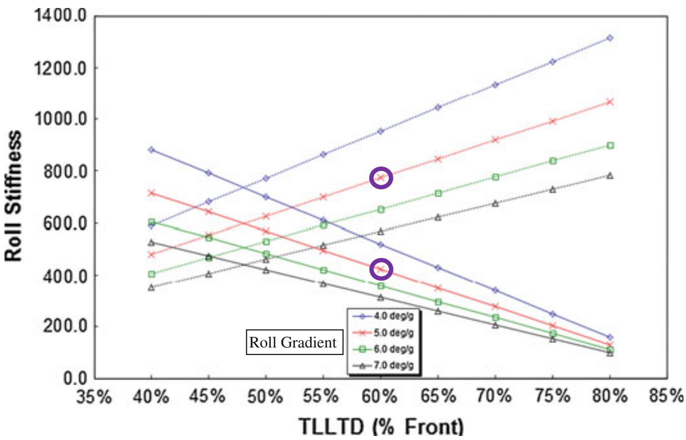


Fig. 5 Front and rear roll stiffness vs. TLLTD

Figure 5 shows the output from a synthesis tool showing relationship of the suspension roll and rear roll stiffness vs. TLLTD. In order to meet the design requirements: 780 and 410 Nm/deg are selected (the points with circle) for the front and rear roll stiffness respectively. The front roll stiffness and rear roll stiffness are the part of the suspension subsystem technical specifications.

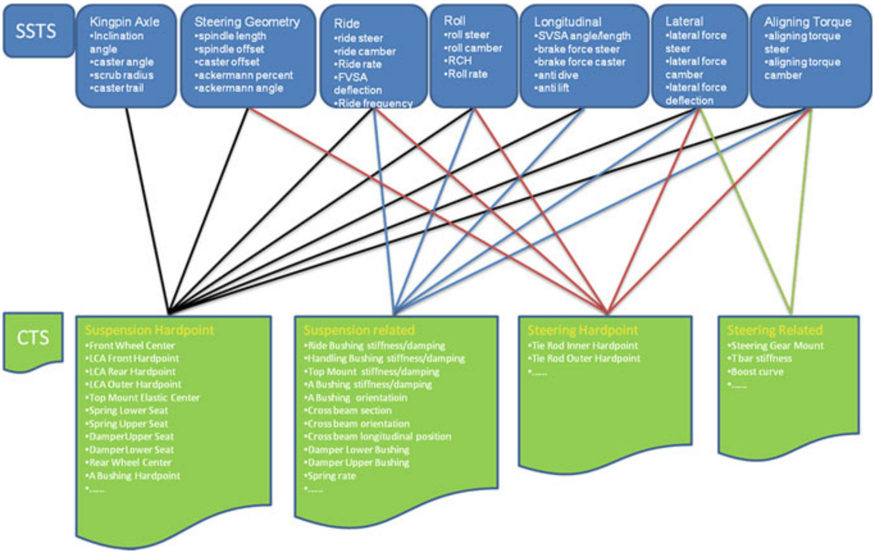


Fig. 6 Flow down from SSTS to CTS

2.3 Third Phase: From SSTS to CTS

The third phase of the process is to transform the subsystem specifications into component technical specifications, see Fig. 6. This requires more precise simulation modelling tools for analysis in order to understand the effects of design parameters on performance.

Roll performance is used as an example here to illustrate the SSTS to CTS flow down process.

In the second process, the vehicle technical specification of body roll gradient of 5 deg/g is the design target. 780 Nm/deg front roll stiffness and 410 Nm/deg roll stiffness are set as part of front and rear suspension subsystem specifications.

The third phase of the process is to set the design parameters for the front and rear suspensions individual components in order to achieve the roll stiffness while meeting all the other subsystem specifications such as ride rate.

In order to meet the roll stiffness requirements, suspension key parameters such as spring rate, roll-center height, and stabilizer bar size are defined. In the process of defining these key parameters, suspension ride frequency and packaging requirements need to be balanced carefully to obtain an optimum chassis performance.

In order to determine the suspension components specification, suspension simulation model ADAMS [2] is used to determine the roll stiffness of the suspension from the suspension components. Figure 7 shows the ADAMS model of the front and rear suspension of a compact passenger vehicle.

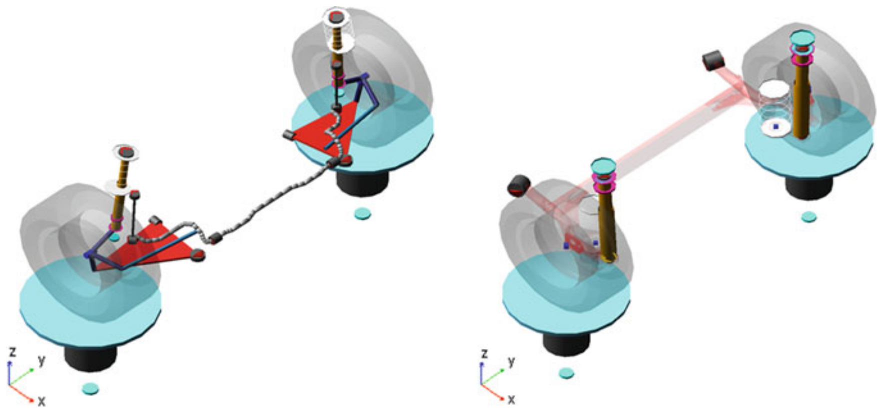


Fig. 7 Front and rear suspension model

Suspension Component Specifications to Meet SSTS Requirements:

Spring Rate:	Front 19 N/mm	Rear 18 N/mm
Stab Bar Size:	Front 22 mm	Rear none (solid twist axle)

Once the stabilizer bar mounting point and stiffness are determined, the mount point stiffness requirements have to be provided to the body structure development team as a body structure design criteria.

The first round of the three phases of the vehicle dynamics development is completed. All the component design specifications are defined. Prototypes are then built followed by subjective evaluation and objective testing.

Once the hardware prototype is procured, subjective evaluation and tuning begin. The goal is to refine the component specifications while balancing chassis design parameters to meet the vehicle requirements. Subjective evaluation and objective testing work hand-in-hand with simulation analysis in the prototype development stage. Through this process, a well-balanced chassis performance can be achieved.

3 Summary

Due to limited space, only roll dynamics is discussed in detailed. The roll dynamics example is only a small portion of the suspension development based on vehicle dynamics performance. Other areas to be considered including lateral mode dynamic response which is mainly affected by front and rear cornering compliances, and steering response; vertical mode need to be considered including pitch dynamics and ride frequency of the front and rear suspension.

Although the second and third phases of the process are done early in the development before physical hardware is procured. The vehicle level specification, subsystem specification, and component technical specifications are occasionally modified as the vehicle development program proceeds. This can be caused by durability issues, government regulations such as fuel economy requirements, or marketing new trends. New balancing strategies are sometimes applied for the vehicle under development.

References

Knable J, Leffert R (2008) Understanding vehicle dynamics for passenger cars and light trucks, a general motors vehicle system approach. Knable and Associates, Inc

ADAMS/CAR user guide, MSC Inc

http://www.springer.com/978-3-642-33834-2

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