International Journal of Applied Science and Mathematics
Volume 3, Issue 6, ISSN (Online): 2394-2894

The K & C Analysis and Optimization of Macpherson Suspension

Jiao Wang, Xuekai Qu, Jiapeng Han, Shuai Xing
(School of Transportation and Vehicle Engineering Shandong University of Technology, Zibo255049, China)

***Abstract* – This paper focuses on the problem that, under rolling working condition, the height of the roll center is too large, and under the steering condition, Kingpin Offset is too large and Mechanical Trail is too small. The kinematic model of the Macpherson front suspension is established in ADAMS/CAR, and the model is used to analyze the sensitivity of the post-point, external point on Macpherson and the over-point on shock absorber by ADAMS / Insight. According to the results of the analysis and the design requirements, the corresponding hard-point coordinates are modified to obtain the optimal design value, which can solve the above-mentioned problems. The kinematic performance of the suspension has been significantly improved, and this research provides technical support for the suspension kinematics analysis.**

***Keywords* – The K & C Analysis and optimization, Macpherson suspension, Kinematics simulation.**

I. Introduction

Suspension kinematics analysis is the most important part of the chassis tuning, and it is the basic guarantee to ensure the vehicle to control stability. Literature [4] and [5] by using the geometric structure parameters carry on a spatial kinematic analysis of Macpherson suspension, literature [2] carry on the establishment and optimization of the parameterized model of Macpherson suspension, which require accurate mathematical model, have a certain complexity and the accuracy is not high.

The kinematic relationship between the links is composed of the coordinates of the suspension hard points, which determines the change of the suspension kinematics characteristics.

In this paper, by development of motorcycle type of mathematical model for reference, in ADAMS/CAR by establishing the Macpherson suspension model carry on the kinematics simulation and design optimization, then getting the optimization of the curve and the results of the comparison analysis.

II. The Establishment of Macpherson Front Suspension

A. Structural Analysis of Macpherson Suspension

Such as the Mathematical model based on CATIA in Figure 1 and Macpherson structure is shown in Figure 2, the Macpherson suspension structure is mainly composed of an ‘A’ shaped under arm, shock absorber, steering knuckle. An ‘A’ shaped under arm is conducted as the main force components, the front and rear of the swing arm are connected to the frame by a bushing to provide some of the lateral support force for the wheel and born before and after all the stress direction. Upper pivot point of absorber is connected with bushing and the vehicle body, however, mechanical spring is covered with traveller of absorber in order to avoid the shift around the direction of the force, that bear the vibration of the upper and lower direction. The roll stiffness of suspension can be improved with stabilizer bar. They have many advantages, such as simple structure, low cost, reliable operation and long service life. Generally speaking, it is the first choice of automotive front suspension.

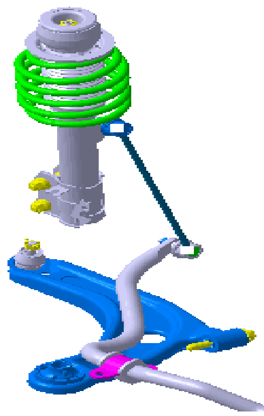

Fig. 1. Mathematical model based on CATIA
Fig. 2. Macpherson suspension

B. The Establishment of Virtual Prototype Model

According to the CATIA mathematical model to determine the corresponding hard point coordinates, the establishment of ‘A’ shaped under arm of the Macpherson independent suspension, shock absorber and steering knuckle and other geometric components. Establishing model of damper damping of suspension is used a benchmark vehicle to test the damping characteristic curve and modify the properties file to complete. Spring in suspension with linear stiffness. The various connections in the model are connected by a bushing. The bushing data is obtained through experimental tests.

Finally, according to the connection of the components to establish the relevant connection, complete suspension model is consisted of matching the corresponding installation and communication devices, as is shown in figure (3).

International Journal of Applied Science and Mathematics
Volume 3, Issue 6, ISSN (Online): 2394-2894

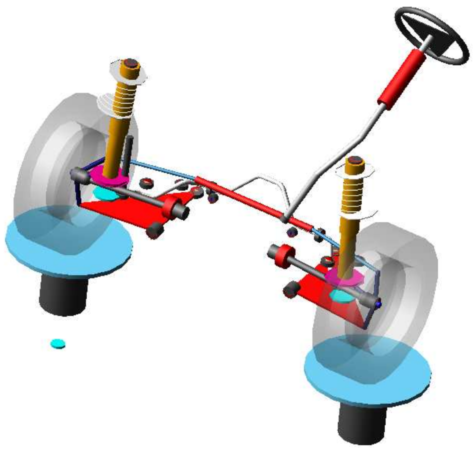

Fig. 3. Macpherson front suspension

III. Kinematics Simulation Analysis of Macoherson Suspension Model

The kinematic characteristics of the suspension system are mainly manifested in the change characteristics of the wheel alignment parameters with the wheel steering and up and down. This paper is used the same loading method as in the vehicle suspension K&C test bench carrying roll condition and steering conditions, then seeing the change curve of the corresponding parameters.

A. The Design of Roll Condition Test and Simulation Analysis

The roll condition in ADAMS/CAR , setting the number of simulation step is 100, only carrying the kinematic characteristics of the simulation type .Specific simulation settings is shown in table 1:

Table 1. Setting simulation parameters of roll condition

Setting	Parameters
Number of Steps	100
Mode of Simulation	interactive
Vertical Setup Mode	Wheel center
Roll Angle Upper	5
Roll Angle Lower	-5
Vertical Mode	Length
Fixed Vertical Length	0

The simulation setup is completedin ADAMS obtaining the change curve of camber angle, roll center height and roll angle, as shown in Figure 4, shown in figure 5.

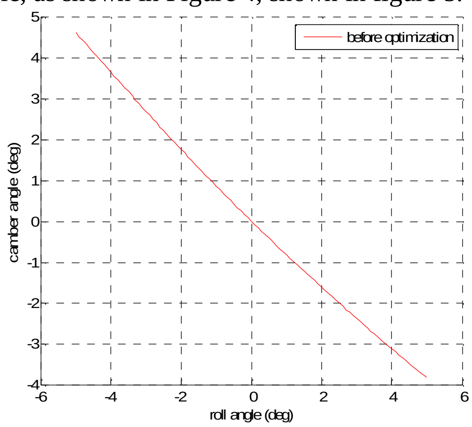

Fig. 4. Camber angle vs Roll angle

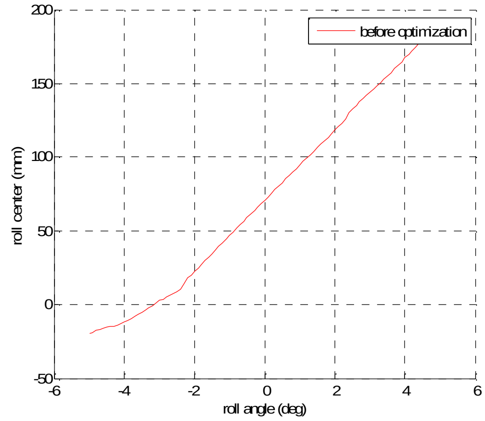

Fig. 5. Roll center vs Roll angle

The car is in the process of turning, the change of camber angle is impacted on lateral force seriously. Hope to follow the car body side inclination has a positive trend of rapid change .Keeping the tyres as much as possible for maximum lateral adhesion and improving the lateral stability of turning. Track change and roll center height has a direct relationship, design of sidewise center is higher, the greater the track changes, the vertical tangent is shorter, tire wear is severer.

Table 2. The simulation results and calculation of rolling working condition

Result	Before optimization	Standard values	Meet or not
Camber Angle gradient (deg/deg)	-0.836	＜0．85	meet
Roll center (mm)	69.831	（30,55）	not meet

As can be seen from table 2, camber angle is changed with body roll angle, camber angle is -0.824deg/deg.It is met the design requirements of less than 0.85. However, the height of roll center is 69.831mm, it does not conform to design standard contract similar vehicle between 40mm and 60mm and should be further optimized.

B. The design of steering condition test and simulation analysis

Table 3. Setting simulation parameters of roll condition

Setting	Parameters
Number of Steps	100
Mode of Simulation	interactive
Vertical Setup Mode	Wheel center
Upper Steering Limit	560
Upper Steering Limit	-560
Control Mode	Relative
Steering Input	Angle

After the simulation is completed, obtaining the change curve of Kingpin Inclination Angle, Kingpin Offset, Caster Angle, Mechanical Trail are changed with steering wheel angle. As is shown in Figure 6, Figure 7, figure 8, figure 9, figure.

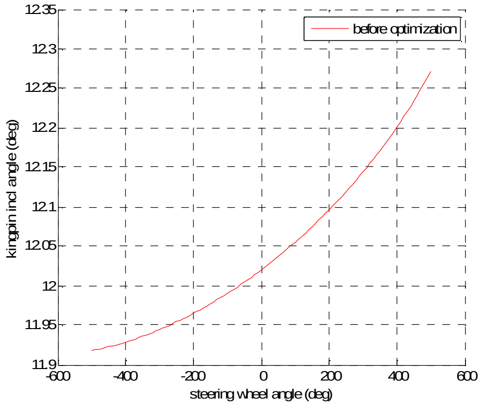

Fig. 6. Kingpin inclination angle vs steering wheel angle

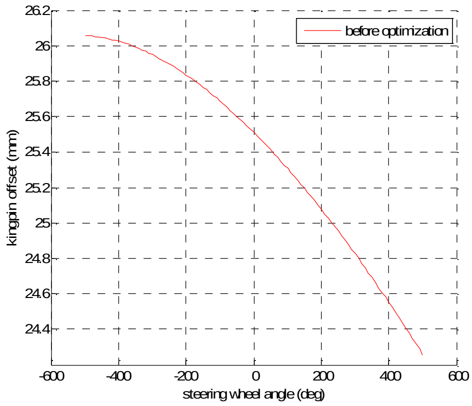

Fig. 7. Kingpin offset vs steering wheel angle

Kingpin Inclination Angle is the leading factor to keep the stability of the vehicle at low speed. In the process of steering, Kingpin Inclination Angle is gradually increased along with the steering wheel angle, which will produce a positive effect under the action of gravity, which will increase the steering force of the steering wheel. Initial design value of Kingpin Inclination Angle is generally positive, should not be too large or too small. If it is too large , that can increase the friction between the tire and the road surface and accelerated tire wear. Instead, if it is too small, that can not conducive to the stability of low speed straight line. Kingpin Inclination Angle and Kingpin Offset are mutually influenced. At the beginning of design ,generally, having a smaller Kingpin Offset, even designing negative Kingpin Offset so that the car itself has a resistance deviation trend.

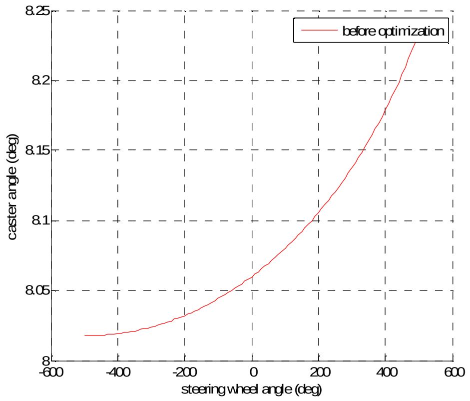

Fig. 8. Caster angle vs steering wheel angle

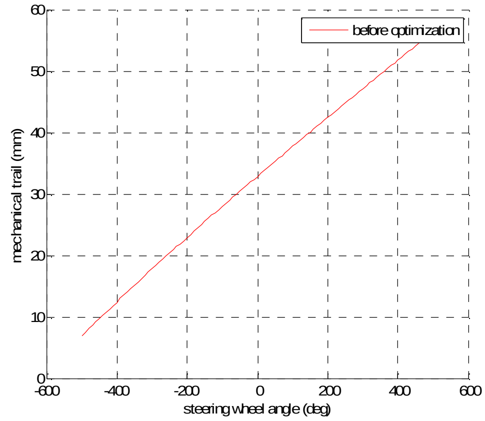

Fig. 9. Mechanical trial vs steering wheel angle

Caster Angle is the leading factor to keep the stability of high speed straight line. The initial value of Caster Angle is generally positive. The size of the design value is related to the arrangement form of the transmission system and the form of the rotary power. In the process of steering, a positive moment is formed from the torque of the mechanical trail and the lateral force which is used to maintain the stability of high speed travel. The mechanical trail is too large to resist the lateral force of the interference, the steering system of the feedback is relatively large and the steering wheel force is too heavy.

Table 4. The simulation results and calculation of steering condition

result	Before optimization	Standard values	Meet or not
Kingpin inclination angle(deg)	12.017	（12,14）	meet
Kingpin offset(mm)	25.512	（-10,10）	Not meet
Caster angle(deg)	8.063	（4，9）	Meet
Mechanical trail(mm)	32.697	（35,40）	Not meet

As can be seen from table 3, initial value of Kingpin Inclination is 12.107 deg, which meet similar design between 12deg and 14deg the design standard .Instead, Kingpin Offset is 25.514mm, is far greater than the same car -10mm-10mm design standards, so that need further optimization.

Initial value of Caster Angle is 8.063deg, slightly meeting the design standard of 4 degrees 9 the same car. The design of mechanical trail is 32.697mm,design standard is slightly larger with the same car of 35mm-40mm, need further optimization design.

IV. Analysis of Optimal Design of MacPherson Suspension Model

Analysis of suspension kinematics is hard point considering suspension guiding links arrangement. Changing hard point arrangement will cause the change of the link position, however hard point and kinematics is many to many mapping, hard point adjustment needs a comprehensive analysis.

International Journal of Applied Science and Mathematics
Volume 3, Issue 6, ISSN (Online): 2394-2894

A. Analysis of the Fitting Degree of Optimization Parameters

According to automotive overall design parameters and suspension design theory, considering the design models, adjustment of hard points are impacted on design space position and subsequent assembly. Outer the point and after the point of the lower arm, upper fulcrum of shock absorber and XYZ three directions of the coordinate values can been changed. Relative adjustment range (-10mm, 10mm) is obtained with full factorial design method by carrying on 512 iterative optimization. Finally see the fitting index of each item.

Table 5 the fitting values between the optimized parameters

Parameters	R2	R2adj	P	R/V
Roll center	0.948	0.945	3.21*10-33	362
Kingpin inclination angle	0.992	0.977	4.26*10-27	233
Caster angle	0.989	0.948	3.54*10-38	541

As is shown in Table 5,according to the analysis of the chart data fitting: R2 and R2adj is fitting. The closer the R2 value is, the better the 1 is. The value of R2adj is conducted as the second R2, infinitely close to 1 better. The P value is used to determine the degree of kneading .Smaller value is showed that the fitting process more useful. P/V value is determined the predicted result value, higher value is showed that prediction results is better, the optimization results is more ideal.

The corresponding HTM format is derived, and the influence degree of the optimization variables is analyzed, and the compromise of the hard point is optimized according to the influence degree.

B. After Optimization, the Corresponding Hard Point Data is Compared.

In order to keep the relative design parameters of the vehicle, the kinematic performance of the whole is not affected, and the hard point is only slightly adjusted.

Table 6. Compare with hard point

Hardpoint	Before optimization	After optimization
Hpl_lca_outer_X	-13.553	-22.553
Hpl_lca_outer_Y	-619.488	-629.488
Hpl_lca_outer_Z	-105	-90
Hpl_top_mount_Y	-510.142	-505.142
Hpl_top_mount_Z	409.43	413.43

According to the new hard point change model and used the same loading method as in the vehicle suspension K&C test bench carrying roll condition and steering condition, then seeing the change curve of the corresponding parameters and compared with before optimization.

C. Contrast Simulation Results of Roll Condition

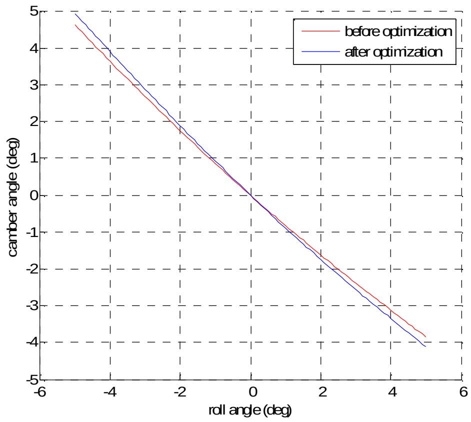

Fig. 10. Camber angle vs roll angle

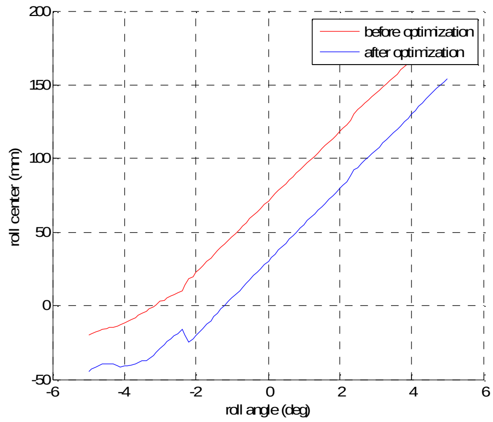

Fig. 11. Roll center vs roll angle

As is shown in Figure 10 and Figure 11, comparative analysis of the optimization results of the camber angle and roll center height. Comparison of optimization before and after optimization, the Camber Angle of optimization before is -0.836deg, the Camber Angle of optimization after is -0.924deg, the relative increase of 10.5%. roll center height significantly reduce from 69.831mm to 34.278mm, relative decrease of 50.9%. By this design, the results of optimization reach the design standard of similar vehicle and meet the design requirements. The specific variation parameters are shown in table 7.

Table 7. The calculate of contrast simulation results of roll condition

result	Before optimi-zation	After optimi-zation	percent	Standard vlues	Meet or not
Camber angle gradient (eg/deg)	-0.836	-0.924	10.5%	＜0．85	meet
Roll center (mm)	69.831	34.278	50.9%	(30,55)	meet

D. Contrast Simulation Results of Steering Condition

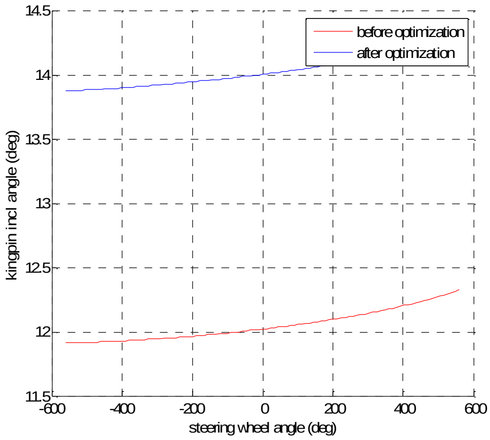

Fig. 12. Kingpin inclination angle vs steering wheel angle

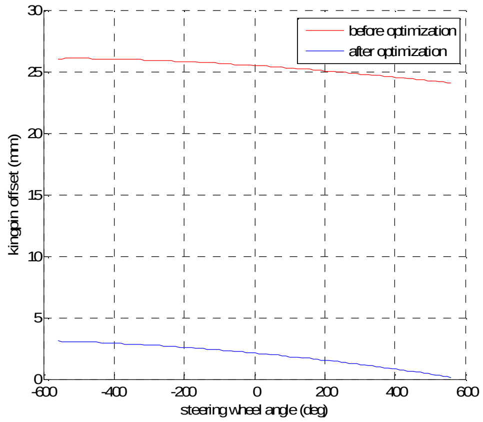

Fig. 13. Kingpin offset vs steering wheel angle

As is shown in Figure 13 and Figure 12, comparative analysis of the optimization results of the Kingpin Inclination Angle and Kingpin Offset. Comparison of optimization before and after optimization, Kingpin Inclination Angle of optimization before is 12.017deg, the Kingpin Inclination Angle of optimization after is 13.927deg, the relative increase of 15.9%. Kingpin Offset significantly reduce from 25.512mm to 2.34mm, relative decrease of 90.8%. By this design, the results of optimization reach the design standard of similar vehicle and meet the design requirements.

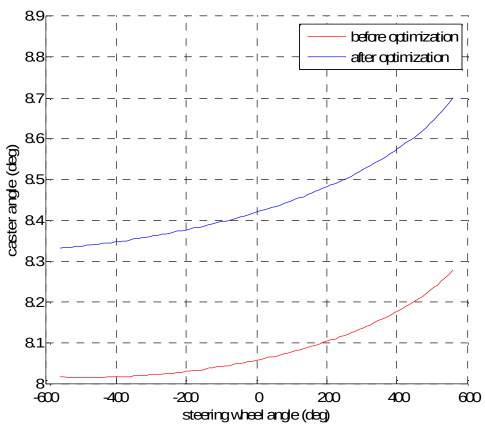

Fig. 14. Caster angle vs steering wheel angle

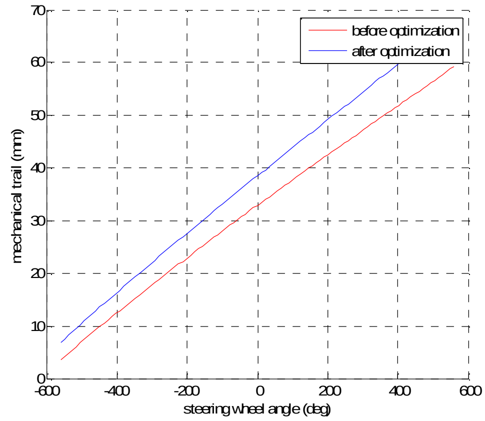

Fig. 15. Mechanical trial vs steering wheel angle

As is shown in Figure 14 and Figure 15, comparative analysis of the optimization results of the Caster Angle and mechanical trail. Comparison of optimization before and after optimization, the Caster Angle of optimization before is 8.063deg, the Caster Angle of optimization after is 8.423deg, the relative increase of 4.5%.Mechanical trial significantly increase from 32.697mm to 38.371mm, relative decrease of 17.4%. By this design, the results of optimization reach the design standard of similar vehicle and meet the design requirements. The specific variation parameters are shown in table 8.

Table 8. The calculate of contrast simulation results of roll condition

Result	Before Optimi-zation	After Optimi-zation	Percent	Standard value	Meet or not
Kingpin Inclination Angle(deg)	12.017	13.927	15.9%	（12，14）	meet
Kingpin Offset(mm)	25.512	2.34	90.8%	（-10,10）	meet
Caster Angle(deg)	8.063	8.423	4.5%	（4，9）	meet
Mechanical Trail(mm)	32.697	38.371	17.4%	（35,40）	meet

V. Conclusion

In this paper, we use ADAMS/CAR to establish the model of Macpherson front suspension. The roll condition has problems that the roll center height is too large, the steering Kingpin Offset is large and Backward Drag is small. Multi objectives collaborative optimization is analyzed by using insight. The simulation curves were compared and analyzed between before and after optimization. Through the analysis of the results, some problems that the roll center height is too large, the Steering Kingpin Offset is large and mechanical trail is small can be solved. By this design, not only improving the performance of the suspension, but also meeting the design standards of similar vehicles.

REFERENCES

[1] Chen jun. MSC.ADAMS Technology and Engineering Analysis Example [M]. Beijing:China Water Power Press,2008

[2] Hou yongtao ,Meng lingfei. Construction of parameters and simulation optimization system of McPherson suspension [J].Machinery Design and Manufacture,2015(3):217-224

[3] Gao lixin, Zhou huihui, Hu yanping, Kinematics analysis of Macpherson front independent suspension based on spatial analytic geometry [J] Journal of Hefei University of Technology: Natural Science, 2009, 32(11):1656-1659

[4] Yu zhisheng, Car Theory [M].Beijing; Mechanical Industry Press, 2009

[5] Geng qingsong ,Qin wei, The spatial kinematics analysis on MacPhersion suspension [J] Machinery Design and Manufacture,2015(1):20-23

[6] Kang, D-O, Heo, S-J, Kim, M-S, Robust design optimization of the McPherson suspension system with consideration of a bush compliance uncertainty [J] .Proceedings of the Institution of Mechanical Engineers,2010,224(6):705-716

[7] Ma jun, Qian lijun, Optimization design and experiment study on alignment parameters [J] Automotive Engineering, 2014,36(2): 231-235

[8] [1] Sun Yanwei. Modeling and Simulation of Mcpherson suspension based on ADAMS/CAR environment [A]. Henan Automotive Engineering Institute. Proceedings of the ninth Henan automotive engineering and technical seminar [C]. Henan Automotive Engineering Society: 2012:3.

[9] Xia xiaojian, Shao yuehua, Ding hua, Kinematical analysis and structural parameter optimization of Macpherson suspension [J]. Transactions of the Chinese society for Agricultural Machinery,2005,36(12):25-28

[10] Chen lijun, Mechanical System Dynamics Analysis and Application Tutorials of ADAMS [M]. Beijing: Qinghua University Press,2005

AUTHORS' PROFILES

JiaoWang
She was born on April, 1994 in Shandong Province, China. She is a graduate student at Shandong University of Technology, major in transportation engineering. Her research direction is Unmanned vehicle

Xuekai Qu
He was born on December, 1990 in Shandong Province, China. He is a graduate student at Shandong University of Technology, major in transportation engineering. His rese-arch direction is Vehicles Handling Performance Research Based on the Suspension K&C Characteristics.

Jiapeng Han
He was born on 26thJuly,1965in Shandong Province, China. He is an associate professor at Shandong University of Technology. His main research direction is monitoring technology of safe driving and technical evaluation of road traffic accident.

Shuai Xing
He was born Born in February 1991 in shan dong province. Studying in shan dong university of technology. Majoring in vehicle engineering. His research is finite element analysis of vehicles.