

Influences of Parameters at Vehicle Rollover

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1 Abstract

The influence of vehicle and driving situation parameters in a rollover event are evaluated by numerical simulation. Sensors and an algorithm for the deployment decision are necessary for occupant protection with restraint systems. The algorithm must decide in a timely manner to deploy the restraint systems for various rollover scenarios. Given the great variety in rollover situations a numerical vehicle simulation is needed and is the suitable tool to cover all cases.

All the different cases were divided into 6 test configurations for this simulation investigation. The computer programs ADAMS and MADYMO were used for the rollover simulation.

The results from the vehicle dynamic simulation are the sensor input signals for the algorithm (angular rate and acceleration signal) and these signals are also the values for the MADYMO occupant simulation. In addition, the requirements for the restraint system activation in the different rollover scenarios are also obtained from MADYMO.

In real world rollover events with variations in the rollover parameters (i.e. vehicle speed, angle, etc.), the algorithm has to be robust to cover all requirements.

STOOLS, the simulation tool developed by Siemens Automotive, is used to check the algorithm robustness with the data generated from ADAMS vehicle simulation.

This investigation of intensive use of numerical computer simulation shows the importance and capability of simulation in the automotive safety development process for actuators, vehicle behavior in an accident, sensor development, and algorithm development for electronic control units.

2 Introduction

The analysis of accident statistics shows that vehicle rollovers account for 5% of accidents resulting in injury. 20% of accidents with fatalities in Europe involved rollovers. In North America 20% of all accident fatalities are rollovers. The severe injuries and fatalities are caused by head contact with the vehicle interior or ejection of the occupant.

This shows the importance of restraint systems and the timely safety device activation by the electronic control unit in rollovers. The detection of the vehicle rollover and the restraint system activation will become an additional functionality of the electronic airbag control units. The main restraint system is the belt pretensioner to fix the occupant and prevent occupant movement in the

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vehicle during rollover and to avoid occupant ejection. To prevent the exposure of arms or the head out of the side window, inflatable curtains will be used.

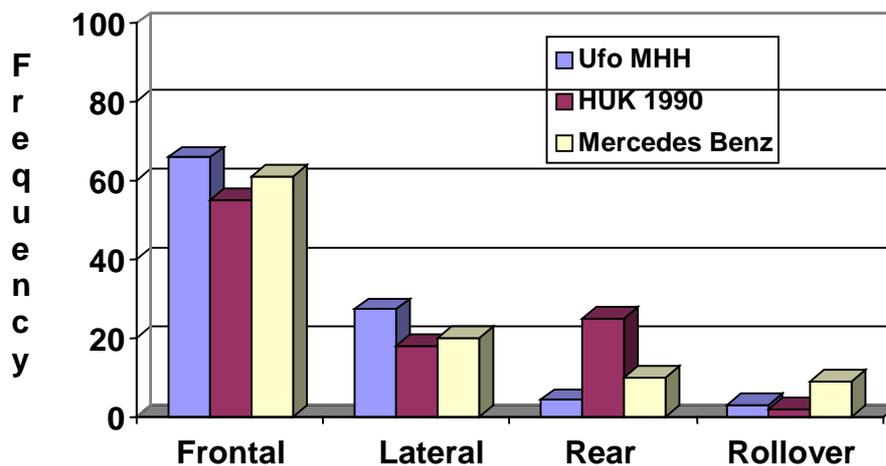


Figure 1: Accident statistics

3 Rollover Characteristics

The field statistics of the MHH shows that 34% of all rollover accidents happen after a collision with an object, which means these rollovers are concatenated events and occurred due to the first contact with the first object.

The onsite field analysis rollovers show that 82% occur in a countryside and 18% take place in towns. Most of the rollovers (66%) occurred during driving situations like braking maneuvers or vehicle skidding. The main influence comes from the vehicle velocity, the road pavement, and the friction change.

60% of all rollover occurs by driving on an embankment. Due to this fact a closer look at this situation will be taken in this paper.

This situation will be simulated by ADAMS and MADYMO and discussed in detail. Rollover accidents can not be categorized, in contrast to frontal crashes or side impacts, in a few different types.

To develop an algorithm for rollover detection there are many rollover vehicle tests required to obtain the sensor data to develop a reliable design for all the real world scenarios.

Taking into account all the different rollover types and collecting all the parameters which have an influence on the roll behavior of a vehicle results in the following lists:

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Rollover Situations

- Critical sliding
- Lane change
- Embankment
- Ramp test (Corkscrew)
- Curb trip (lateral)
- Curb trip (frontal)
- Static rollover
- FMVSS 208 (23° Dolly)

Parameters

- Velocity
- Vehicle mass / load
- steering angle
- Spring characteristics
- Damper characteristics
- Tires
- Obstacle geometries
- Road conditions

Because of all the different test situations it is obvious that the numerical simulation should be used as a tool to get all the necessary data from these tests. Additionally, the numerical simulation offers the possibility of accurate reproducibility in comparison with real vehicle tests.



Figure 2: Rollover situations

Additionally to the rollover tests, the so-called misuse tests are necessary. These will be performed by testing under driving situations which do not lead to vehicle rollovers, but generate sensor

signals for the algorithm. The algorithm has to be immune against these sensor signals to activate the restraint systems. The following list shows a variety of such misuse tests:

- Rough surfaces
- Extreme embankment driving
- Jump over hill (with airborne phase)
- Double lane change
- Ramp test
- Swerving
- Curb trips
- Front/side crashes
- Banked curve

4 Development Concept for the Sensors and the Restraint System

For the design of the sensors and the specification of, for example, the measurement range or the dynamic range and for the deploy / non deploy algorithm development there are three development procedures applied.

Measurement of reference sensor data in real vehicle rollovers is necessary for the sensor and algorithm requirement thresholds. These data from real tests are also necessary for the car model validation of the ADAMS model.

Knowledge from physics and mechanical engineering which deals with rollover of a rigid body or a multi body system is necessary to understand the theory for the algorithm. These theories show already that a rollover depends on parameters like center of gravity, moment of inertia, and some other values which are not fixed for a vehicle. The fact that a car can contain only the driver or additional occupants with some baggage can lead to a different center of gravity and moment of inertia for the same vehicle.

The numerical simulation of vehicle rollovers as the third procedure is necessary in order to study the influence of different parameters on the rollover sensor signals. It is very important to evaluate the variety of the sensor signals for the algorithm behavior.

The development concept with an increased usage of numerical simulation for rollover is displayed in figure 3.

At the beginning of this development, each of the tests listed in the table must be performed to get the real vehicle test data to correlate the ADAMS simulation model as a baseline.

Using the ADAMS software there are simulated vehicle test situations like embankment, ramp, curb and so on. Additionally there are different skidding situations simulated with the target always to find the limits when the vehicle rolls.

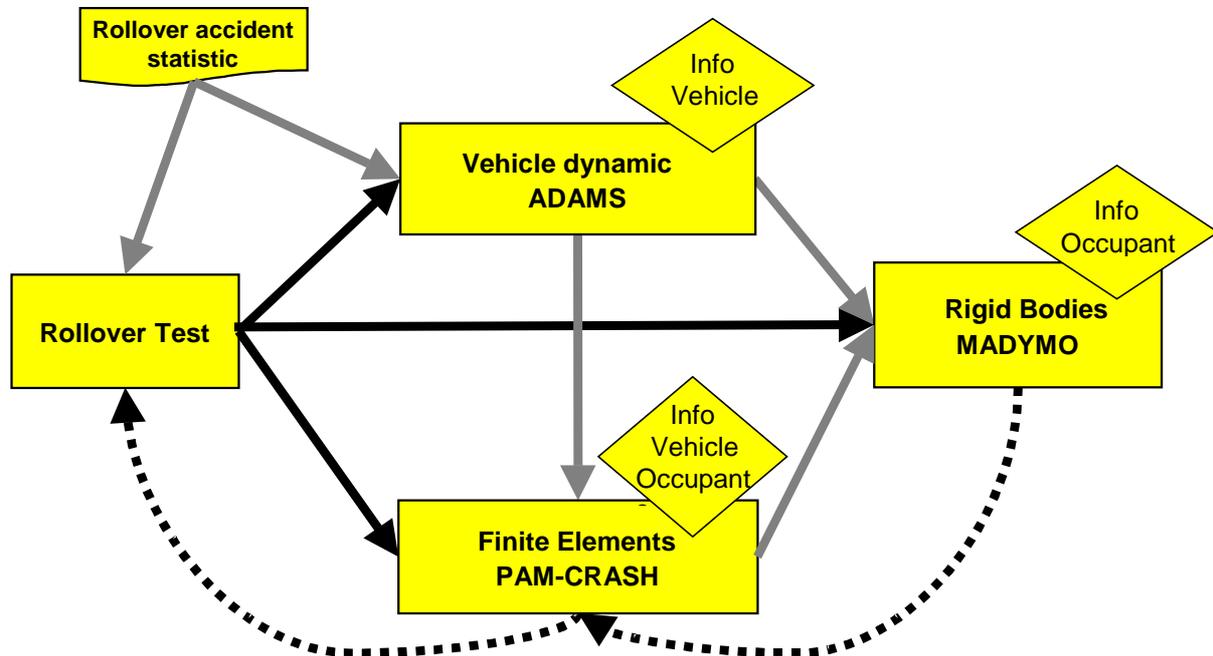


Figure 3: Simulation tool chain

The target for the sensor design is to detect this limit situation correctly and a timely activation of the restraint systems with the algorithm.

The ADAMS simulation uses a validated model provided by an OEM. In the following picture the ramp test simulation is shown.

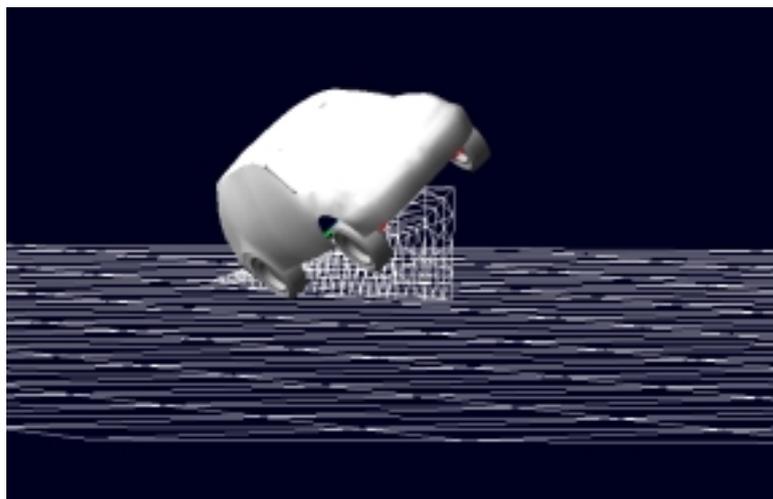


Figure 4: ADAMS simulation of ramp test

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The results of this ADAMS simulation are correct until the vehicle body contacts the ground after the flight phase. After contacting the ground the deformation phase starts which can only be simulated by FEM program and not with a multi body simulation.

The data sets of the accelerations and angular rates from the flight phase simulation before ground contact are sufficient for the algorithm development.

At ADAMS there are no validated models of dummies and restraint systems available. Therefore for the simulation of the occupant and the restraint systems another tool must be used.

For this a FEM simulation program like PAM-CRASH is used. The results from the ADAMS simulations are used as an input for PAM-CRASH. The disadvantage of the FEM simulation is the enormous demand on CPU resources.

Before the deformation phase starts, a multi body simulation tool called MADYMO is used for the dummy and the restraint system simulation. The car movement information, which is required for the MADYMO simulation, is provided by the ADAMS simulation.

The MADYMO model consists of the vehicle body, the dummies, the belt pretensioners, and the side window curtains which can be seen in figure 5.

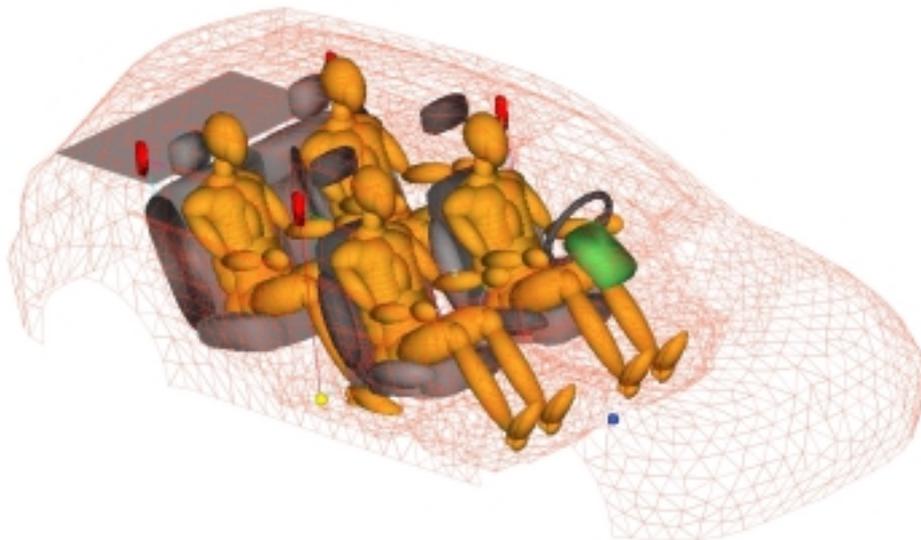


Figure 5: MADYMO model

Using such a simulation method the CPU runtime for a simulation is in a practicable range.

In the first step the trigger time for the restraint systems are calculated which is a necessary requirement for the sensor and algorithm system. In the next step the restraint systems will be defined. A first rough definition will be done using MADYMO. The final design will be performed by using

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the FEM simulation. Finally, it is possible to bring the deformation from the FEM simulation in the multi body simulation.

The following driving situations were simulated for the rollover investigation:

- swerving
- lane change
- embankment
- ramp test

For all situations these parameters were varied:

- loading: only driver, full load
- spring characteristic: hard, normal, soft
- damper stiffness: hard, normal, soft
- tires: different types
- velocity

In the ramp test the height of the ramp was also varied. All tests were simulated with an ADAMS model. Additional simulations with a MADYMO model were carried out for the critical cases. Figure 6 shows the different phases of a corkscrew situation simulated with an ADAMS model of the vehicle.

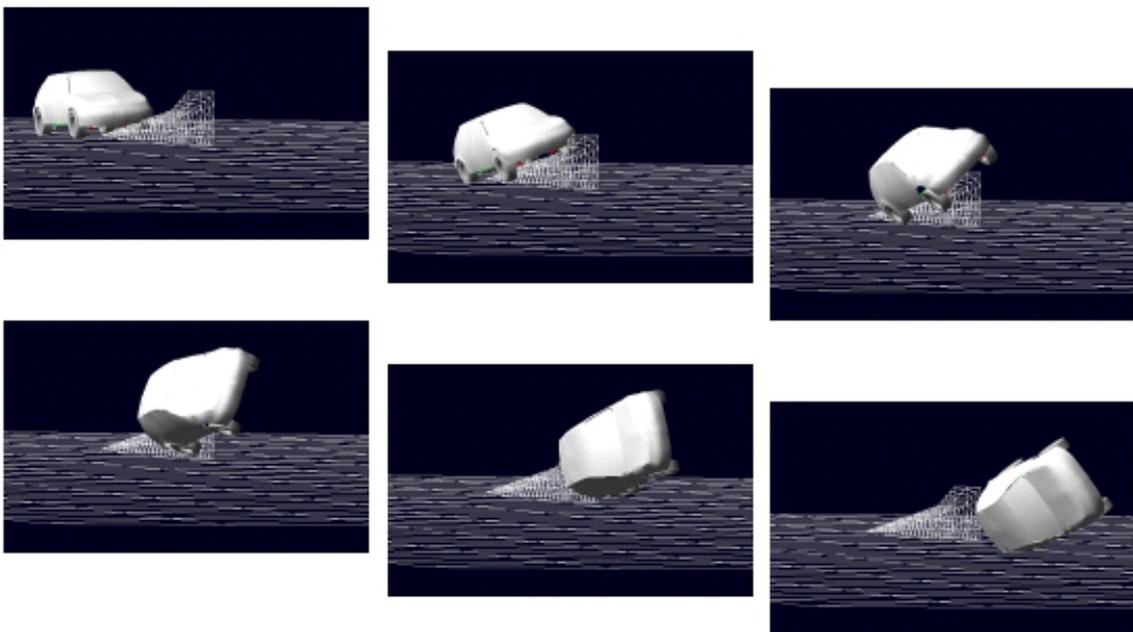


Figure 6: Corkscrew with ADAMS model

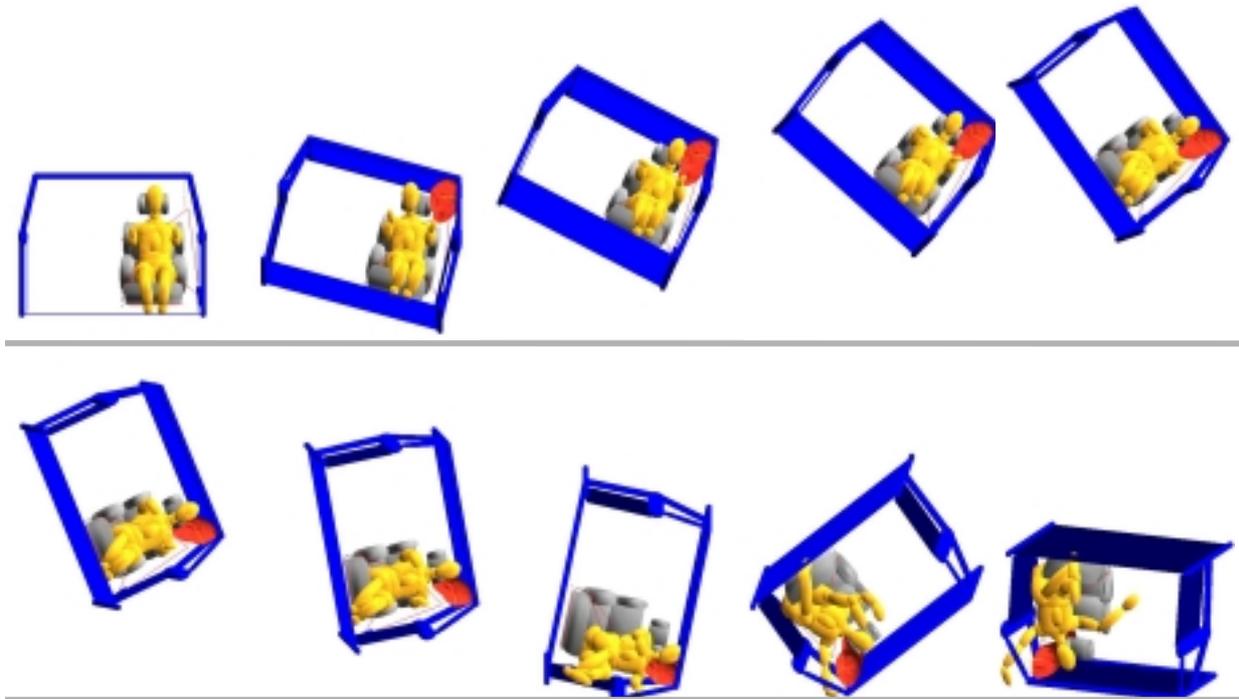


Figure 7: Cork screw simulation with the MADYMO model

Figure 7 shows the corkscrew situation simulated with MADYMO. This simulation run was done with the data obtained from the ADAMS simulation shown in Figure 6.

In order to verify the vehicle dynamic simulation data, the values have to be compared to the data gained from a real vehicle rollover. Therefore, the real rollover was exactly imitated by the ADAMS simulation. The result has confirmed the correctness of the simulation.

The variation of vehicle velocity, ramp height and mass loading of the vehicle for the ramp tests shows an influence in the vehicle rollover. The variation of the parameter spring force, damper and tire type shows no significant influence on the rollover. The influence of the velocity on the rollover behavior is shown in the figure below.

The vehicle movement data from the ADAMS simulation are used as an input for the MADYMO simulation. The MADYMO model with 4 occupants was used for the occupant movement simulation in these different ramp tests. The results are the trigger time for the inflatable curtains. The model are calculated in the first phase without any deformation. In the next step of the development the FE models where also include in the simulation process which allows to take into account the vehicle deformation also in the MADYMO model.

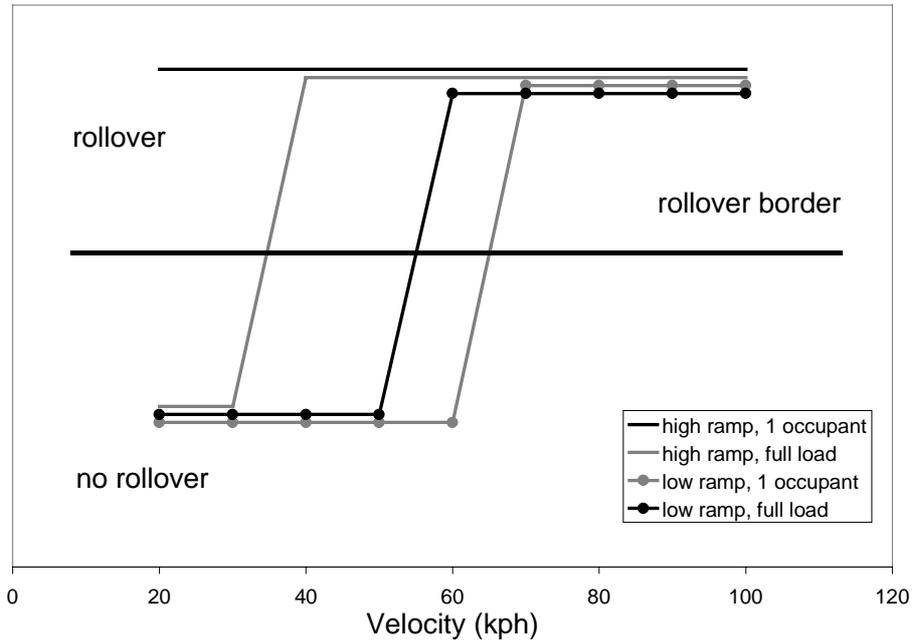


Figure 8: Velocity influence on rollover

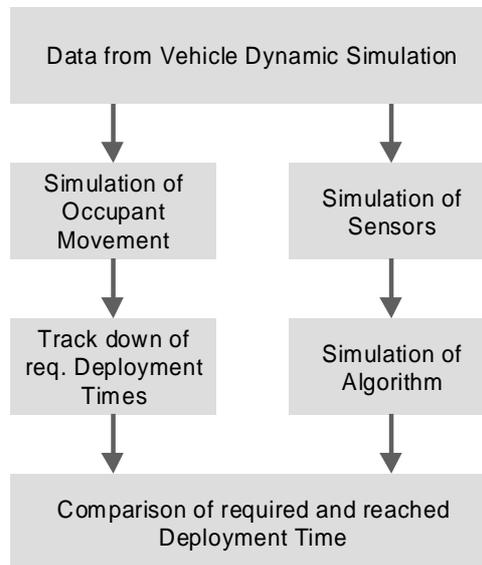


Figure 9: Robustness analysis process

5 Algorithm Robustness Analysis

A basis for the robustness analysis are the physical values of the accelerations and angular rates, which were generated for a specific point in a vehicle (ECU position). They are utilized as inputs for the simulation of the sensors and the rollover detection algorithm. The result of this simulation is the time of deployment calculated by the algorithm, or a degree of robustness in the cases where restraint systems must not be activated (Figure 9).

6 Sensor simulation

In order to simulate the behavior of the ECU very closely, the properties of the sensors have to be taken into account. The points of interest within this are:

- measuring range
- transfer function
- tolerances

A precise description of these points was realized with MATLAB. All steps of the signal processing performed by the sensors themselves and the following stages can be described very exactly. One thing which has to be taken into account within the signal processing is the limited bandwidth of the acceleration and angular rate signals obtained from the simulation. In order to achieve exactly the resulting bandwidth limitation of the signal chain before the A/D converter, the limitation caused by the simulation had to be compensated.

Due to the fact, that the whole signal processing chain was simulated with all details, all the component tolerances could be taken into account. With a worst case analysis all extreme cases were found, which can be used within a simulation of the complete system.

7 Algorithm Concept

The inputs for the algorithm are angular rate along with the lateral and vertical accelerations of a vehicle at its center of gravity. As shown in [2], these are the signals containing the main information about the vehicle movement during a rollover situation.

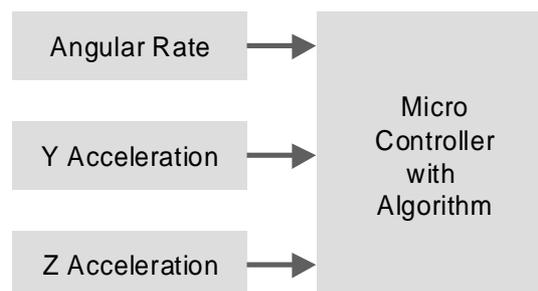


Figure 10: Algorithm Input

The concept of the algorithm for an early detection of vehicle rollovers is the comparison of a criterion with a dynamic threshold. The criterion is calculated with the main information about the rotation of a vehicle around its longitudinal axis, the angular rate. The dynamic threshold is a combination of the calculated vehicle inclination and terms, which assess the vehicle movements, that are characteristic for a roll situation. A rollover situation is detected, when the criterion exceeds the dynamic threshold. With this result different restraint systems can be triggered. For example an

inflatable curtain can be activated on the side to which the vehicle rolls. If the vehicle rolls more than a specified angle, the remaining curtain at the other side can also be activated.

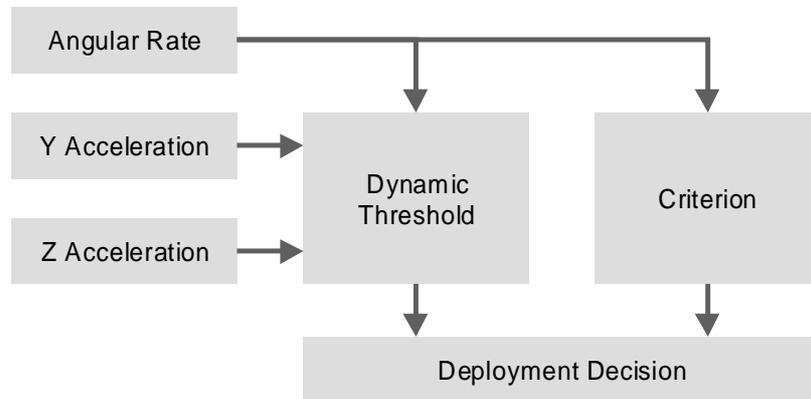


Figure 11: Algorithm concept

The algorithm can be adapted for different types of vehicles by adjusting the algorithm parameters. A base for the parameterization is vehicle specific data and physical backgrounds. The final security about the quality of the parameter setting is provided by the simulation of the algorithm with actual rollover data, where the influence parameters were varied.

8 Algorithm Simulation

Within the algorithm different criteria, terms and thresholds are calculated. The calculations are for example scaling, integration's, and filters. In order to simulate all effects that occur during the calculation of the algorithm within the ECU (e.g. quantization or word length effects), all the properties of the used controller have to be taken into account. Hence the source code of the algorithm used in the ECU has to be simulated. The tool used for this purpose is the simulation tool for airbag algorithms STTOOLS, which was developed by Siemens Automotive. In the simulation, this tool is fed with the data obtained from the vehicle dynamic simulation and the corresponding sensor simulation. During a simulation run sensitivity fluctuations of the sensors, external noise or distortions are simulated. The results are activation times for the rollover conditions on the one hand, and the robustness of the algorithm in extreme driving or misuse situations on the other hand.

As an example for the algorithm simulation two test situations are shown below. In a test series of ramp tests the parameter 'vehicle velocity' was varied between 40kph and 80kph. The border for a roll and a no roll situation was found to be between 60kph and 70kph.

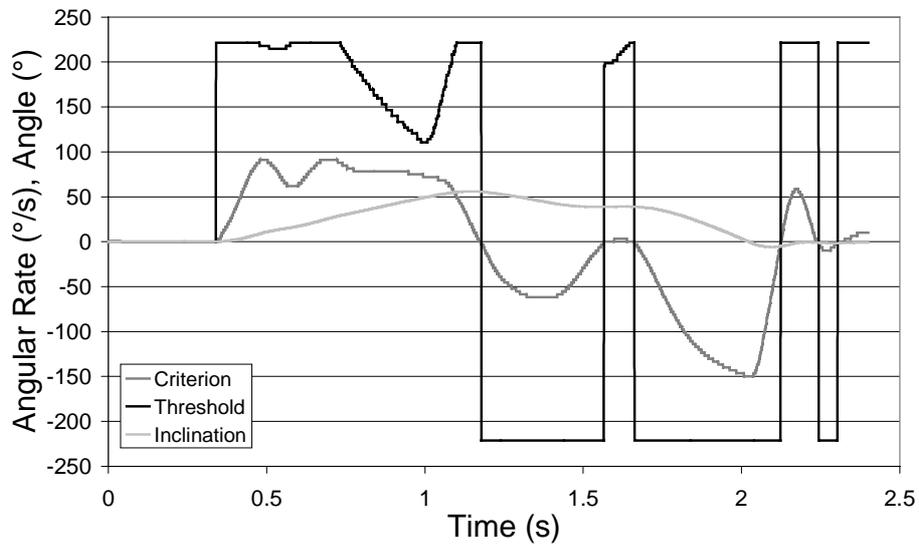


Figure 12: Ramp test, no roll condition

During this test the vehicle reached an inclination of about 56°. The trace of criterion and threshold within the first second could be interpreted as a rollover situation. After that the algorithm detects, that the position of the vehicle is stabilized for a short time period. With the following negative angular rate it is detected, that the vehicle finally rolls back and gets full contact with the surface again.

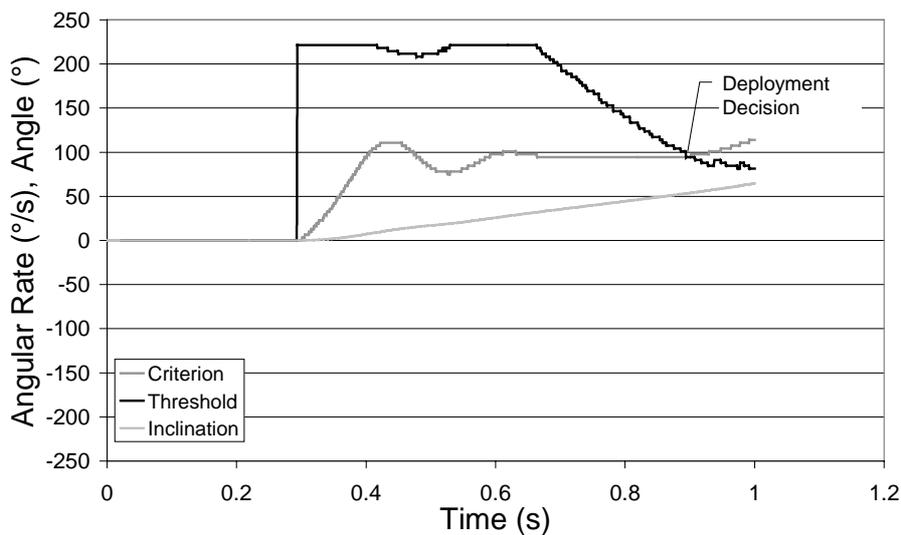


Figure 13: Ramp test, rollover

The course of this test is quite similar to the no roll condition during the first phase. The vehicle inclination is increased continuously. With the combination of the angular rate and vertical acceleration the algorithm distinguishes after about 0.9s, that the situation leads to a rollover. The vehicle inclination at this point of time amounts to about 55°.

9 Comparison of Required and Reached Deployment Times

All driving situations, which were investigated by vehicle dynamic simulation, were used for the algorithm simulation. The result is, that all vehicle rollovers were detected in time, and that for all no roll situations a sufficient margin between criterion and threshold was present.

10 Investigations of the Influence of Different Loads

The aim of these simulations was to find out to what extent different vehicle loads influence the behavior of a vehicle in a rollover situation. The vehicle load affects of course the total vehicle weight but also the position of the center of gravity. Despite the fact that the parameters were changed in a way which influenced the rollover behavior of the vehicle the algorithm still distinguished all roll and no roll situations. The graph below shows the trigger times over the velocity. Here it can be seen that at one velocity the different conditions led both to rollover and no roll situations. (A no deploy decision is displayed as deployment time 0ms)

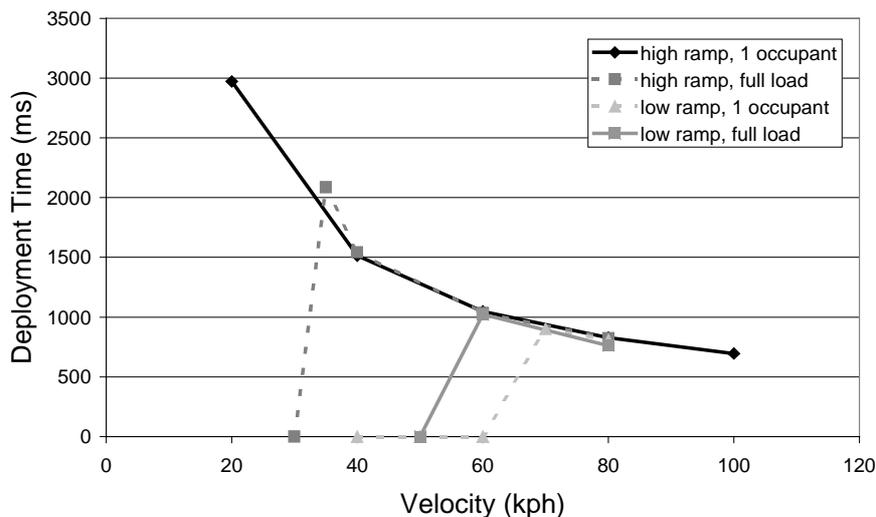


Figure 14: Algorithm trigger times

11 Investigations of the Influence of Different Spring and Damper Settings

An important point of interest is the knowledge about the influence of parameters, which can change during operation or over life time. As an example, the influence of the spring and damper parameter characteristics on the angular rate is shown in the graph below. The result is that fluctuations of the spring/damper characteristics have only a small influence at this corkscrew situation. The required deployment times as well as the algorithm deployment times changed only within ± 10 ms.

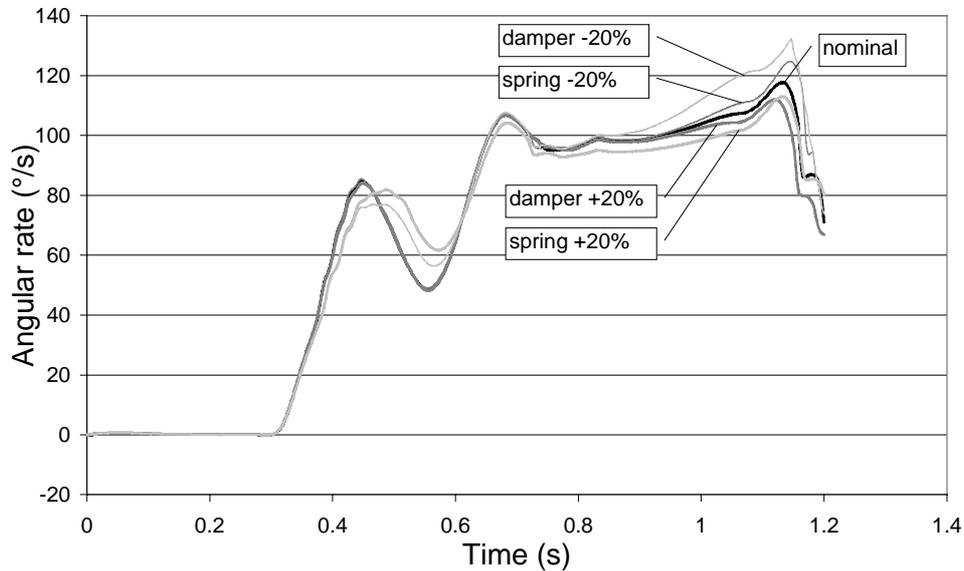


Figure 15: Variation of spring and damper

12 Conclusion

It has been proved that the use of multi body simulations is a powerful tool for the simulation of vehicle rollovers. By an aimed variation of different parameters the influences on the vehicle during a rollover situation could be investigated in a very detailed manner.

The result of the simulation is the knowledge about the behavior of the vehicle during the rollover and the physical dimensions describing the vehicle movement.

For the development of a rollover detection algorithm the simulation results are used to gain a certain capability in terms of an in time triggering of restraint systems and a robust behavior in extreme driving and misuse situations.

The investigations shown within this paper points out an increasing importance of numerical simulation in the development of automotive electronic devices.

In future all vehicle electronic systems and sensors will be connected via local networks like CAN. Active dampers and springs for the suspension system will be available and additionally the real vehicle mass will be sensible via wheel load sensing systems. If all these values are available for the rollover detection algorithm then new algorithm technologies will come up.

13 References

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- [2] Frimberger, M.; Wolf, F.; Glaser, T.; Zechmair, D.; Achhammer, G.: *Algorithm Concepts for Rollover Detection to Activate Advanced Restraint Systems*. SAE Technical Paper Series 2000-01-0057. Warrendale, PA 2000.
- [3] Achhammer, G.; Frimberger, M.; Glaser, T.; Wolf, F.; Zechmair, D.: *Vehicle Tests and Simulation Tools for Rollover Sensing*. SAE Technical Paper Series 1999-01-0438. Warrendale, PA 1999.
- [4] Schiehlen, W: *Multibody Systems Handbook*. Springer-Verlag, Berlin Heidelberg, 1990
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- [6] Eger, R.; Rachid, M.; Nasr, N.: *Rollover Simulation Based on Nonlinear Model*. SAE Technical Paper Series 980208. Warrendale, PA 1998.

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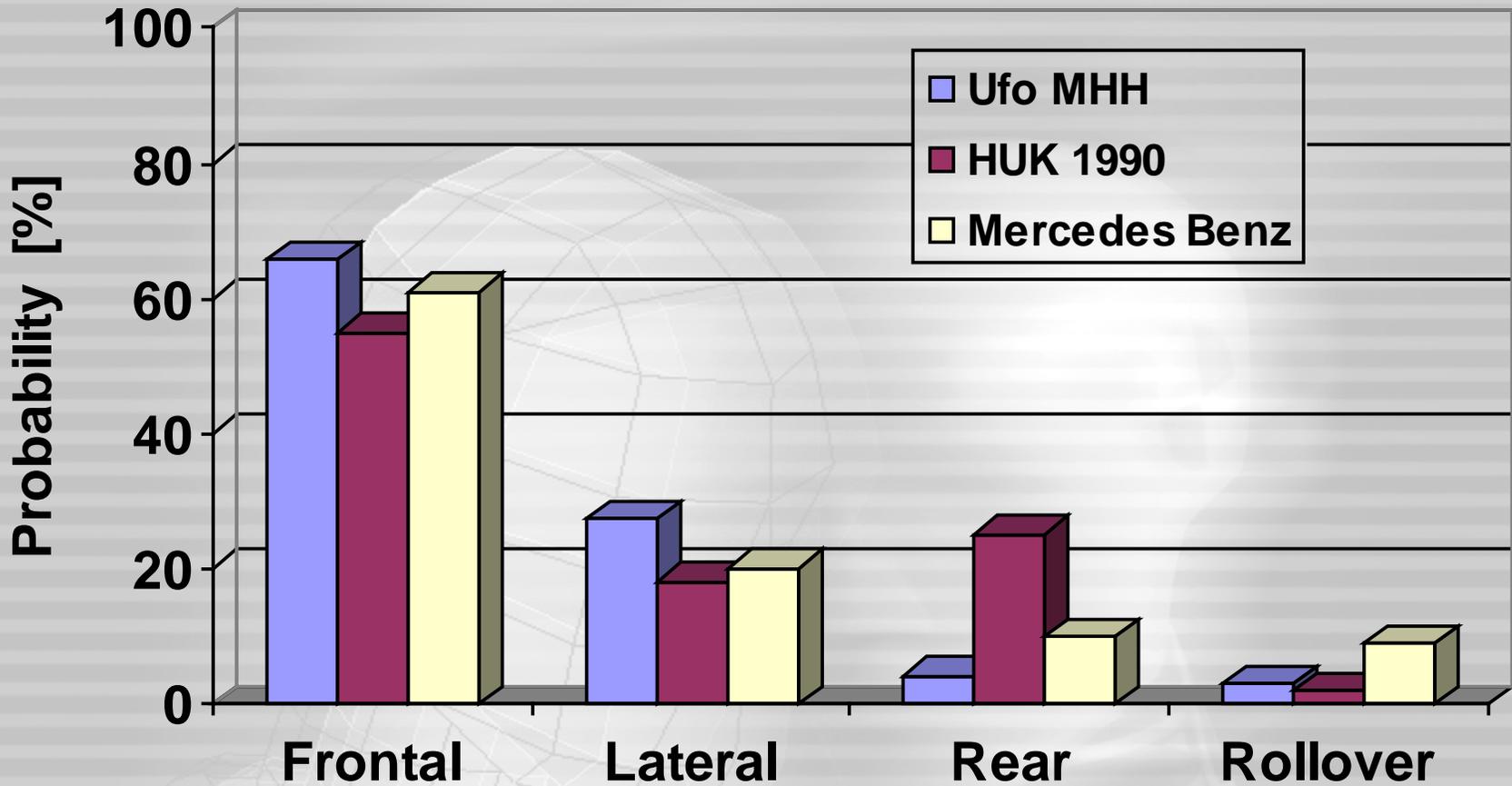
Influences of Parameters at Vehicle Rollover



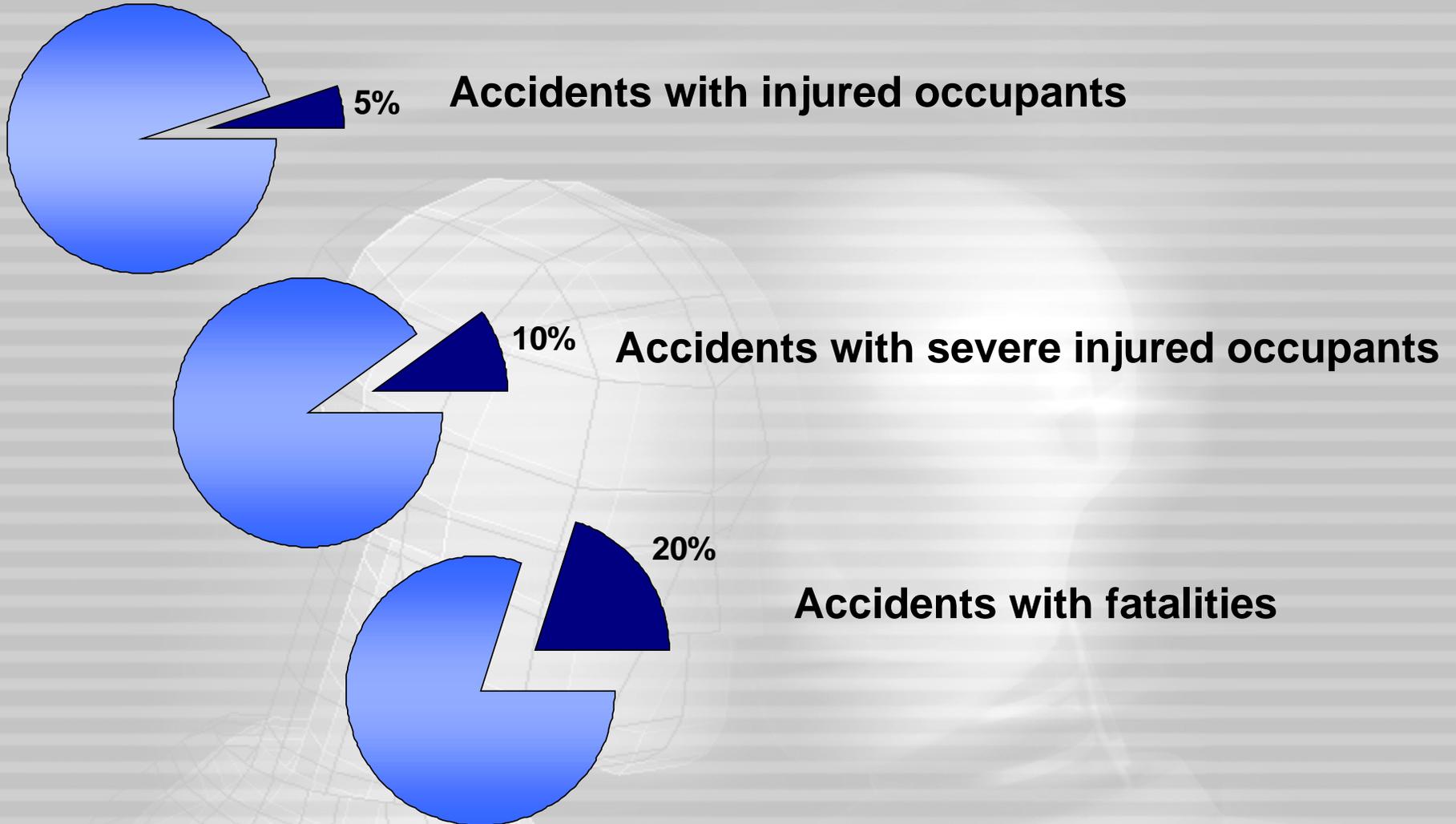
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15th ADAMS European User's Conference
15th - 16th November 2000, Rome, Italy

- ◆ **Rollover Statistics in the Field**
- ◆ **Rollover Situations**
- ◆ **Development Concept**
- ◆ **Algorithm Robustness Analysis**
- ◆ **Deploy / No Deploy Threshold**
- ◆ **Conclusion**



Rollover Penetration in Accident Severity



Rollover Situations and Parameters with Influences on Rollover

Rollover Situations

- ◆ Critical Sliding
- ◆ Lane Change
- ◆ Embankment
- ◆ Ramp Test (Cork Screw)
- ◆ Curb Trip Frontal
- ◆ Curb Trip Lateral
- ◆ Static Rollover
- ◆ FMVSS 208 (Dolly Test)

Parameter

- ◆ Velocity
- ◆ Vehicle Mass / Load
- ◆ Steering Angle
- ◆ Spring+Damper Charact.
- ◆ Tires
- ◆ Embankment Angle
- ◆ Ramp Geometry
- ◆ Road Condition

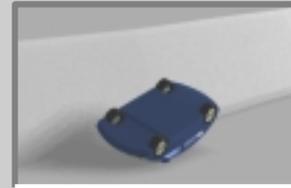
FMWSS 208
23° Dolly



Cork Screw



Embankment



Curb Trip



Rough Road Test

Manhole covers, body twist, washboard, undulating road

Hill Driving

Serpentines, zigzag path uphill and downhill

Extreme Driving

Elchtest, U-turn, figure eight, sliding

Impact Tests

Curb impact, sliding curb impact

Ground Leaving

Jump over hill, ramp test

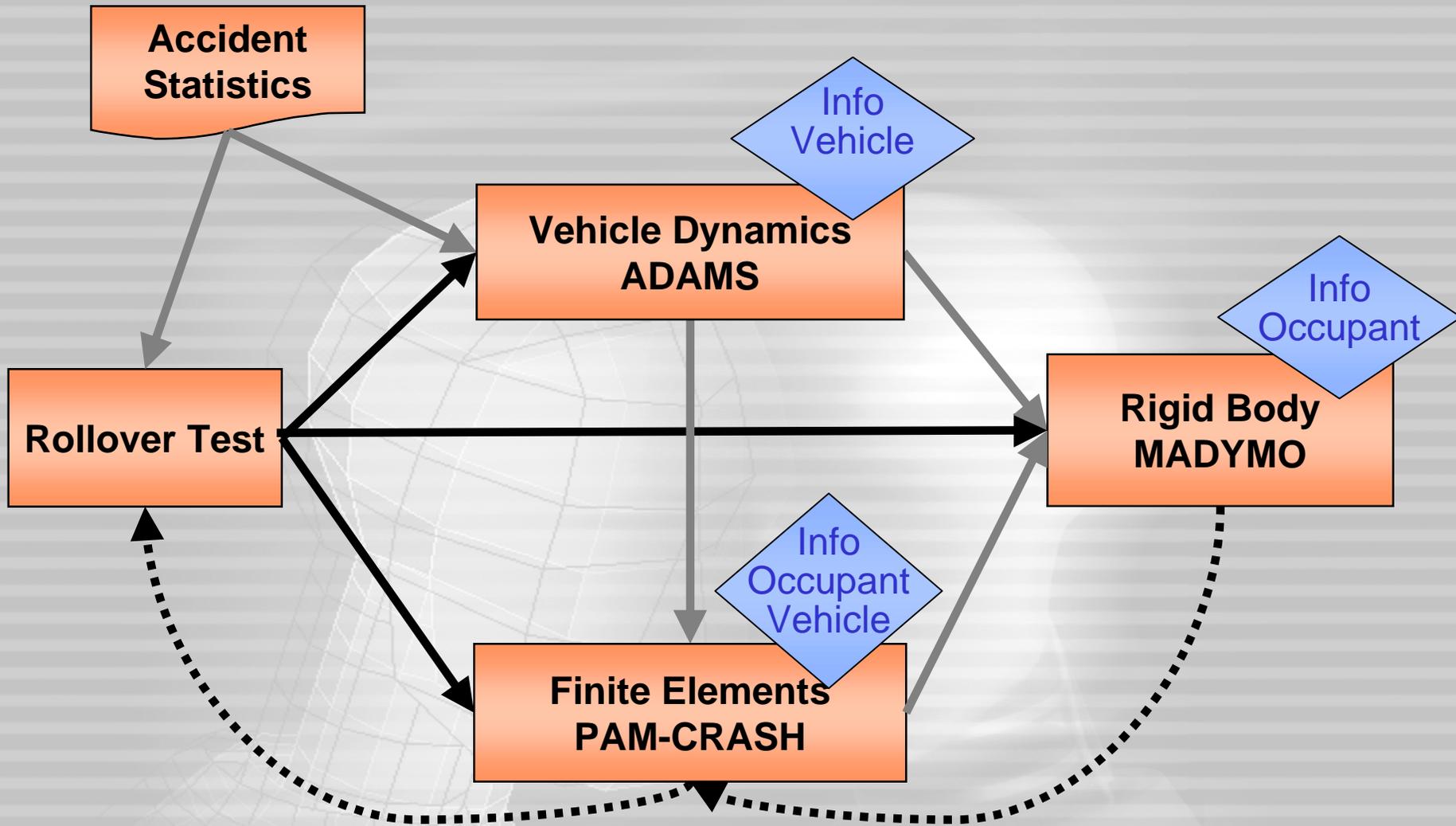
Offroad Tests

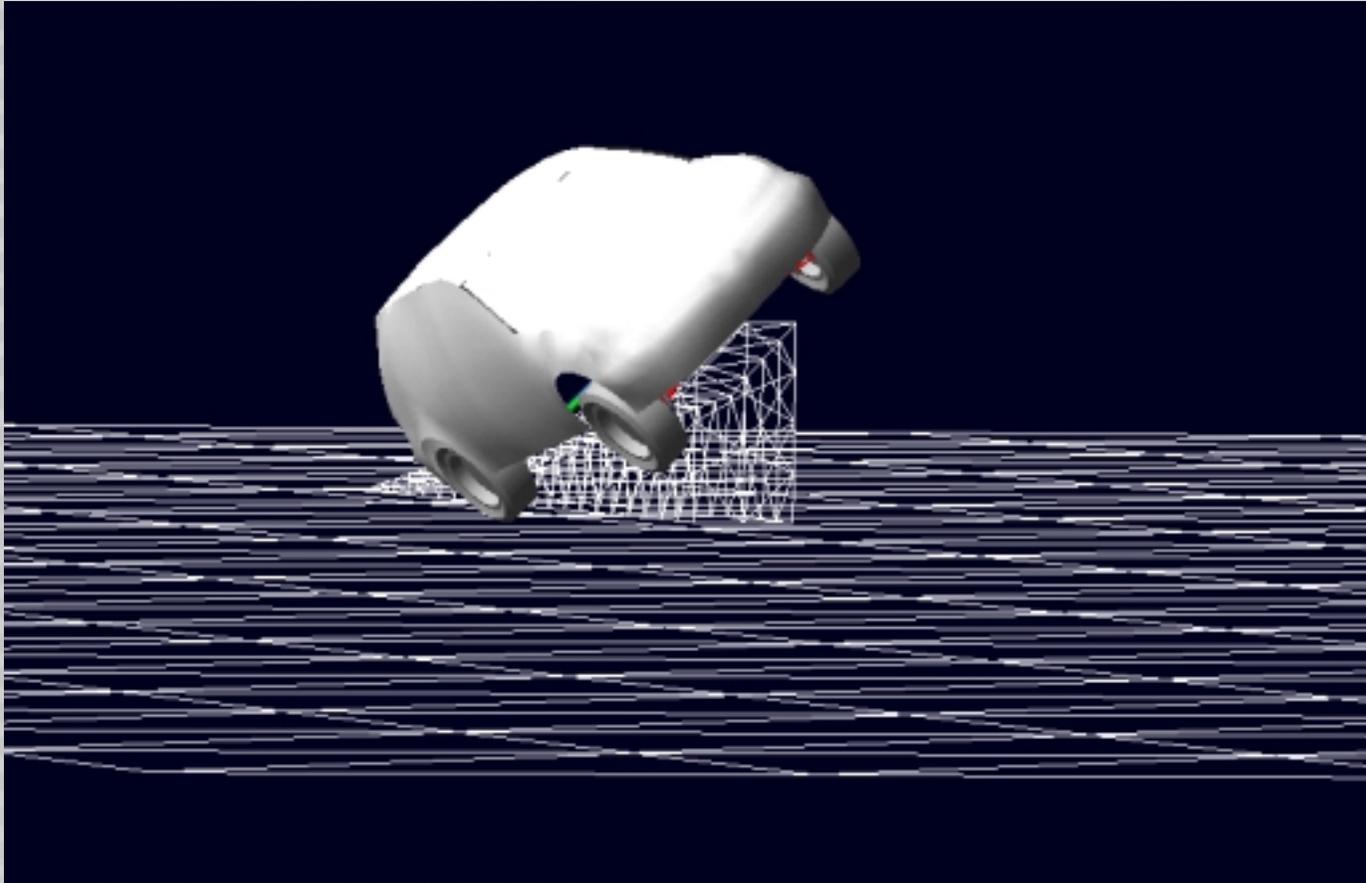
Embankment

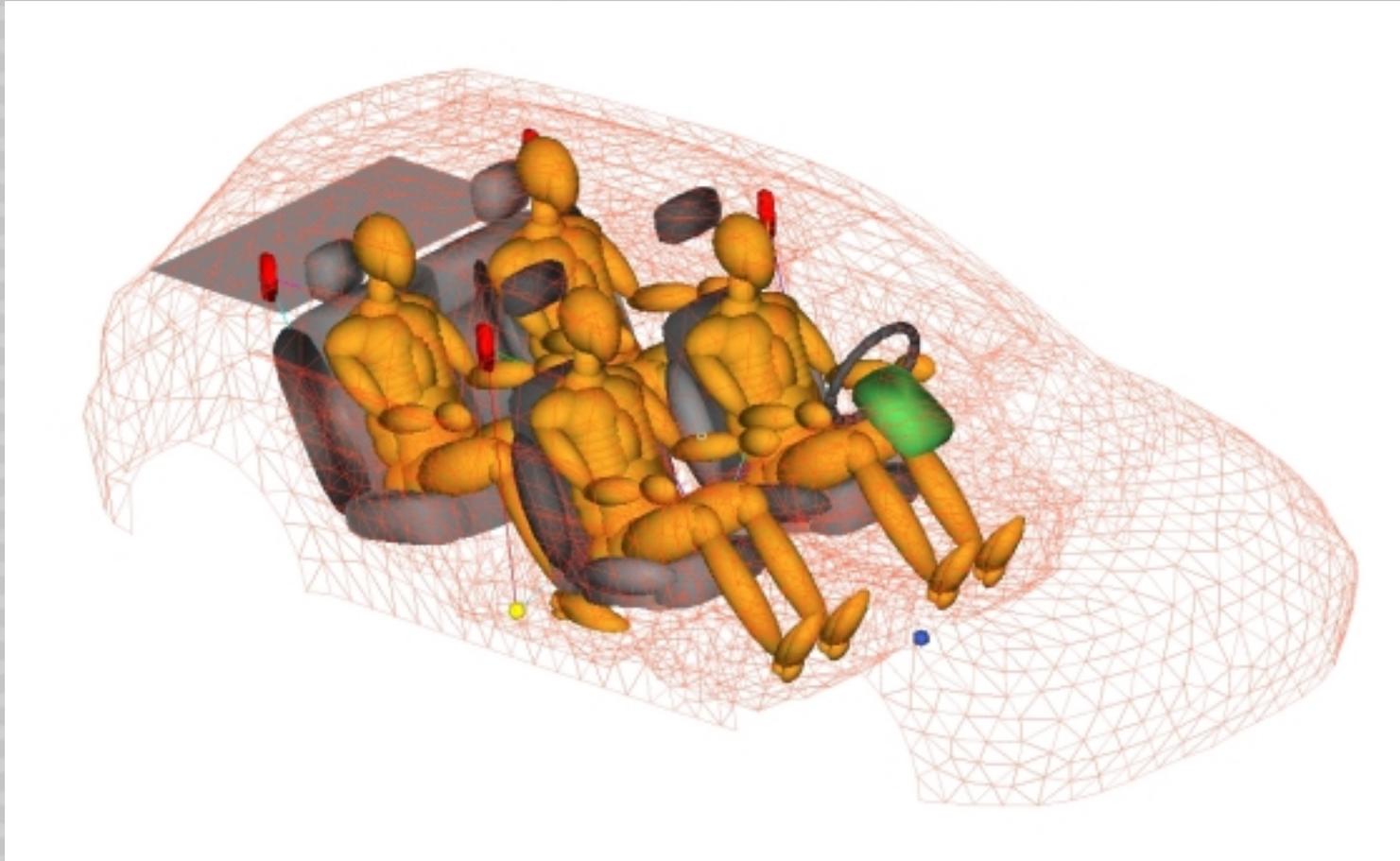
Algorithm Development Procedure

- ◆ **Measuring the sensor data from reference sensor in vehicle rollover tests**
- ◆ **Knowledge from physics and classical mechanical engineering of rigid body and multi body systems in rollover for developing a theory for the algorithm which takes care the COG, mass, vehicle geometry,**
- ◆ **Using the numerical simulation for studying the influence of these different parameters and the algorithm robustness on variation of this parameters.**

General Development Concept





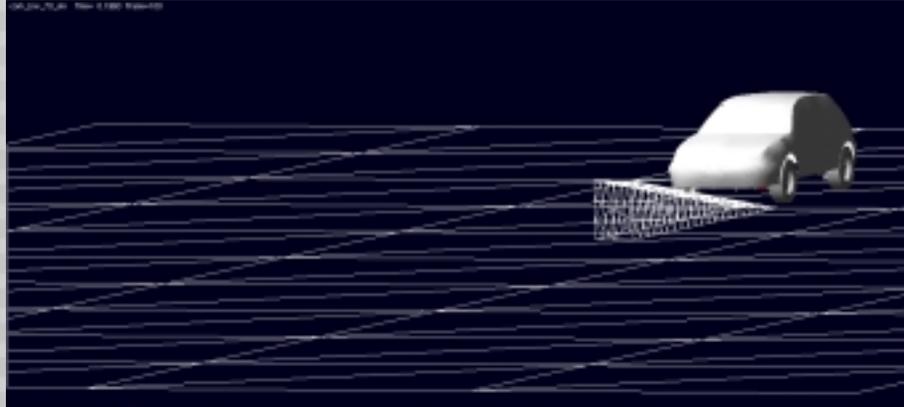


Matrix of Parameters

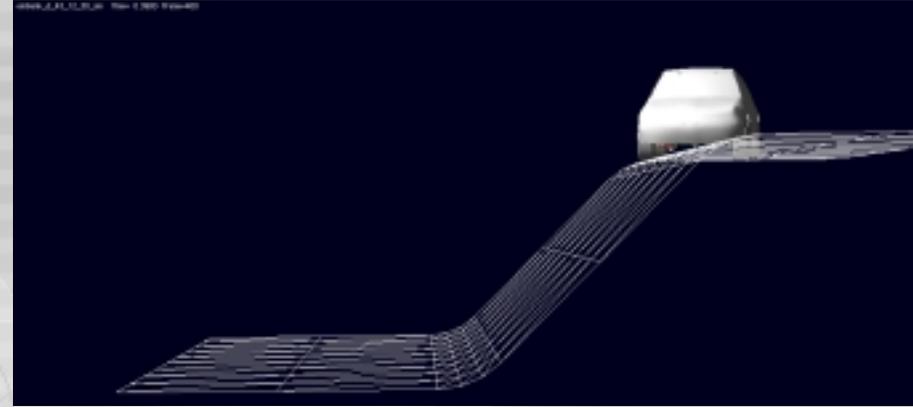
Driving Situation	Velocity [kph]	Load	Spring	Damper	Ramp	Tyre Modells [No]
critical sliding	40-120	Driver 4 Occupants Luggage	stiff medium weak	stiff medium weak	-	3
lane change	40-100				-	3
embankement	30-100				-	1
ramp test	20-100				high low	1
curb trip	30-80				-	1

ADAMS Simulationen

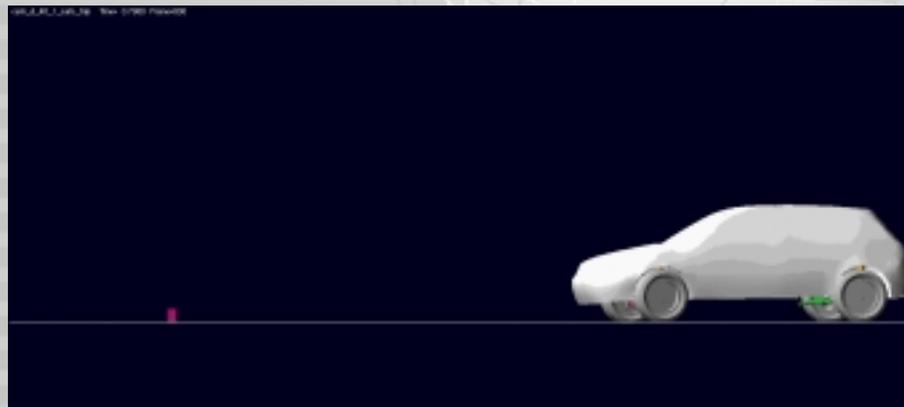
Ramp Test



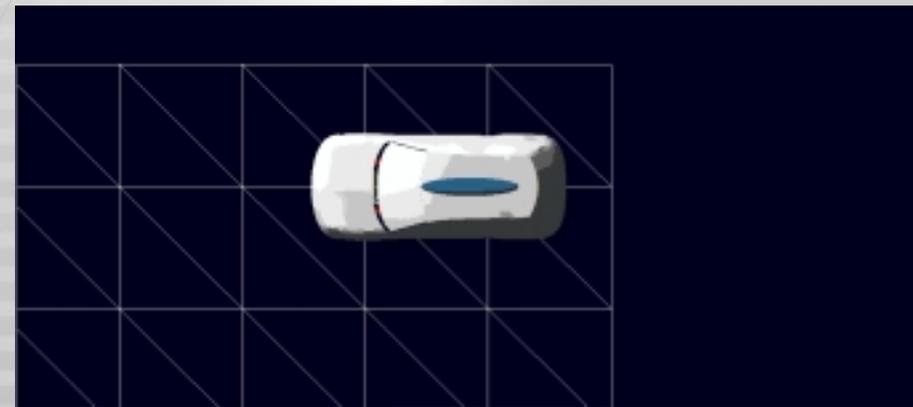
Embankment



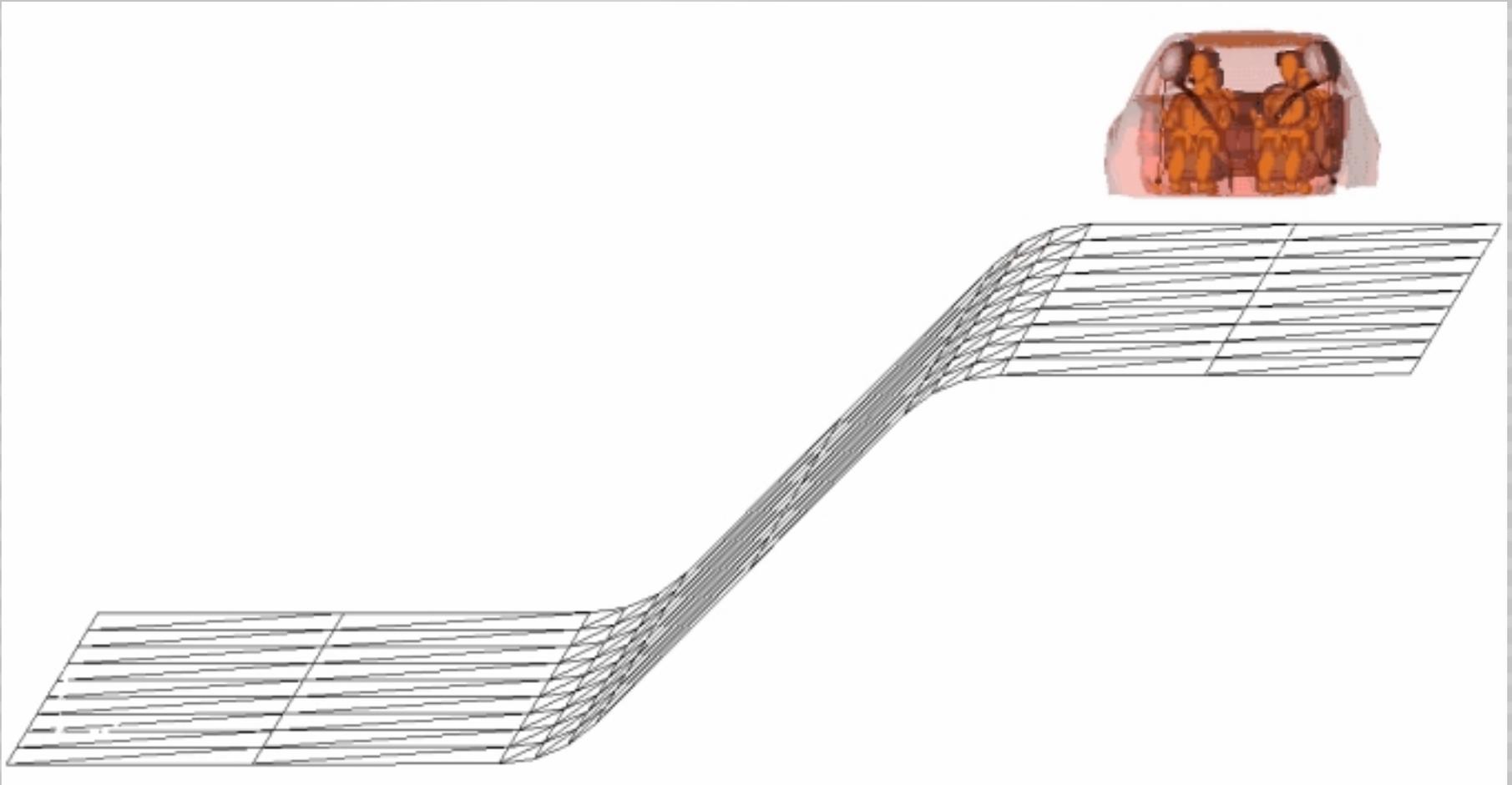
Curb Trip



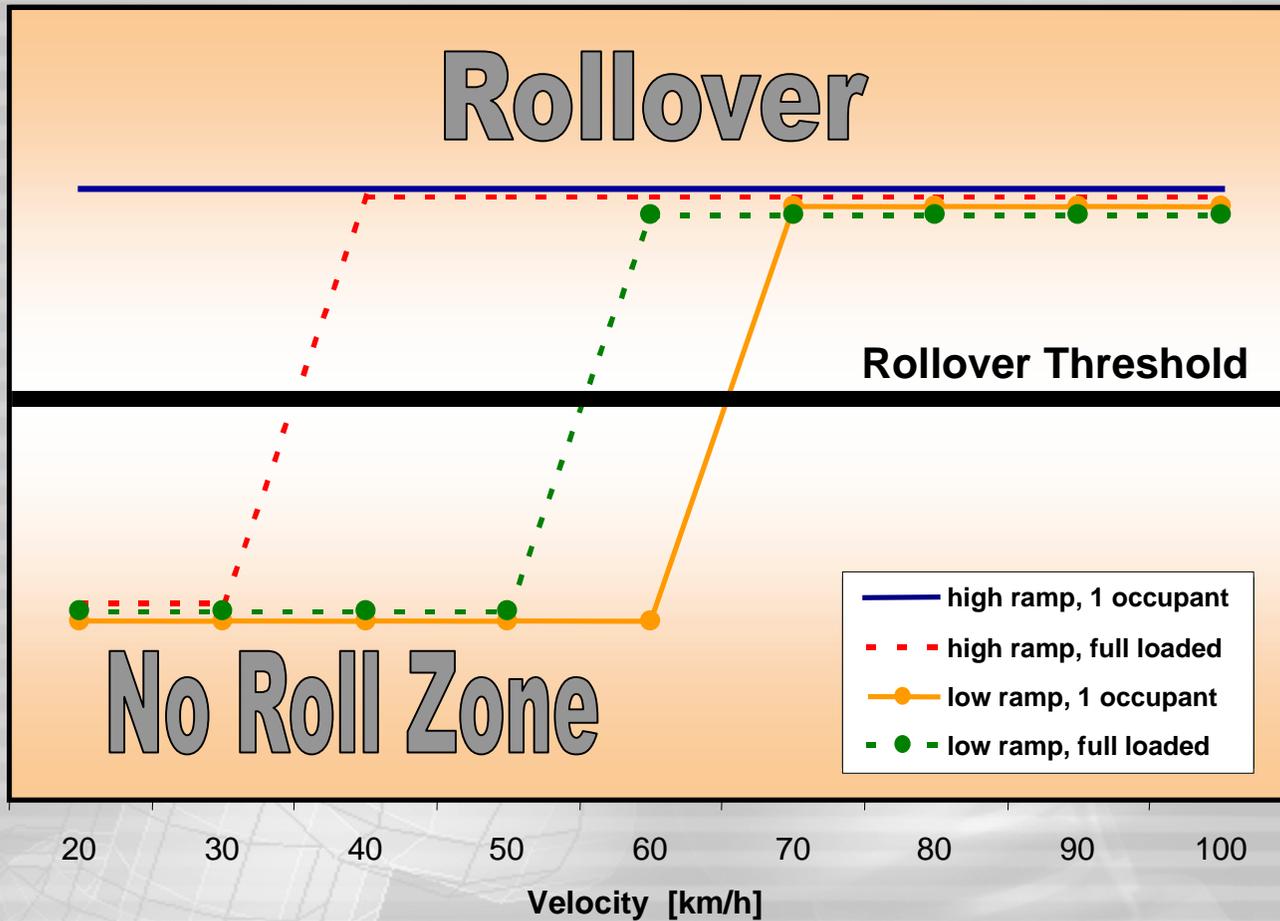
Lane Change



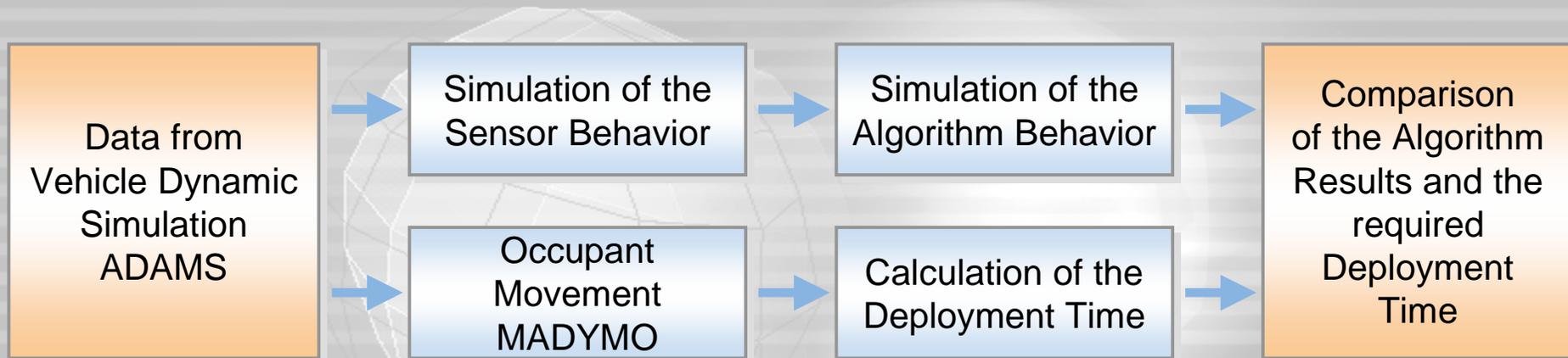
Embankment, 45°



Influence on Ramp Geometry in Rollover

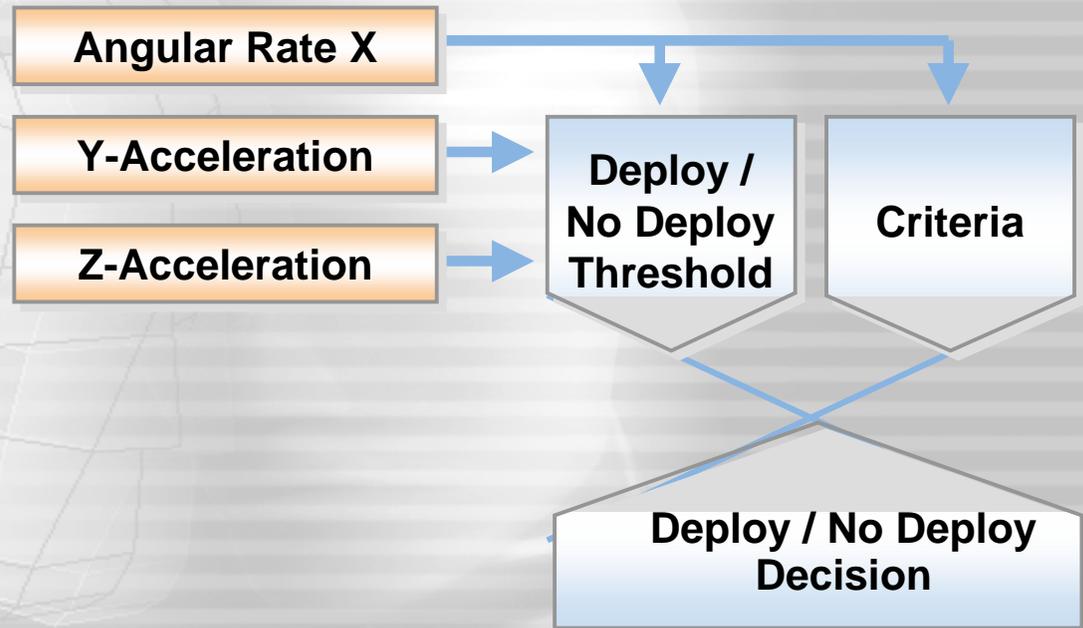


Robustness Analysis of the Deploy / No Deploy Algorithm



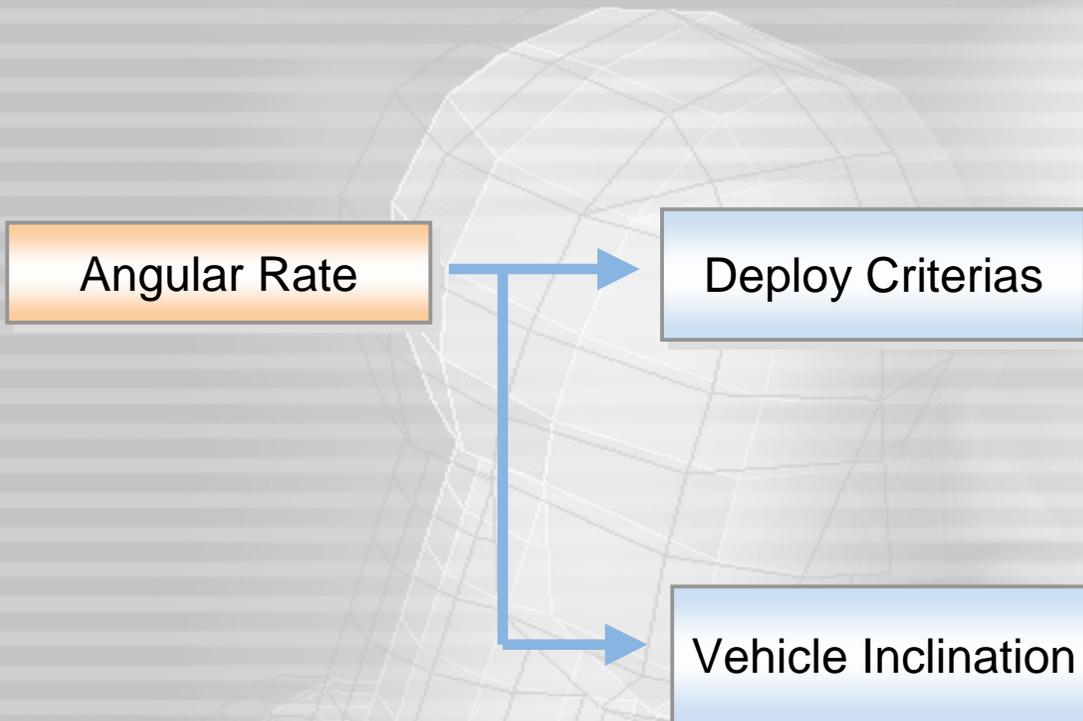
Rollover Algorithm SARA^M

- ◆ Evaluation of the physical relevant values:
 - Vehicle rotation speed around the X-axis
 - Lateral acceleration
 - Vertical acceleration
- ◆ Timely detection of the different rollover cases
- ◆ Robustness against No Deploy and misuse situations
- ◆ Safing functionality



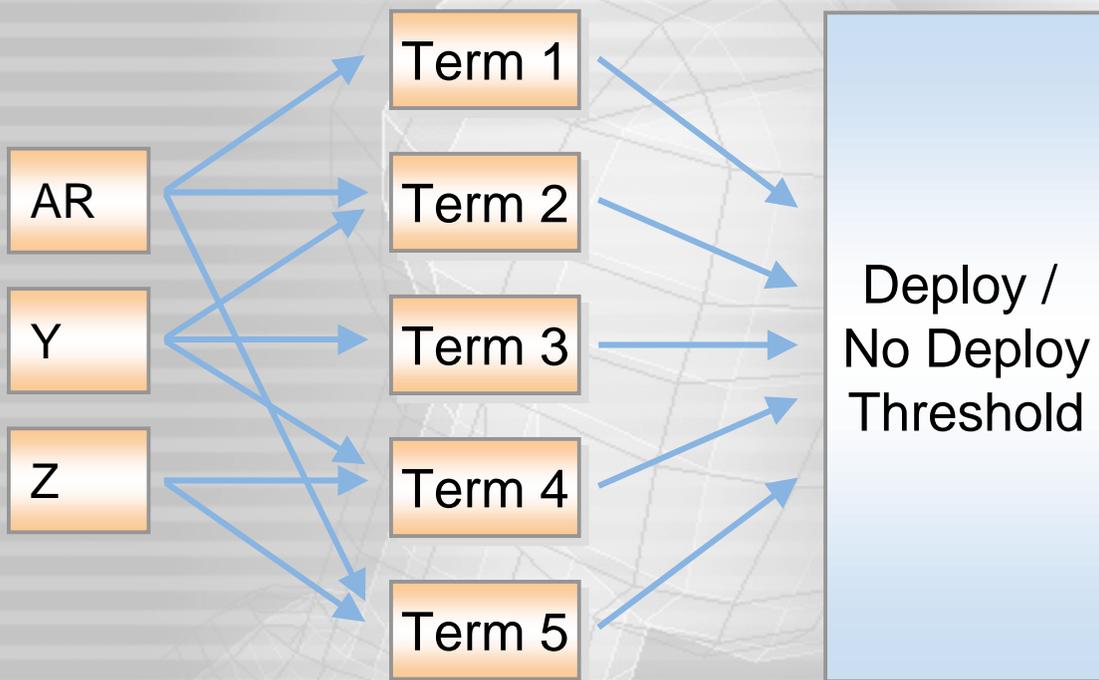
(SARA = Stand Alone Rollover Algorithm)

Deploy / No Deploy Criteria



- ◆ **The angular rate is the main information in a vehicle rollover**
- ◆ **The integration of the angular rate provides the vehicle inclination**
- ◆ **The criteria will be compared with the dynamic threshold for the Deploy / No Deploy decision**

Deploy / No Deploy Threshold



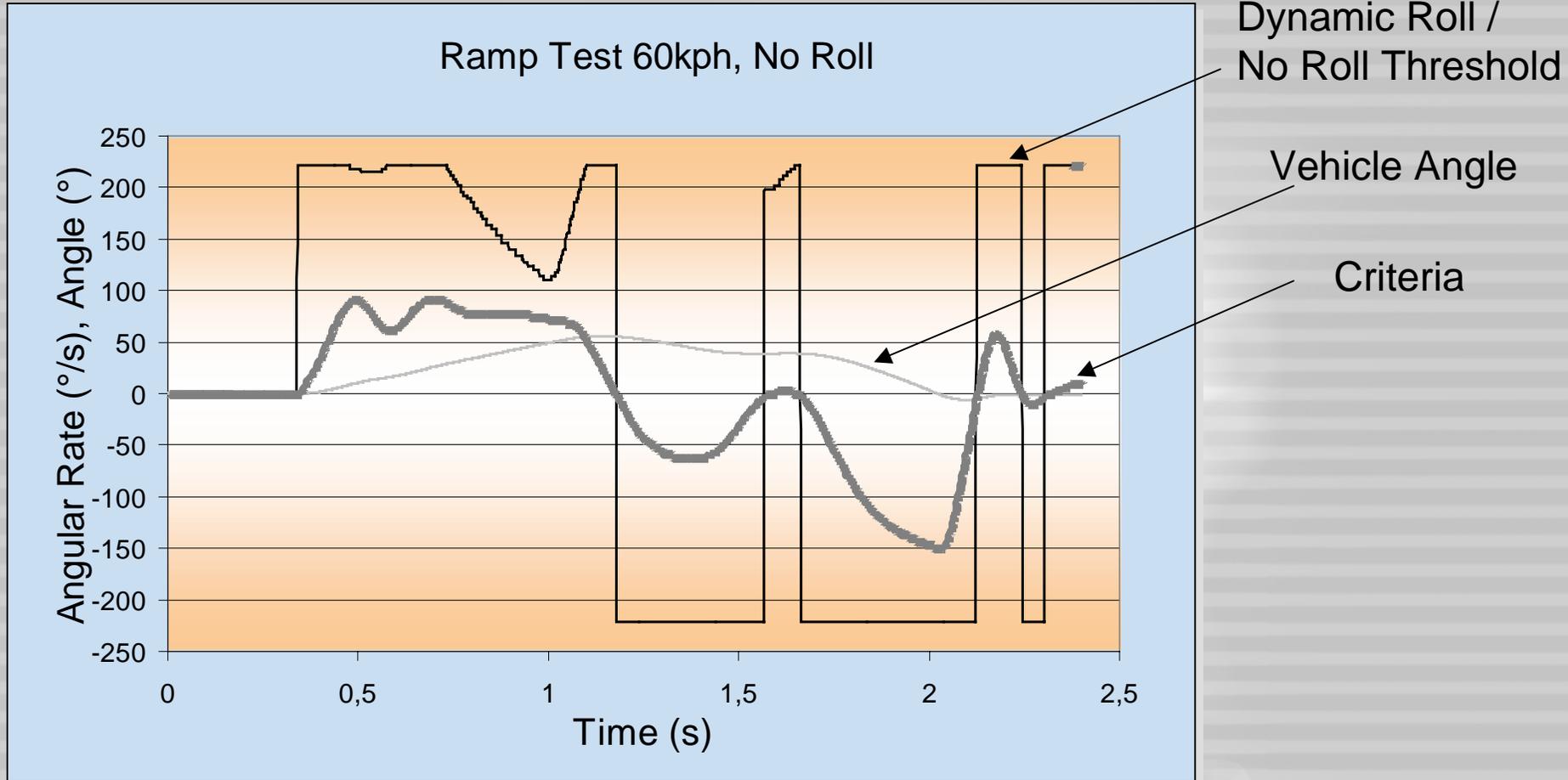
- ◆ The terms contains the charakteristica about the vehicle body movement
- ◆ The terms will be scaled and combined for the threshold

Deploy / No Deploy Decision

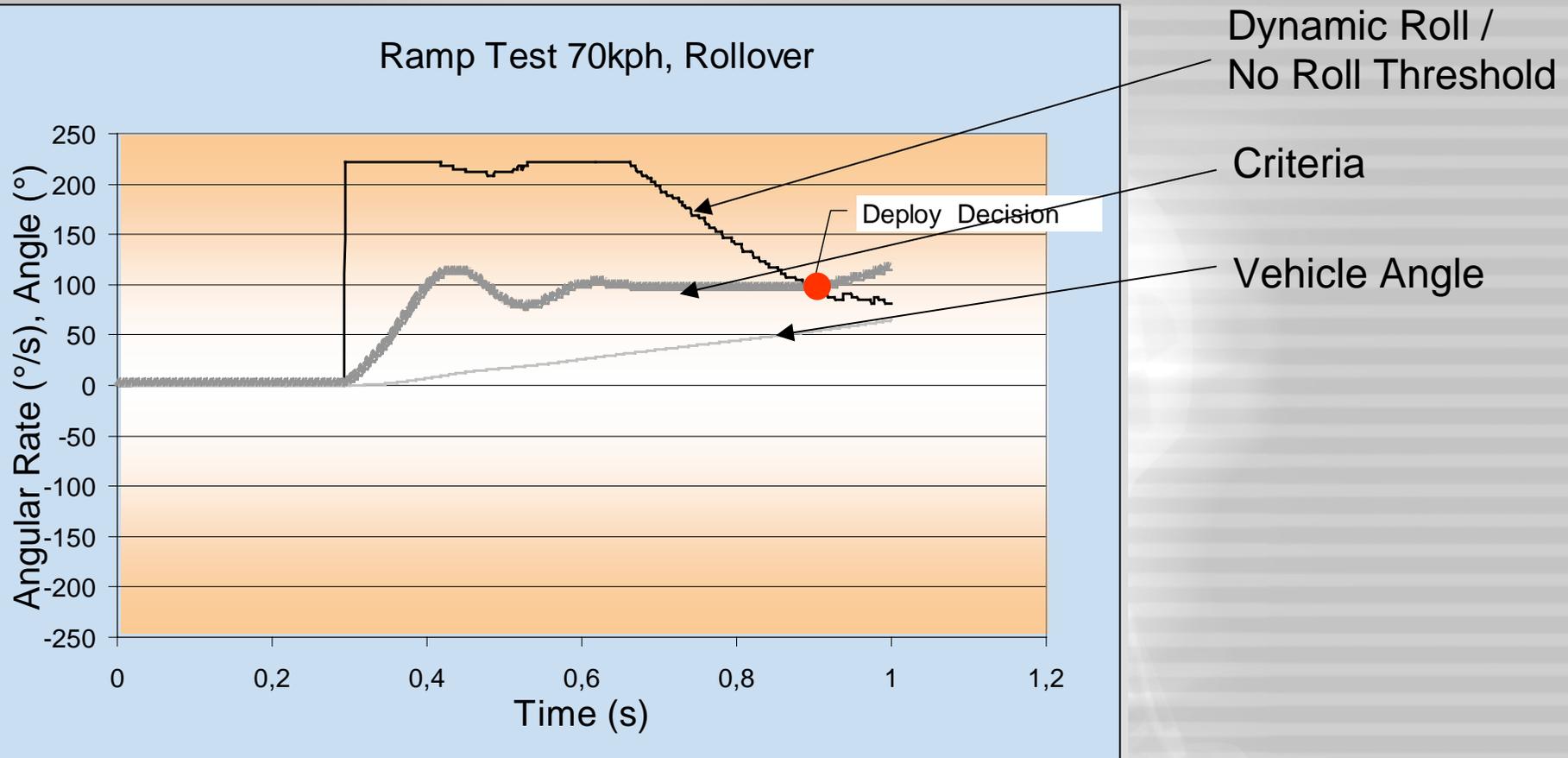


- ◆ Criteria will be compared with the threshold
- ◆ Deploy / No Deploy decision in case of the criteria exceeds the threshold
- ◆ Reliable concept
- ◆ Safing functionality
- ◆ Detects all different rollover cases
- ◆ Robust in misuse situations

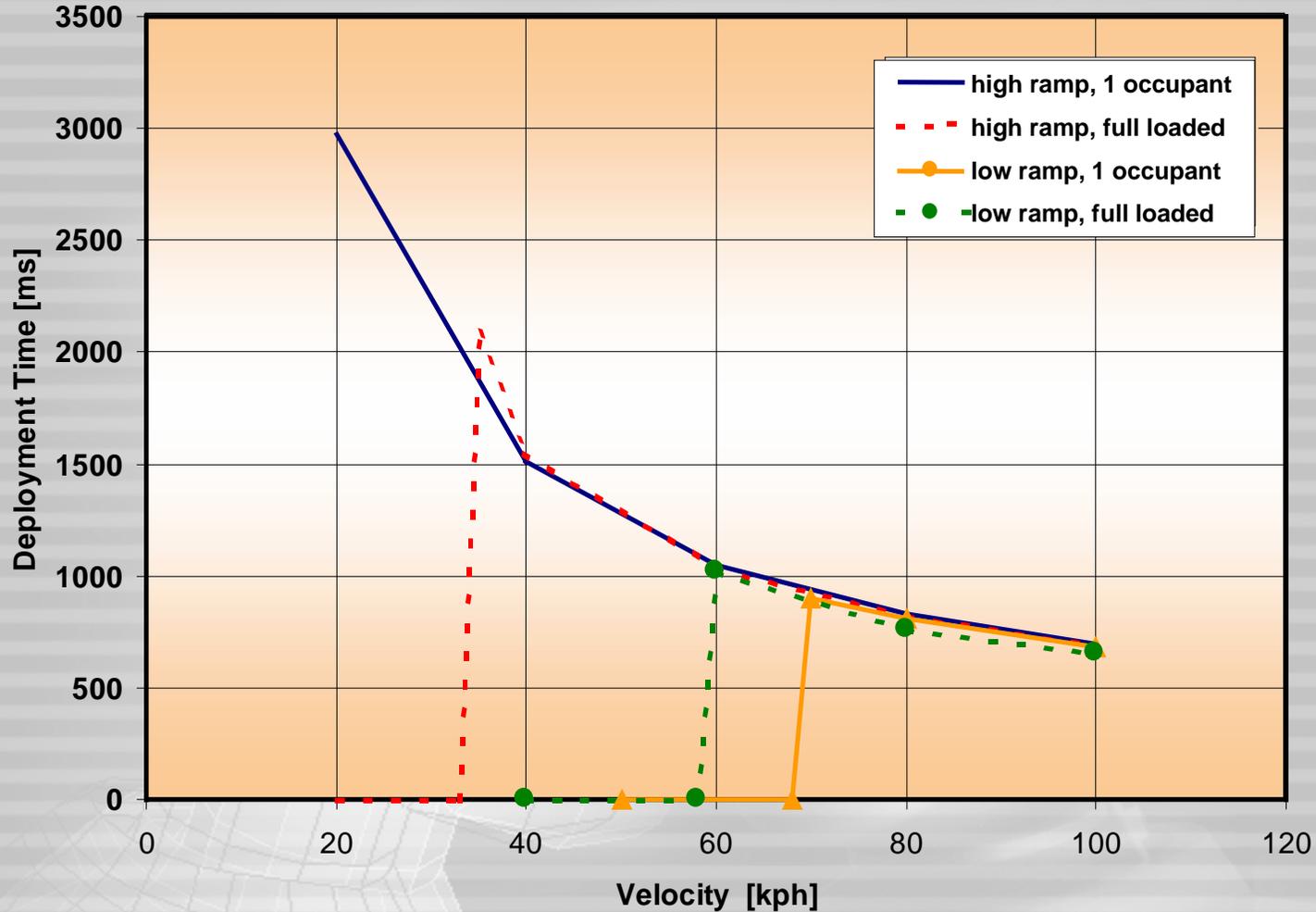
Algorithm Simulation of a No Roll Case



Algorithm Simulation of a Rollover



Deployment Times in Ramp Test



- ◆ **The numerical simulation is an essential tool for a sensor data source from different rollover scenarios for the algorithm development**
- ◆ **The test of the parameter setting for an algorithm release can be supported by using numerical simulation and can also be part of a “Hardware in the Loop” procedure**
- ◆ **Due to an increased computing power it will be also possible to use FE-Models in the future**
- ◆ **Reduction of development time, costs and resources will be possible by using numerical simulation**