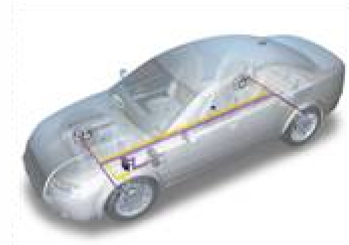
# Enhancement of Trailer Sway Mitigation
## by Using Trailer Brakes











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# Overview

- Introduction
- Trailer Sway Modeling
- Trailer Sway Damping Control
- Simulation Setup and Results
- Summary

# Introduction

→Results from accident statistics (ATZ 4/2002):

- 609 accidents involving passenger cars with trailers on German motorways were reported in 1999
- outside built-up areas (excluding motorways), there were 1000 accidents with vehicle trains

→Assumption: speed is one cause of such accidents: passenger cars with trailers tend to sway around the vertical axis more or less strongly depending on the speed

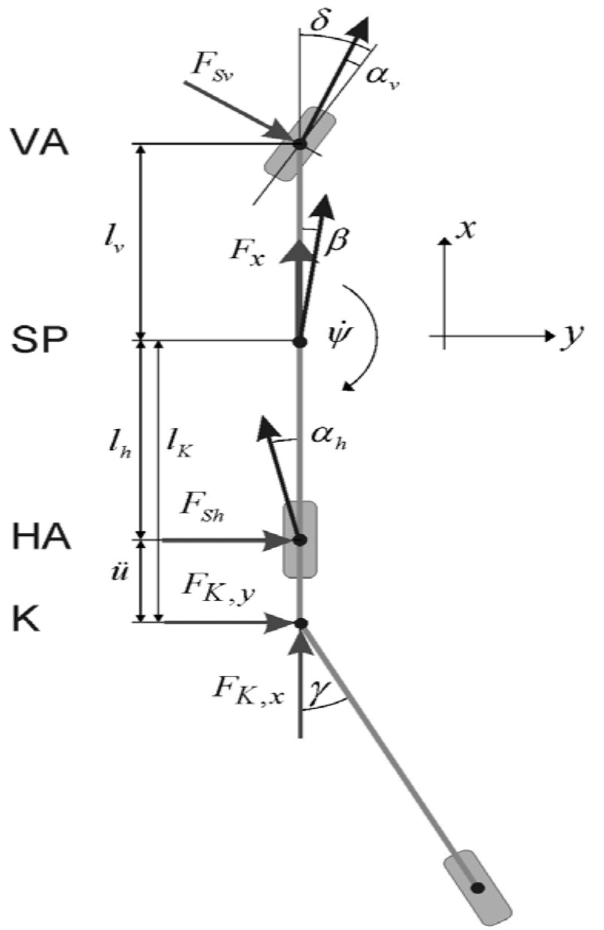
## Introduction

Trailer sway can already occur in the standard driving range (v ≈ 80 km/h):

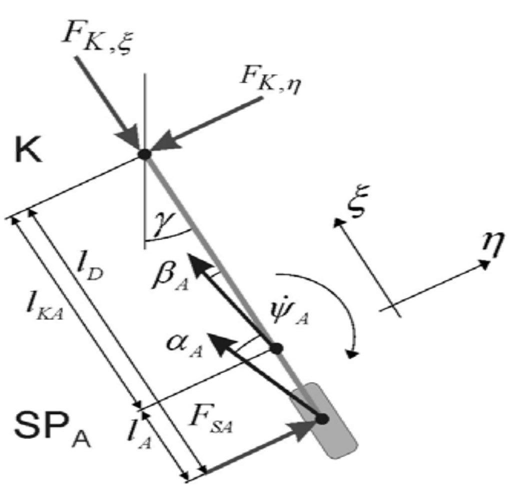
- reasons are e.g. small steering motions or side wind
- above the so-called critical velocity (v ≈ 90...130 km/h), the oscillations are increasing in amplitude
- the critical velocity depends among other things on the mass distribution of the trailer and geometrical data of the vehicle train (e.g., a heavy boat-trailer with a small vertical coupling load yields a small critical velocity and so a poor driving stability)

# Bicycle models of towing vehicle and trailer

### Vehicle and Trailer




### Trailer



## Equations of Motion for the towing vehicle:

$$m a_x = F_x + F_{Kx} \approx m \dot{v}_x$$ ------- x direction

$$m a_y = F_{Sv} + F_{Sh} + F_{K,y}$$ ------- y direction

$$J_z \ddot{\psi} = F_{Sv} l_v - F_{Sh} l_h - F_{Ky} l_K + M_z$$

$$a_y = \dot{v}_y + v_x \dot{\psi} = v_x \left(\dot{\beta} + \dot{\psi}\right) + \dot{v}_x \beta$$

$$F_{Sv} = C_{\alpha v} \alpha_v \quad , \quad F_{Sh} = C_{\alpha h} \alpha_h$$

$$\alpha_v = \delta - \beta - \frac{l_v \dot{\psi}}{v_x} \quad , \quad \alpha_h = -\beta + \frac{l_h \dot{\psi}}{v_x}$$

## Equation of Motion for the trailer:

$m_A a_{\xi A} = -F_{K\xi} - F_{B\xi A} \approx m_A \dot{v}_{\xi A}$ ------- $\zeta$ direction

$m_A a_{\eta A} = F_{SA} - F_{K,\eta}$ ------- $\eta$ direction

$$J_{zA}\ddot{\psi}_A = -F_{SA} l_A - F_{K\eta}(l_D - l_A)$$

$$a_{\eta A} = v_{\xi A}(\dot{\beta}_A + \dot{\psi}_A) + \dot{v}_{\xi A}\beta_A$$

$$F_{SA} = C_{\alpha A}\alpha_A$$

$$\alpha_A = -\beta_A + \frac{l_A \dot{\psi}_A}{v_{\xi A}}$$

## Constraint at coupling point:

**Assumption: no relative motion at hitch**

$$\Delta\vec{v}_K = \vec{v}_{KF} - \vec{v}_{KA} = \vec{0}$$

**Assumption: stiff damping at hitch (modelled by rigid spring/damper system)**

$$\vec{F}_K = -d_K \cdot \Delta\vec{v}_K - c_K \cdot \Delta\vec{s}_K$$

$$\Delta\dot{\vec{s}}_K = \Delta\vec{v}_K$$

# Trailer Sway Modeling

## Nomenclatures:

| | |
|---|---|
| VA, HA | Front Axle, Rear Axle |
| SP | Center of Gravity |
| K | Trailer Coupling/Hitch |
| A | Trailer (as subscript) |
| $\beta, \beta_A$ | Body Slip Angles |
| $\dot{\psi}, \dot{\psi}_A$ | Yaw Rates |
| $a_x, a_y$ | Longitudinal, Lateral Acceleration in the Center of Gravity |
| $\delta$ | Steering Angle |
| $\gamma$ | Angle between Longitudinal Axes of Towing Vehicle and Trailer |
| $v_x$, $v_y$ | Longitudinal And Lateral Velocity of Vehicle |
| $a_v, a_h, a_A$ | Side Slip Angles |
| $m, m_A$ | Masses |
| $J_z, J_{zA}$ | Moments of Inertia about the Vertical Axes |
| $F_{Sv}, F_{Sh}, F_{SA}$ | Lateral Forces |
| $F_{Kx}, F_{Ky}$ | Coupling Force, Longitudinal and Lateral Component |
| $F_{K\xi}, F_{K\eta}$ | Coupling Force, Longitudinal and Lateral Component in the ($\xi$, $\eta$) Coordinate System |
| $F_x$ | Resulting Longitudinal Force (towing vehicle) |
| $M_z$ | Yaw Moment |
| $l_v, l_h, l_K$ | Distance between Center of Gravity to Front or Rear Axle or Trailer Coupling/Hitch |
| $C_v$, $C_h$, $C_A$ | Side Slip Stiffness |



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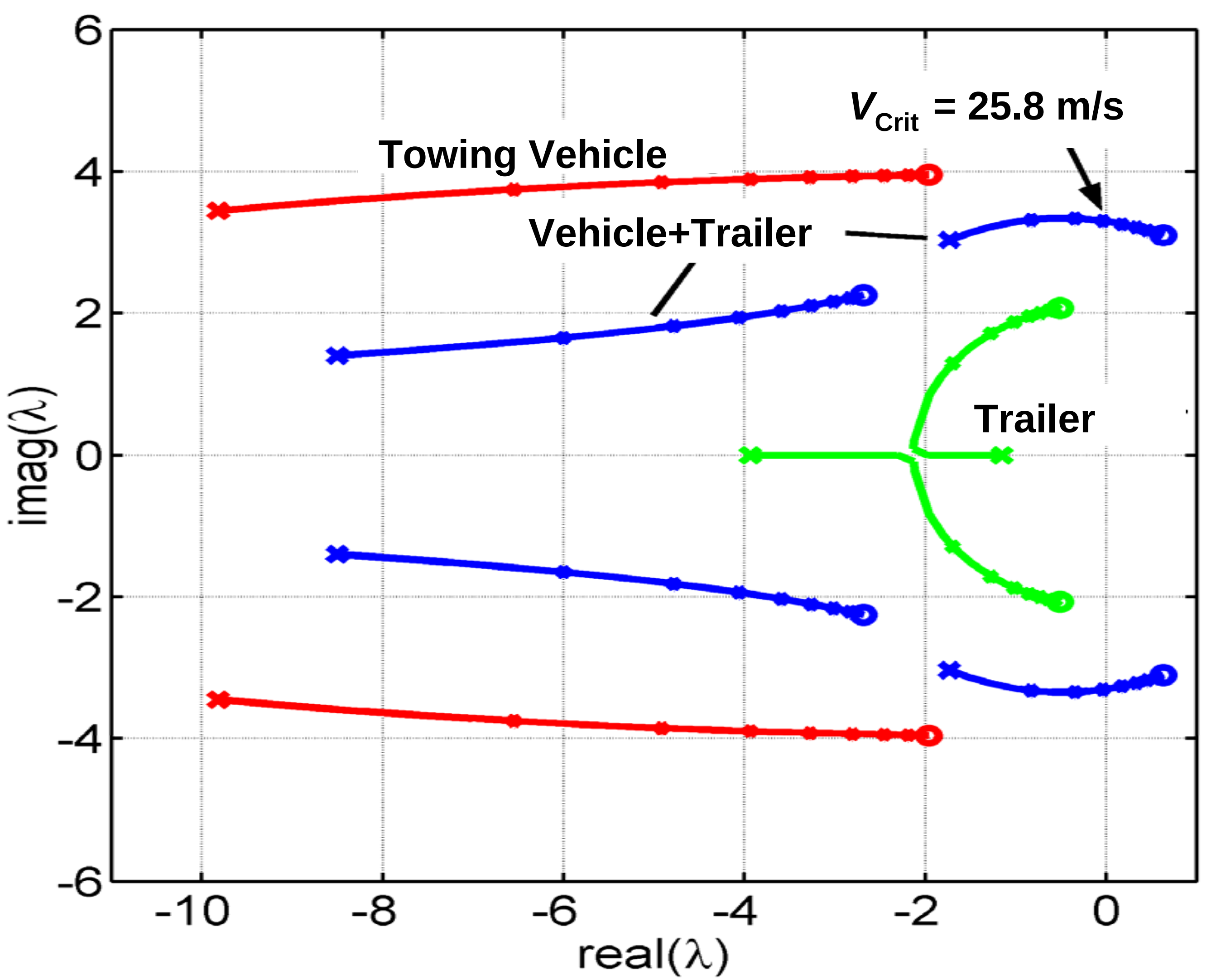
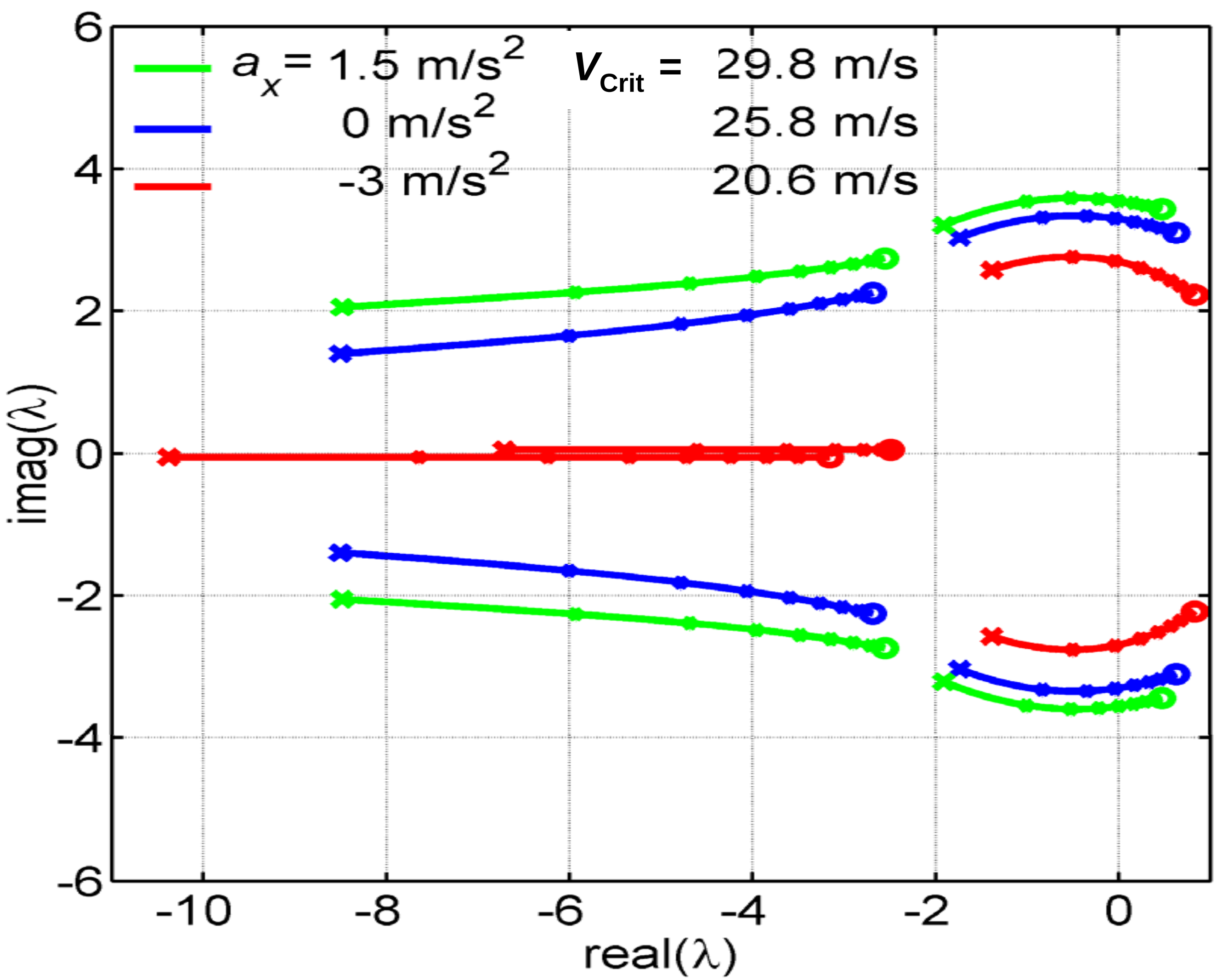
# Trailer Sway Modeling



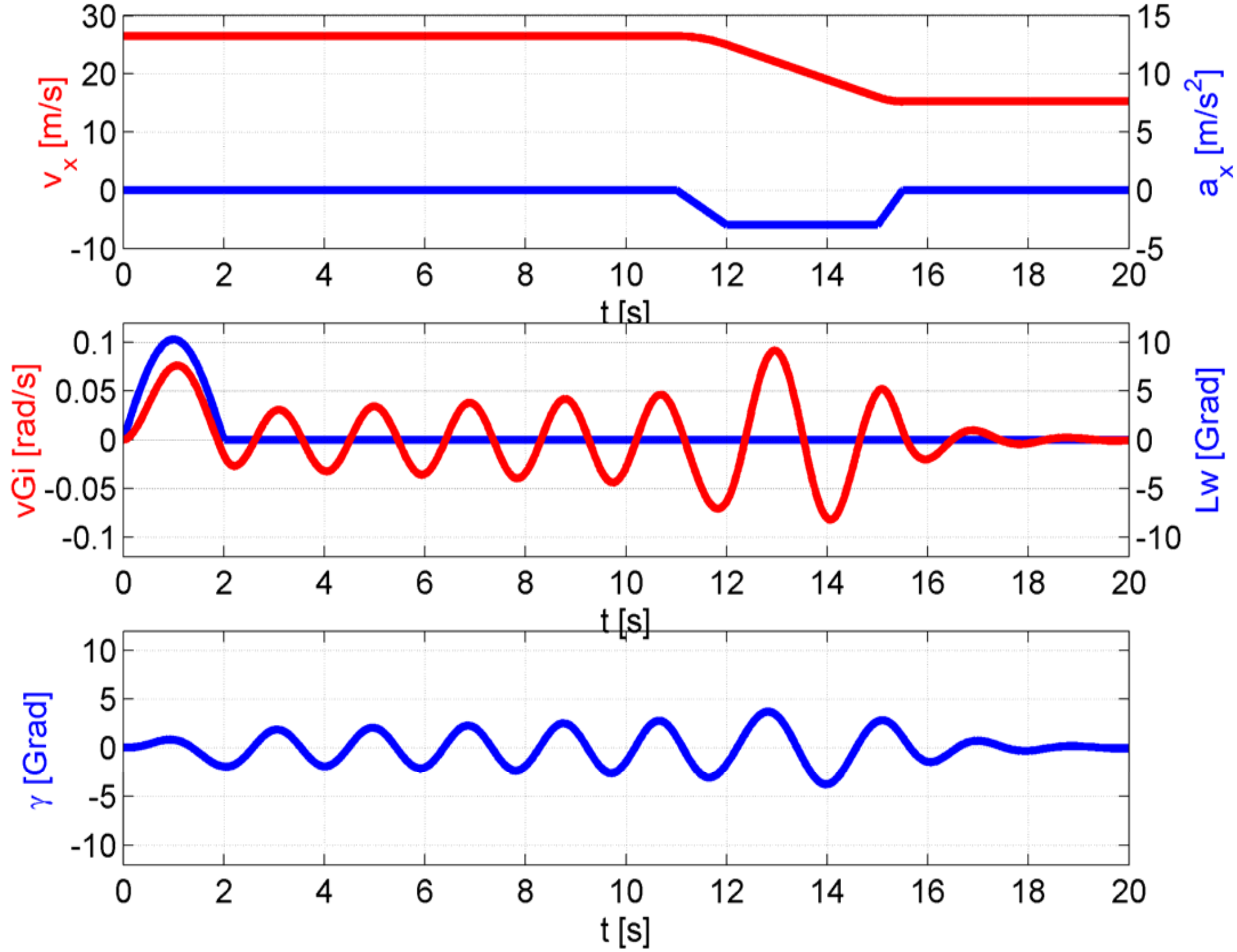

**Eigen value behavior vs. vehicle speed for towing vehicle, trailer and vehicle train (starting point i.e. first cross = 10m/s, the end point i.e. circles = 50m/s)**

# Trailer Sway Modeling



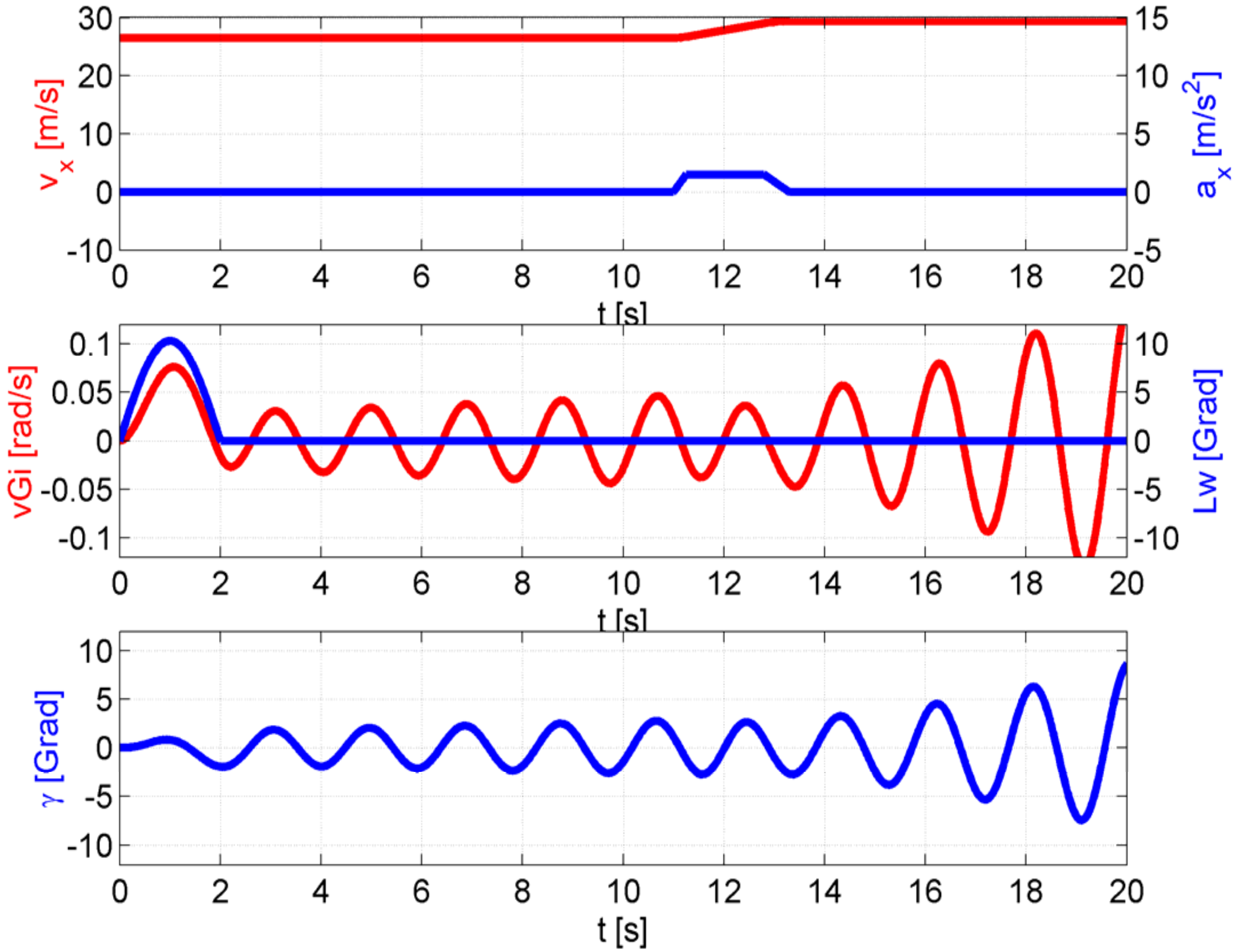

**Eigen value behavior vs. vehicle acceleration for the vehicle train (high acceleration (1.5m/s^2) with high critical speed, high deceleration (-3m/s^2) with low critical speed.**

# Trailer Sway Modeling



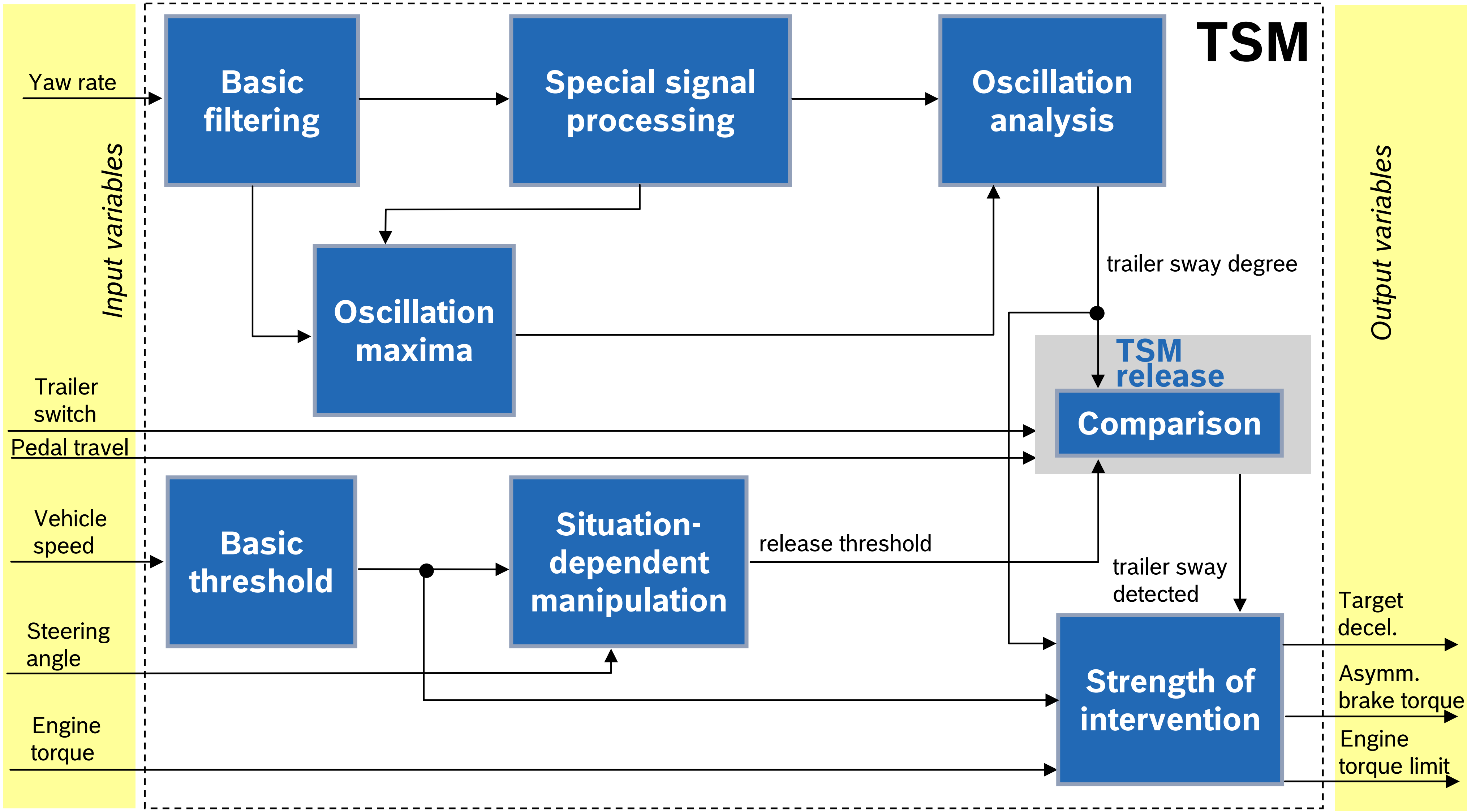

**The vehicle yaw rate and γ angle increased temporarily, when the vehicle is under deceleration between 11 and 15 second.**

# Trailer Sway Modeling




**The vehicle yaw rate and γ angle decreased temporarily, when the vehicle is under acceleration between 11 and 13 second.**

# Trailer Sway Damping Control





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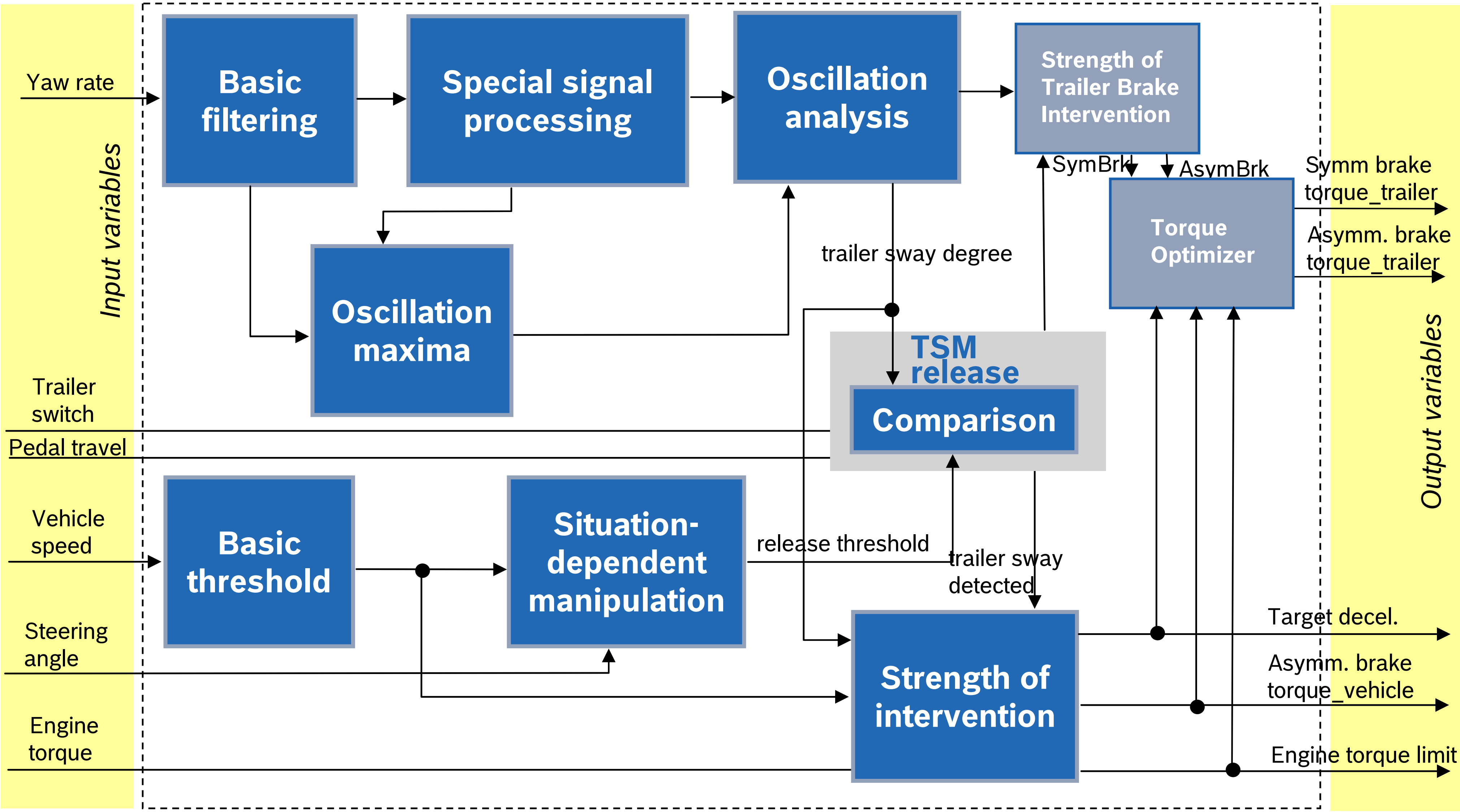
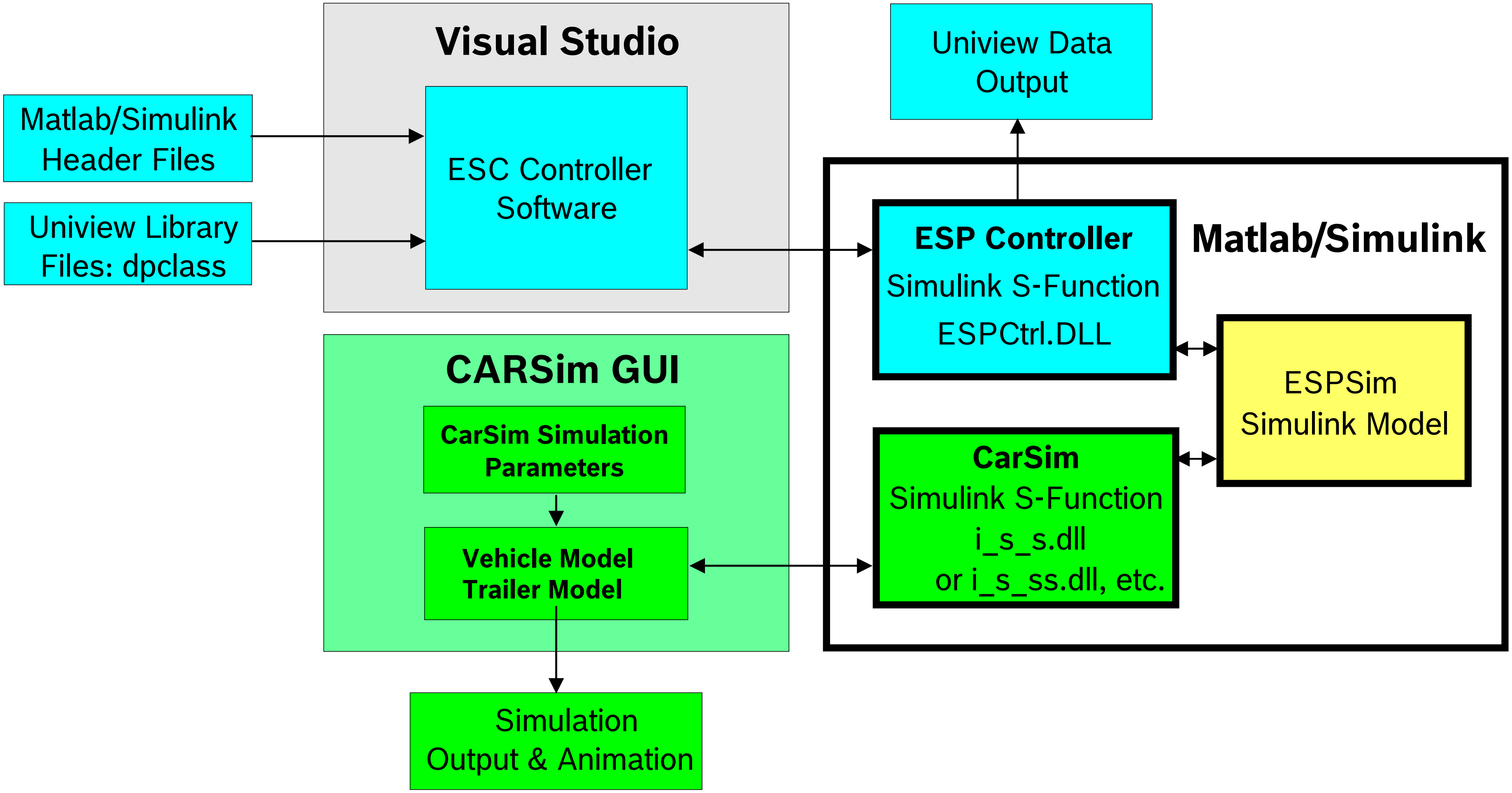


# Simulation Setup and Results



# Simulation Setup and Results

**Simulation parameters:**

**vehicle model: Carsim truck model from O.E.M.**

**trailer model: Carsim internal trailer model**

| | vehicle | | trailer | |
|---|---|---|---|---|
| | symmetric | asymmetric | symmetric | asymmetric |
| vehicle/trailer #1 | | | | |
| vehicle/trailer #2 | x | x | | |
| vehicle/trailer #3 | x | x | x | |
| vehicle/trailer #4 | x | x | x | x |

Simulation animation #1: straight line(85kph, constant speed)

Simulation animation #2: cornering(70 kph, constand speed)

# Summary

→To reduce trailer oscillation, it is necessary to reduce vehicle speed below critical speed

→Reducing vehicle speed by braking the vehicle can momentarily cause a slight increase in trailer oscillation

→To solve this dilemma, there are two ways: 1. create a yaw moment by braking vehicle wheels side-by-side. 2. create a drag force by braking the trailer

→The trailer oscillation cannot be damped out safely, if the vehicle speed is over the critical speed too much. i.e. the damping forces created by braking vehicle and trailer have their own limits which are determined by the tire characteristic.