Simulink and ADAMS Co Simulation for ABS & ESC testing and Validation with Physical Test

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Agenda:-

1. Introduction
2. Objective
3. Vehicle & Controller Modelling
4. Progressive braking test
5. Sine with Dwell test
6. Conclusion
Introduction:-

➢ Vehicle development process warrants changes in vehicle parameters like GVW, spring rate and damper characteristics for weight reduction and performance improvement initiatives.

➢ In such scenarios, virtual vehicle model with ABS will ensure the impact of vehicle level changes on ABS and braking performance before making physical prototype. The physical test can be reduced significantly to accelerate the development process.

➢ Co-simulation model is useful to study the vehicle level changes and its impact on ABS controller upfront.
Objective :-

➢ Methodology is established for ADAMS-Simulink co-simulation
➢ To improve simulation accuracy for road load simulations of brake events by implementing the ABS controller Simulink model in the Adams/Car full vehicle model, called coupled simulation and abbreviated as co-simulation.
➢ The co-simulation results are validated by measurements performed at MRV.
Vehicle Modeling:

- **Adams Model Consist of following subsystems**
  - Front and rear suspensions
  - Steering system
  - Brake system
  - Tires
  - Chassis
  - Front and rear anti roll bars

- **Adams Input and Output Plants**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Plant Inputs</th>
<th>Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Front left Pressure input</td>
<td>Brake</td>
</tr>
<tr>
<td>2</td>
<td>Front Right Pressure input</td>
<td>Brake</td>
</tr>
<tr>
<td>3</td>
<td>Rear left Pressure input</td>
<td>Brake</td>
</tr>
<tr>
<td>4</td>
<td>Rear right Pressure input</td>
<td>Brake</td>
</tr>
<tr>
<td>5</td>
<td>Cylinder Pressure Output</td>
<td>Brake</td>
</tr>
<tr>
<td>6</td>
<td>Chassis Velocity Vx</td>
<td>Chassis</td>
</tr>
<tr>
<td>7</td>
<td>Chassis Velocity Vy</td>
<td>Chassis</td>
</tr>
<tr>
<td>8</td>
<td>Chassis Velocity Vz</td>
<td>Chassis</td>
</tr>
<tr>
<td>9</td>
<td>Chassis Roll rate</td>
<td>Chassis</td>
</tr>
<tr>
<td>10</td>
<td>Chassis Pitch Rate</td>
<td>Chassis</td>
</tr>
<tr>
<td>11</td>
<td>Chassis Yaw Rate</td>
<td>Chassis</td>
</tr>
<tr>
<td>12</td>
<td>Steering wheel angle</td>
<td>Steering</td>
</tr>
</tbody>
</table>

- **Booster characteristics**
  - Output Pressure (Bar) vs Input load (kg)

![Vehicle Model Diagram]
Controller Modeling :-

➢ **Simulink ABS controller** model has the blocks of Wheel speed sensors, Electronic control unit, Hydraulic control unit and brake system.

➢ Controller model received from Supplier

➢ **Adams Model** : This models need vehicle speed, wheel speeds and master cylinder pressure as input from the Adams model. The control logic modulates the brake caliper pressure for each wheel based on the threshold slip control algorithm and send back the caliper pressure to the vehicle MBD model.
Solvers exchange:-

➢ Simulink acts as a master solver in this simulation and the two solvers exchange information at certain time steps

Co-Simulation Procedure
Co-Simulation Setup:

Adams Simulink block
Co-Simulation Setup for ABS :-

**Inputs from ADAMS/car**
1. Front Left Wheel Speed
2. Front Right Wheel Speed
3. Rear Left Wheel Speed
4. Rear Right Wheel Speed
5. Vehicle Speed (Vx, Vy & Vz)
6. Master Cylinder Pressure

**Outputs from Simulink ABS**
1. Front Left Caliper controlled Pressure
2. Front Right Caliper controlled Pressure
3. Rear Left Caliper controlled Pressure
4. Rear Right Caliper controlled Pressure

Adams Simulink block

ABS inputs
Co-Simulation Setup for ABS + ESC:

**Inputs from ADAMS/car**
1. Front Left Wheel Speed
2. Front Right Wheel Speed
3. Rear Left Wheel Speed
4. Rear Right Wheel Speed
5. Vehicle Speed (Vx,Vy & Vz)
6. Master Cylinder Pressure
7. Steering wheel
8. Yaw Rate

**Outputs from Simulink ABS**
1. Front Left Caliper controlled Pressure
2. Front Right Caliper controlled Pressure
3. Rear Left Caliper controlled Pressure
4. Rear Right Caliper controlled Pressure

Adams Simulink block
ESC inputs
ABS inputs
Anti Lock Braking System Introduction:-

➢ ABS prevents locking of wheels during braking

➢ ABS modulates the brake line pressure independent of the pedal force, to bring the wheel speed back to the slip level range that is necessary for optimal braking performance.

➢ ABS allows the driver to maintain steering control while braking and shorten braking distances on slippery surfaces like wet or icy surfaces.
Progressive Braking Inputs for simulation:

➢ Progressive Braking physical test was conducted in MRV
➢ The following Progressive Braking Simulation inputs are measured from test

Initial vehicle velocity: 120kmph
Pedal ratio = 3
Input @ pedal: Pedal force Vs time

Max pedal force = 55kgf
Booster input force = Max pedal force * Pedal ratio
Progressive Braking Inputs for simulation:

- Without ABS
- With ABS

[Graph showing braking performance with and without ABS]
Progressive Braking Simulation Results :-

Results
Progressive Braking Simulation Results:

- Vehicle stopping distance

14m lesser stopping distance is achieved in Progressive braking with ABS vehicle.
Progressive Braking Simulation Results:

- **Wheel speeds**

![Graphs showing wheel speed variations over time](image-url)
Progressive Braking Simulation Results:

• Vehicle Speed and Pressure Modulation

ABS is activated same time in Testing and Simulation
Electronic Stability Control (ESC):  

➢ System of sensors, actuators, and computers to enhance vehicle directional stability prevent loss of control due to oversteer or understeer  

➢ If the stability control software in the ABS control module detects a difference in the normal rotational speeds between the left and right wheels when turning, it immediately reduces engine power and applies counter braking at individual wheels as needed until steering control and vehicle stability are regained
Sine with Dwell simulation Inputs:

- Initial vehicle velocity: 80 kmph
- Steering wheel angle: 270 deg
Sine with Dwell with and with out ESC Animation:-

- With ESC
- With out ESC
Sine with Dwell simulation :-

Results
Sine with Dwell simulation Results:-

• Yaw Rate measurement

Vehicle Yaw rate (Deg/sec) vs Time (S)

- With_Out_ESC
- With_ESC

Criterion_1: 73.2% < 30%
Criterion_2: 55.5% < 20%
Criterion_1: 0.5% < 30%
Criterion_2: 0.6% < 20%
Sine with Dwell simulation Results:

- Vehicle lateral Displacement(mm) measurement

Higher lateral displacement is achieved in Vehicle with ESC model
Sine with Dwell simulation Results:

- Modulation pressures

ESC is applied brakes at front left means vehicle is in oversteer condition while taking right turn
Sine with Dwell simulation Results:-

- Lateral Acceleration and Vehicle speed
Conclusion:-

➢ Co-simulation methodology is established using Adams/Car and Matlab Simulink for ABS and ESC

➢ Achieved good CAE correlation with test results for Progressive braking

➢ ESC Validation is work in progress
Thank You!!!
Annexure:-

• Lateral Stability Criteria Test Measurements:
  ➢ “Lateral stability” is defined as the ratio of vehicle yaw rate at a specified time to the first local peak yaw rate generated by the 0.7 Hz Sine with Dwell steering reversal

The lateral stability criteria can be represented in the mathematical notations as follows:

\[
\frac{\psi(t_0)_{1.00}}{\psi_{Peak}} \times 100 \leq 35\% \text{ (Criterion #1), and}
\]

\[
\frac{\psi(t_0)_{1.75}}{\psi_{Peak}} \times 100 \leq 20\% \text{ (Criterion #2)}
\]

Where,

- \(\psi_t\) = Yaw rate at time \(t\) (in seconds)
- \(\psi_{Peak}\) = First local peak yaw rate generated by the 0.7 Hz Sine with Dwell steering input
- \(t_0\) = Time to completion of steering input
Annexure:-

➢ The responsiveness criterion will be used to measure the ability of a vehicle to respond to the driver’s inputs during an ESC intervention

\[
\text{Lateral Displacement} = \int_{t_0}^{t_0+1.07} \int_{t_0}^{t_0+1.07} Ay_{C.G.}(t)dt \\
\begin{cases} 
\geq 1.83 \text{ m, when GVWR } \geq 3,500 \text{ lb} \\
\geq 1.22 \text{ m, when GVWR } < 3,500 \text{ lb}
\end{cases}
\]

Where,
\[t_0\] = Steering wheel input starting time
\[A_{C.G.}\] = Lateral acceleration, corrected for the effect of roll angle and sensor offset from vehicle C.G. position.