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

L Ganesh
Deshmukh Chandrakant
Dr. Balarama Krishna
CAE Dynamics
Mahindra Research Valley
## Agenda:

<table>
<thead>
<tr>
<th></th>
<th>Introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Objective</td>
</tr>
<tr>
<td>3</td>
<td>Vehicle &amp; Controller Modelling</td>
</tr>
<tr>
<td>4</td>
<td>Progressive braking test</td>
</tr>
<tr>
<td>5</td>
<td>Sine with Dwell test</td>
</tr>
<tr>
<td>6</td>
<td>Conclusion</td>
</tr>
</tbody>
</table>
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 system</td>
</tr>
<tr>
<td>2</td>
<td>Front Right Pressure input</td>
<td>Brake system</td>
</tr>
<tr>
<td>3</td>
<td>Rear left Pressure input</td>
<td>Brake system</td>
</tr>
<tr>
<td>4</td>
<td>Rear right Pressure input</td>
<td>Brake system</td>
</tr>
<tr>
<td>S.No</td>
<td>Plant Outputs</td>
<td>Subsystem</td>
</tr>
<tr>
<td>1</td>
<td>Front left wheel velocity</td>
<td>Brake system</td>
</tr>
<tr>
<td>2</td>
<td>Front Right wheel velocity</td>
<td>Brake system</td>
</tr>
<tr>
<td>3</td>
<td>Rear left wheel velocity</td>
<td>Brake system</td>
</tr>
<tr>
<td>4</td>
<td>Rear right wheel velocity</td>
<td>Brake system</td>
</tr>
<tr>
<td>5</td>
<td>Cylinder Pressure Output</td>
<td>Brake system</td>
</tr>
<tr>
<td>6</td>
<td>Chassis Velocity Vx</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>7</td>
<td>Chassis Velocity Vy</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>8</td>
<td>Chassis Velocity Vz</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>9</td>
<td>Chassis Roll rate</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>10</td>
<td>Chassis Pitch Rate</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>11</td>
<td>Chassis Yaw Rate</td>
<td>Chassis subsystem</td>
</tr>
<tr>
<td>12</td>
<td>Steering wheel angle</td>
<td>Steering system</td>
</tr>
</tbody>
</table>

*Booster characteristics*

*Output Pressure (Bar)*

*Input load (kg)*
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:-
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
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

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial vehicle velocity</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Pedal ratio</td>
<td>3</td>
</tr>
<tr>
<td>Input @ pedal: Pedal force Vs time</td>
<td></td>
</tr>
<tr>
<td>Max pedal force</td>
<td>55 kgf</td>
</tr>
<tr>
<td>Booster input force = Max pedal force * Pedal ratio</td>
<td></td>
</tr>
</tbody>
</table>

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

- With out ABS
- With ABS

![Graphs showing braking performance with and without ABS](image)

**Legend:**
- Green: With ABS
- Red: With out 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**

---

**Left Front speed (RPM)**

**Time (s)**

---

**Left Rear speed (RPM)**

**Time (s)**

---

**Right Front speed (RPM)**

**Time (s)**

---

**Right Rear speed (RPM)**

**Time (s)**

---
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
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

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

\[
\frac{\psi_{t=1.00}}{\psi_{peak}} \times 100 \leq 35\% \text{ (Criterion \#1), and} \\
\frac{\psi_{t=1.75}}{\psi_{peak}} \times 100 \leq 20\% \text{ (Criterion \#2)}
\]

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.

\[
\text{Lateral Displacement} = \int_{t_0}^{t_0+1.07} \int_{t_0}^{t_0+1.07} A_{y_{c.g.}}(t) \, dt
\]

\[
\begin{align*}
\geq 1.83 \text{ m, when GVWR} & \geq 3,500 \text{ lb} \\
\geq 1.22 \text{ m, when GVWR} & < 3,500 \text{ lb}
\end{align*}
\]

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.