MATLAB EXPO 2018

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

Mahindra
Rise.

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

Rise.

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.

Mahindra Rise.

Vehicle Modeling :-

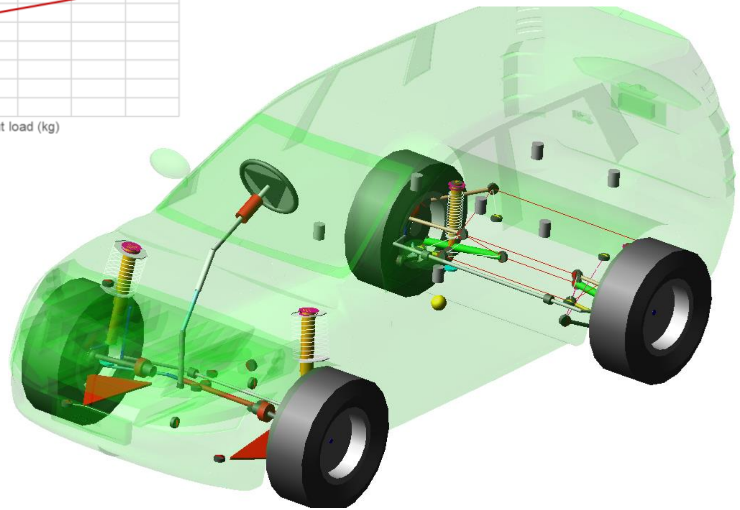
- **Adams Model Consist of following subsystems'**

> ➢ Front and rear suspensions
>
> ➢ Steering system
>
> ➢ Brake system
>
> ➢ Tires
>
> ➢ Chassis
>
> ➢ Front and rear anti roll bars

- **Adams Input and Output Plants**

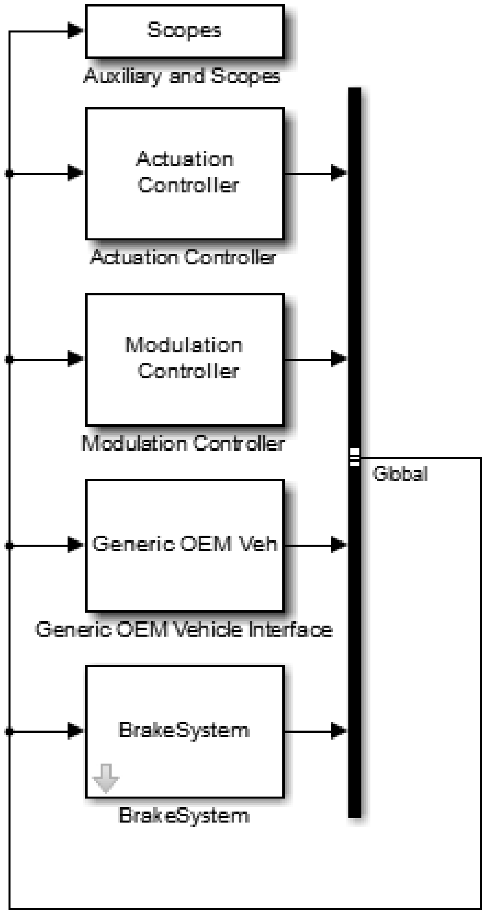
S.No	Plant Inputs	Subsystem
1	Front left Pressure input	Brake system
2	Front Right Pressure input	
3	Rear left Pressure input	
4	Rear right Pressure input	
S.No	**Plant Outputs**	**Subsystem**
1	Front left wheel velocity	Brake system
2	Front Right wheel velocity	
3	Rear left wheel velocity	
4	Rear right wheel velocity	
5	Cylinder Pressure Output	
6	Chassis Velocity Vx	Chassis subsystem
7	Chassis Velocity Vy	
8	Chassis Velocity Vz	
9	Chassis Roll rate	
10	Chassis Pitch Rate	
11	Chassis Yaw Rate	
12	Steering wheel angle	Steering system

Vehicle Model



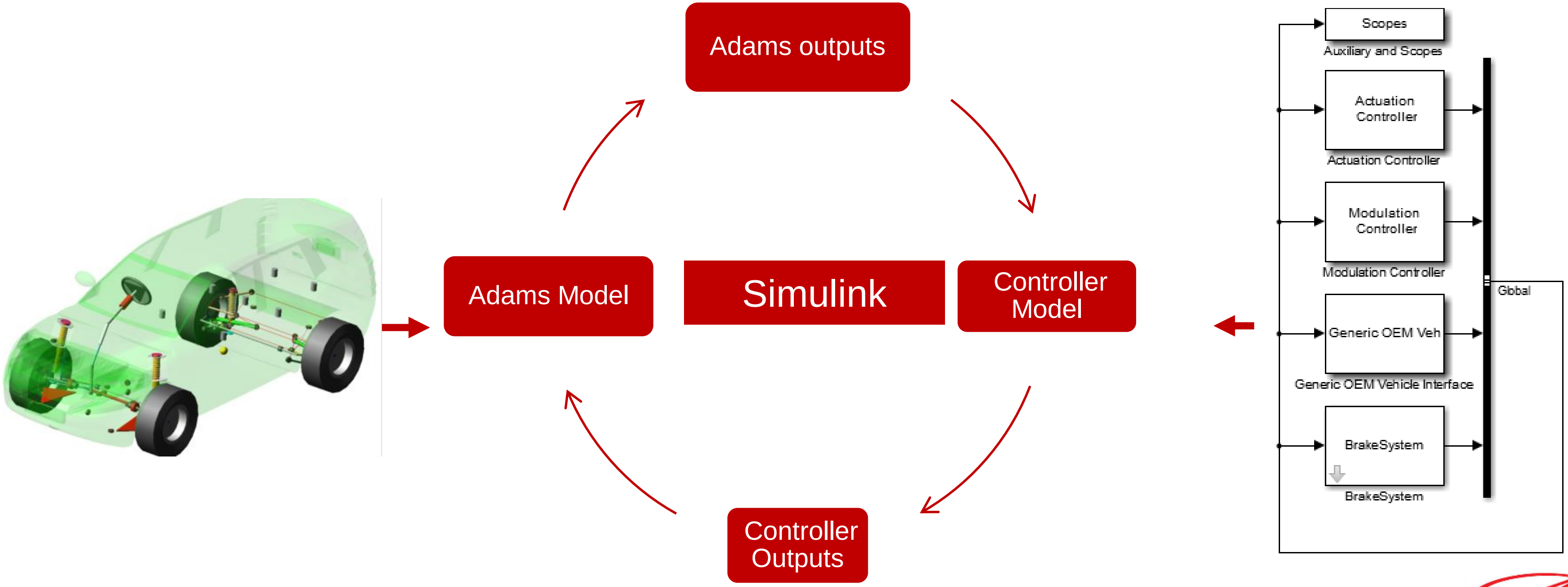
Controller Modeling :-

- **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:-

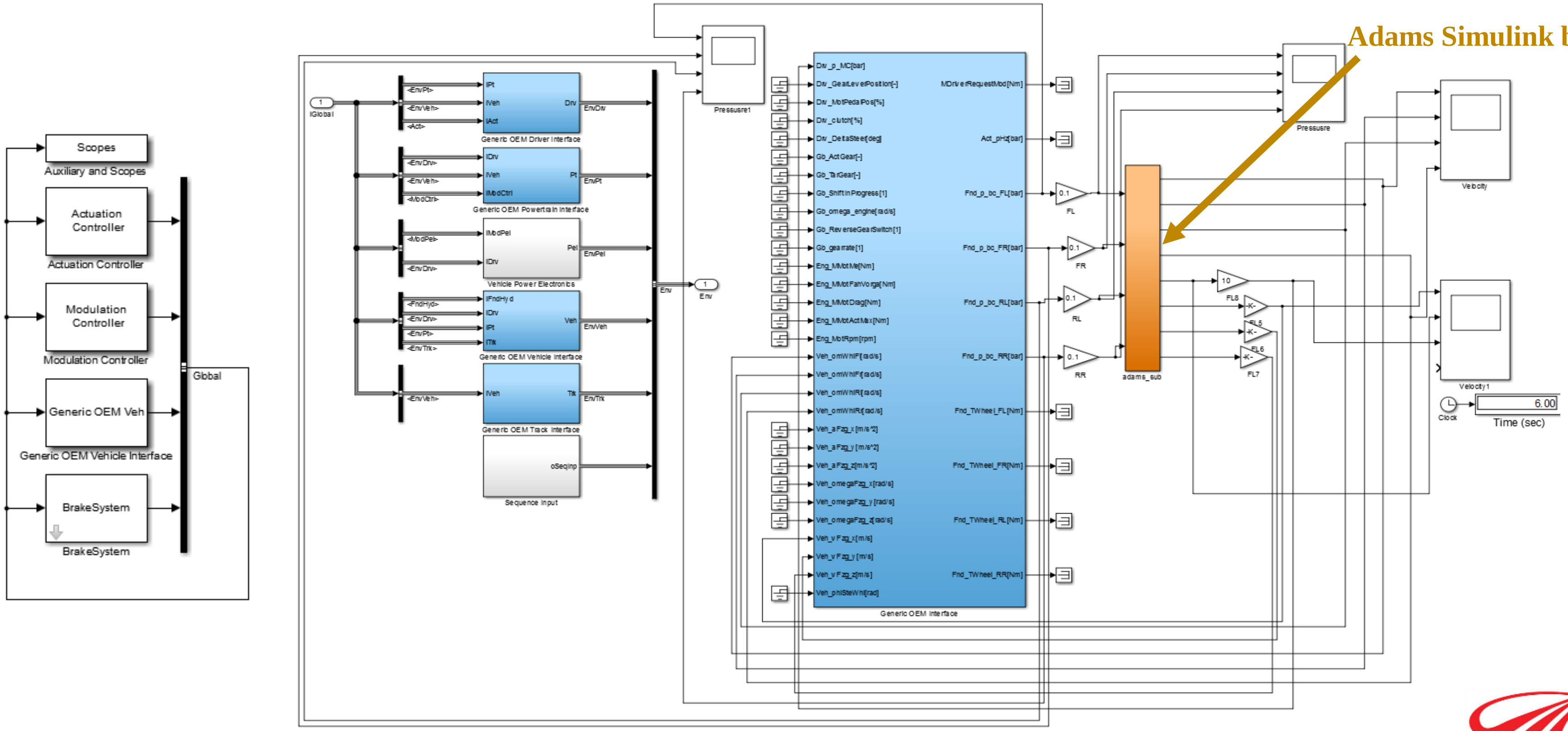
- Simulink acts as a master solver in this simulation and the two solvers exchange information at certain time steps



Co-Simulation Procedure

Co-Simulation Setup:-

Adams Simulink block



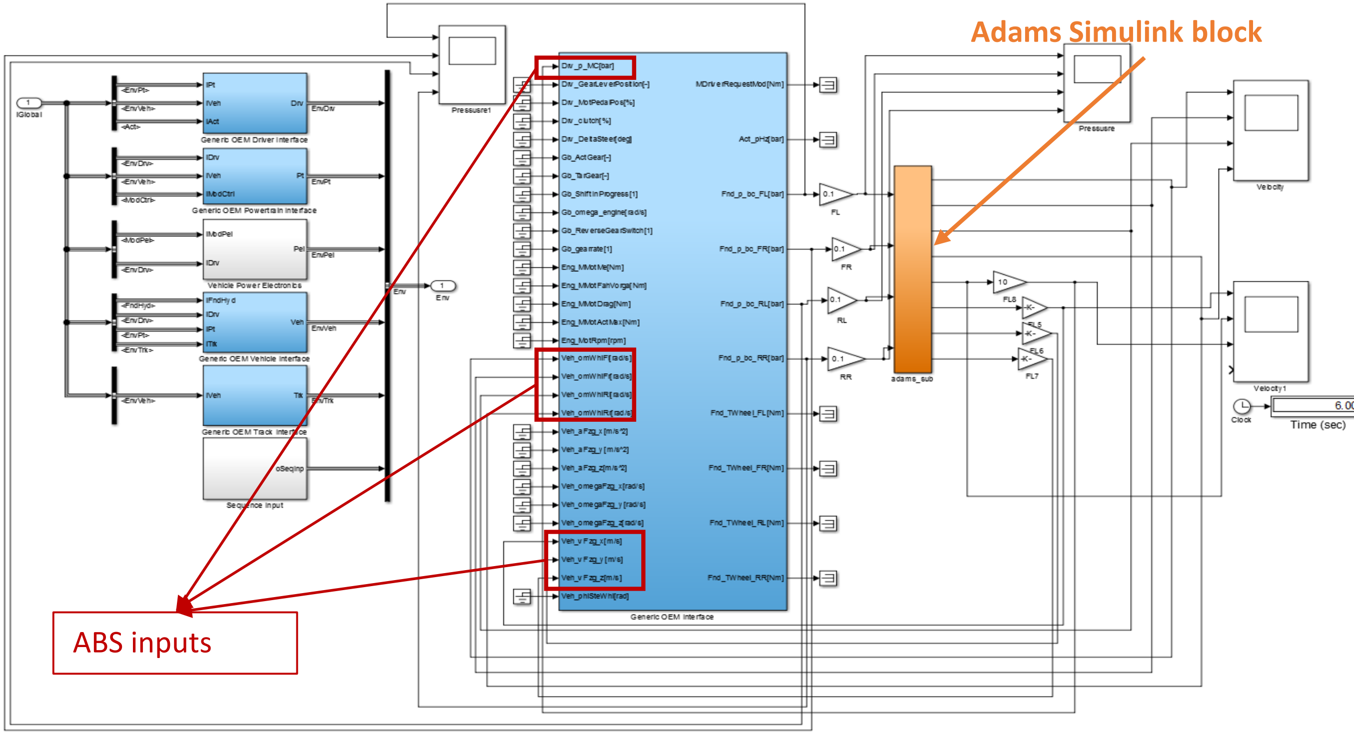
Co-Simulation Setup for ABS :-

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

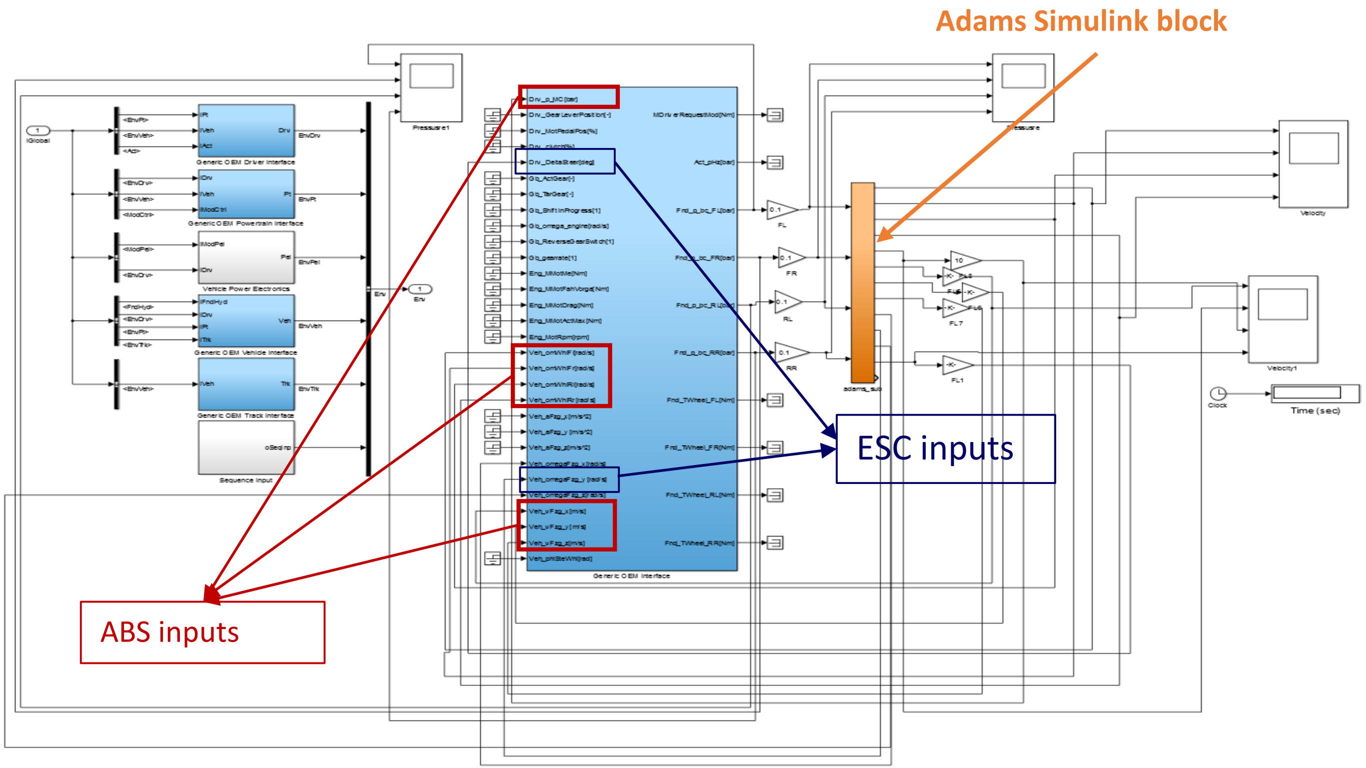
1. Front Left Caliper controlled Pressure
2. Front Right Caliper controlled Pressure
3. Rear Left Caliper controlled Pressure
4. Rear Right Caliper controlled Pressure



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

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.

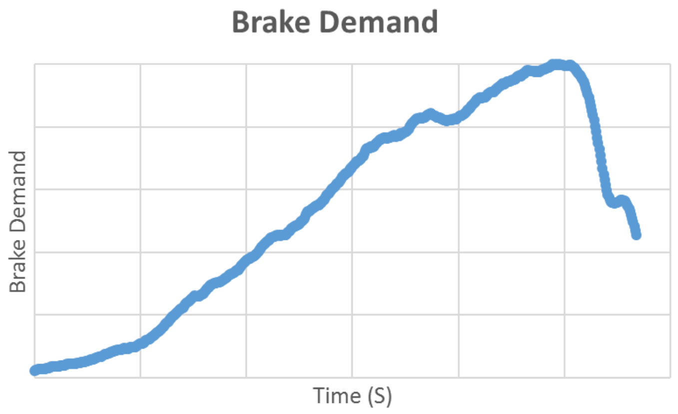
Mahindra Rise.

Progressive Braking Inputs for simulation:-

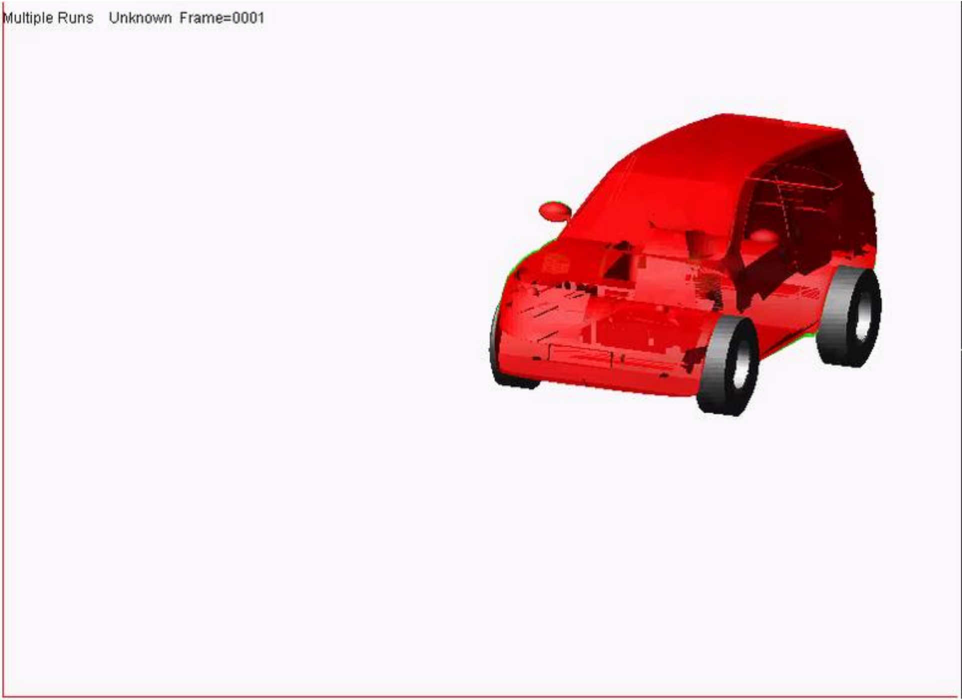
- Progressive Braking physical test was conducted in MRV
- The following Progressive Braking Simulation inputs are measured from test

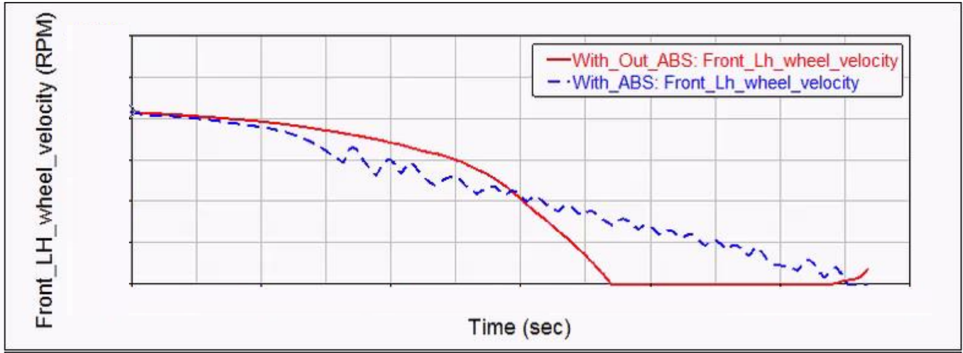
Initial vehicle velocity:120kmph
Pedal ratio =3
Input @ pedal: Pedal force Vs time

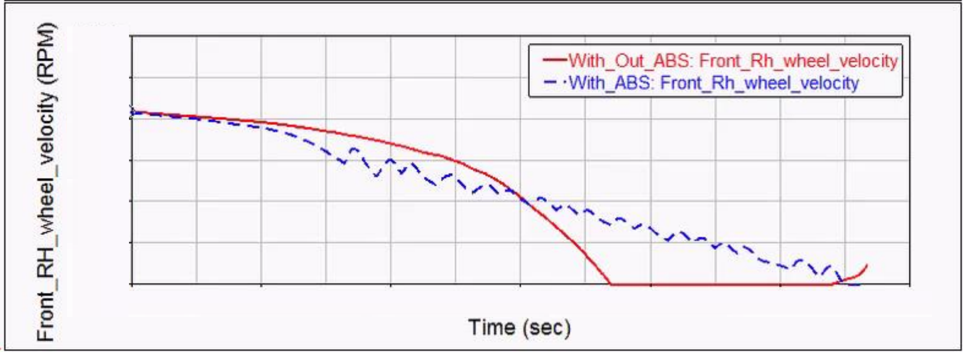
Max pedal force = 55kgf
Booster input force = Max pedal force * Pedal ratio



Progressive Braking Inputs for simulation:-







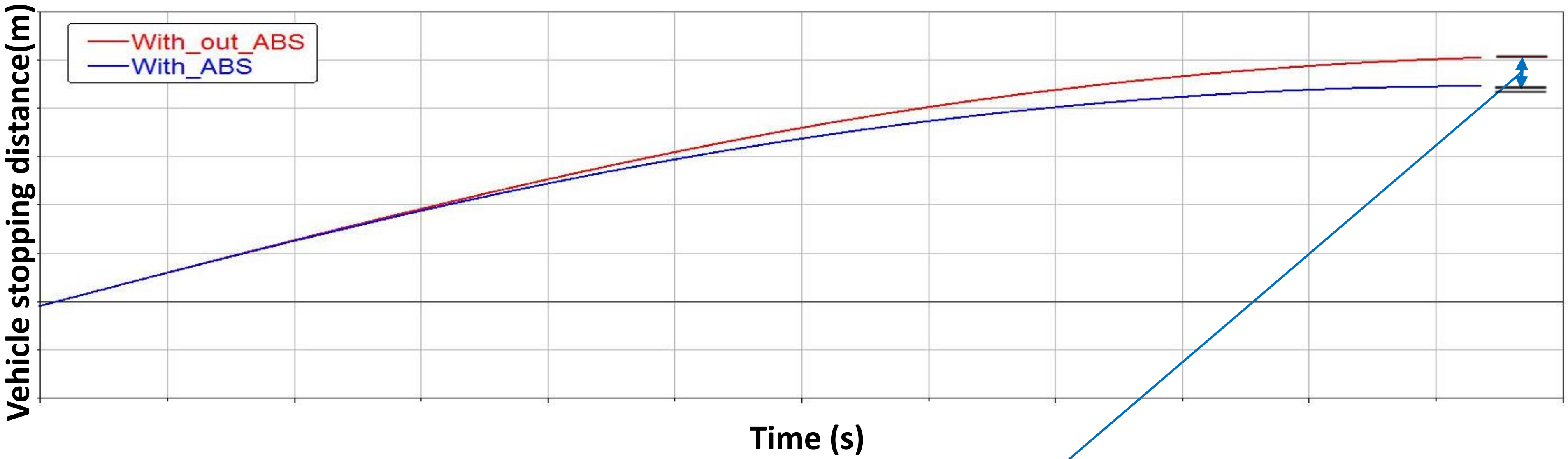
With ABS With out ABS

Progressive Braking Simulation Results :-

Results

Progressive Braking Simulation Results:-

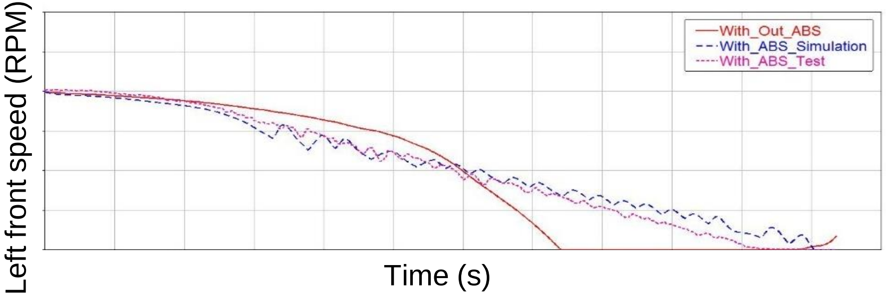
- Vehicle stopping distance

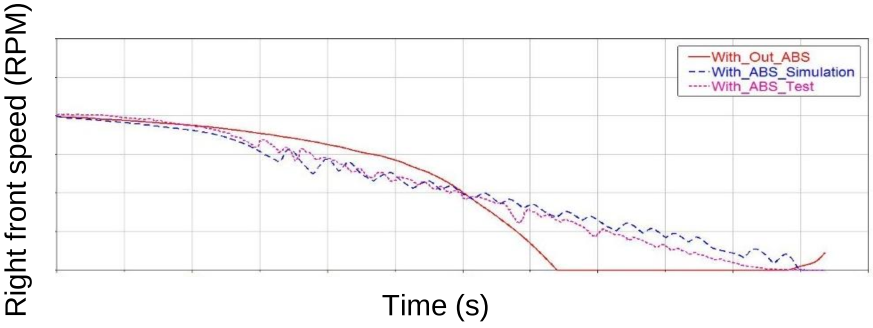


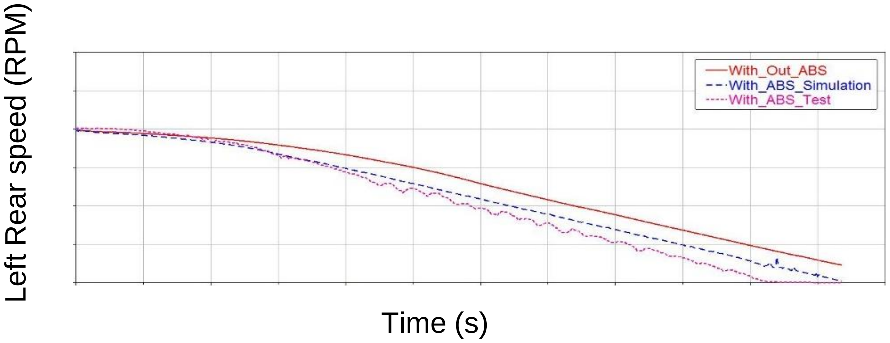
14m lesser stopping distance is achieved in Progressive braking with ABS vehicle

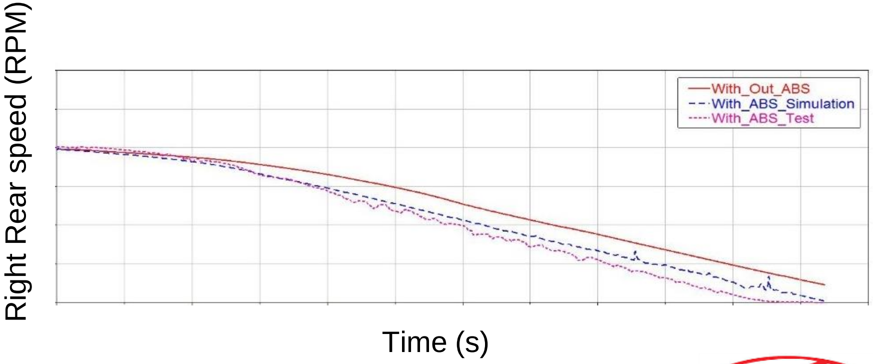
Progressive Braking Simulation Results:-

- <u>Wheel speeds</u>



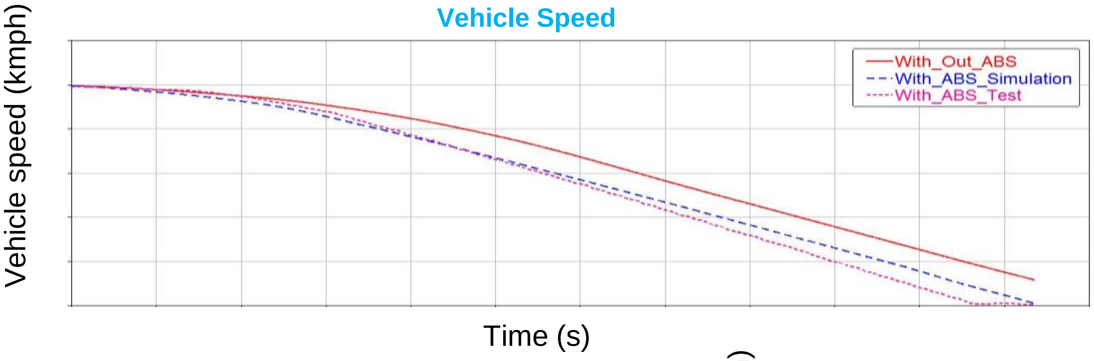


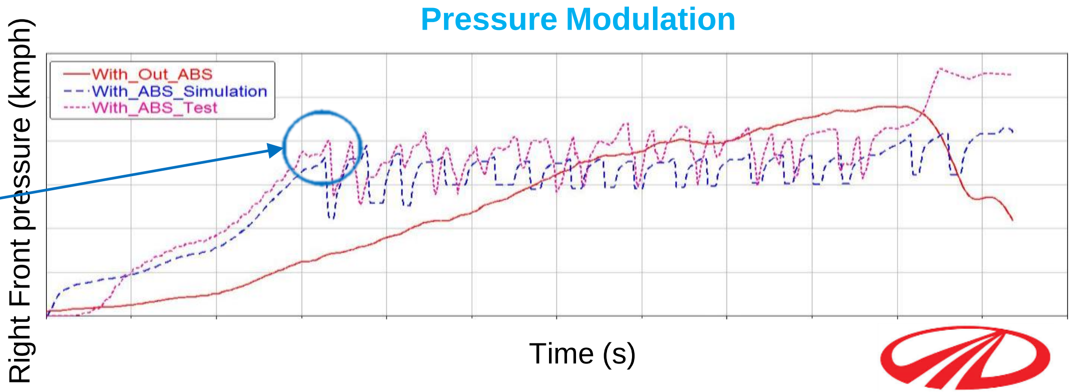




Progressive Braking Simulation Results:-

- Vehicle Speed and Pressure Modulation

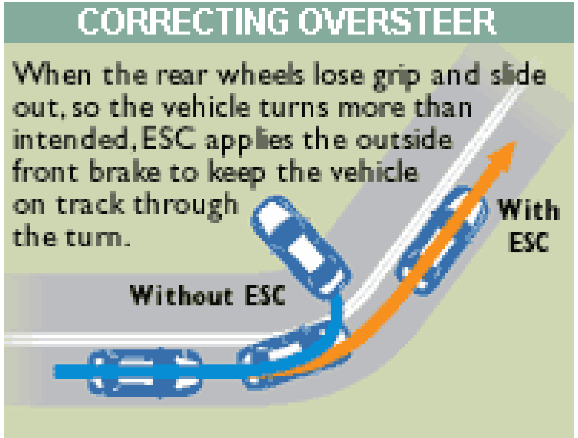


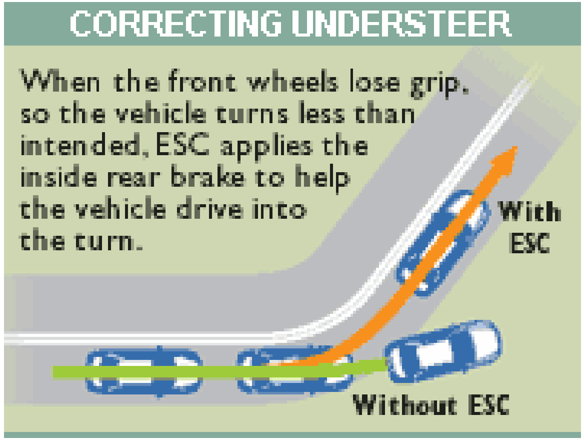


ABS is activated same time in Testing and Simulation

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

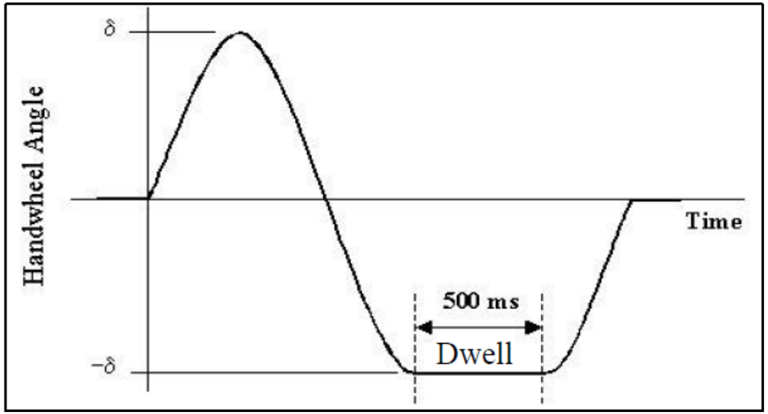




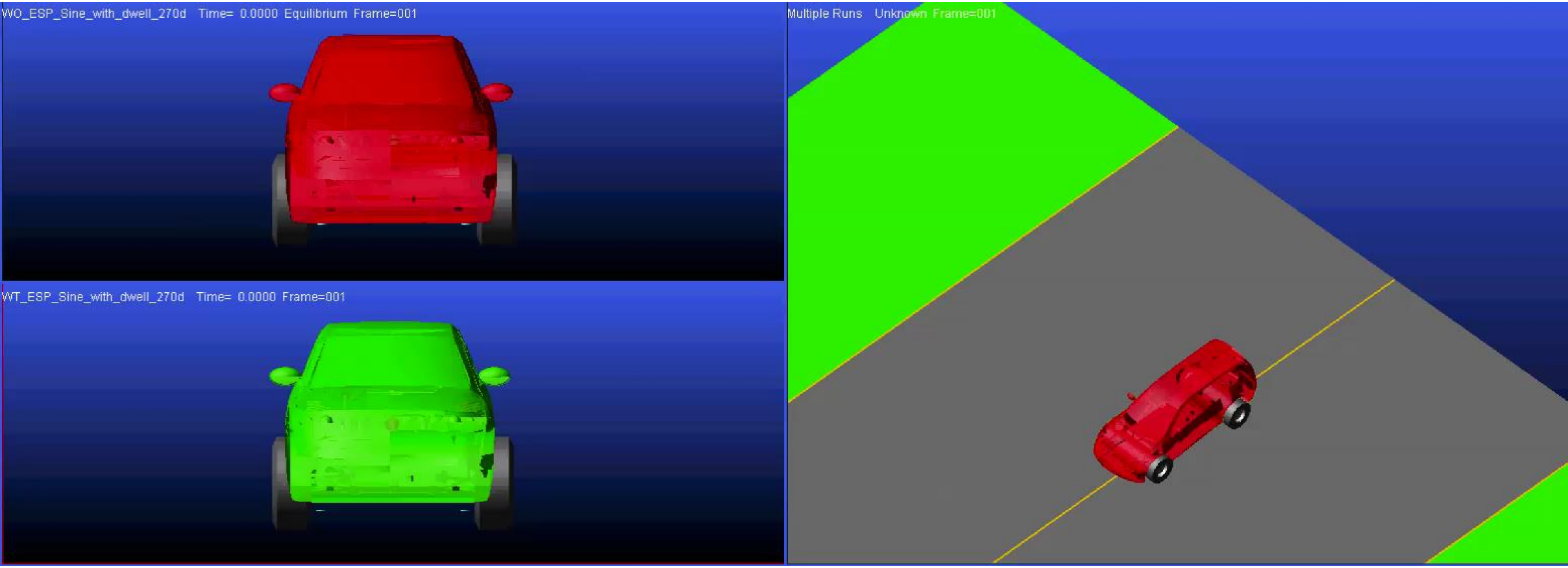
Mahindra Rise.

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

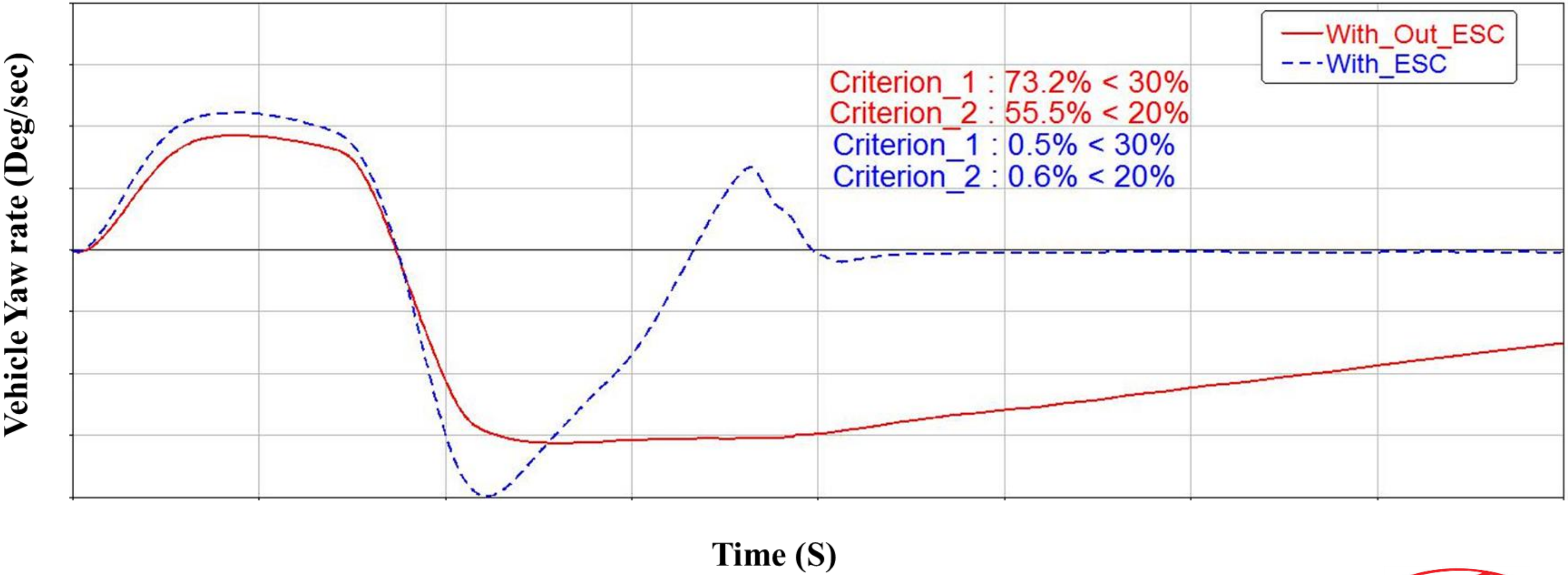
With out ESC

Sine with Dwell simulation :-

Results

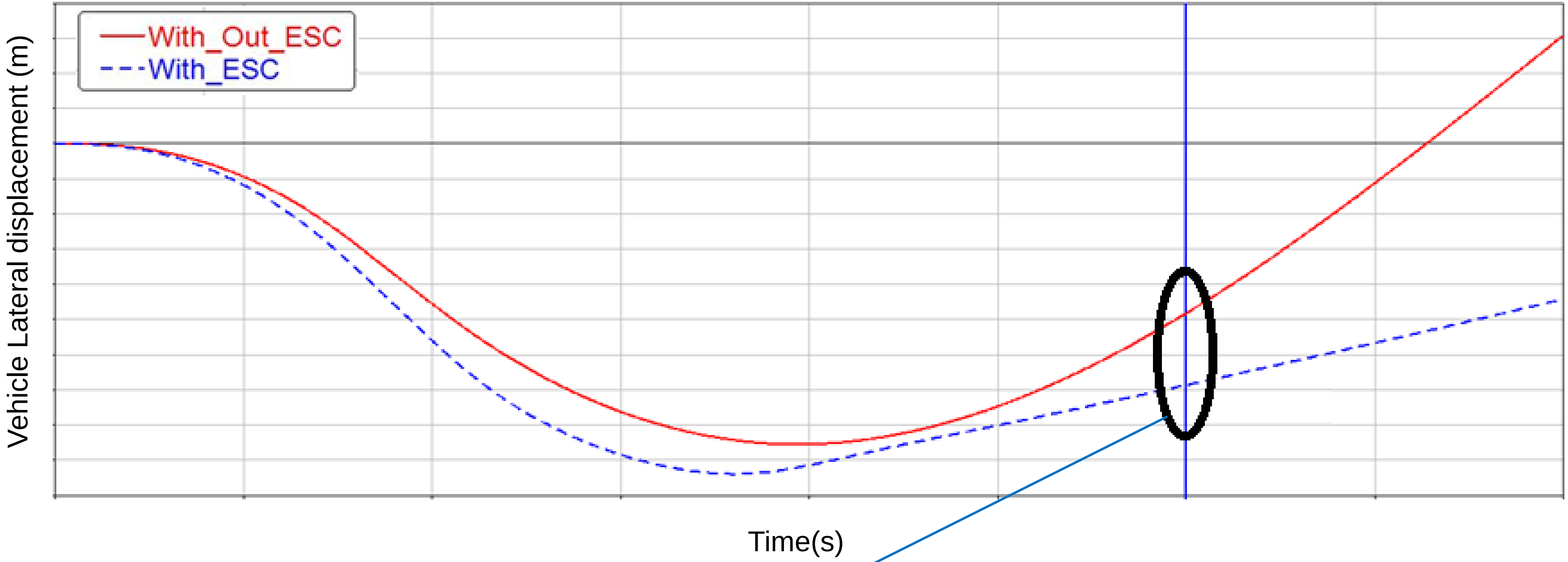
Sine with Dwell simulation Results:-

- Yaw Rate measurement



Sine with Dwell simulation Results:-

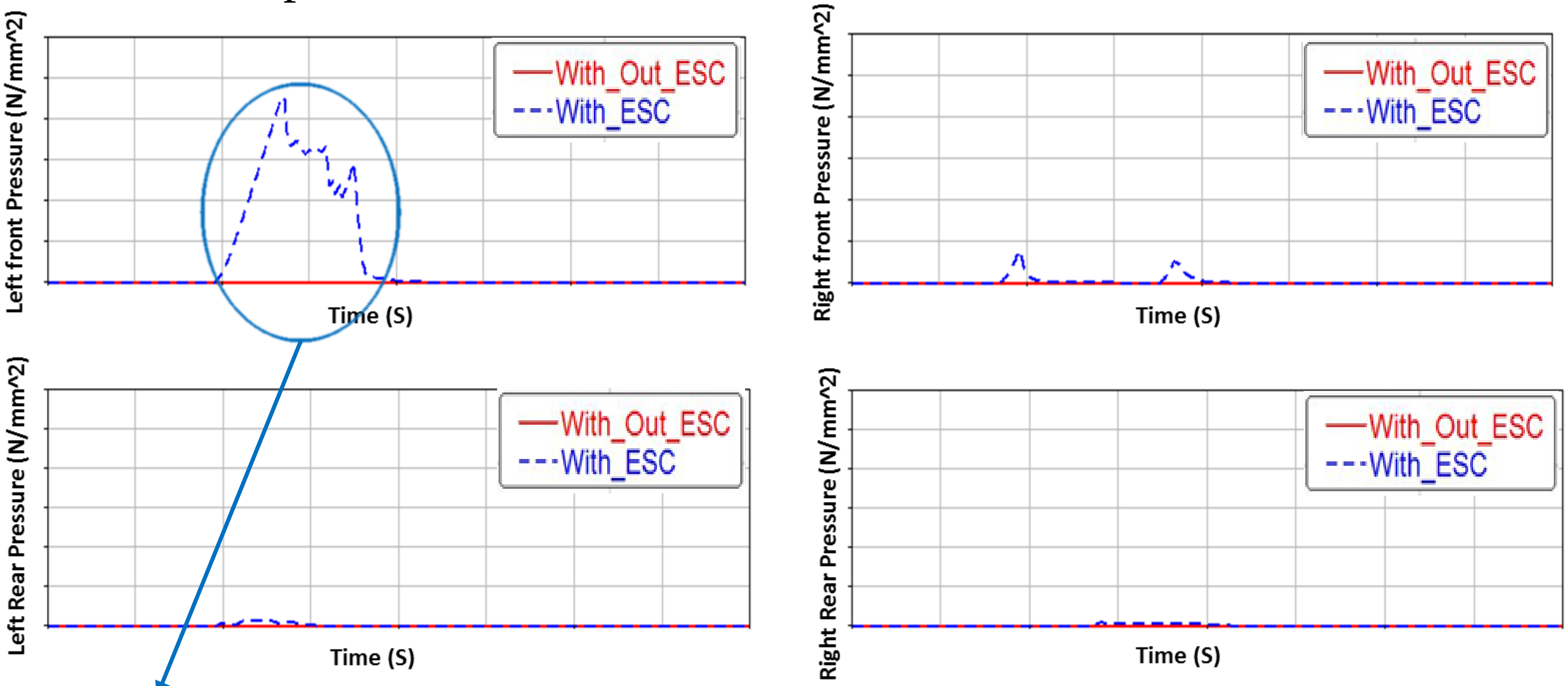
- Vehicle lateral Displacement(mm) measurement



Higher lateral displacement is achieved in Vehicle with ESC model

Sine with Dwell simulation Results:-

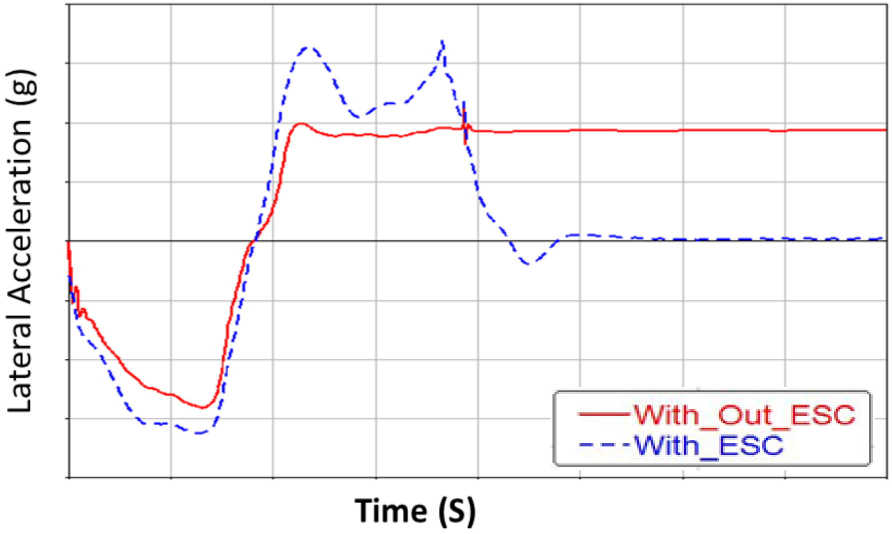
- Modulation pressures

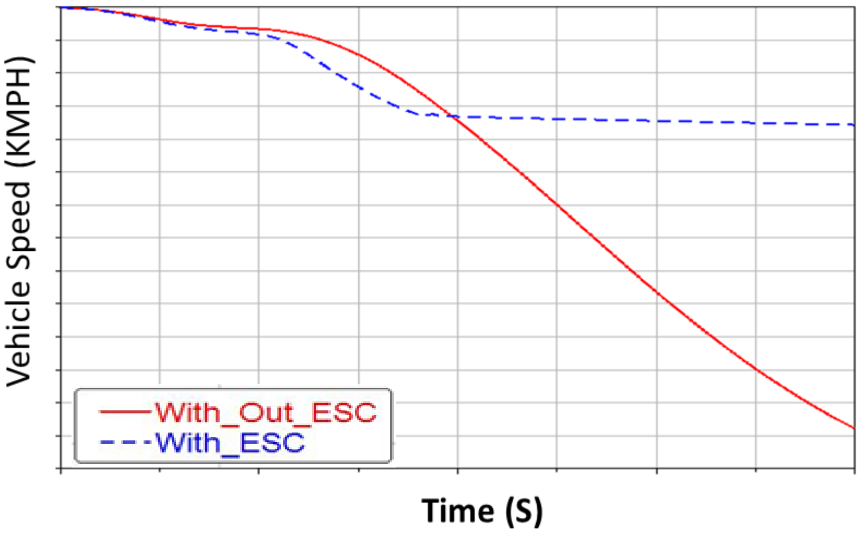


ESC is applied brakes at front left means vehicle is in oversteer condition while taking right turn

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

Mahindra Rise.

Thank You!!!

Mahindra
Mahindra RACING
e VERITO
AVIS
IHG Rewards Club
Julius Bär
IndianOil
Mahindra
MICHELIN
23

Annexure:-

- <u>Lateral Stability Criteria Test Measurements:</u>

➢ "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:

$$\frac{\dot{\psi}_{(t_0+1.00)}}{\dot{\psi}_{Peak}} \times 100 <= 35\% \quad \text{(Criterion \#1), and}$$

$$\frac{\dot{\psi}_{(t_0+1.75)}}{\dot{\psi}_{Peak}} \times 100 <= 20\% \quad \text{(Criterion \#2)}$$

Where,

$\dot{\psi}_t$ = Yaw rate at time t (in seconds)

$\dot{\psi}_{Peak}$ = First local peak yaw rate generated by the 0.7 Hz Sine with Dwell sterring input

t_0 = Time to completion of steering input

Mahindra Rise.

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.