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IMPACT OF AERODYNAMIC PROPERTIES ON CARSIM & TRUCKSIM SIMULATIONS

AUTHOR – XITADEL CAE TECHNOLOGIES INDIA PRIVATE LIMITED & AIRSHAPER

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Introduction

Aerodynamics are crucial to many industries and to the transportation industry in particular. Not only are aerodynamics responsible for over half the fuel/power consumption at highway speeds, but they also greatly impact the stability of vehicles under windy conditions or travelling at high speeds. With passenger safety at stake, understanding and optimizing the aerodynamics of vehicles is crucial, whether it concerns cars, trucks or bikes.

In this document, two of the most relevant cases where aerodynamics impact vehicle performance & safety are analyzed:

- Sidewind sensitivity: in the first case, the effects of a sudden sidewind are studied. Sidewinds cause both aerodynamic forces & aerodynamic moments on the vehicle. The magnitude of these forces depends on the aerodynamic coefficients of the vehicle (which, in turn, depend on the geometry of the vehicle). To indicate the sensitivity to these coefficients, they were increased by 10% to analyze the effect on vehicle stability. The result on vehicle stability & safety can clearly be observed by analyzing steering wheel angle torque, roll angle, and so on.
- Fuel consumption: as mentioned, aerodynamic drag is responsible for well over 50% of the required power (and thus fuel) to keep a vehicle moving at highway speeds. In this scenario, the vehicle virtually performs the EPA Highway Fuel Economy Test Cycle. Again, the aerodynamic coefficients were increased by 10% to illustrate the sensitivity of the end result (fuel/battery power consumption) to these parameters. The effect on fuel/energy consumption is very clear and indicates the importance of a streamlined design.

Both of the scenarios above were performed for 2 vehicle types, i.e. a car and a truck, to illustrate the difference in aerodynamic behaviour and the effect on dynamic stability, safety & fuel/energy consumption. The set-up and execution of the simulations in CarSim and TruckSim software were performed by XITADEL CAE Technologies India Private Limited.

In conclusion, the effects of aerodynamics are crucial for amongst others:

- Vehicle stability: side winds can seriously impact the vehicle course. Understanding this impact is crucial for the design of safe vehicles or the design of a controller strategy for an autonomous vehicle.
- Fuel/energy consumption: when simulating the run of a vehicle over a specified driving cycle, the aerodynamic resistance contributes greatly to the fuel/energy consumption, even for the low-speed driving cycle that was applied in this study.

Obtaining accurate aerodynamic coefficients is crucial to running accurate vehicle dynamics simulations. These coefficients can be obtained through CFD (computational fluid dynamics) simulations at AirShper (www.airshaper.com) and/or physical wind tunnel testing.

CarSim Simulations

1. Test Scenario: Crosswind Testing

1.1. Set-up:

- Constant vehicle speed of 80 km/hr. on a straight flat road with µ=0.85
- Crosswind of 100 km/h from the left and right fans as shown in Figure 1
- Parameters like steering wheel angle, yaw rate and lateral acceleration etc. are mapped @ the sprung mass (see section 5.1)
- The simulation was carried out for 2 cases:
  a) Case 1 – Run cross wind simulations with below set-up
     - No Aerodynamics
     - With Aerodynamics
     - 10% increase for all aerodynamics coefficient
  b) Case 2 – Run cross wind simulations with below set-up
     - No Aerodynamics
     - With Aerodynamics
     - 10% increase for just the lateral force coefficient

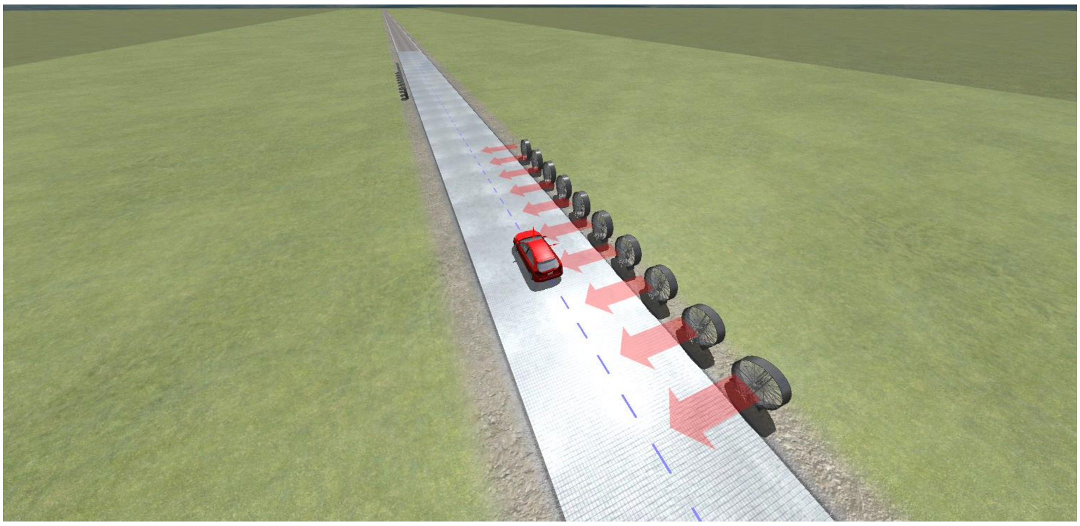

Figure 1: Crosswind Procedure setup

1.2. Results:

1.2.1. Steering wheel angle deviation

1.2.1.1. Case 1:

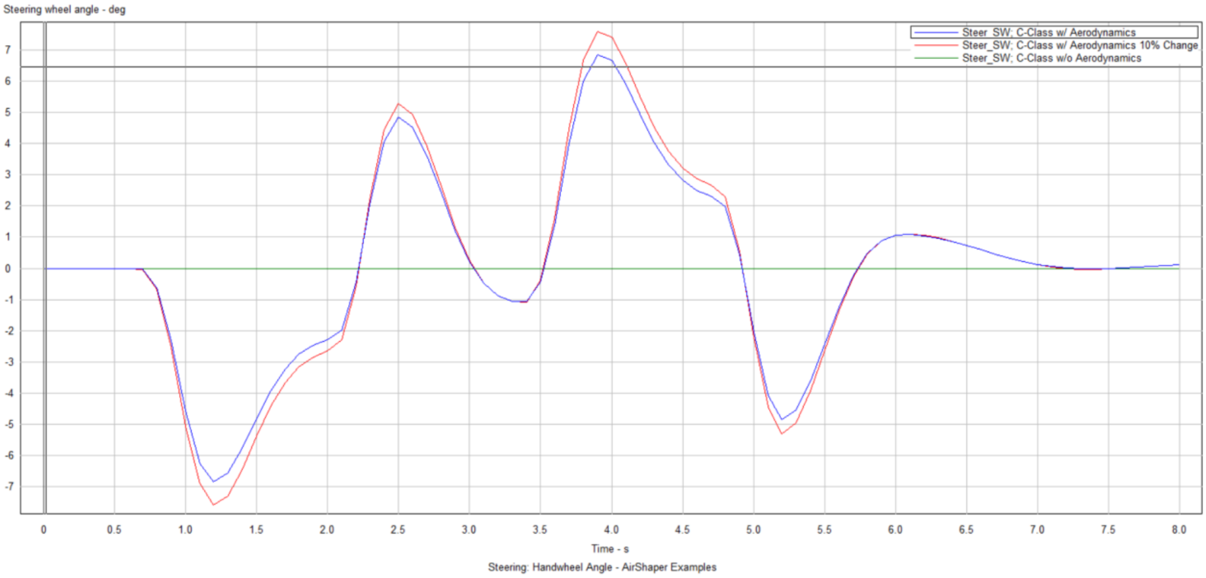

Figure 2: Steering wheel angle deviation due to crosswinds *<u>all coefficients changed</u>*

1.2.1.2. Case 2:

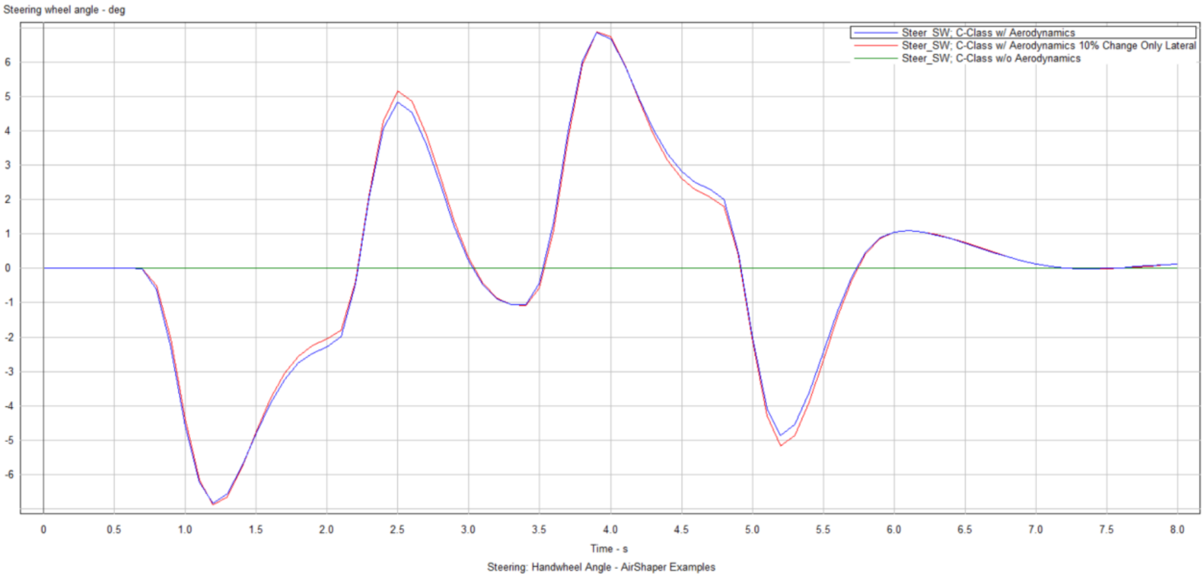

Figure 3: Steering wheel angle deviation due to crosswind *<u>only lateral coefficient changed</u>*

1.2.2. Yaw angle deviation

1.2.2.1. Case 1:

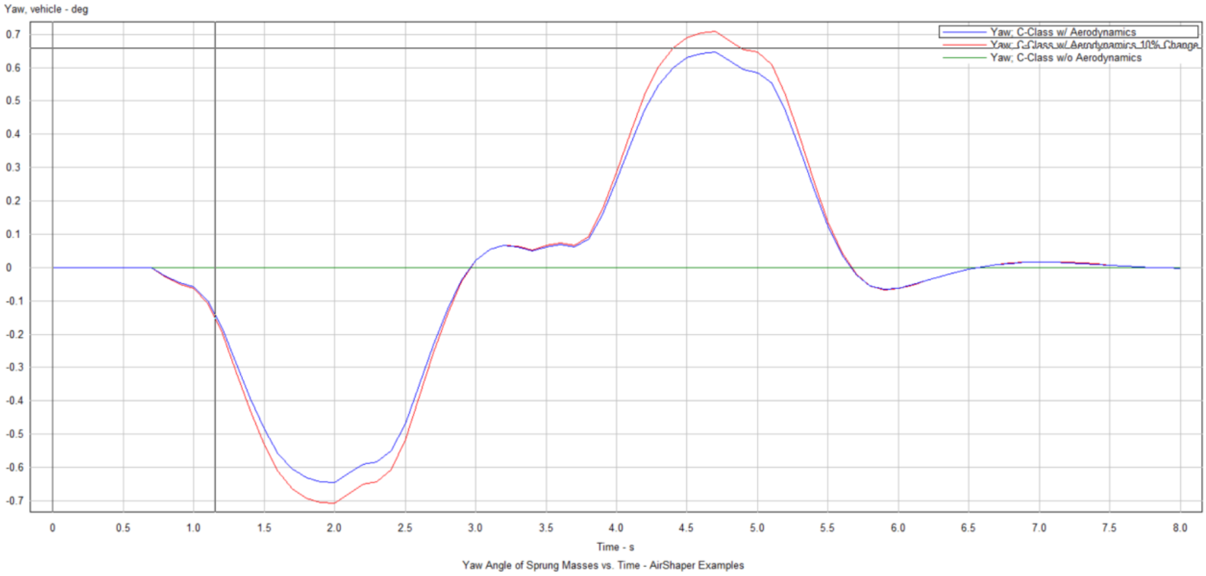

Figure 4: Yaw angle deviation due to crosswinds <u>all coefficients changed</u>

1.2.2.2. Case 2:

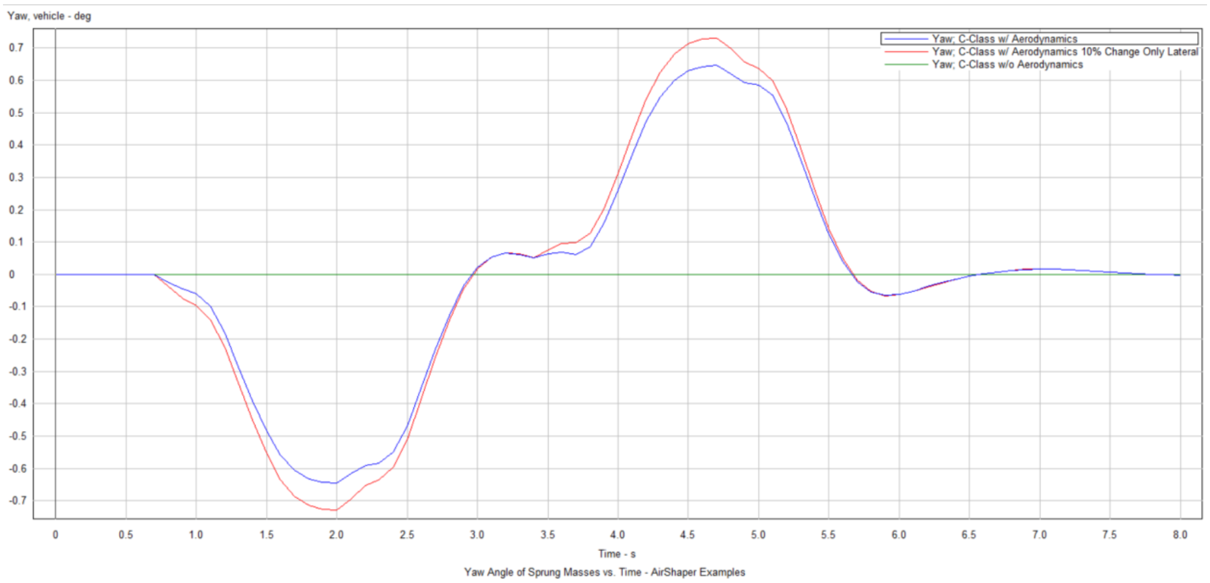

Figure 5: Yaw angle comparison crosswind <u>only lateral coefficients changed</u>

1.2.3. Roll angle variation

1.2.3.1. Case 1:

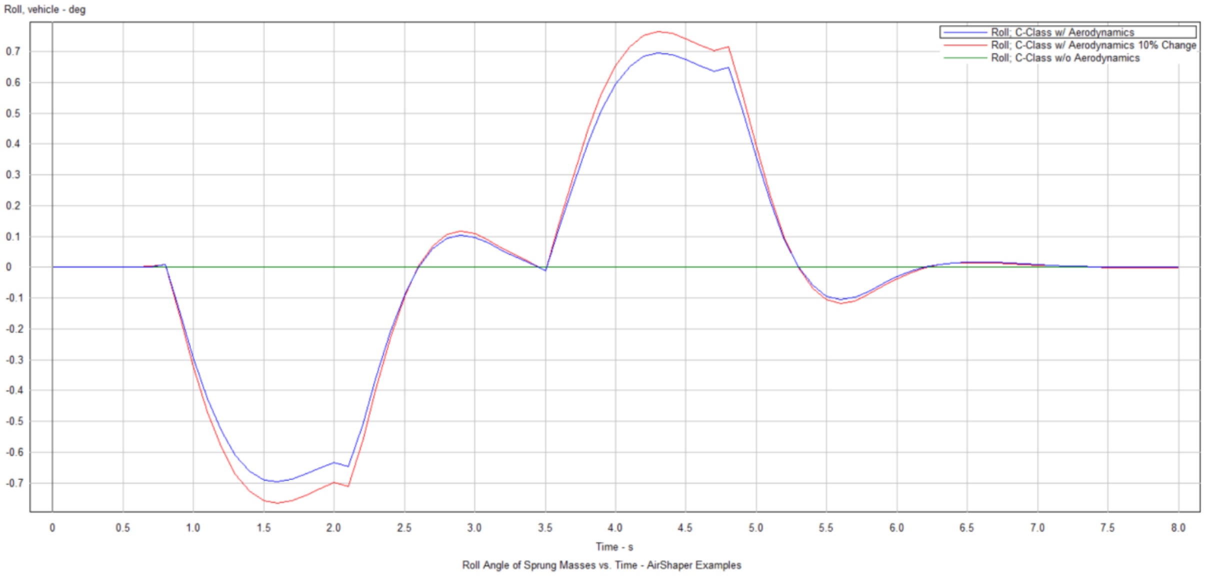

Figure 6: Roll angle variation due to Crosswinds <u>all coefficients changed</u>

1.2.3.2. Case 2:

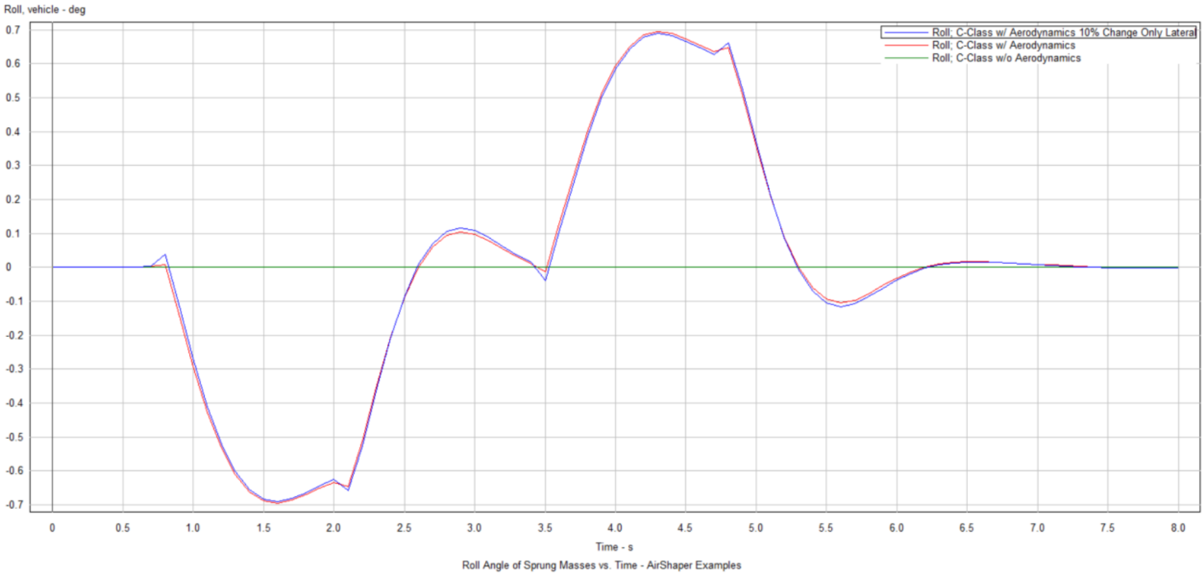

Figure 7: Roll angle variation due to Crosswinds <u>all lateral coefficients changed</u>

1.2.4. Lateral Acceleration

1.2.4.1. Case 1:

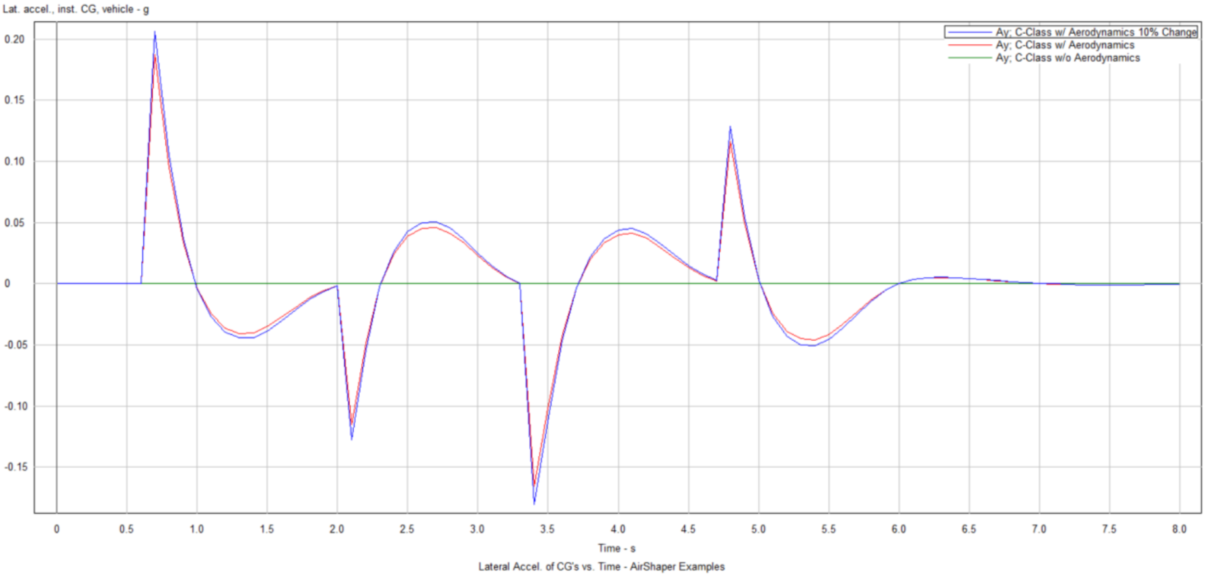

Figure 8: Lateral Acceleration comparison crosswind <u>all co-efficient changed</u>

1.2.4.2. Case 2:

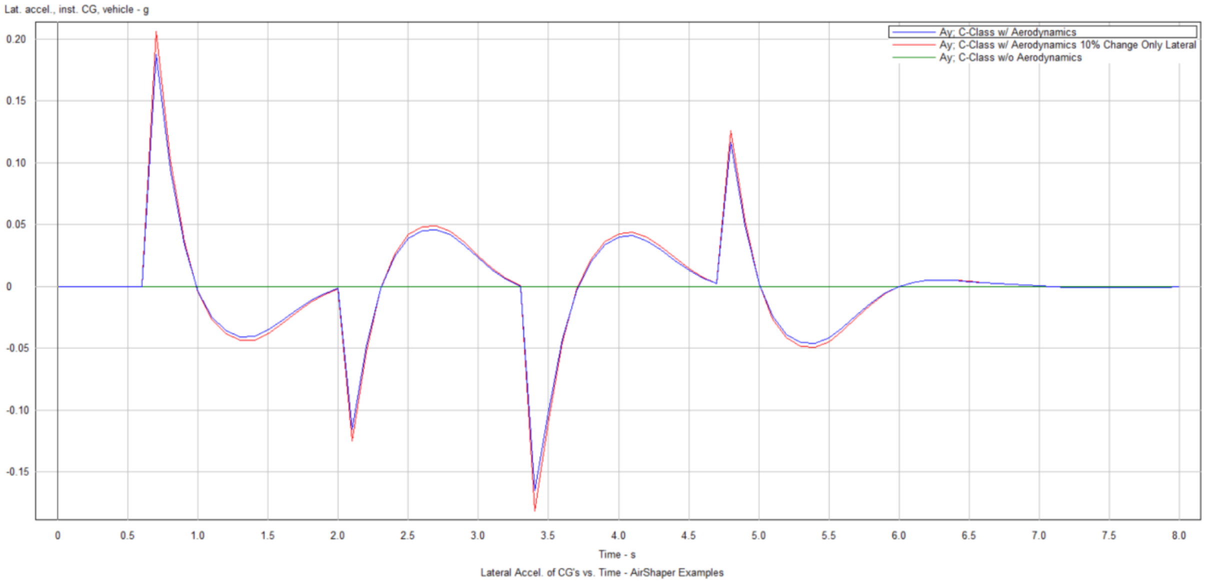

Figure 9: Lateral Acceleration comparison crosswind <u>only lateral coefficients changed</u>

1.2.5. Steering torque

1.2.5.1. Case 1:

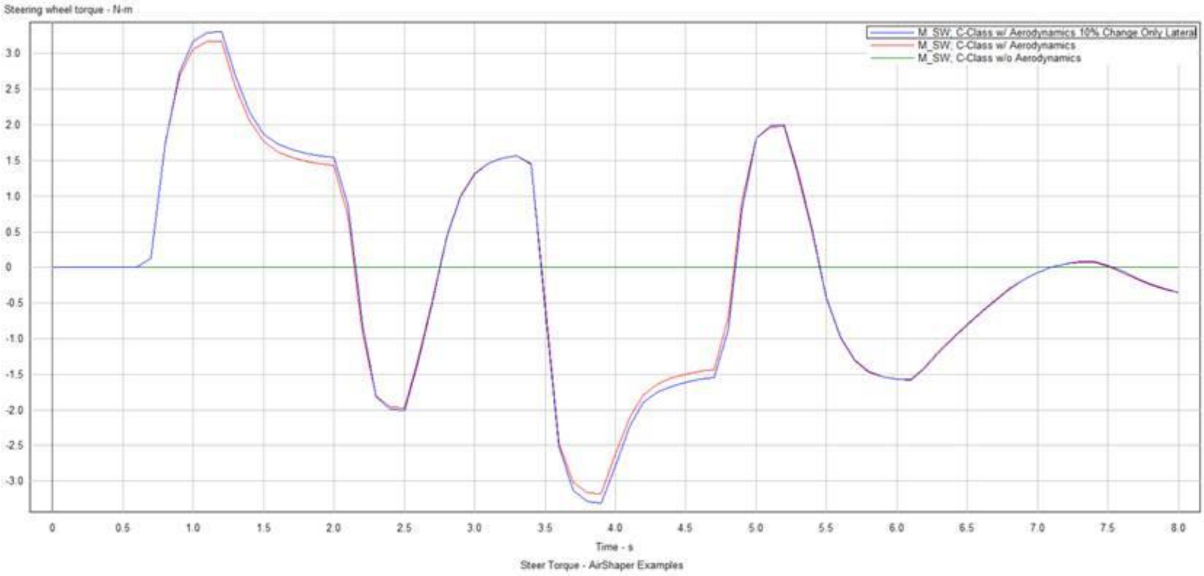

Figure 10: Steering Torque v/s time comparison crosswind <u>all co-efficient changed</u>

1.2.5.2. Case 2:

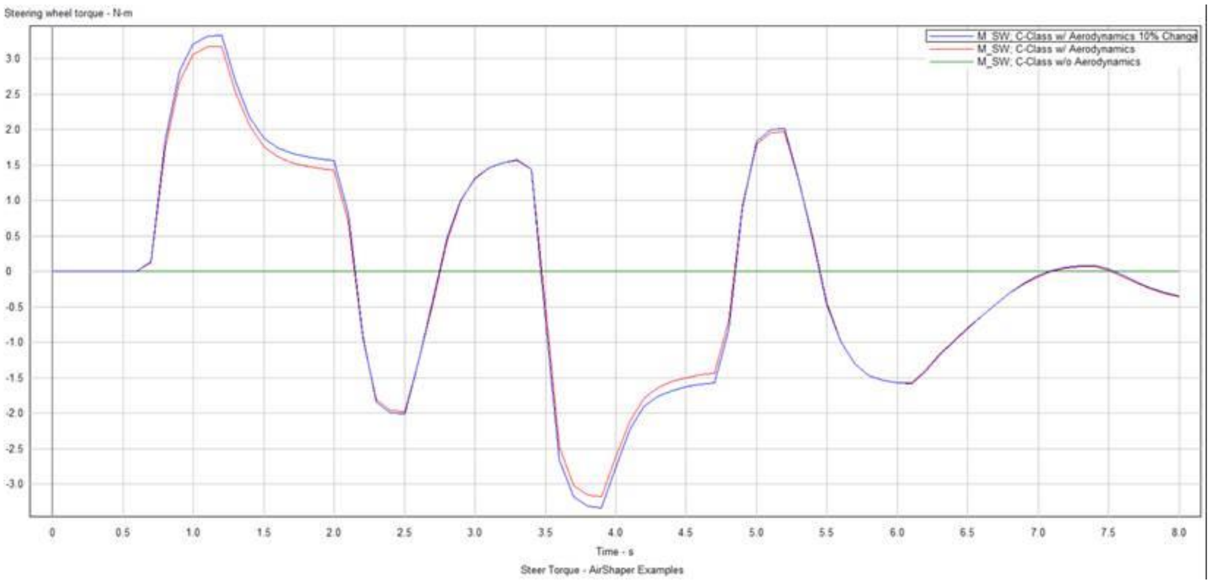

Figure 11: Steering Torque v/s time comparison crosswind <u>only lateral coefficients changed</u>

1.3. Observations

- Disabling the aerodynamic coefficients: as expected, this eliminates the wind forces on the vehicle entirely. Therefore, no changes in the steering wheel angle, yaw angle etc. are observed in the crosswind simulations.
- Increase the aero coefficients by 10%: this shows considerable changes in steering angle, yaw angle, lateral acceleration etc.
- Increase only the lateral aero coefficients by 10%: shows considerable changes in steering angle, yaw angle, lateral acceleration etc. but not much change is observed in the roll angle.

2. Test Scenario: Fuel Economy Testing

2.1. Set-up:

- Vehicle speed profile as per EPA Highway Fuel Economy Test Cycle (HWFET) on a straight flat road
- Fuel consumed over the cycle is measured
- The simulation was carried out for three cases:
    a) No Aerodynamics
    b) With Aerodynamics
    c) 10% increase in aerodynamics coefficient as shown in Figure 1 to 6

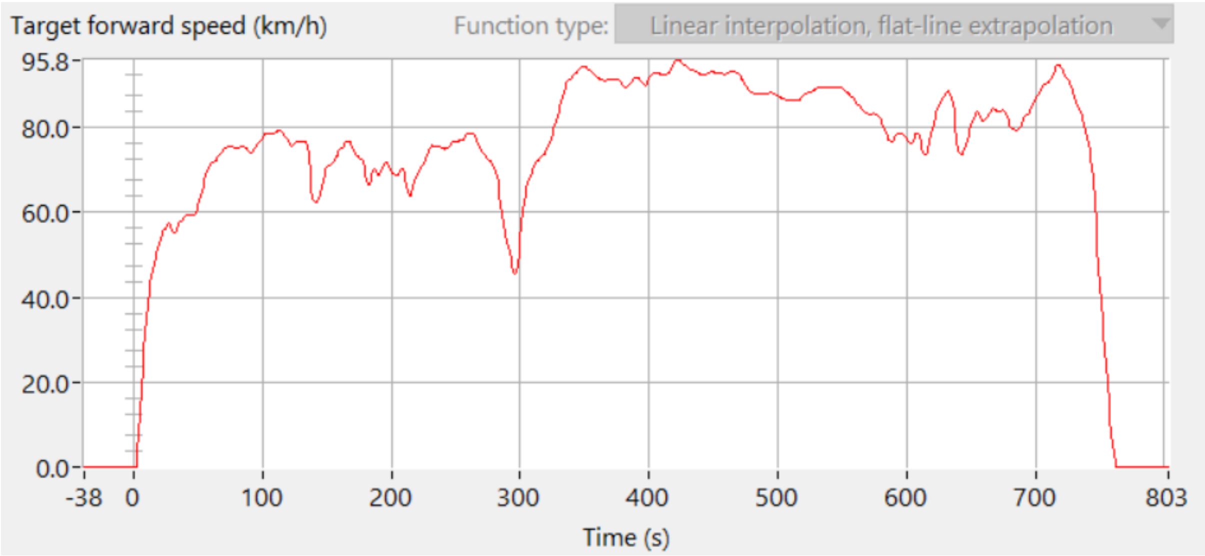

Figure 12: Vehicle Speed Profile EPA Highway Cycle

2.2. Results

1.1.1. Fuel consumption

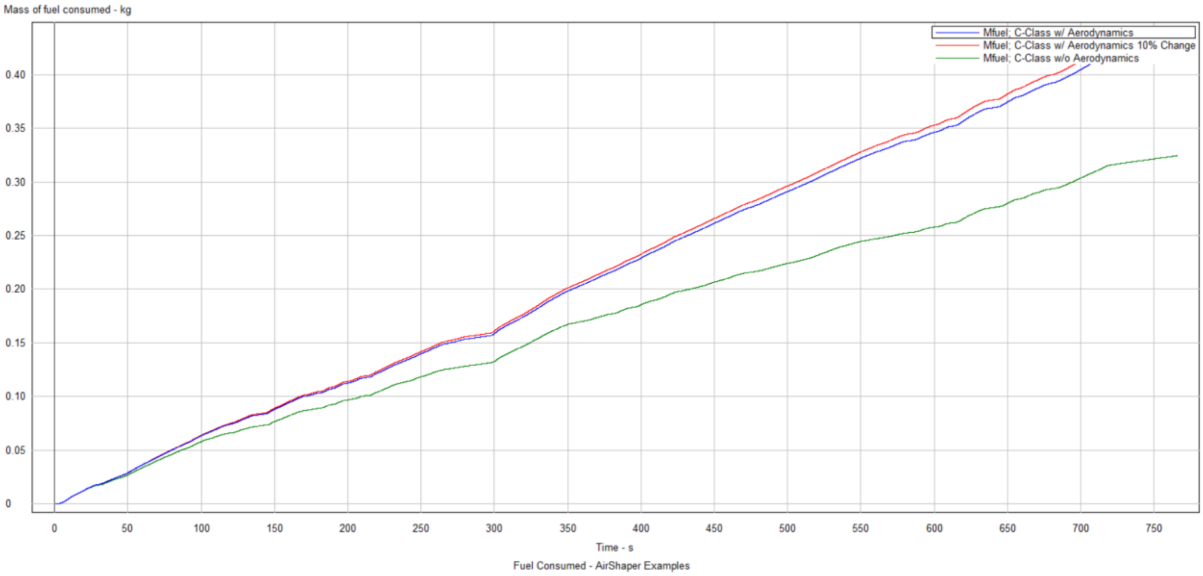

Figure 13: Fuel Consumed Over EPA Highway Cycle

2.3. Observations:

- Disabling the aerodynamic coefficients: as expected, this eliminates any wind resistance and thus greatly reduces fuel consumption.
- Increase the aero coefficients by 10%: this shows a change in fuel consumption over the EPA cycle of around 3% - a considerable amount.

TruckSim Simulations

3. Test Scenario: Crosswind Testing

2.1. Crosswind Testing:

- Constant vehicle speed of 80 km/hr. on a straight flat road with μ=0.85
- Crosswind of 100 km/h from the left and right fans as shown in figure 12
- Parameters like steering wheel angle, yaw rate and lateral acceleration etc. are mapped @ the sprung mass (see section 5.2)
- The simulation was carried out for below Case:
    a) No Aerodynamics
    b) With Aerodynamics
    c) 10% increase in aerodynamics coefficient as shown below

Figure 14: TruckSim Crosswind Simulation

2.2. Results:

2.2.1. Steering wheel angle deviation

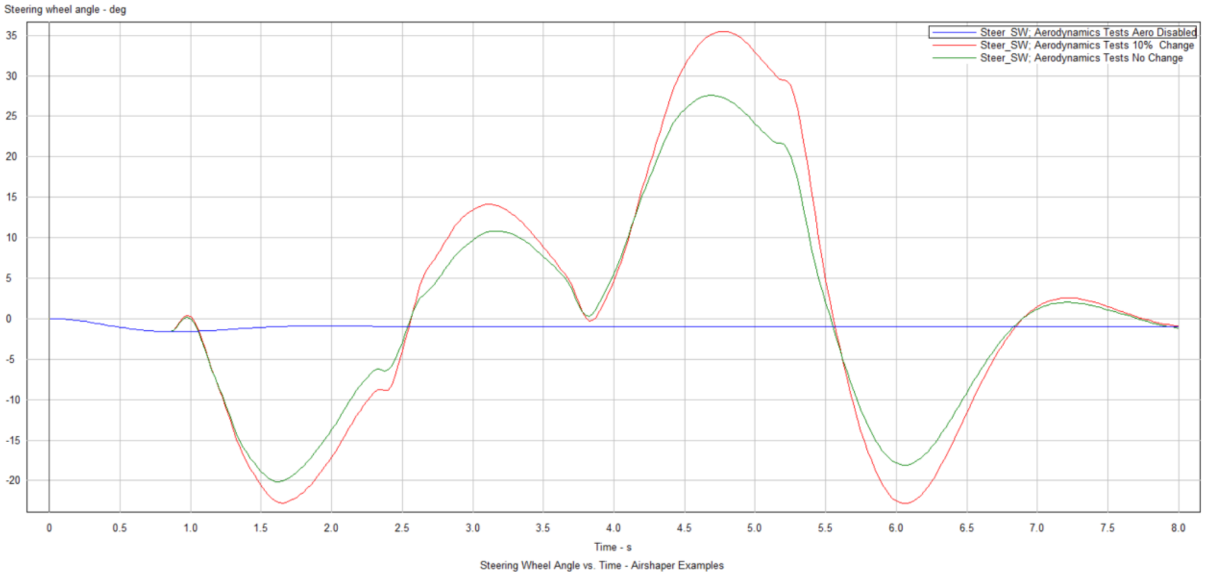

Figure 15: Steer angle versus time for different aero conditions

2.2.2. Yaw angle deviation

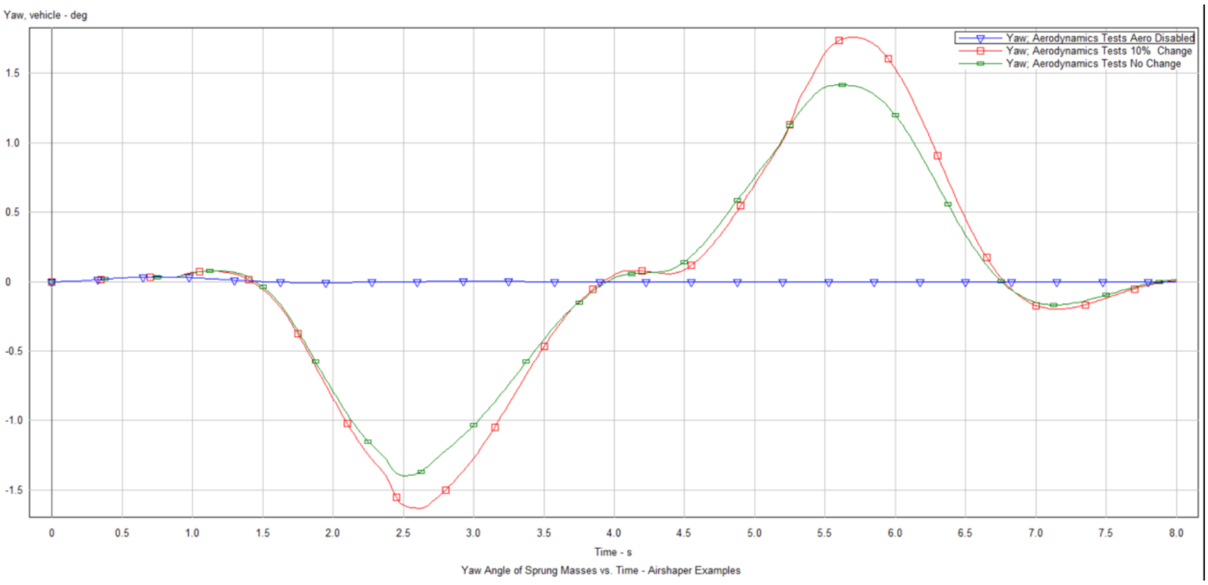

Figure 16: Yaw angle versus time for different aero conditions

2.2.3. Roll angle variation

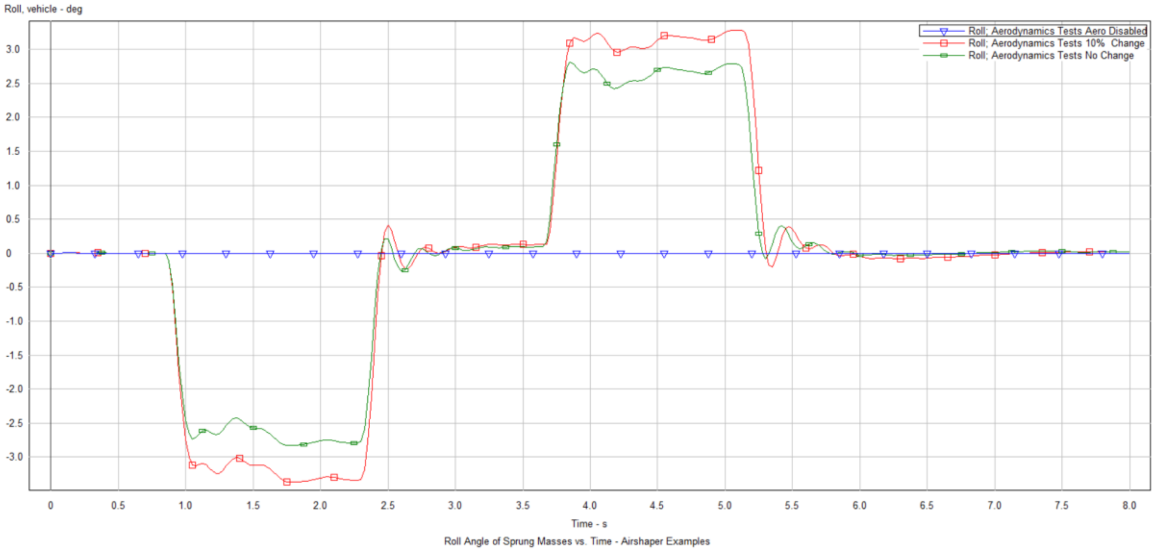

Figure 17: Roll angle versus time for different aero conditions

2.2.4. Lateral Acceleration

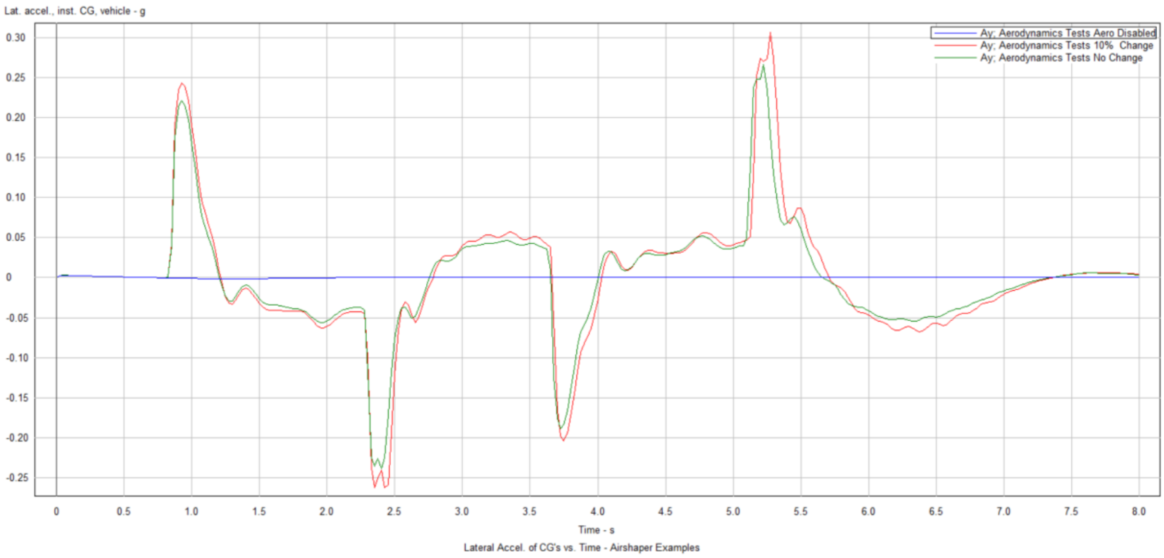

Figure 18 : Lateral acceleration versus time for different aero conditions

2.2.5. Steering torque

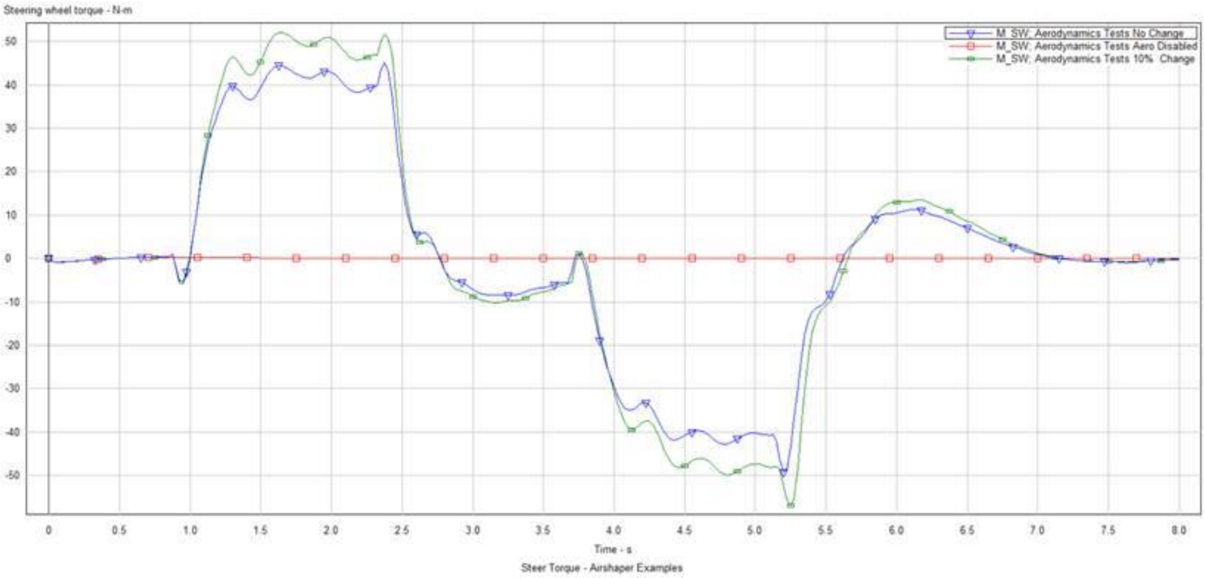

Figure 19 : Steering torque versus time for different aero conditions

2.3. Observations:

1. Disabling the aerodynamic coefficients: as expected, this eliminates the wind forces on the vehicle entirely. Therefore, no changes in the steering wheel angle, yaw angle etc. are observed in the crosswind simulations.
2. Increasing the aero coefficients by 10%: this shows considerable changes in steering angle, yaw angle, lateral acceleration etc. These relative changes are often larger than the relative change of the coefficients themselves, so the effect is super-linear.

4. Fuel Economy Testing:

4.1. Set-up:

- Vehicle speed profile as per EPA Highway Fuel Economy Test Cycle (HWFET) on a straight flat road
- Fuel consumed over the cycle is measured
- The simulation was carried out for three cases:
  a) No Aerodynamics
  b) With Aerodynamics
  c) 10% increase in aerodynamics coefficient as shown in the appendix

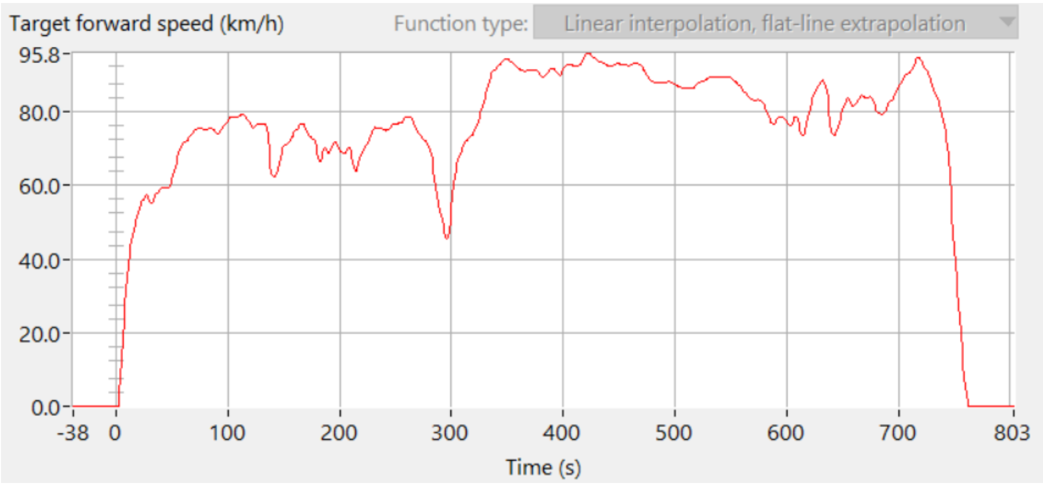

Figure 20: Vehicle Speed profile EPA Highway cycle

4.2. Results

3.2.2. Fuel consumption

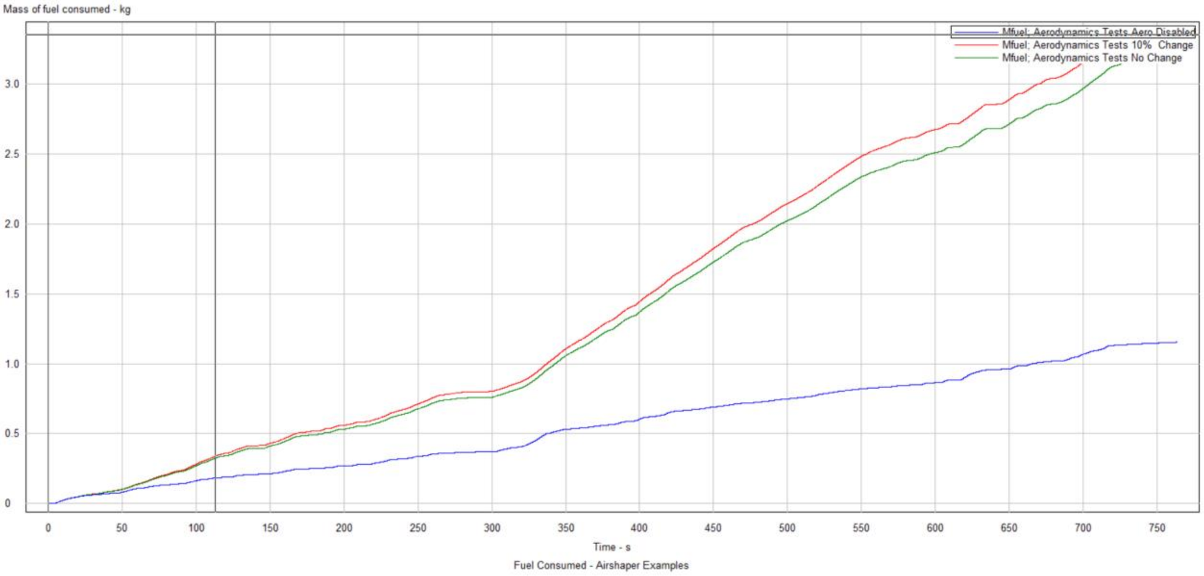

Figure 21 : Fuel Consumption over EPA Highway cycle

4.3. Observations:

- Disabling the aerodynamic coefficients: as expected, this eliminates any wind resistance and thus greatly reduces fuel consumption.
- Increase the aero coefficients by 10%: this shows a change in fuel consumption over the EPA cycle of around 5% - a considerable amount.

5. Appendix

5.1. CarSim Set-up: Cross Wind Simulation

<u>General</u>

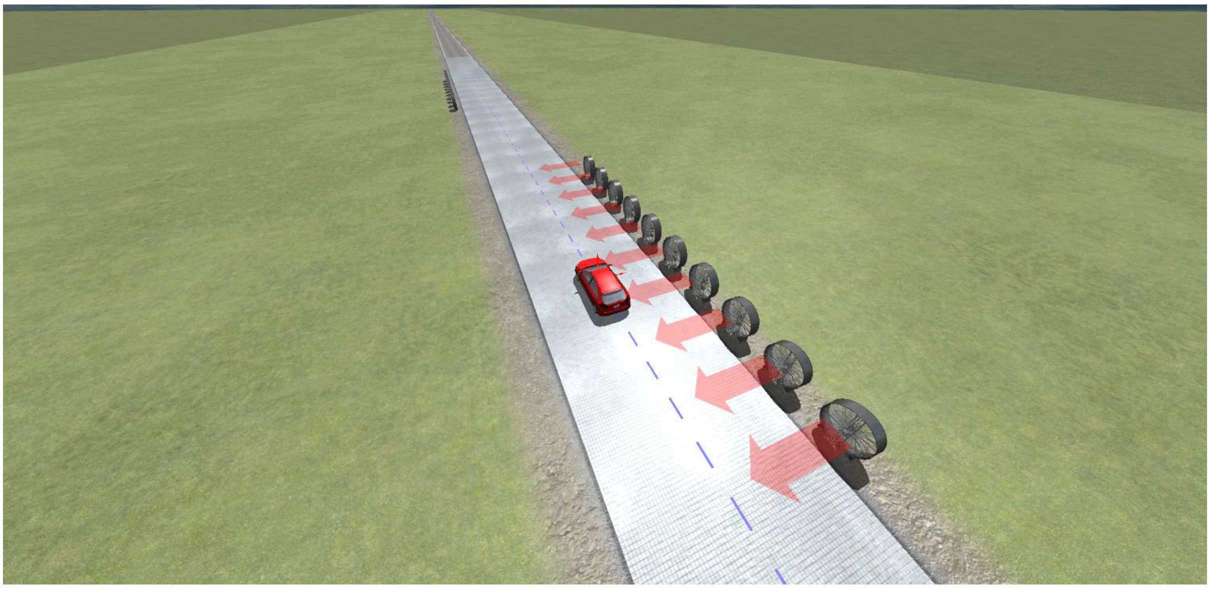

Figure 22: Crosswind Procedure setup

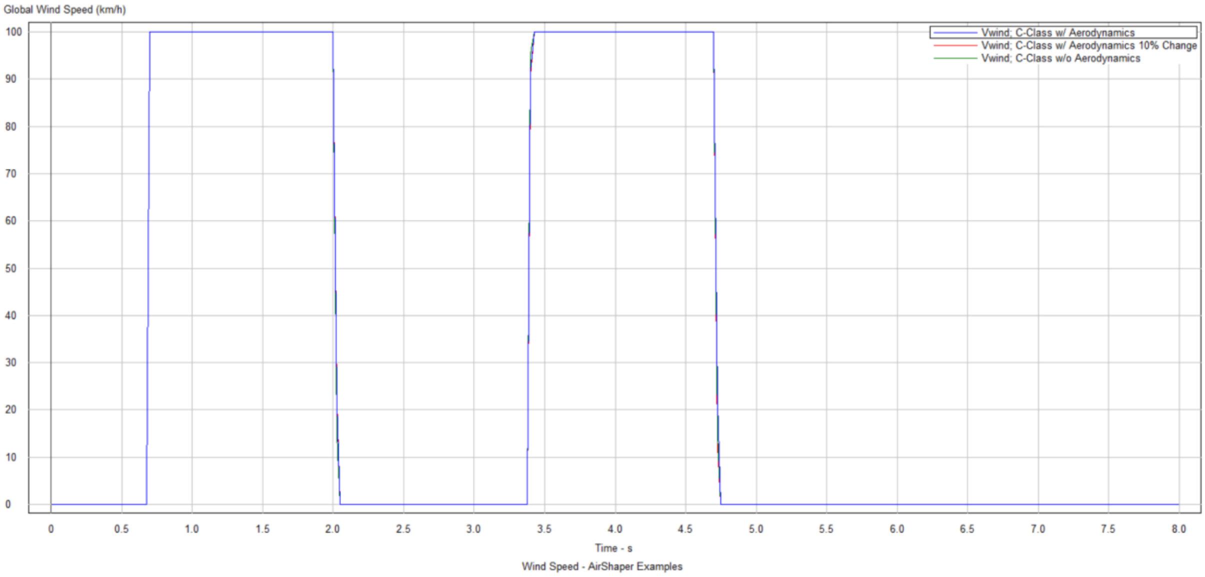

Figure 23: Crosswind velocity inputs 100kmph

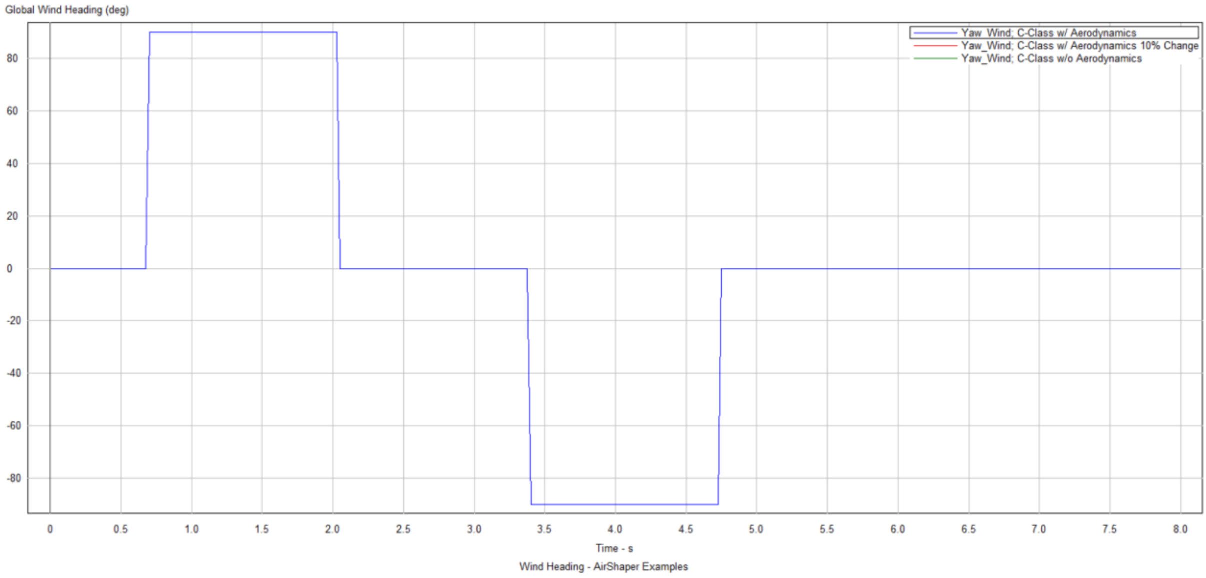

Figure 24: Crosswind heading angle input +90 deg & -90 deg

<u>Aerodynamic parameters</u>:

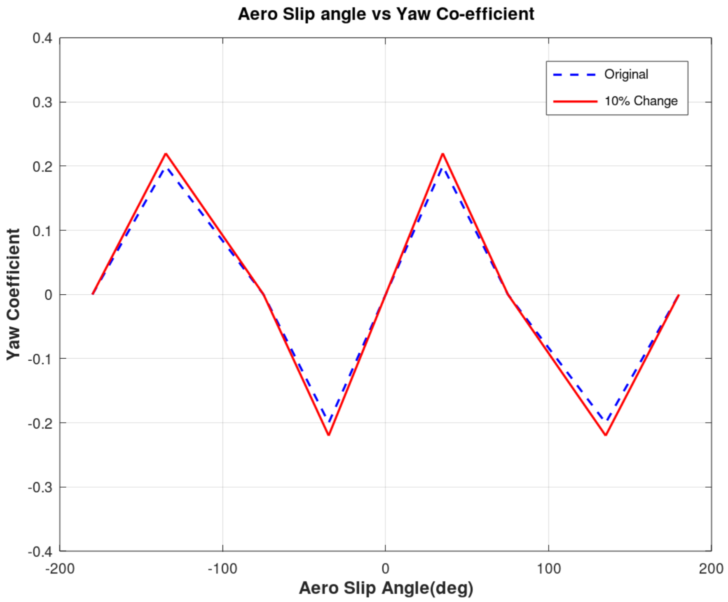

Figure 25: Yaw coefficient versus Aero Slip Angle

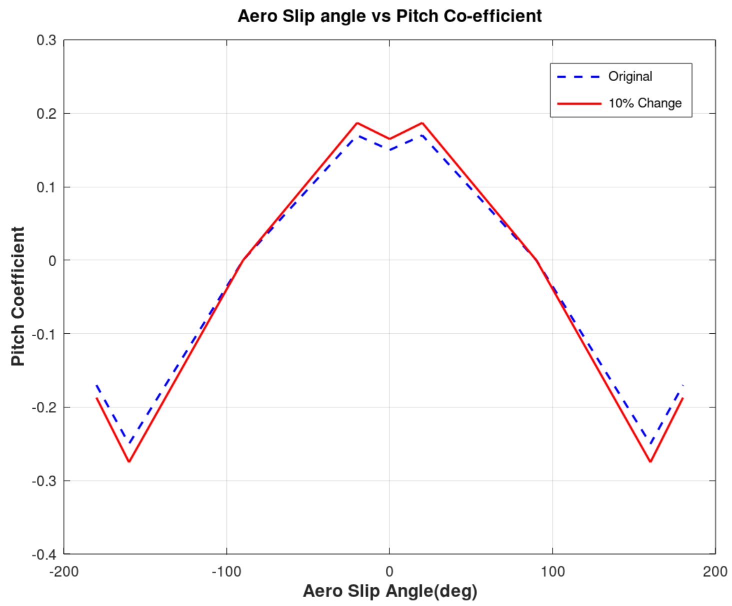

Figure 26: Pitch coefficient versus Aero Slip

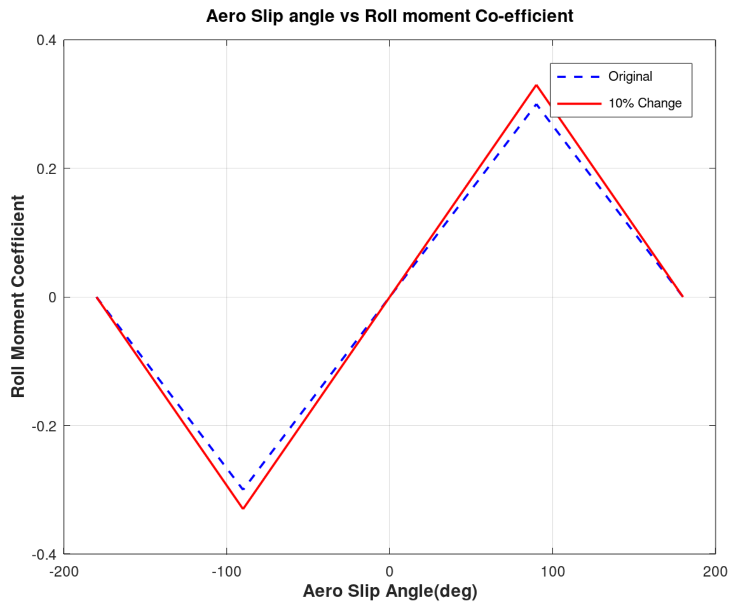

Figure 27: Roll Moment versus Aero slip

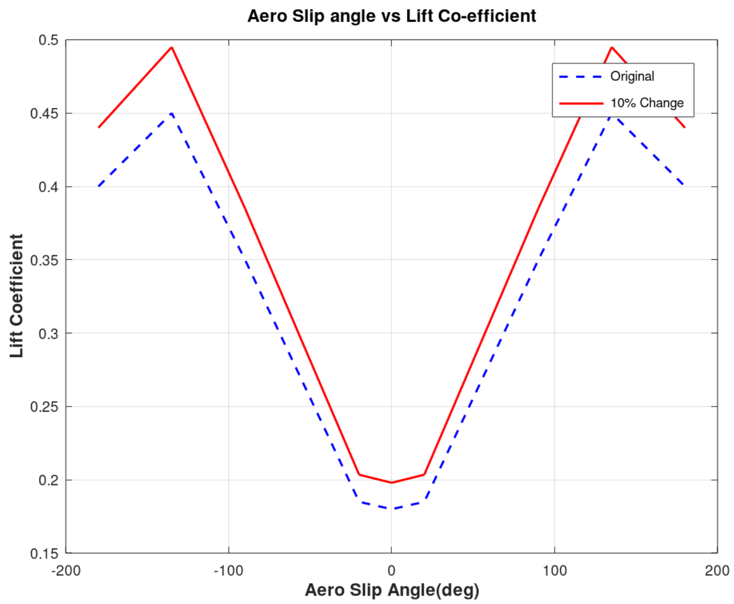

Figure 28: Lift Coefficient versus Aero Slip

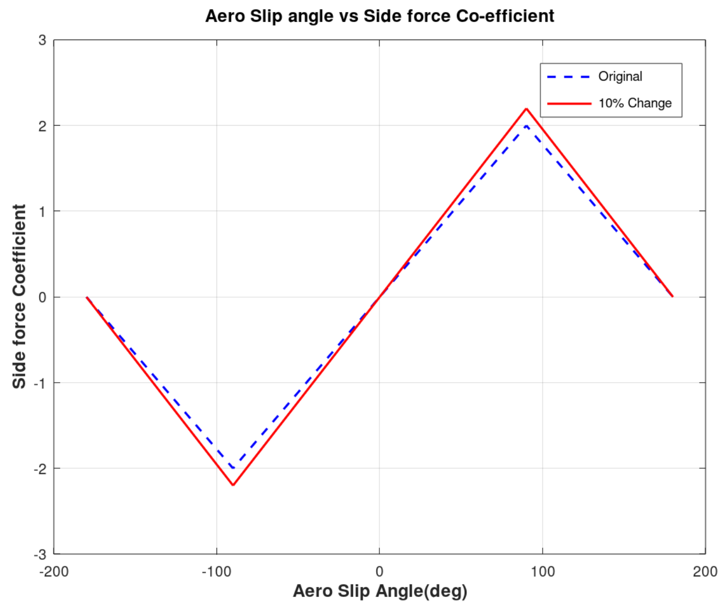

Figure 29: Side force coefficient versus Aero Slip

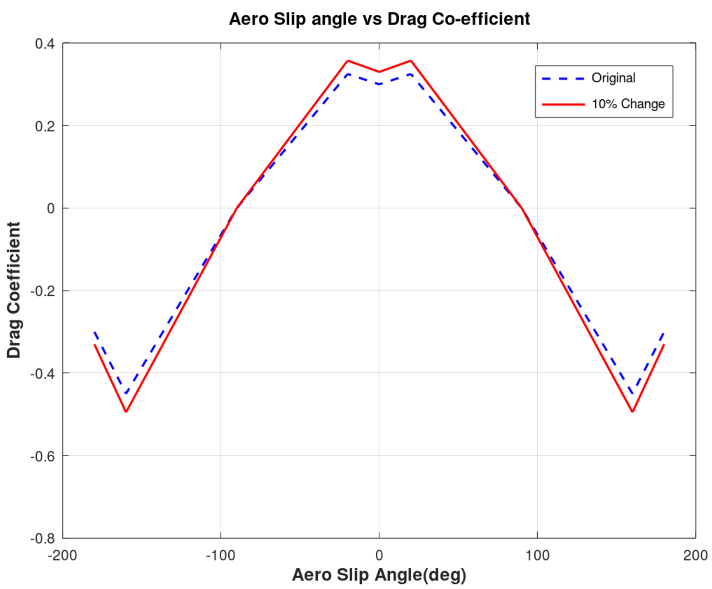

Figure 30 : Drag Coefficient versus Aero Slip

5.2. TruckSim Set up: Cross Wind Simulation

Figure 31: TruckSim Crosswind Simulation

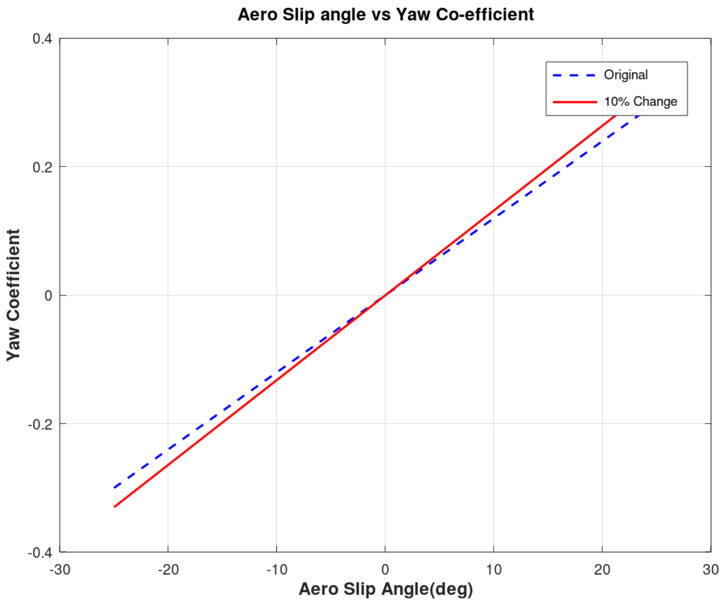

Figure 32: Aero Slip versus yaw co-efficient

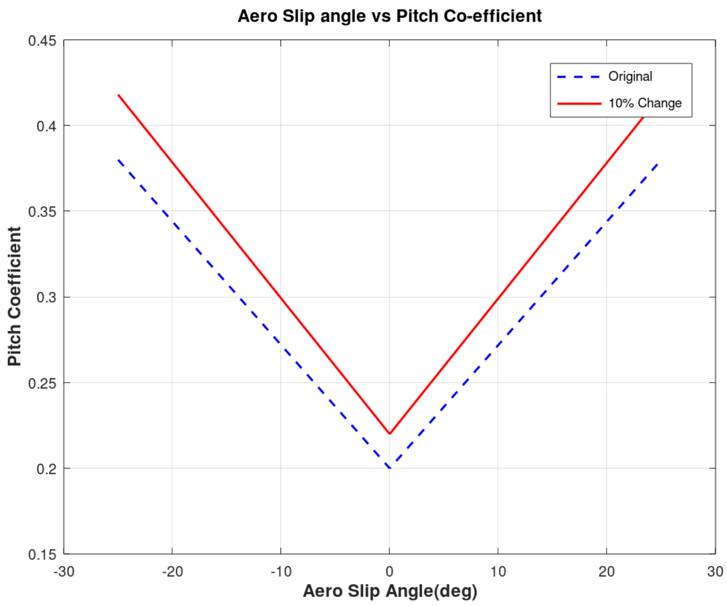

Figure 33: Aero Slip versus pitch co-efficient

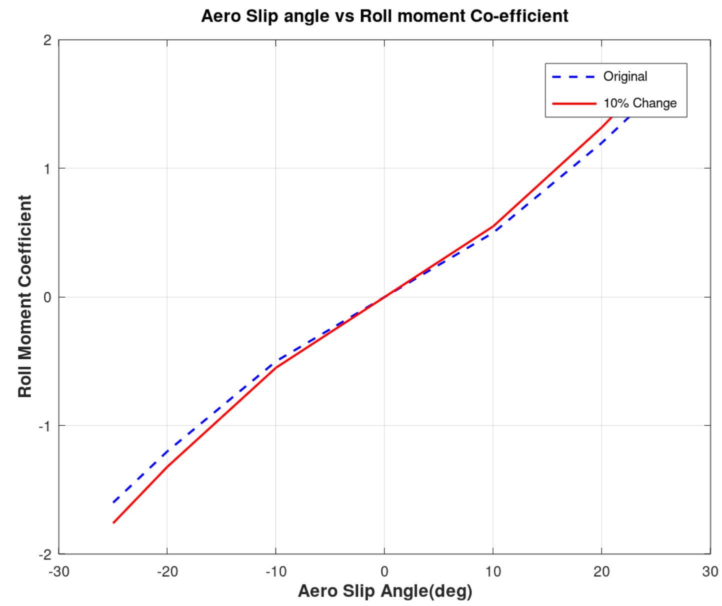

Figure 34 : Aero Slip versus roll moment co-efficient

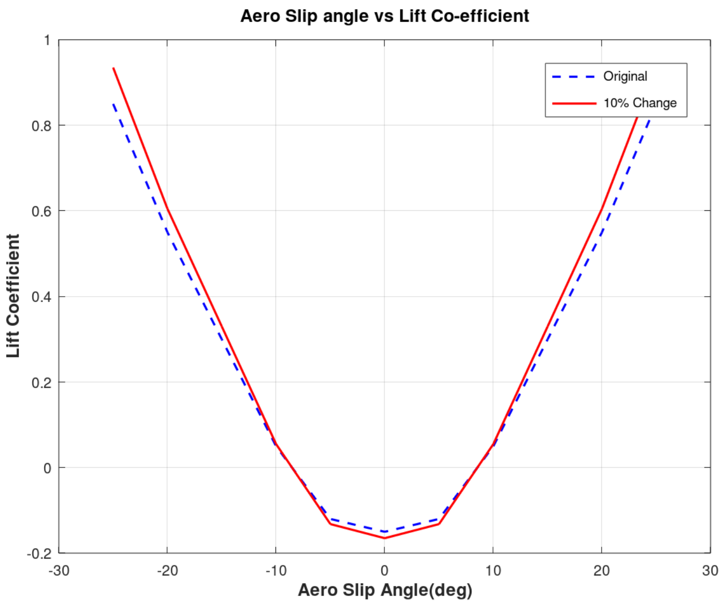

Figure 35: Aero Slip versus lift co-efficient

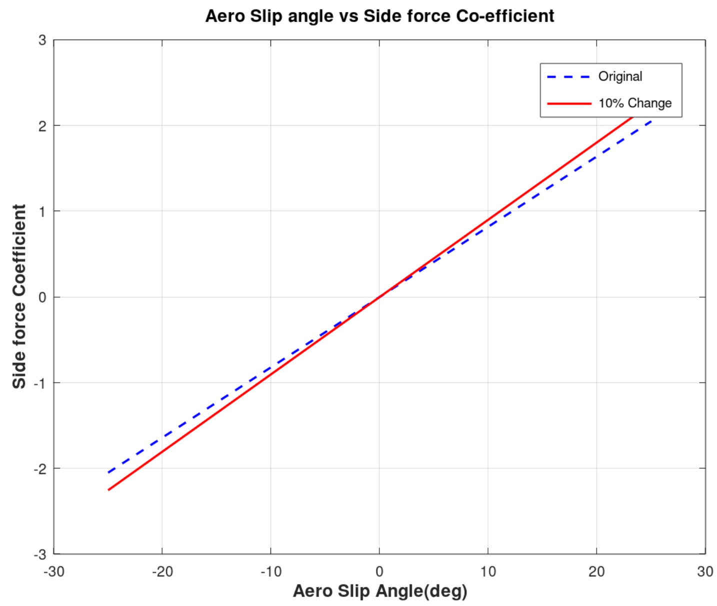

Figure 362 : Aero Slip versus side co-efficient

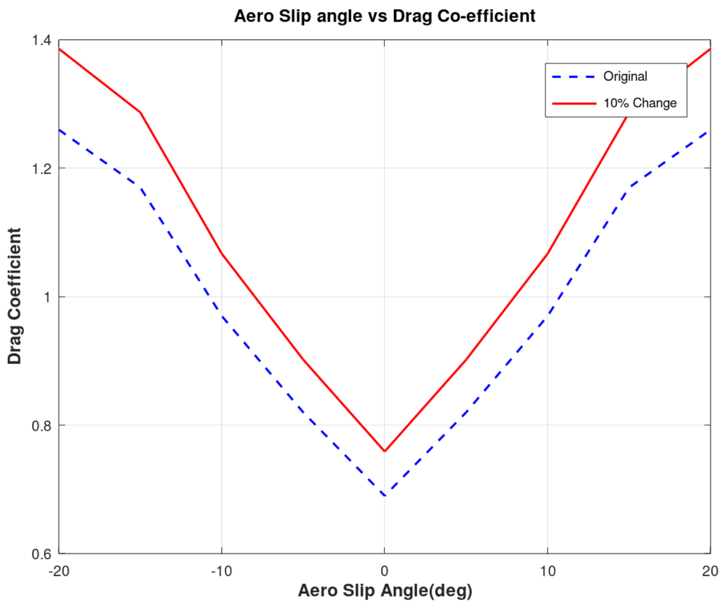

Figure 37: Aero Slip versus drag co-efficient