R140 ESC – Sine with dwell case study

Input from the expert of EC - JRC

TF FADS #24

Disclaimer

- This is an initial analysis on how ADS vehicles are affected by the lateral displacement requirement of para. 7.3. of the regulation.
- The analysis is focusing only on the responsiveness criterion (minimum lateral displacement), the stability criteria were not considered.
- The simulation results shown in this presentation are purely for demonstration purposes and might contain inaccuracies.
- The simulations do not contain any ESC intervention. ESC would enhance responsiveness, therefore lateral displacement values would be higher.

The approach

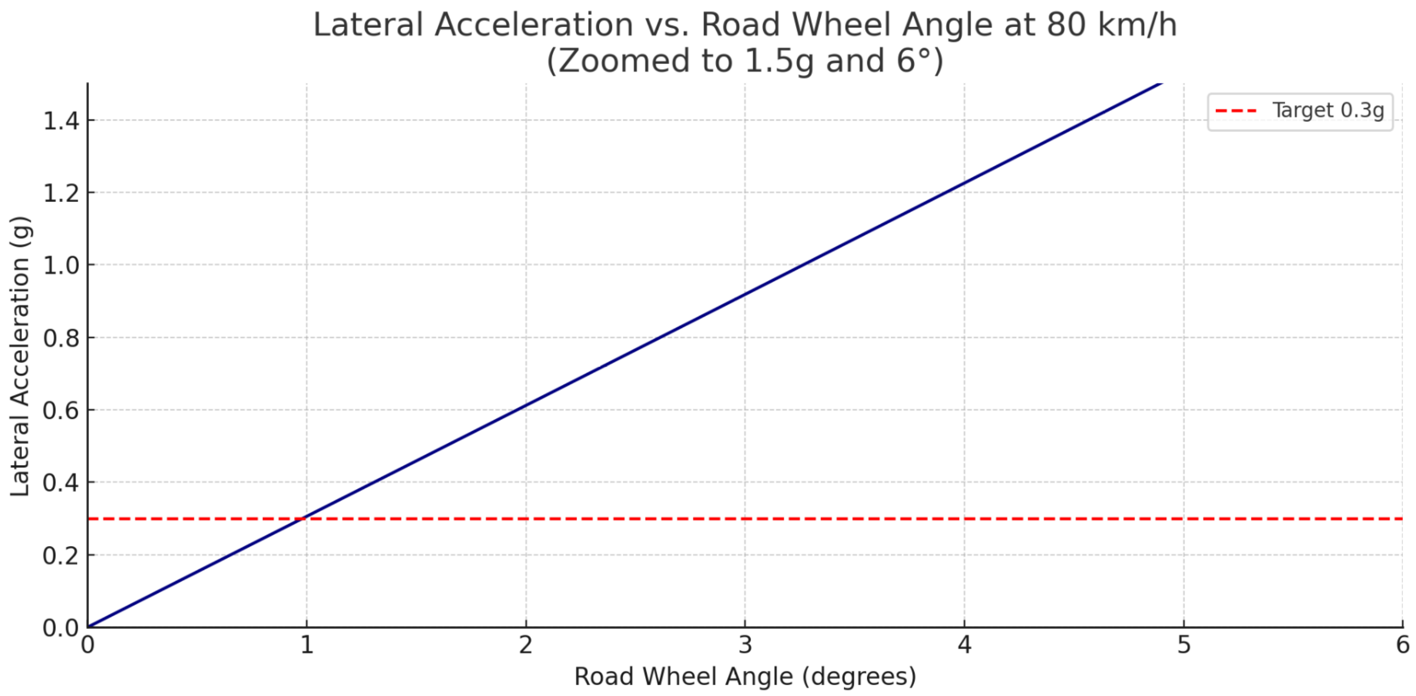
- Simulate a car carrying out the prescribed tests runs for the Sine with Dwell test, considering each step from 1.5A to 6.5A with different model characteristics:
  - Simple kinematic model
  - Linear slip model
  - Non-linear slip model

The car: Volvo V60 T6 AWD

Parameter	Value
Model	2024 Volvo V60 Recharge T6 AWD
Curb Weight	2,064 kg (4,550 lbs)
Wheelbase	2,872 mm (113.1 inches)
Length	4,778 mm (188.1 inches)
Width	1,850 mm (72.8 inches)
Height	1,432 mm (56.4 inches)
Front/Rear Track Width	1,610 mm (63.4 inches)
Steering Ratio	16.2:1
Turns Lock-to-Lock	3.0
Front Tire Size	235/45 R18
Rear Tire Size	235/45 R18
Front Brake Diameter	345 mm
Rear Brake Diameter	320 mm

Determination of “A”

- Results using a **kinematic bicycle model**:
  - To reach **0.3g lateral acceleration** at 80 km/h:
  - The **road wheel angle** needs to be approximately **0.98°**
  - The corresponding **steering wheel angle (A)** is about **15.89°**



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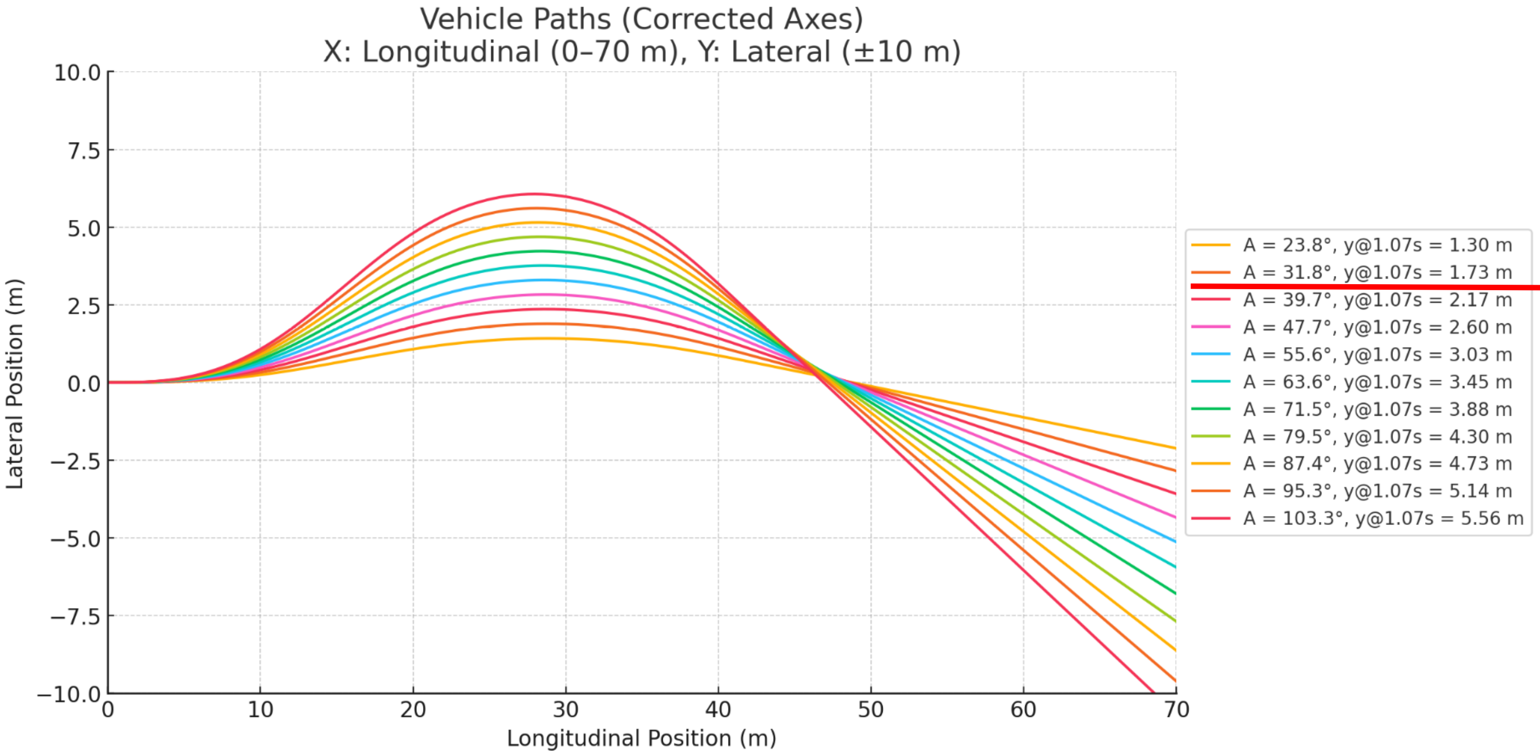
Simple kinematic model

- Model without tire slip, infinite force can be transmitted through the tire-ground connection, etc.



In an ideal world…

5A, lateral displacement > 1.83m

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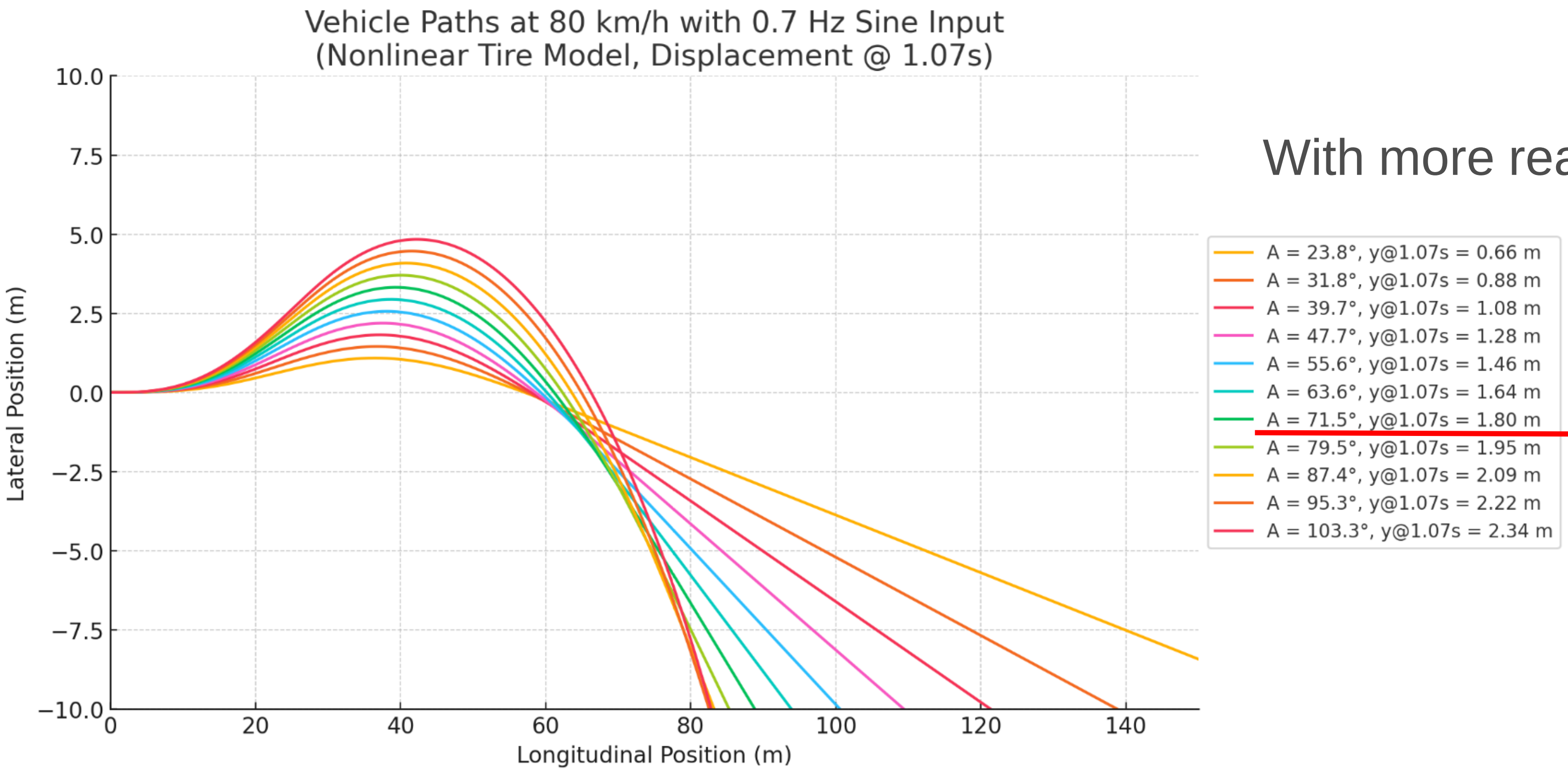
Non-linear tyre slip

$$F_y = -C \cdot \tan(\alpha) \cdot \frac{1}{\sqrt{1 + \left(\frac{C \cdot \tan(\alpha)}{F_{\max}}\right)^2}}$$

- Assumption 1: weight distribution is 50/50 → approx. 1010 kg per axle
- Assumption 2: Max lateral force per axle = 1010 x 9.81 x 0.9 ≈ 8920 N (Friction coefficient = 0.9)



With more realistic assumptions:

5A, lateral displacement > 1.83m

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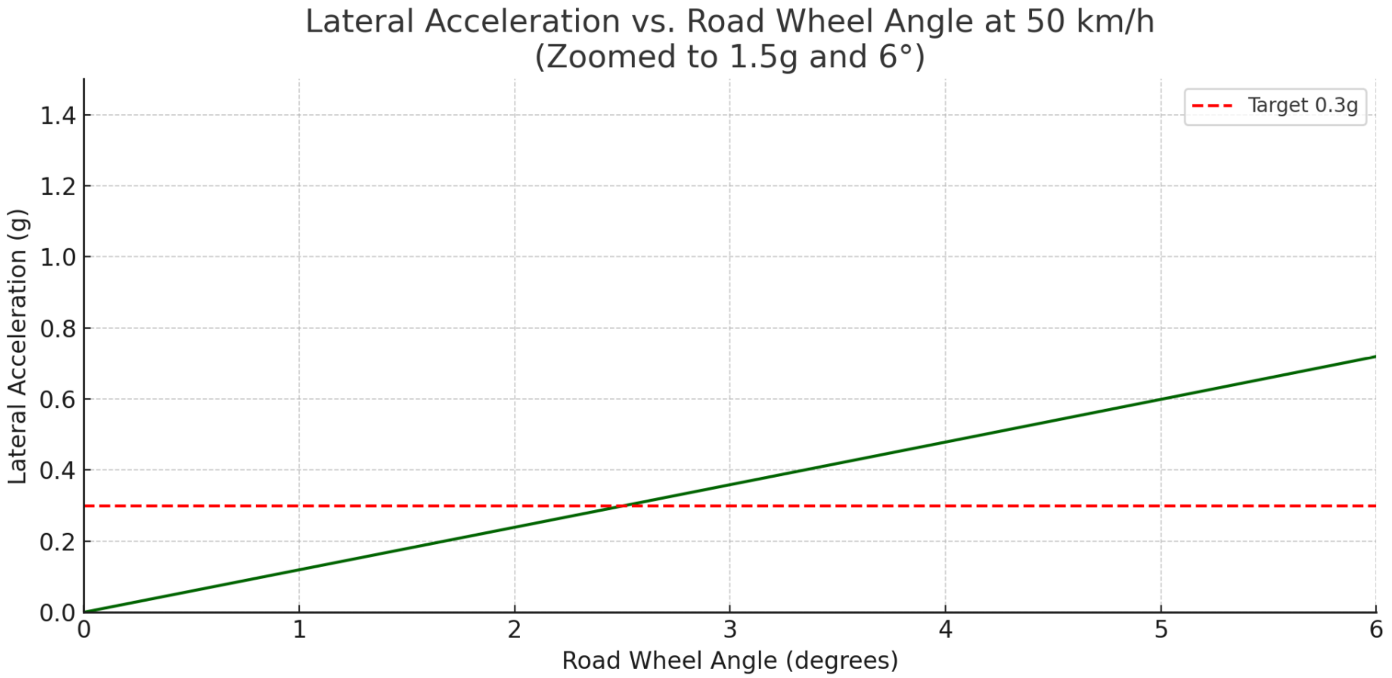
Conclusions 1

- A new car without ESC gets close to fail the type approval for R140.
- Car response with ESC is probably closer to the simple kinematic model results due to the active, wheel selective braking function of the ESC.
- These results are simulated with 80 km/h and 0.7 Hz sine frequency.
- What would happen in case of an X or Y vehicle with limited maximum speed and/or steering power?

Case study: urban ADS vehicle

- Let’s assume an urban shuttle with 50 km/h max speed, which can still maintain the prescribed 0.7 Hz sine frequency.
- All other vehicle parameters are the same.



At **50 km/h**, the vehicle needs:

- A **road wheel angle** of approximately **2.51°**
- Corresponding to a **steering wheel angle** “A” of about **40.64°**

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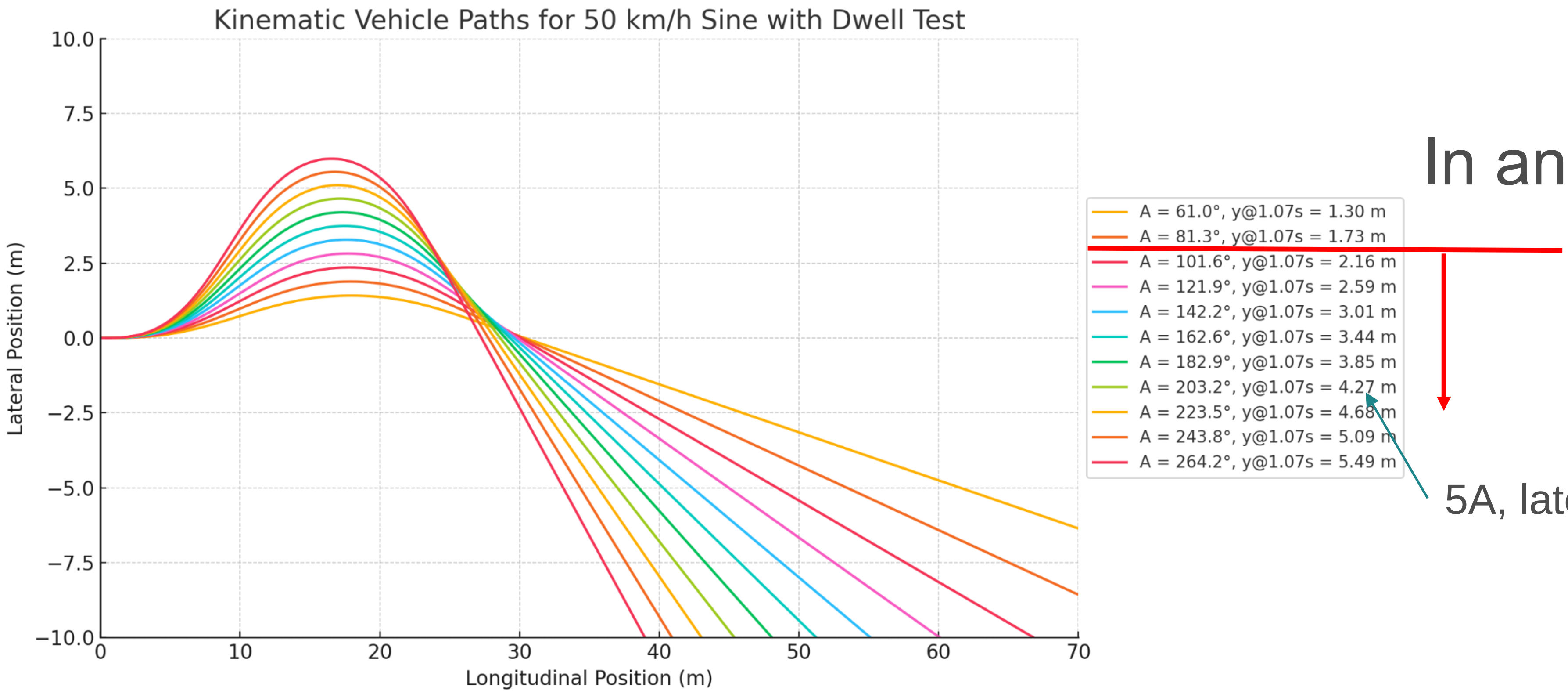
Simple kinematic model with 50 km/h

- The value of “A” is tied to normalised lateral acceleration (g): the higher steering wheel rotation values will correspond to a higher lateral displacement.

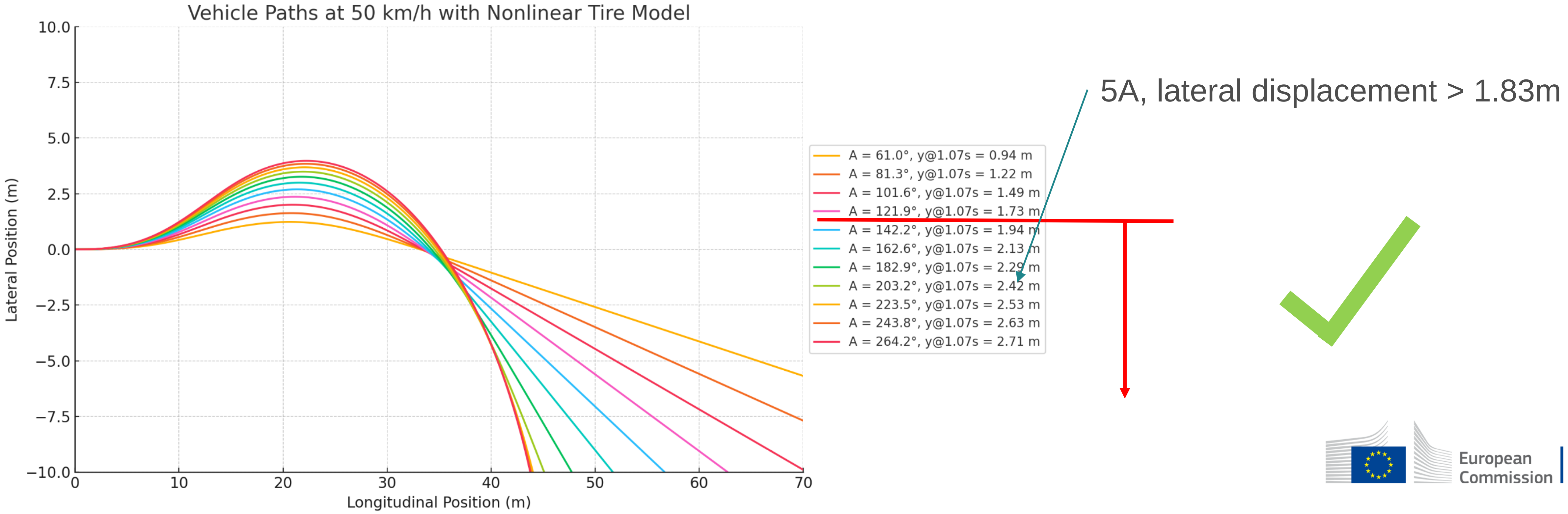


In an ideal world…

5A, lateral displacement > 1.83m

Results with nonlinear tyre slip at 50 km/h

- Tyre slip is nonlinear: lower speeds result in a more dynamic response, lateral displacement increases.



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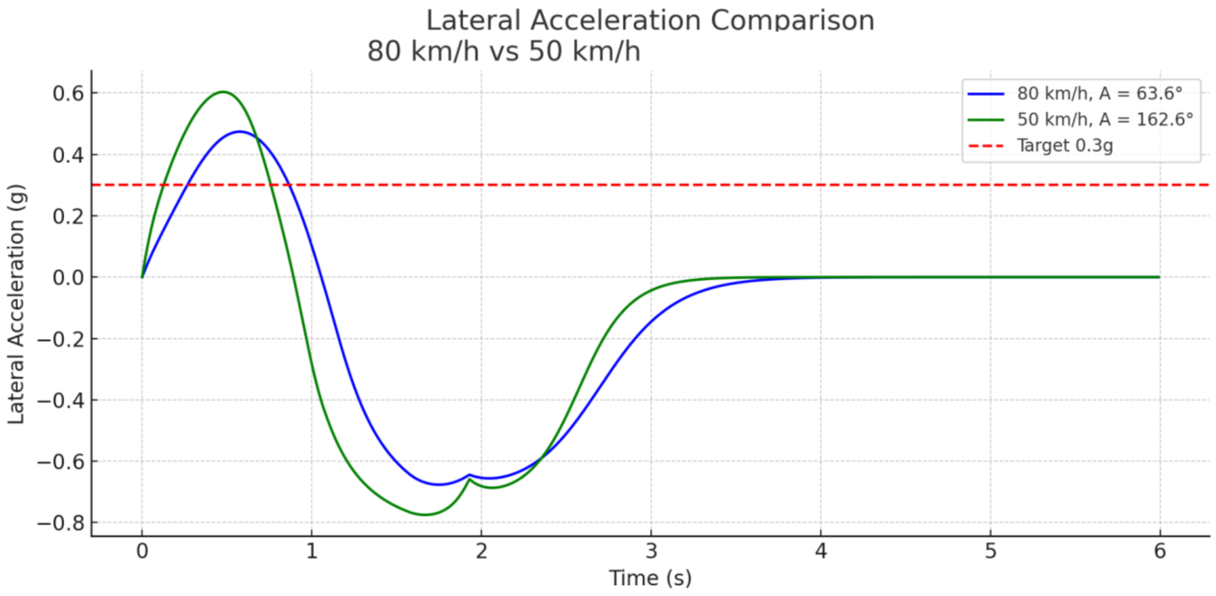
Conclusions 2

- “A” is defined **as a function of gravitational acceleration** (g), therefore **lower speed will result in higher road wheel angles** and at the same “g” rate.
- Despite the lower speed, the **lateral acceleration will be very similar**, because the higher road wheel angle compensates for the speed change:



Note: the “Target 0.3g” refers to the identification of “A”, not relevant here
Steering input is 4A.

Conclusions 3

- If the **maximum vehicle speed is lower** than the prescribed 80 km/h test speed, the test sequence **may still give relevant information** about the vehicle dynamic behaviour and ESC intervention:
  - Because the **higher steering wheel angle** required through "A" **compensates** for the lower speed, and
  - It results in a **similar lateral acceleration**.

However:

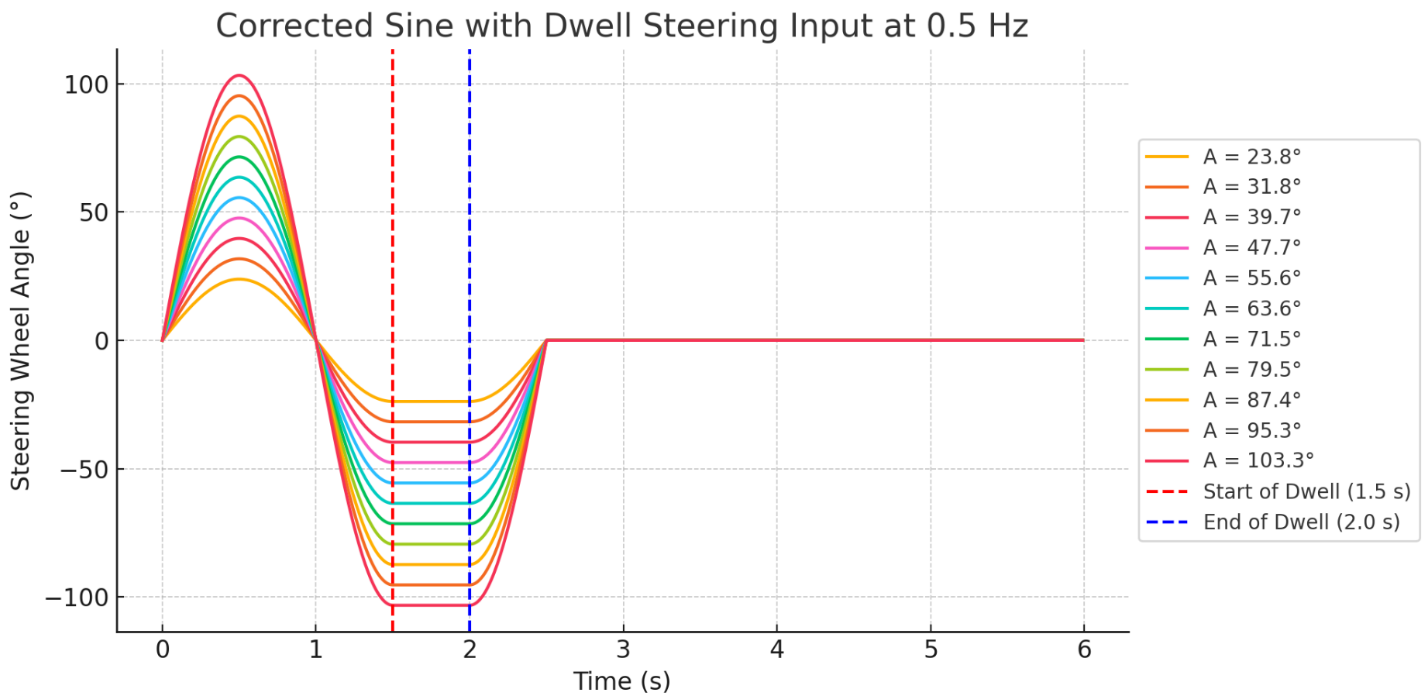
At lower speed, the vehicle turns more tightly, and stay in the turn longer → even with the similar peak lateral acceleration, it drifts further sideways.

↓

The lateral displacement will be higher, therefore it will be easier to comply with the responsiveness requirement.

Case study: ADS vehicle with small steering power

- What happens if the steering equipment can’t follow the 0.7 Hz sine pattern?
- Sine with dwell results with 0.5 Hz (**dwell begin time needs to be adjusted** to 1.5s instead of 1.07s):



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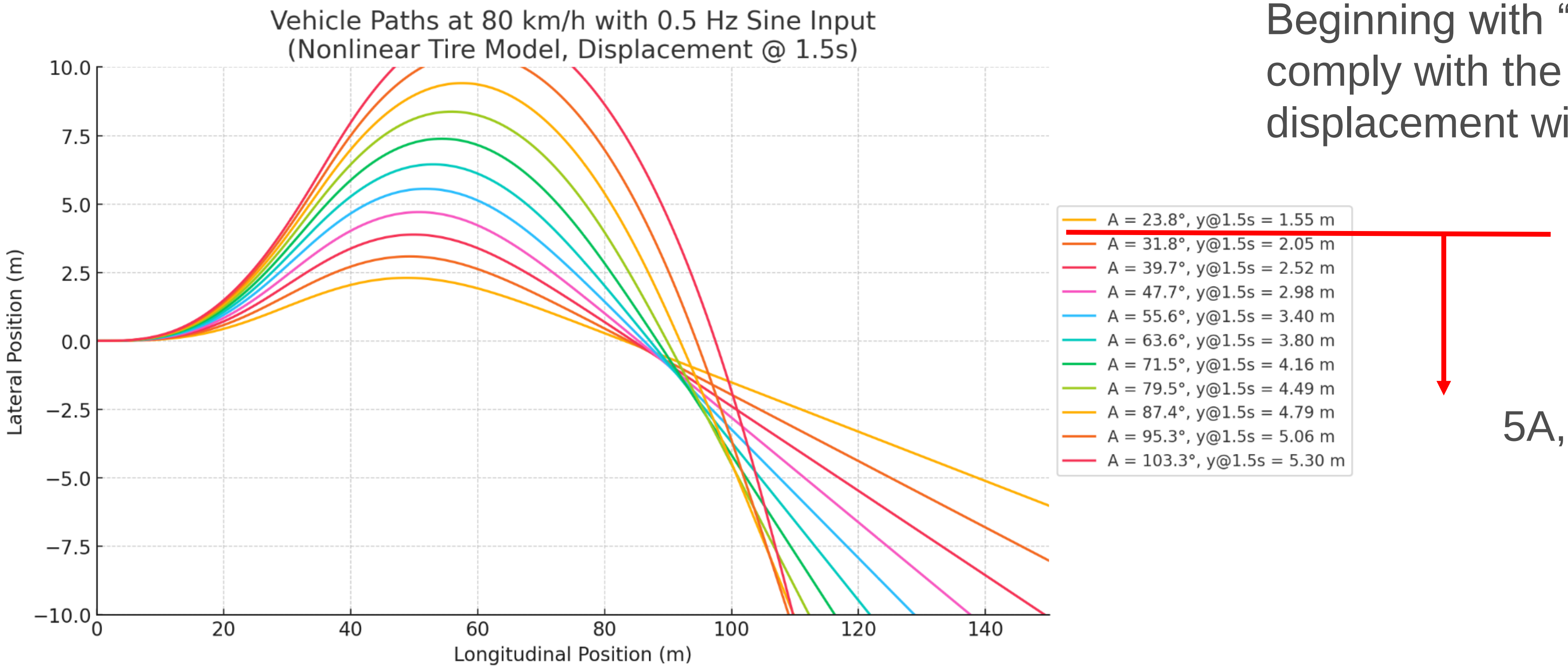
Results with nonlinear tyre slip and 0.5 Hz sine frequency

- Vehicle starts to loose traction around “4A” steering input.



Beginning with “2A”, all test cases comply with the threshold: lateral displacement will be much larger.

5A, lateral displacement > 1.83m

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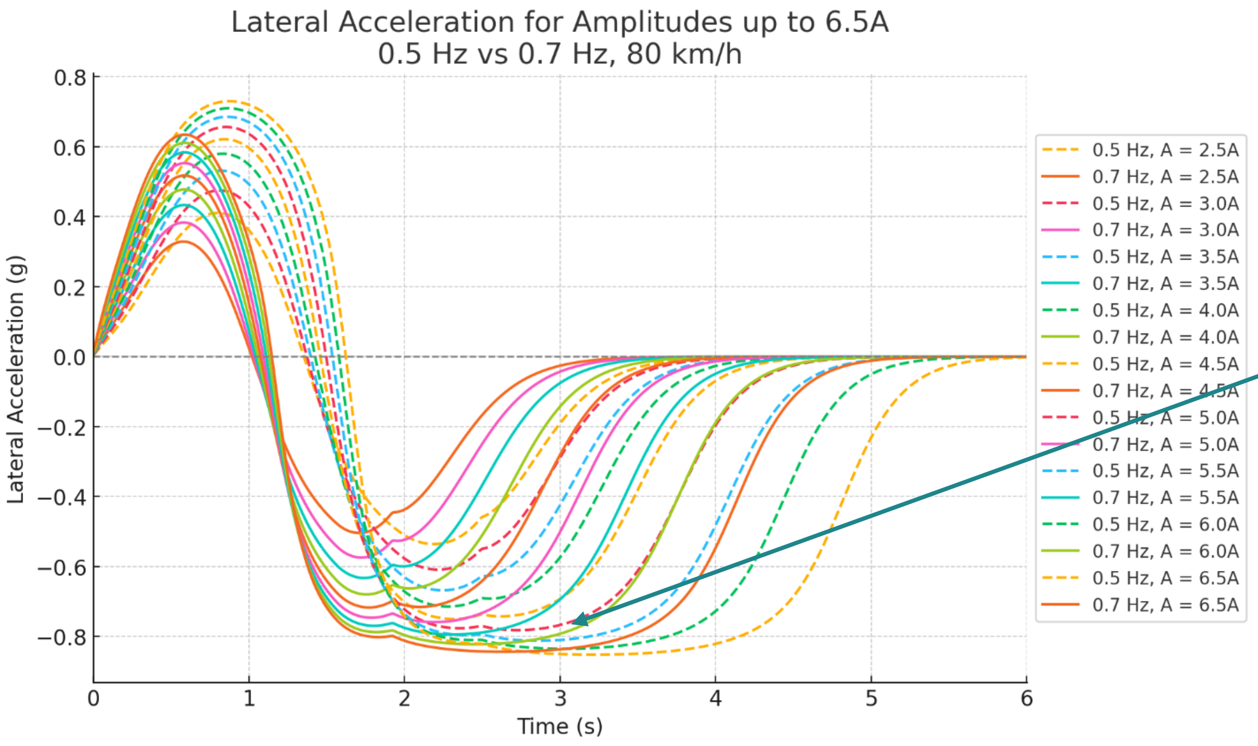
Lateral acceleration from the 0.5 Hz SwD

- Lower frequency sine wave (less powerful steering motor) produces higher lateral acceleration!



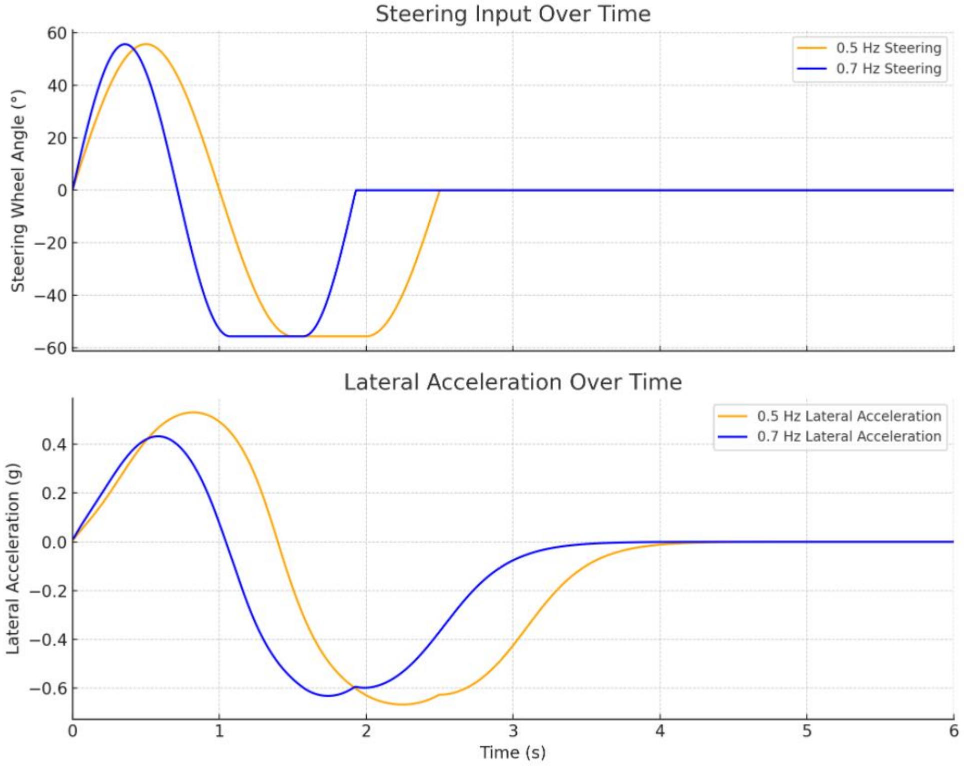
Lateral acceleration reaches a clear plateau: additional steering input **doesn't significantly increase** lateral acceleration beyond ~3.5A

Conclusions 4

- At **0.5 Hz**, the sine wave evolves more slowly:
  - The steering angle stays near its **peak values longer**
  - The vehicle's yaw rate and lateral velocity **have time to build up**
  - The transient effects (which are damped and take time) can **settle more fully**, allowing lateral acceleration to reach a higher peak

Conclusions 5

- Vehicle dynamics introduce **phase lag** - the yaw rate and lateral acceleration **lag behind** the steering input.
  - At **higher frequencies**, this lag causes **misalignment** between peak input and peak response.
  - At **lower frequencies**, the system **stays near peak input long enough** for the response to catch up.
  - So the **effective alignment of yaw, lateral motion, and steering input improves.**
  - Therefore the **lateral acceleration will be higher** for the same peak input, and
  - The lateral displacement will be much higher for the same input amplitude, **therefore it will be easier to comply with the responsiveness requirement.**



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Conclusion of the conclusions

- Both the lower vehicle speed and the lower frequency sine wave **increase lateral acceleration**.
- Because of this, in both cases (50 km/h and 0.5 Hz) the **vehicle reaches tyre force saturation**.
- This means the ESC will still intervene and **the test may provide meaningful results**.
- However, **the responsiveness requirement is easier to reach** in both cases compared to the original setup (80 km/h and 0.7 Hz).

Thank you

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