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#EVS29

Understeer characteristics for energy-efficient fully electric vehicles with multiple motors

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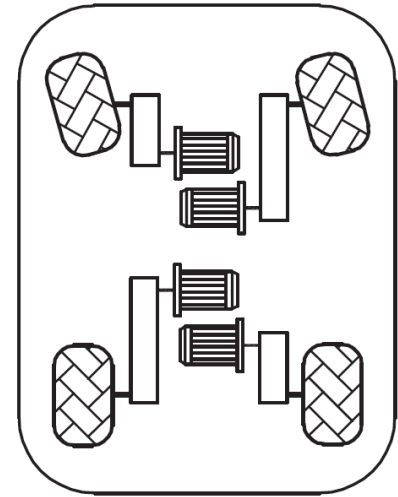


Outline

- Torque-vectoring
- Power losses in EVs
- Motivation and novel idea
- The vehicle demonstrator
- Our contribution
- Conclusions
- Future work

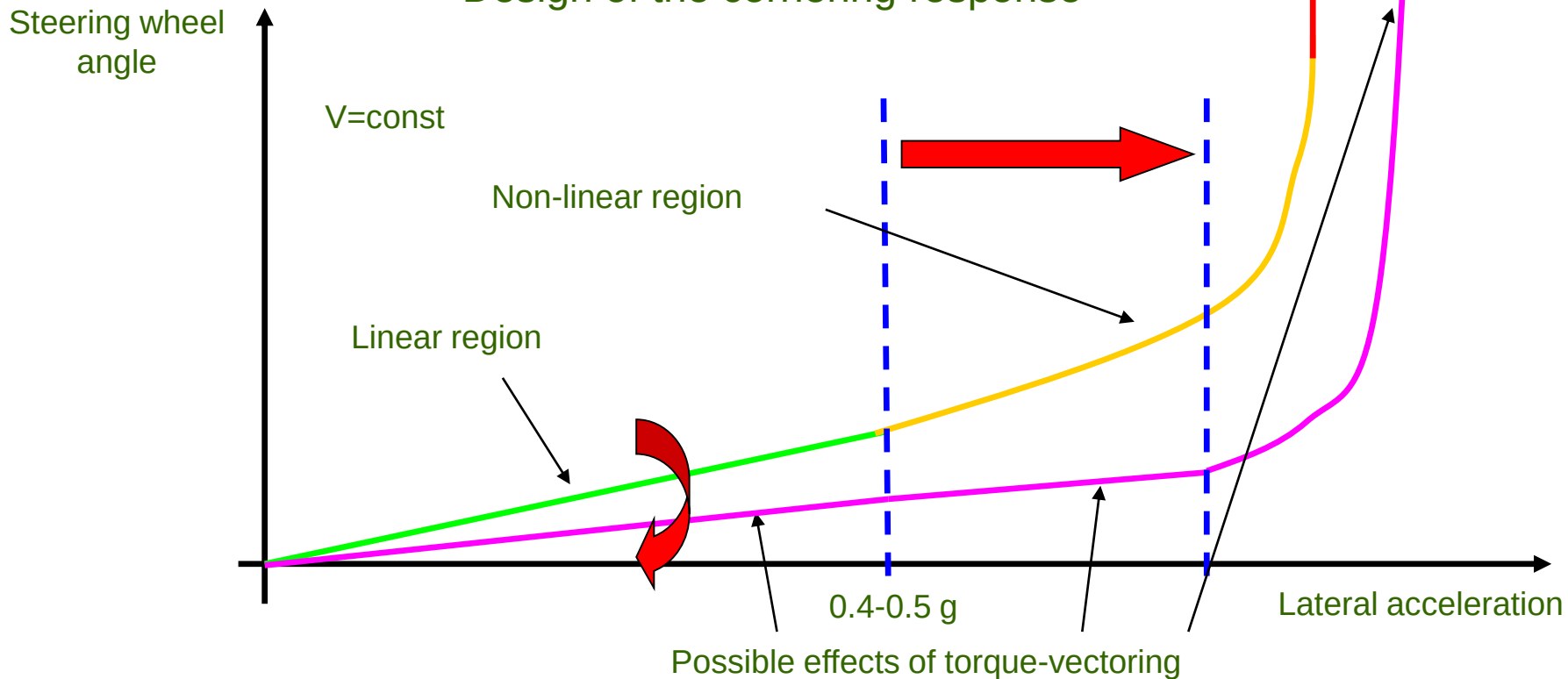
Torque-vectoring

- Electric vehicles (EVs) with multiple motors
- Generation of a direct yaw moment via torque-vectoring (TV) strategies
- Direct yaw moment aiming at achieving a reference yaw rate
- Design of the cornering response, i.e. the *understeer characteristic*



Torque-vectoring

Design of the cornering response



Power losses in EVs

Major sources of power consumption:

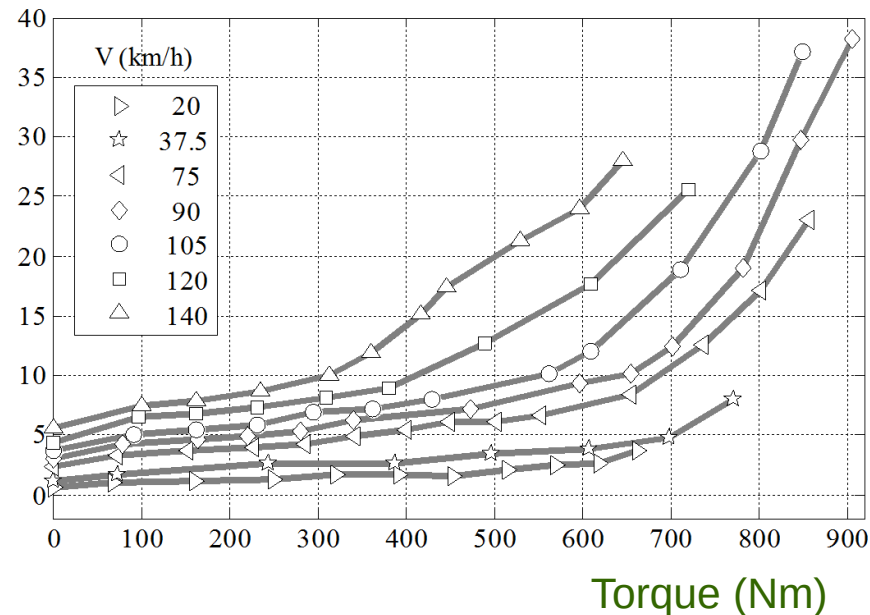
1. Drivetrain power losses

- due to inverters, electric motors, transmission and tire rolling resistance
- depending on torque and speed

2. Tire slip power losses

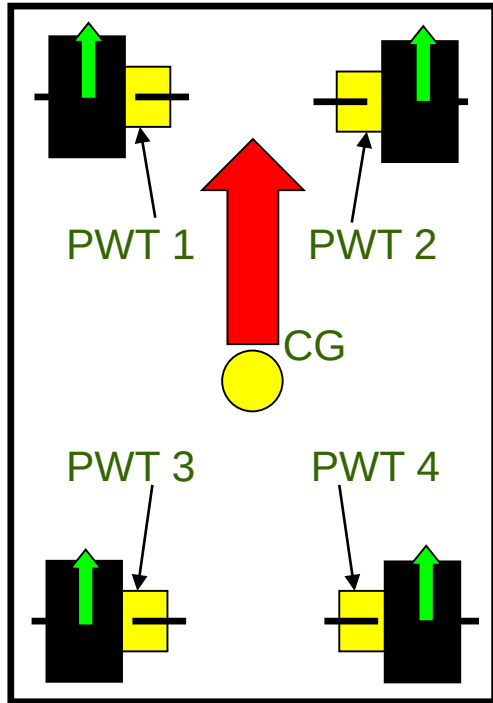
- relevant only at high longitudinal and lateral accelerations

Drivetrain power loss (kW)



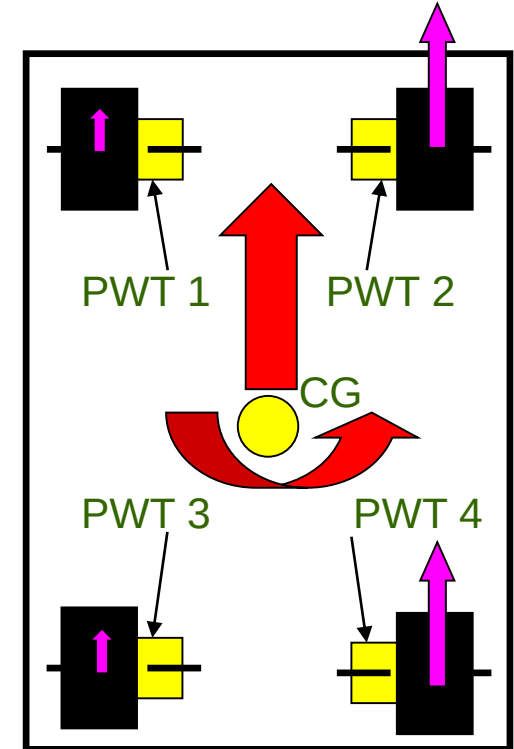
Power losses in EVs

Tire slip power losses



Different longitudinal slips between inner and outer driven wheels

Different slip angles between front and rear axles



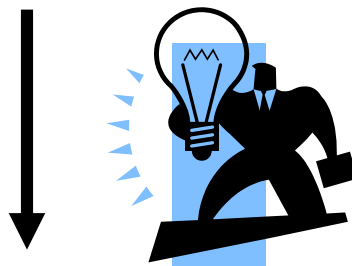
More uniform longitudinal and lateral slip distribution (neutral steering vehicle)

→ **decrease of the overall slip power loss**

Motivation and novel idea

- Yaw moment generation aimed at a target ***understeer characteristic***
- Defined according to ***vehicle dynamics-related criteria***, e.g. change the vehicle cornering behaviour

Gap in the literature: assessing and predicting the impact of the reference level of EV understeer on energy efficiency



Derive the reference understeer characteristic based on the
criterion of the minimum energy consumption

The vehicle demonstrator

Range Rover Evoque prototype (iCOMPOSE)

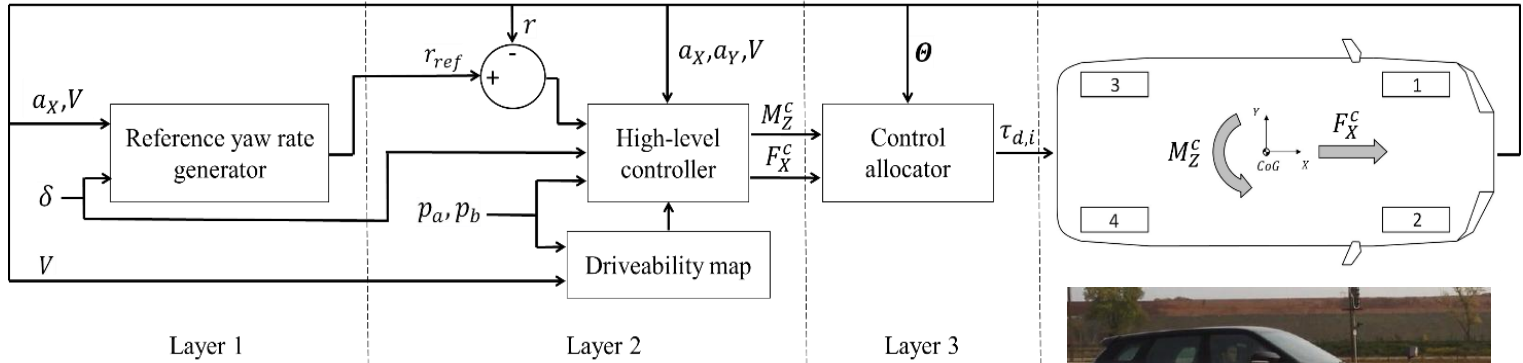
- Four identical on-board drivetrains
- Switched reluctance electric motor, double-stage single-speed transmission system, constant velocity joints, half-shaft



Name and unit	Value
Wheelbase (m)	2.665
Gearbox ratio (-)	10.56
Wheel radius (m)	0.364
Half-track (m)	0.808
No. of motors per axle (-)	2
High-voltage dc bus level (V)	600



The vehicle demonstrator

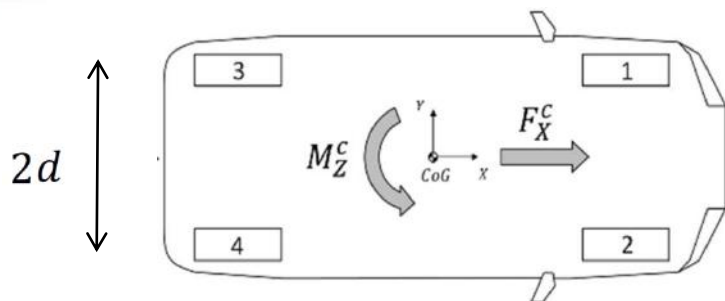


- *Reference generator*: target values of the vehicle states (e.g. reference yaw rate), from other measured/estimated vehicle states

- *High-level controller*: overall traction/braking force and yaw moment (contribution due to TV) demands

- *Low-level controller*: reference wheel torques to generate the reference traction/braking force and yaw moment

The vehicle demonstrator



Side torque demand

$$\tau_{d,L} = 0.5 \left(F_X^c - \frac{M_Z^c}{d} \right) R$$

$$\tau_{d,R} = 0.5 \left(F_X^c + \frac{M_Z^c}{d} \right) R$$

Wheel torque distribution

$$\tau_{d,1} = \tau_{d,3} = \frac{\tau_{d,L}}{2}$$

$$\tau_{d,2} = \tau_{d,4} = \frac{\tau_{d,R}}{2}$$

The power input is affected only by the reference understeer characteristic

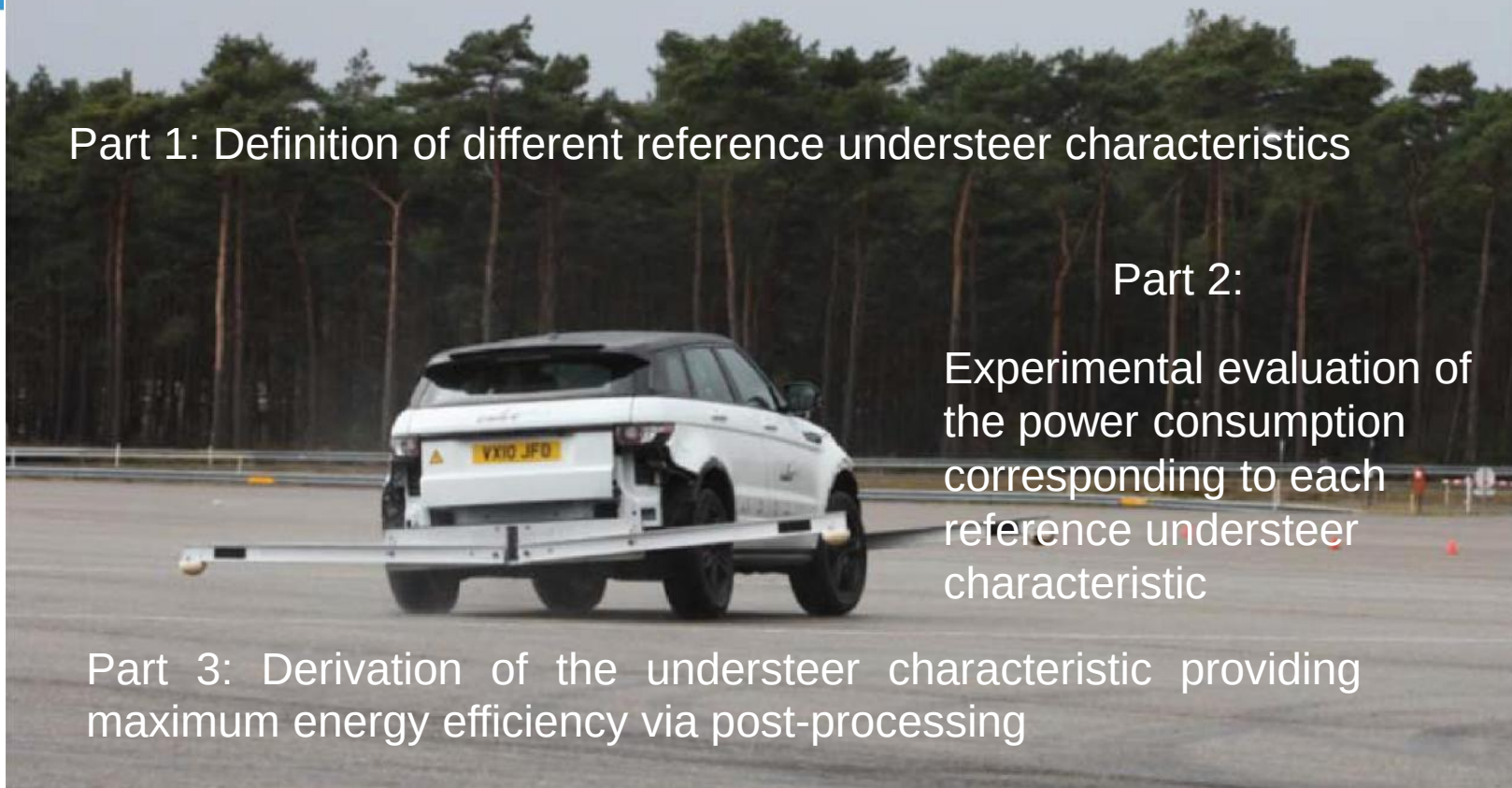
Our contribution

Part 1: Definition of different reference understeer characteristics

Part 2:

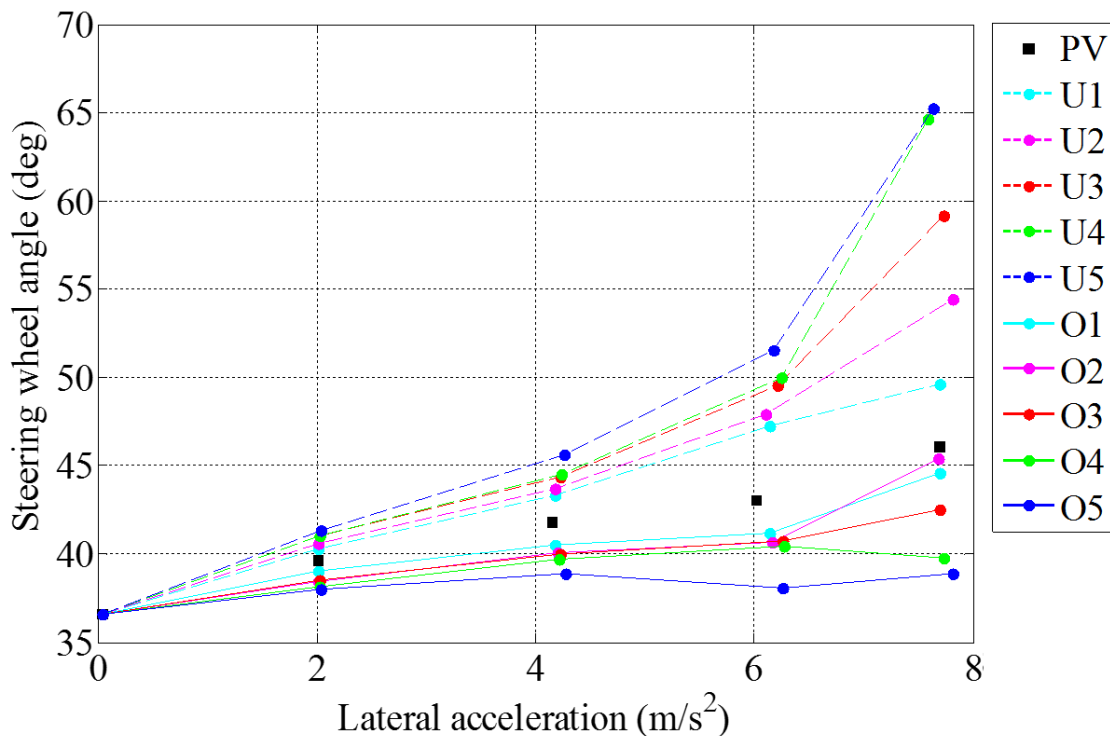
Experimental evaluation of the power consumption corresponding to each reference understeer characteristic

Part 3: Derivation of the understeer characteristic providing maximum energy efficiency via post-processing



Our contribution: Part 1

Reference understeer characteristics



Our contribution: Part 2

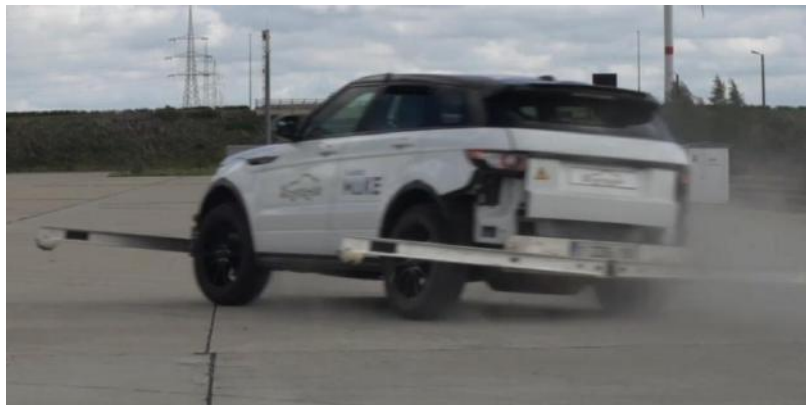
- Skidpad tests: circular path, 60 m radius
- Different lateral accelerations: 2, 4, 6, and 8 m/s²
- Corresponding to vehicle speeds of 39, 56, 68, and 79 km/h



Our contribution: Part 2

Procedure:

- Battery fully charged
- Accelerate from standstill to the specified speed
- PI speed tracking controller: driver controlling only the steering wheel
- Maintain trajectory and speed for two laps
- Overall drivetrain power = battery power output
- Repeat the above steps four times
- Repeat the above steps for all the understeer characteristics and speeds



$$P = V_{batt} I_{batt}$$

Our contribution: Part 2

Results

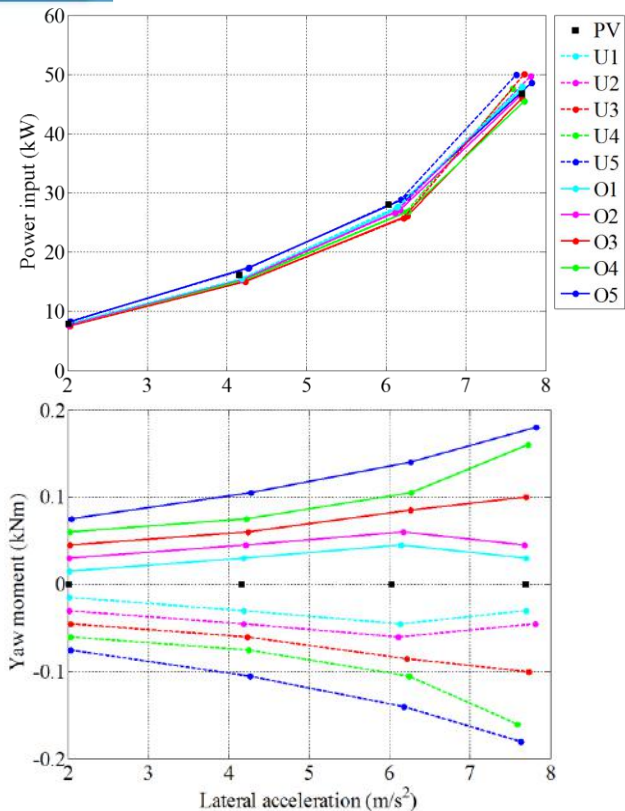
The power input P :

- varies in a repeatable pattern with the understeer characteristic
- is not a monotonic function of the level of vehicle understeer

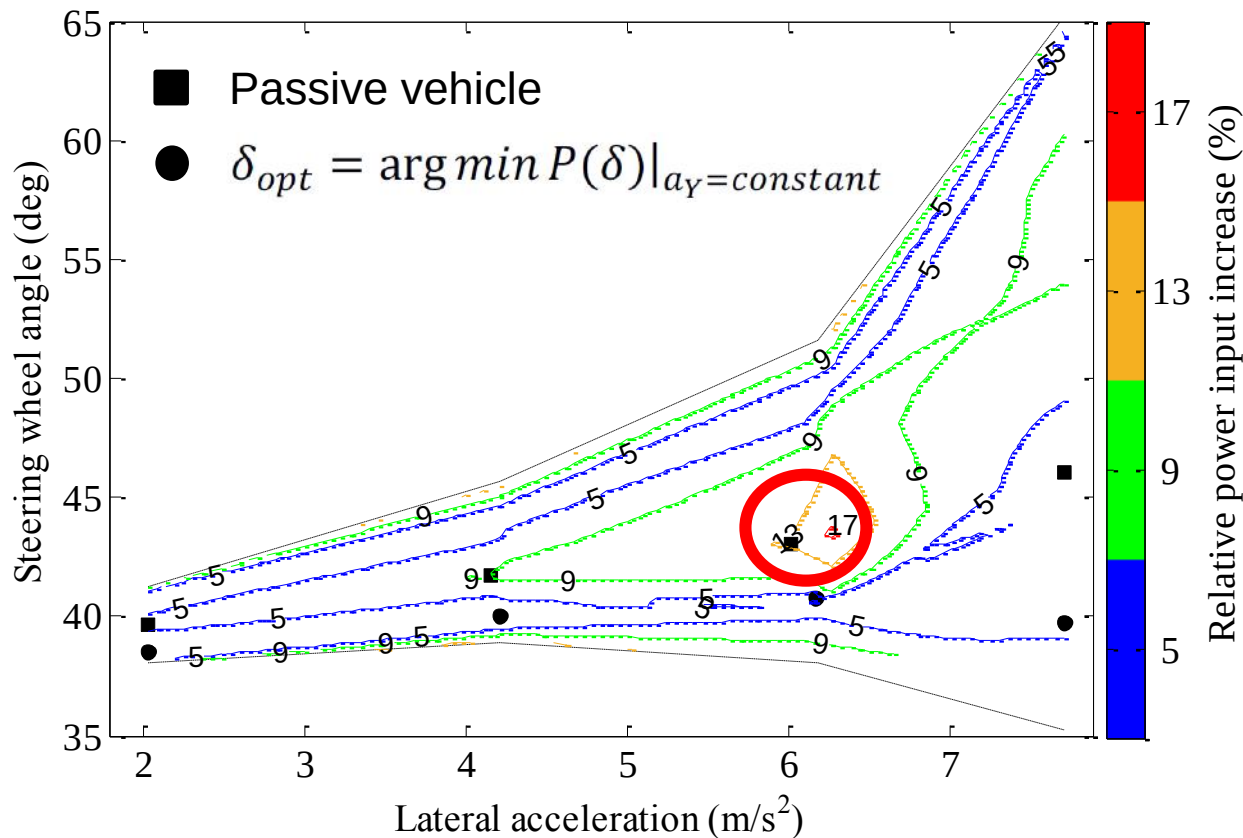


Need for plotting the results in a clearer way: map

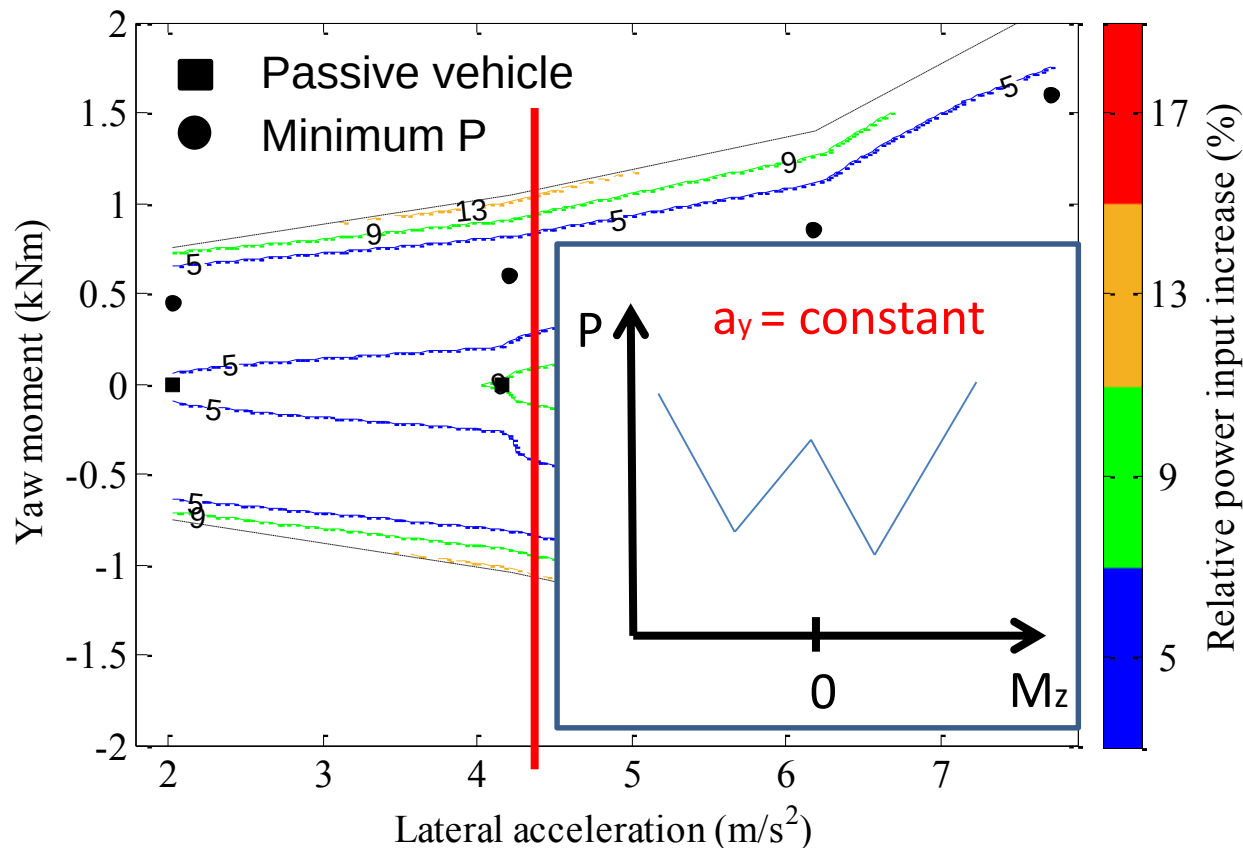
$$P(a_Y, \delta)$$



Our contribution: Part 3

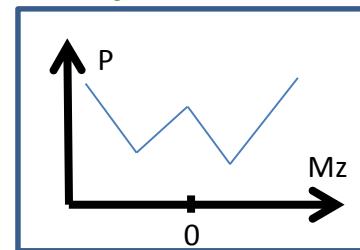


Our contribution: Part 3



Conclusion

- The variation of the reference yaw rate of the torque-vectoring controller has a significant effect on the energy consumption in cornering conditions
- The experimental analysis showed energy savings of up to ~11% with respect to the passive vehicle (> optimal wheel torque allocation strategies)
- The optimal understeer characteristic implies less understeer with respect to the passive vehicle (overall behavior close to neutral steering)
- For a given a_y , the power input as a function of the yaw moment presents a relatively symmetric behavior, with an absolute minimum for destabilizing yaw moments



Future work

- Investigation of the nearly symmetric behavior of the power input as a function of the yaw moment, for given a_y
- Theoretical analysis supporting the experimental results, based on the investigation of each power loss contribution (drivetrain and tire slip)
- Assessment of the overall power saving achievable with torque-vectoring control, through the implementation of both:
 1. energy-efficient reference yaw rate characteristic
 2. energy-efficient wheel torque control allocation strategies



Any questions?



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