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ACOCAR active suspension

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Introduction

- Tuning of a passive automotive suspension is always a compromise between comfort and road holding performance.
- Semi-active suspensions can break this compromise because they can change their characteristics in real time, but can only dissipate energy.
- Active suspensions offer increased performance since they can add energy to the system and generate suspension movements if necessary.
- This presentation will compare the performance of a passive suspension with that of the controlled semi-active and active ACOCAR (Actively COntrolled CAR) suspension, developed by Tenneco.

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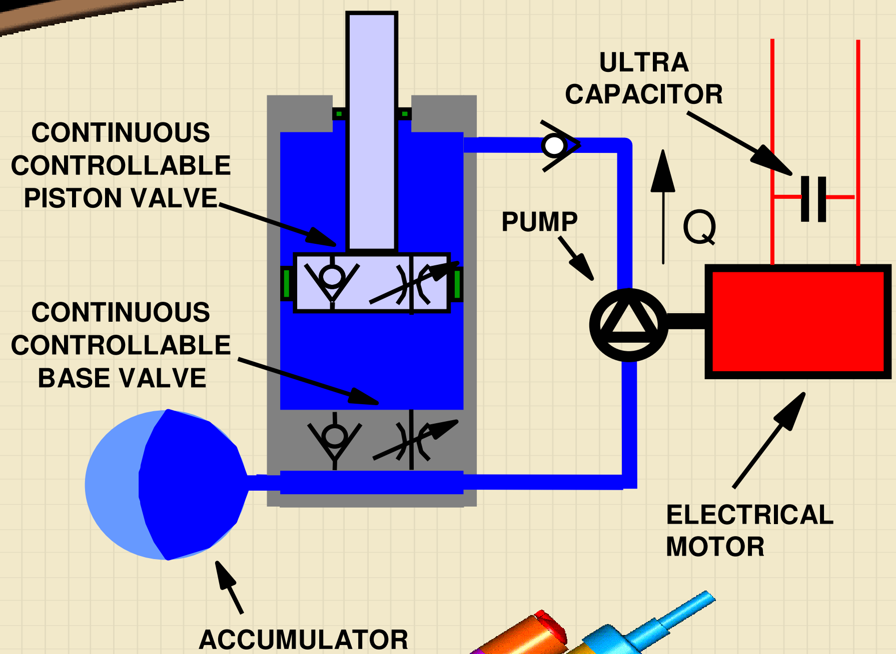
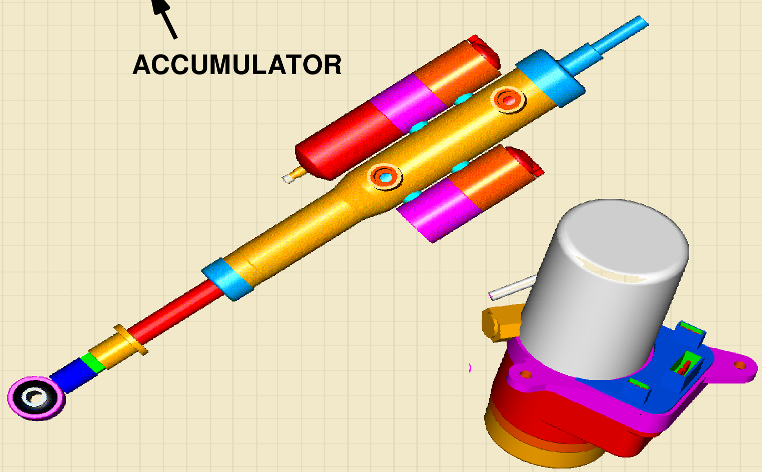
Acocar system overview





- **Acocar corner consists of:**
  - 1 constant flow pump.
  - 1 damper/actuator with 2 servo-valves to control its force.
  - 1 ultracapacitor to flatten out peak currents.
- **Active mode:**
  pump flow of 5 l/min in normal operation.
- **Semi-active mode:**
  pump is switched off.

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Acocar system packaging options

- **Lightweight design under development:**
  - Aluminium valve block & outer tube
  - Plastic spring seats and dust cover

- **4 seperate power packs (1 for each corner), or combine the 2 pumps of 1 axle on 1 electromotor?**

- **System with or without anti-roll bars?**
  - With anti-roll bars:
    - Mechanical fail-safe for roll stiffness
    - Roll stiffness available in semi-active mode
  - Without anti-roll bars:
    - Easier packaging
    - Lower weight

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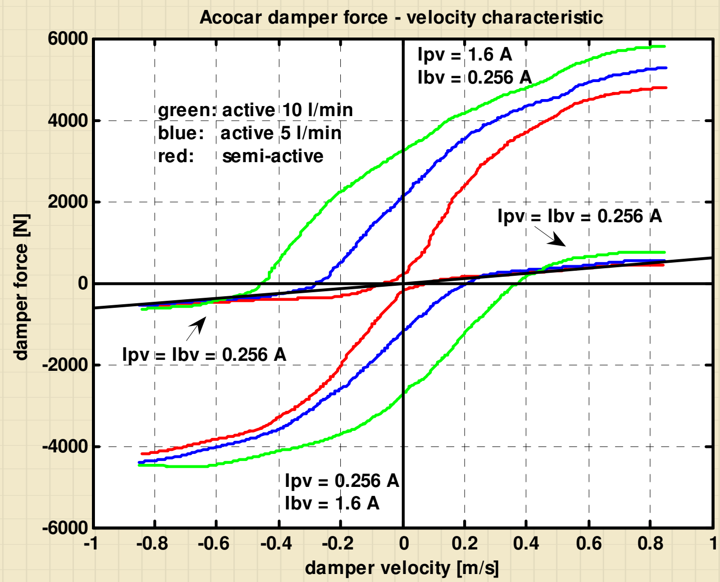
Active suspension hardware

- Semi-active force region only in passive quadrants.
- Active region increases with pump flow rate.
- Actuator force independent of velocity.
- All forces can be generated by adjusting the appropriate servo-valve and keeping the other one open.



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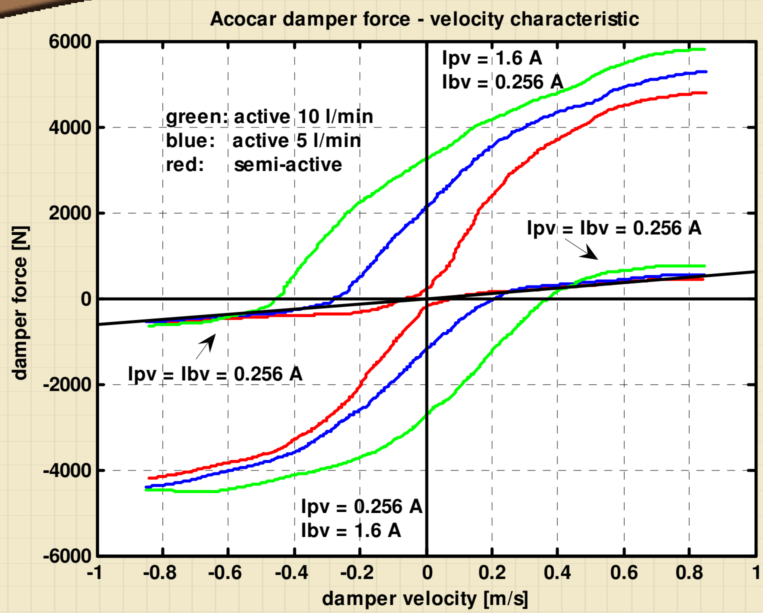
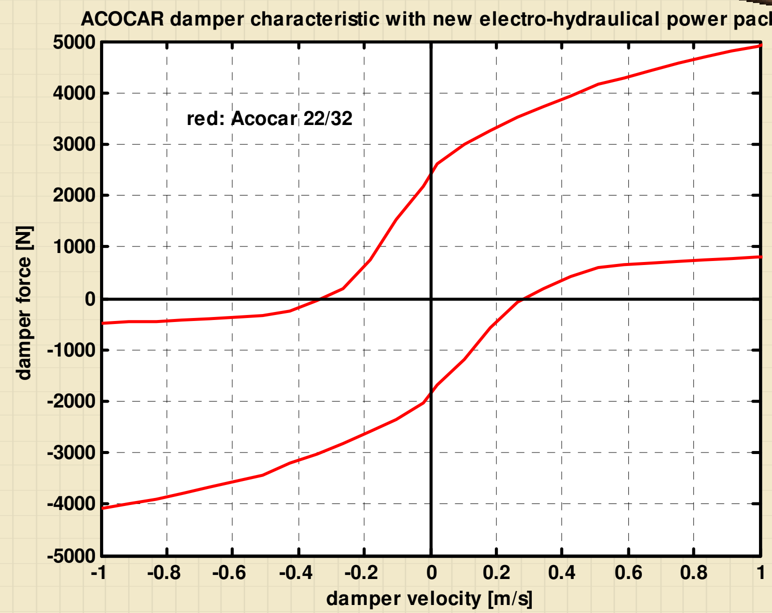
Acocar system targets: performance





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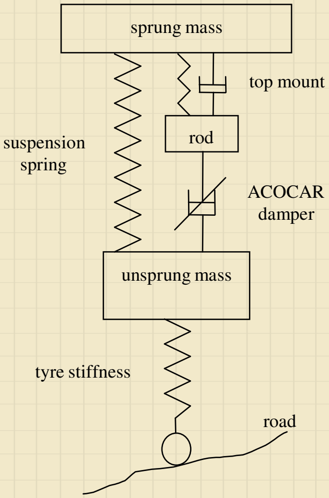
Quarter car test rig

- 25 kN hydraulic actuator to apply road inputs.
- Rear left suspension mounted on a sliding frame.
- Sprung mass = 350 kg, unsprung mass = 45 kg.
- Excellent repeatability.



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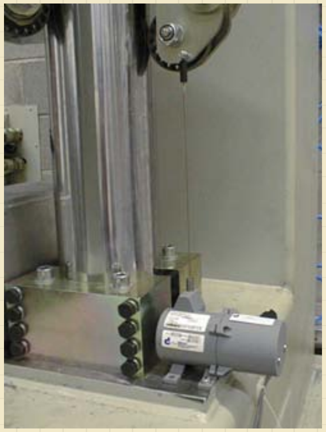
Sensors & real-time control system

- Accelerometers on sprung and unsprung mass.
- Linear displacement sensor to measure relative suspension movement.
- String potentiometer to measure absolute displacement of sprung mass.
- Pc with dSpace 1103 board to control test rig and active suspension and to log measurements.



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- Introduction
- Active suspension hardware
- Quarter car test rig
- Skyhook quarter car control
- Experimental skyhook control results
- Conclusion

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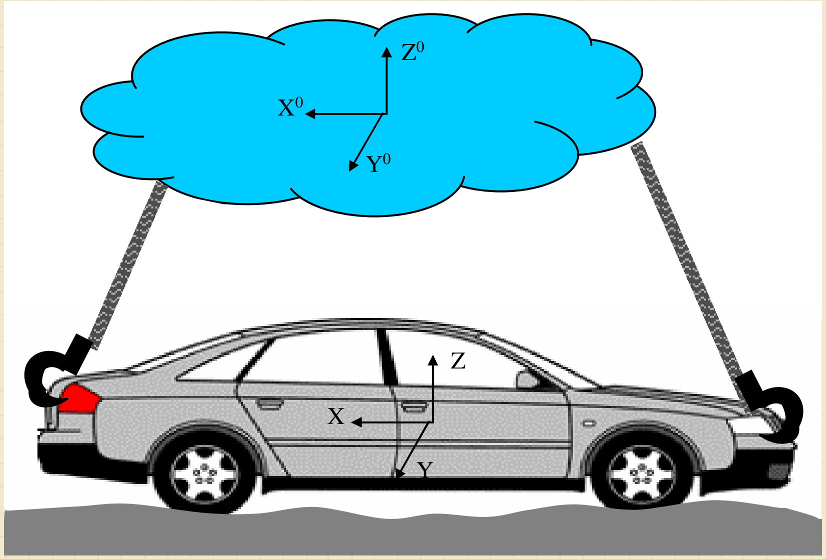
Skyhook quarter car control

- Pure skyhook damping = proportional to the absolute velocity of the sprung mass.
- Damping as if the car was suspended to a fixed point in the sky.
- Additional term is added to provide some passive damping, proportional to relative suspension velocity.

$$f_d = b_g \cdot v_b + r_g \cdot v_r$$



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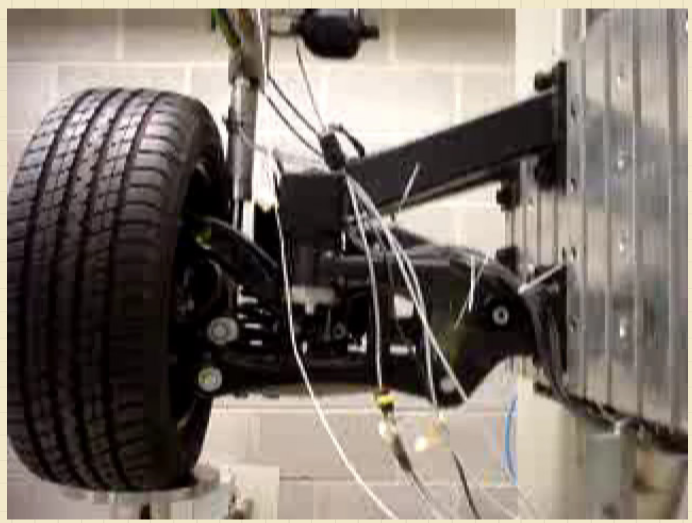
Experimental skyhook control results

passive

active



semi-active

- **Sine excitation: 1.5 Hz, 0.015 m**

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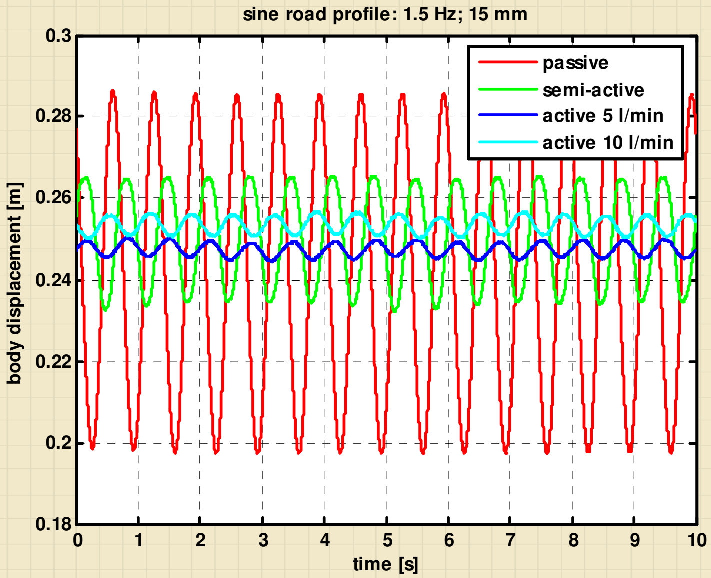
Experimental skyhook control results

- Body displacement peak to peak reduced from 88.5 mm with passive damper to 30.3 mm (34 %) in semi-active mode and 4.7 mm (5.3 %) in active mode (5 l/min)
- Pump flow rate of 5 l/min is sufficient



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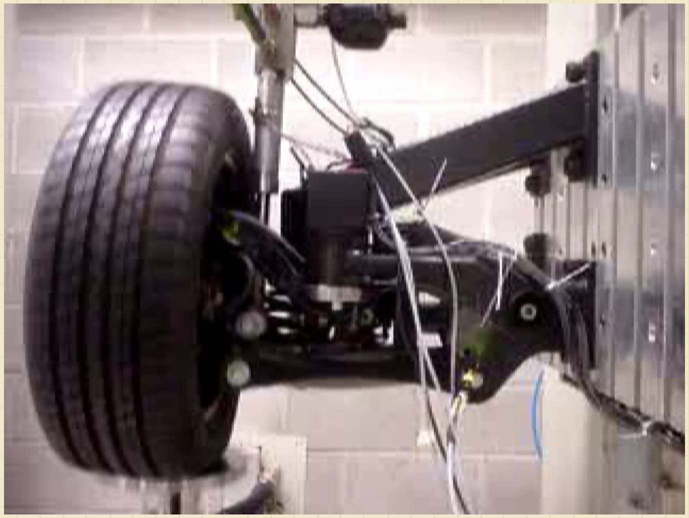
Experimental skyhook control results

passive



active

semi-active

- **Pink noise excitation: f = 1 - 20 Hz, x = +/- 0.025 m, v = +/- 0.7 m/s**

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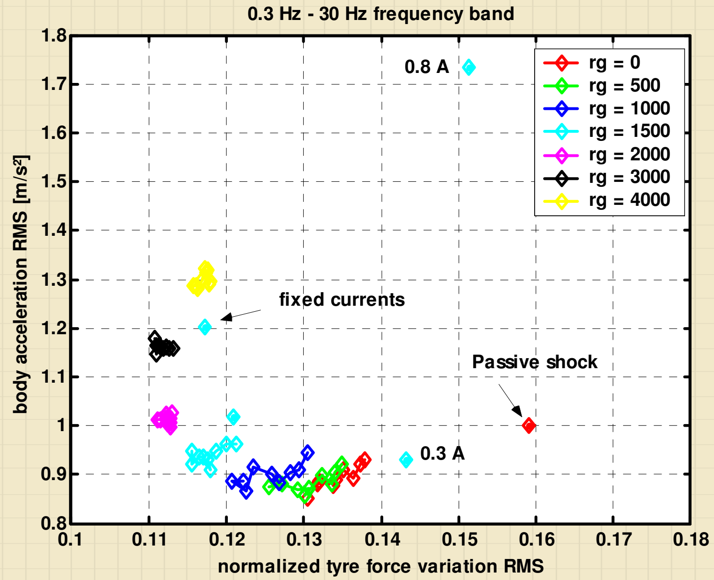
Semi-active performance

- Acceleration (measure for comfort) vs. tyre force variation (measure for handling & safety).
- Semi-active skyhook control reduces body acceleration to ***85 %*** of the level obtained with the passive reference damper.
- Also tyre force variation is reduced to ***70 %***.



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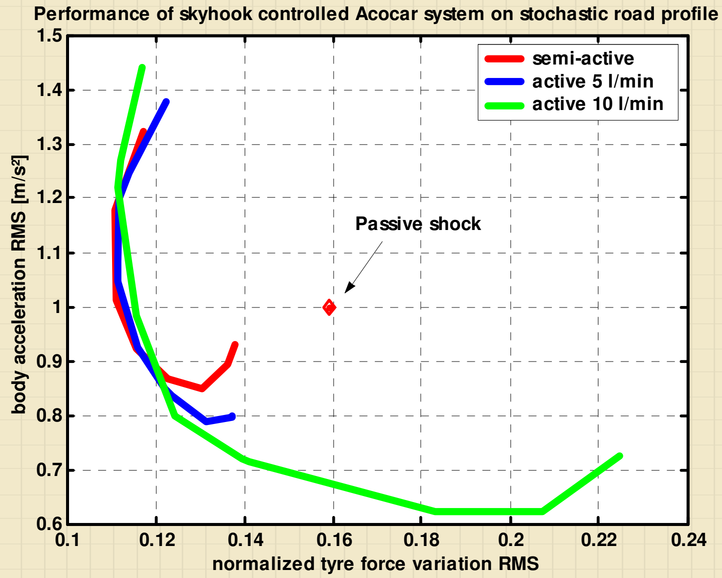
Active performance

- Improved performance for comfort in active mode: reduction of acceleration to ***80 %*** of passive level with pump flow rate of 5 l/min.
- Higher pump flow rate (10 l/min) reduces body acceleration even further on rough road profiles: reduction to ***62 %*** of passive level!
- Performance for handling comparable to semi-active mode: reduction of tyre force variation to ***70 %*** of passive level.



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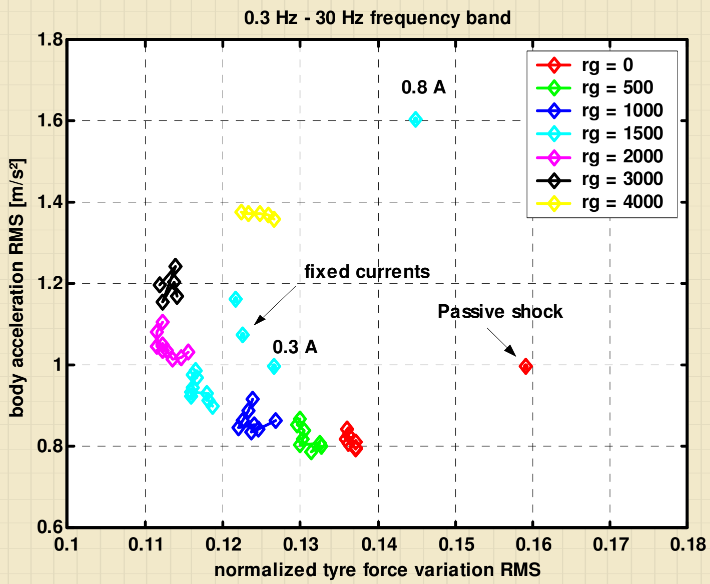
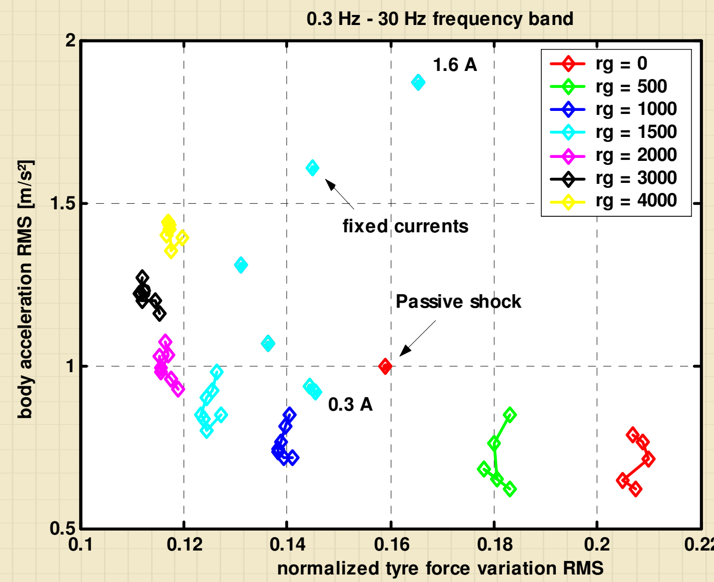
Active performance

5 l/min



10 l/min



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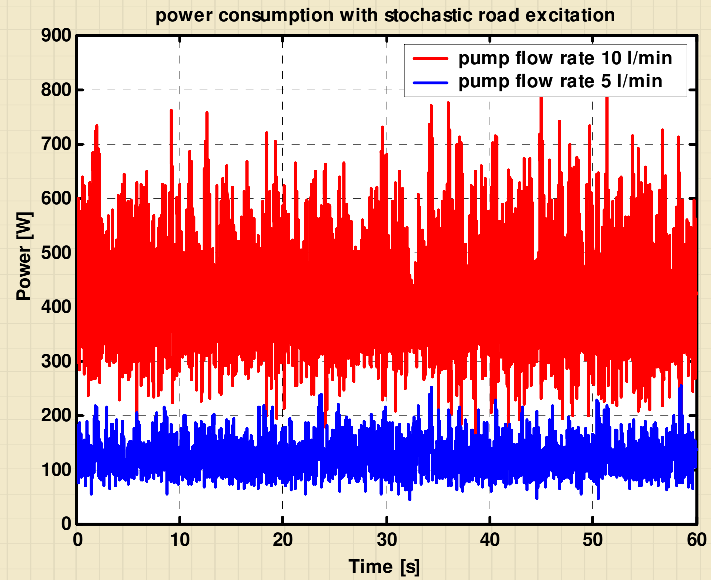
ACOCAR power consumption

- **Full semi-active function possible with pump off**
- **Pump flow rate of 5 l/min**
  - In soft:
    60 W (hydr.) avg. / corner
    110 W (elec.) avg. / corner
    (potential to go lower with additional short-cut valve)
  - On worse road profile or in extreme handling conditions:
    max. avg. 130 W (hydr.) / corner
    max. avg. 240 W (elec.) / corner
- **Pump flow rate of 10 l/min**
  - Worst case:
    max. avg. 420 W (hydr.) / corner
    max. avg. 760 W (elec.) / corner



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Acocar Performance:
Ultimate comfort & safety

		Sine 1.5 Hz, 15 mm	
		Body displacement peak to peak [mm]	
Passive damper		88.5 (100 %)	
Semi-active	Optimal comfort setting	30.3 (34 %)	
Active (5 l/min)	Optimal comfort setting	***4.7 (5.3 %)***	
		Sine 15 Hz, 3 mm	
		Tyre force variation peak to peak [N]	
Passive damper		4360 (100 %)	
Semi-active	Optimal handling setting	1380 (32 %)	
Active (5 l/min)	Optimal handling setting	***1350 (31 %)***	
		Random bad road	
		Body acceleration RMS [m/s²]	Normalized tyre force variation RMS
Passive damper		1.00 (100 %)	0.159 (100 %)
Semi-active	Optimal comfort setting	0.85 (85 %)	0.131 (82 %)
	Optimal handling setting	1.18 (118 %)	***0.111 (70 %)***
Active (5 l/min)	Optimal comfort setting	0.80 (80 %)	0.133 (84 %)
	Optimal handling setting	1.05 (105 %)	***0.111 (70 %)***
Active (10 l/min)	Optimal comfort setting	***0.62 (62 %)***	0.183 (114 %)
	Optimal handling setting	1.22 (122 %)	***0.112 (70 %)***

- **Feasibility proven on 1/4 car**
- **Ability to control driver inputs:**
  body displacement reduced to *5 %* on sine
  ➔ elimination of body roll & pitch
- **Ability to control road inputs:**
  body acceleration reduced to *62 %* of passive level on rough road

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Acocar Performance: Ultimate comfort & safety

- Working on production intended design with integrated pump
- Starting to build prototype car
- Target EU platforms (SOP 2012-) :
  top limousines and performance cars

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