

OEM Vehicle Dynamics Control Systems Application

Including: Torque Vectoring, Active Suspension, Stability & Traction
Control, Battery Electric Vehicles

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Contents

- Summary & My background
- What is an automotive control system?
- Examples
- Development Framework: Models & Systems Engineering
- Development Framework: Networks & Diagnostics
- Battery Electric Vehicles
- Virtual Engineering & Simulation
- Conclusion

Summary

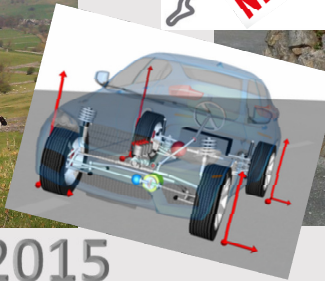
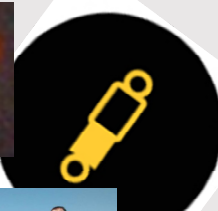
- Aims of Today:
 - Inspiration
 - Employability
 - Engineering Examples
 - Soft Skills Thoughts
- What is an automotive control system?
- Controls Development Framework
- Tools & Examples

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Virtual Verification Subject Matter Expert

Suspension Controls

Chassis & Motion Control Systems



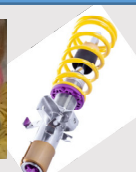
2000

2005

2010

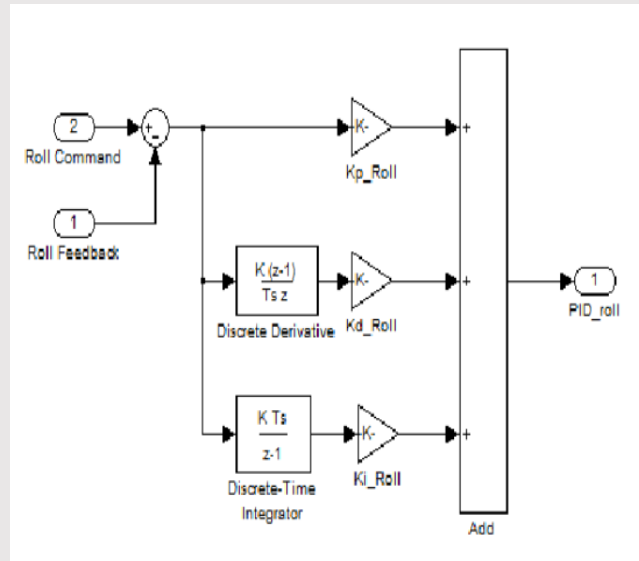
2015

2020



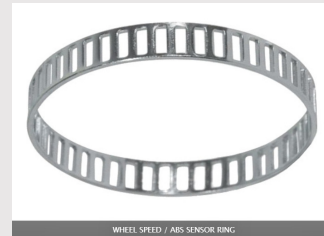
What is an automotive control system?

- Sensors, Control, Actuation



Sensors: Hall Effect / Wheel Speed

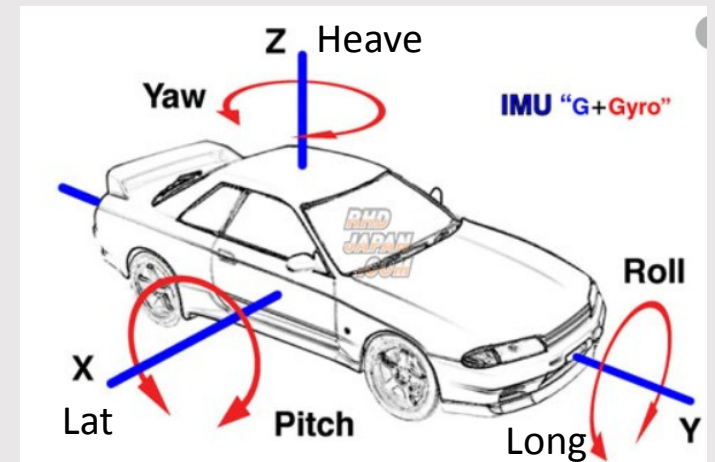
- ABS Sensor
- 2 or 3 wire, Directional?
- Poor at low speed
- Hard Wired



- <https://www.tiepie-automotive.com/en/articles/abs-sensor-hall>
- <https://www.knowyourparts.com/technical-resources/hubs-bearings/wheel-speed-sensors/>

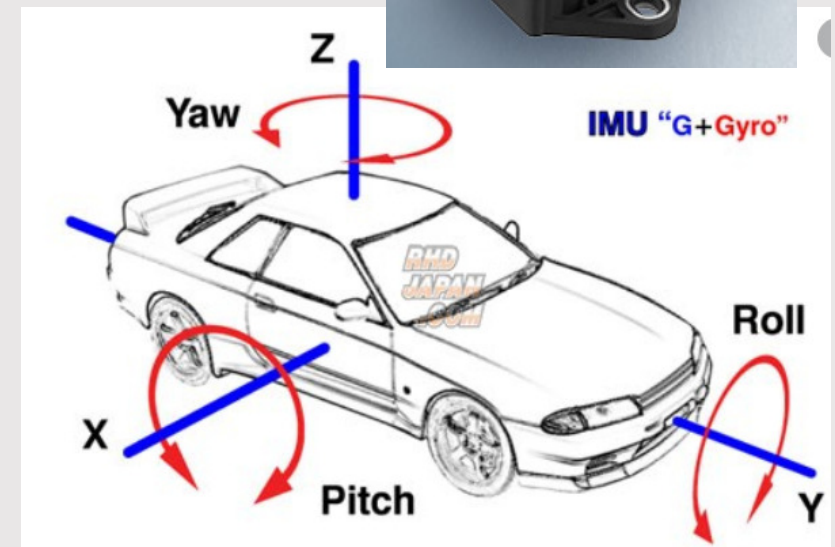
Sensors: Accelerometer

- Lat Acc, Long Acc, Heave, Hubs: m/s^2
- Piezoelectric
 - Electrical charge proportional to force
- Hard Wired or Networked



Sensors: Gyro

- Yaw rate / Pitch rate / Roll Rate: Rad/s
- Multi-piezoelectric or micromechanical (Coriolis)
- Usually Networked
- Often Packaged with Accel: IMU



Sensors: Steering Angle

- Rad, Rad/s, Direction
- **Hand** wheel Angle
- Relative, Absolute
- Why Two Sensors?
 - redundancy, accuracy and diagnostics
- Steering ratio map used to determine **road** wheel angle
- Usually Networked
- <https://www.knowyourparts.com/technical-resources/electrical/steering-angle-sensor-basics/>



Sensors: Height

- meters
- Suspension Height Sensors
- Rotary Potentiometer (0-5v)



- Used to calculate e.g. Wheel travel, Damper travel, Vehicle roll angle
- Headlight aim, Air Sus Height, Active Suspension
- Hard Wired

Sensors: Pressure

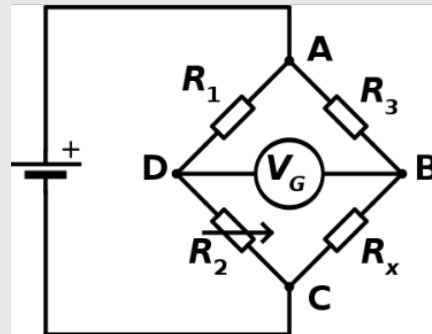
- Pa



- Usually Integrated into ABS module

Sensors: Torque

- Nm
- Strain Gauges
- Wheatstone Bridge



- https://www.lorenz-messtechnik.de/english/company/torque_sensor_coupling.php

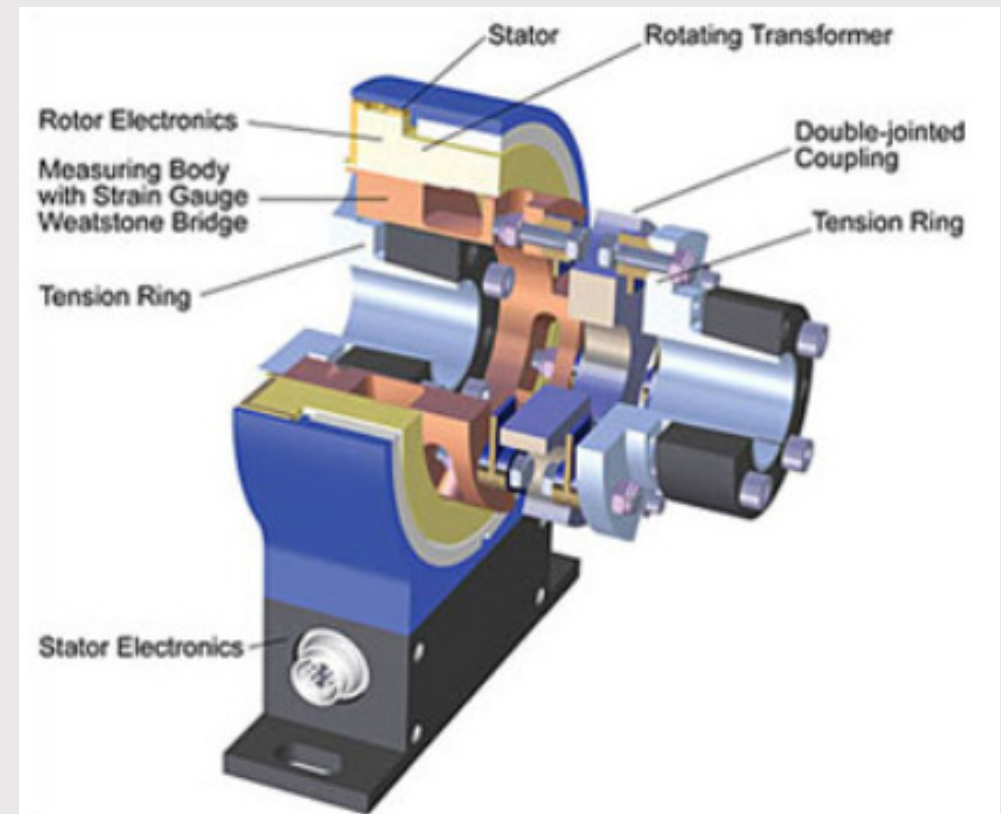


Figure 1: Setup of Torque Sensor DR-2554

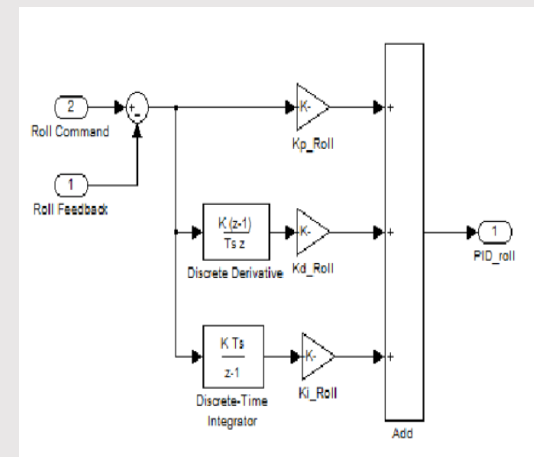
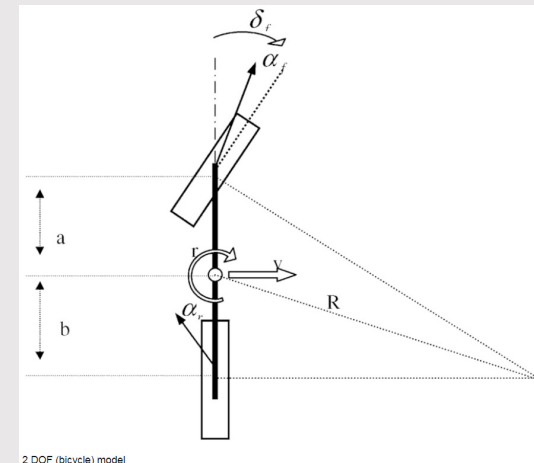
Sensors: GPS

- Not really used
 - Trees, Bridges, £££
- Can be combined with inertial sensors / kalman filters
- Others?
- Radar, Lidar, Cameras: Automated Driving (ADAS)

What is an automotive control system?

- Controls

- Sensor / Input Manipulation
- Simple Vehicle Dynamic Model
- Target Control Signal, e.g:
 - Yaw Rate, Wheel Slip, Vehicle Speed, Roll Angle
- Control / error reduction
 - PID, State Machines
 - System Tuning / Calibration
- Actuation Control
 - Brake Pressure, Engine Torque, Damper valves



What is an automotive control system?

- Actuation

- Hardware Mapping
 - Hydraulic Model (Bernoulli)
 - Brake Torque Model
 - Powertrain / Aero efficiency
 - Damper Valves: Current vs Velocity vs Force
- Controls ECU integration
- Diagnostics



NASA Glenn Research Center

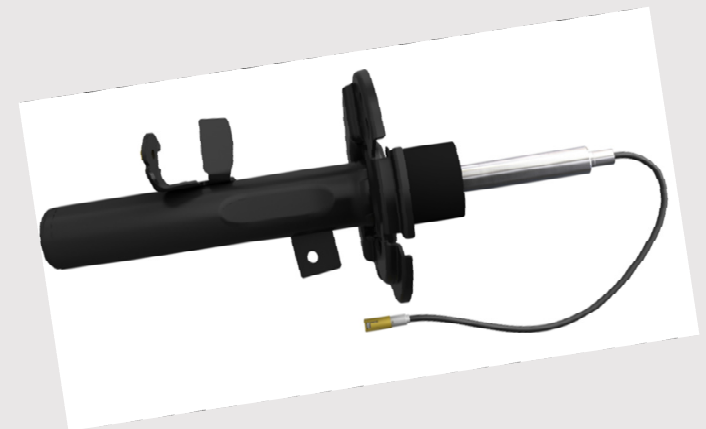
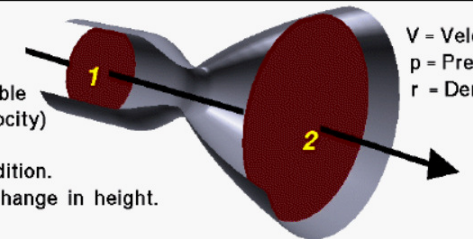
Bernoulli's Equation

Restrictions:
Inviscid
Incompressible (low velocity)
Steady
No heat addition.
Negligible change in height.

Along a streamline:
static pressure + dynamic pressure = total pressure = constant

$$p + \frac{r \times V^2}{2} = p_t$$
$$(p + \frac{r \times V^2}{2})_1 = (p + \frac{r \times V^2}{2})_2$$

Legend:
V = Velocity
p = Pressure
r = Density



Examples

- OEM Vehicle Dynamics Control Systems

- Vehicle Manufacturer Developed

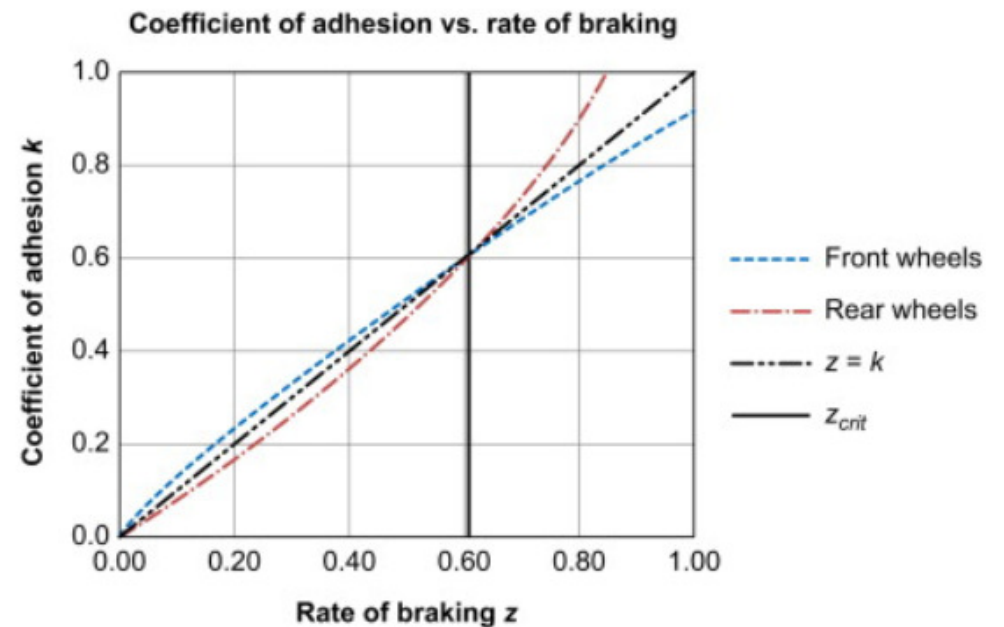
vs

- Tier-One Supplier Developed

Examples: Brake Distribution

- Allows full use of brakes
- Accounts for Longitudinal Weight Transfer
- Helps prevent spinning
 - e.g. wet downhill corner braking
- Slip Based F vs R
- Replaces Bias Valves

• <https://www.sciencedirect.com/topics/engineering/brake-force>



Examples: ABS

- Wheel Slip and wheel acceleration control via
 - Valve control, pump
- Wet, Snow, Ice, Deformable Surfaces
- Maintains controllability on 'split mu' surfaces
- Required = Wheel Speed Sensors (others optional)
 - Reference Speed e.g. 4WD vehicles!
- Enables Steering during Emergency Braking

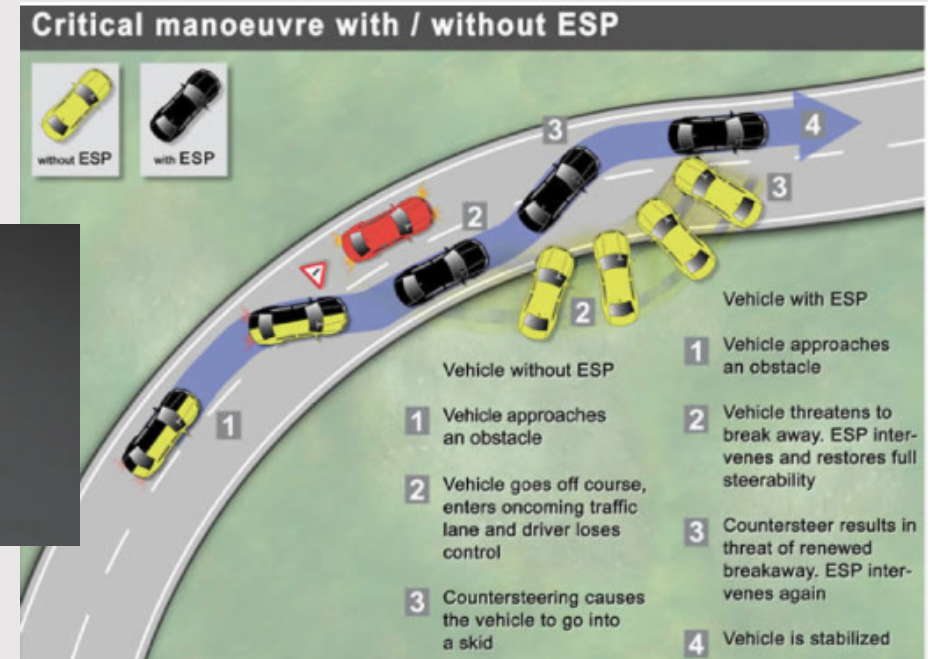
Examples: Traction Control

- RWD: Reduces spinning (oversteer)
- FWD: Reduces understeer
- Engine / Powertrain Control
- Brake Control
- Mue-Split Hill Starts
- What is the operating point / available grip?
- Reference Speed (e.g. 4WD) vs Wheel Slip
- Progress vs stability

- Enables High Power Vehicle Accessibility

Examples: Stability Control

- Multi-pronged control:
 - Brakes (ABS)
 - Engine (TCS)
- Target Yaw Rate (!)
- Understeer
- Oversteer
- Lane Change / Elk / Avoidance
- Comfort (intrusiveness) vs Performance
- Example Regulations: ECE-R13H / NHTSA FMVSS-126 (Steering Robot)
- Enables 'Sporty' Character

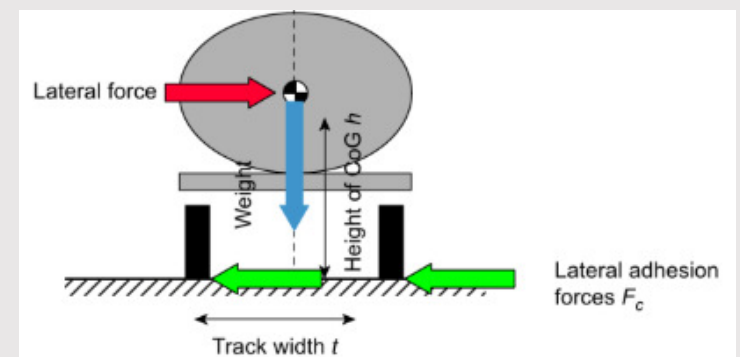


• <https://www.car-engineer.com/esp-electronic-stability-program/>

Examples: Roll-Over Mitigation

- Uses Stability / ABS Modulator
- Wheel Lift
- Tyre Characteristics
 - Lock wheels to reduce Lateral Capability
- Static Stability Factor (SSF) = $t/2h$
- Mitigates high CofG vehicle risk e.g. SUV's

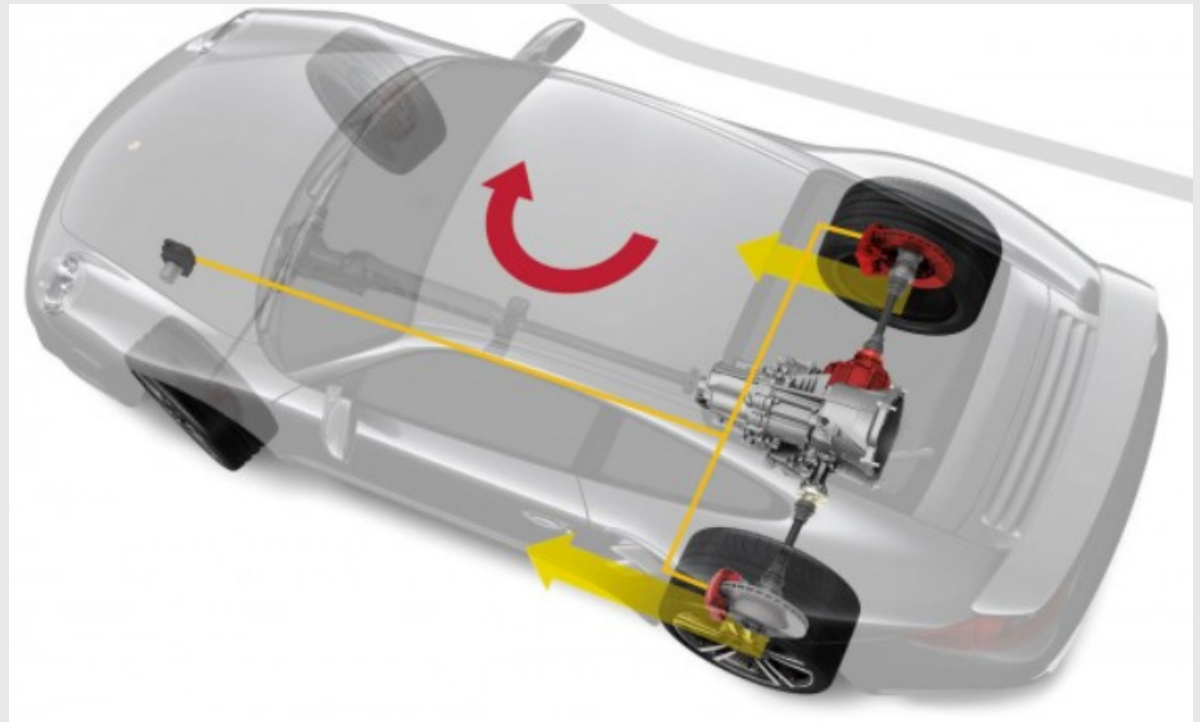
- <https://www.youtube.com/watch?v=LcM9hkWrImU> (33s)
- <https://pdfs.semanticscholar.org/5927/09e47168177a0c9defc6fc32fbd80c40199d.pdf>
- <https://books.google.co.uk/books?id=6TA3AAAAQBAJ&printsec=frontcover#v=onepage&q&f=false>
 - (Braking of Road Vehicles)
- <https://www.safetyresearch.net/rollover-stability>



Examples: Torque Vectoring

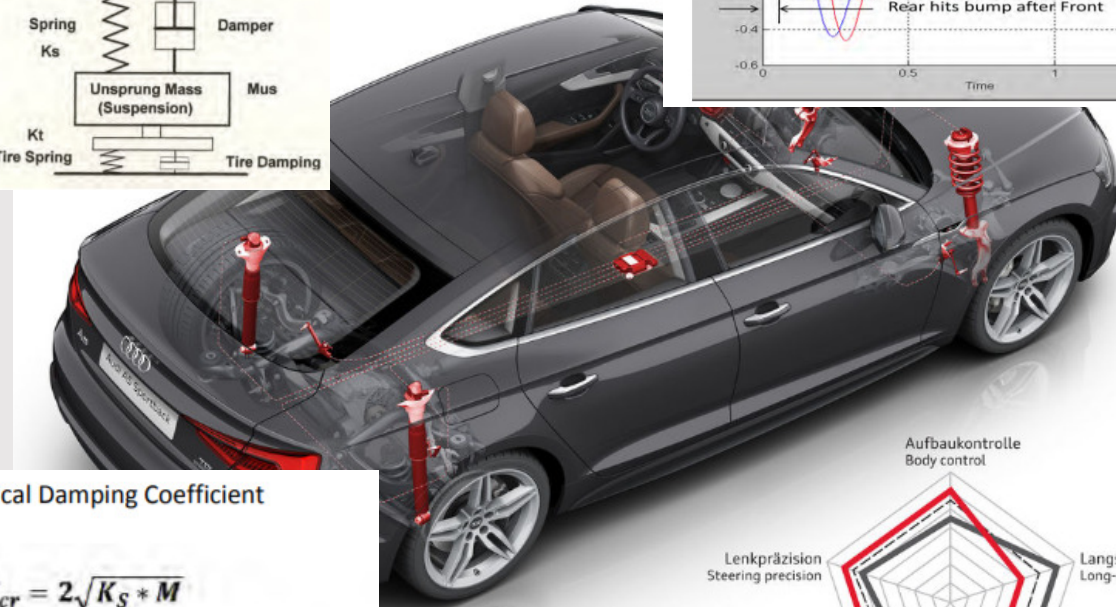
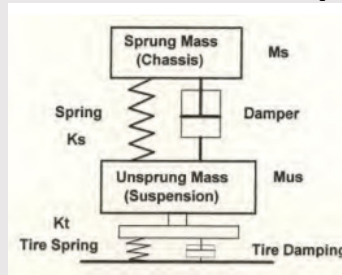
- Stability Control 'Below Limit'
- Differentials
- Brakes
- ABS Modulator Duty
- 'Broadens' Sporty Character

- <http://torque-vectoring.belisso.com/>



Examples: Adaptive Damping

- Comfortable and Sporty
- Driver Modes Optional
- Body Control vs Comfort
 - 'Primary' vs 'Secondary'
- Energy Management

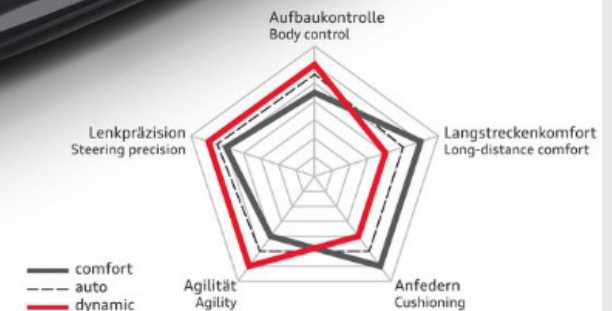
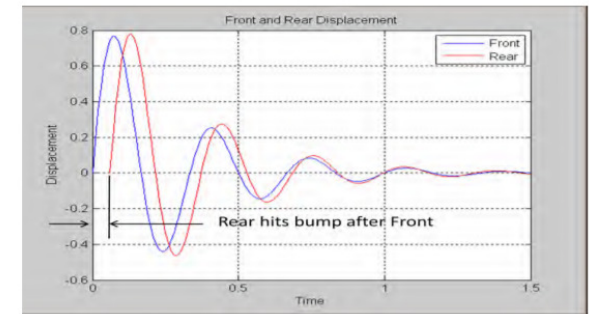


Critical Damping Coefficient

$$C_{cr} = 2\sqrt{K_S * M}$$

C_{cr} = Critical Damping Coefficient (N-s/m)
 K_S = System Spring Rate (N/m)
 M = System Mass (kg)

Different Front and Rear Ride Frequencies



- <https://www.audi-mediacycenter.com/en/photos/detail/adaptive-dampers-suspension-with-adaptive-damper-control-42115>
- <http://www.kaztechnologies.com/wp-content/uploads/2014/03/A-Guide-To-Your-Dampers-Chapter-from-FSAE-Book-by-Jim-Kasprzak.pdf>

Examples: Multi-Chamber Air Springs

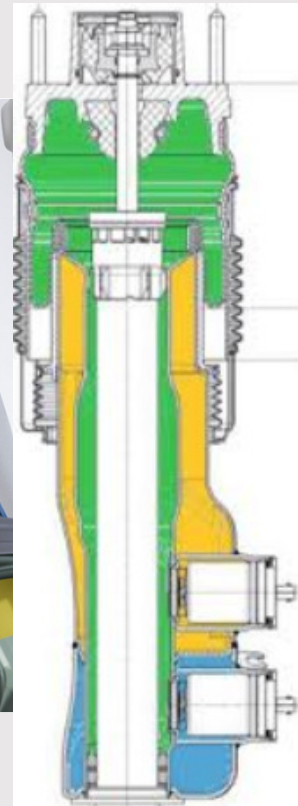
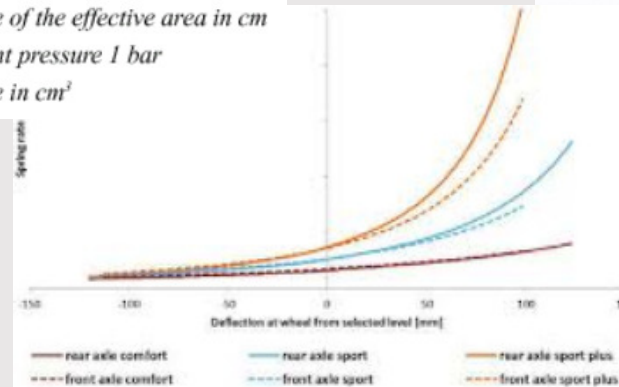
- Multiple Spring Rates: Multi-Volume
- Roll, Pitch..

$$c = 10 \cdot p_{\bar{u}} \cdot \frac{dAw}{ds} + \chi \cdot 10 \cdot (p_{\bar{u}} + p_a) \cdot \frac{Aw^2}{V} \left[\frac{N}{cm} \right]$$

$p_{\bar{u}}$ working pressure
 A_w effective area
 k isentropic exponent air 1.4
 $\frac{dAw}{ds}$ change of the effective area in cm
 p_a ambient pressure 1 bar
 V volume in cm³

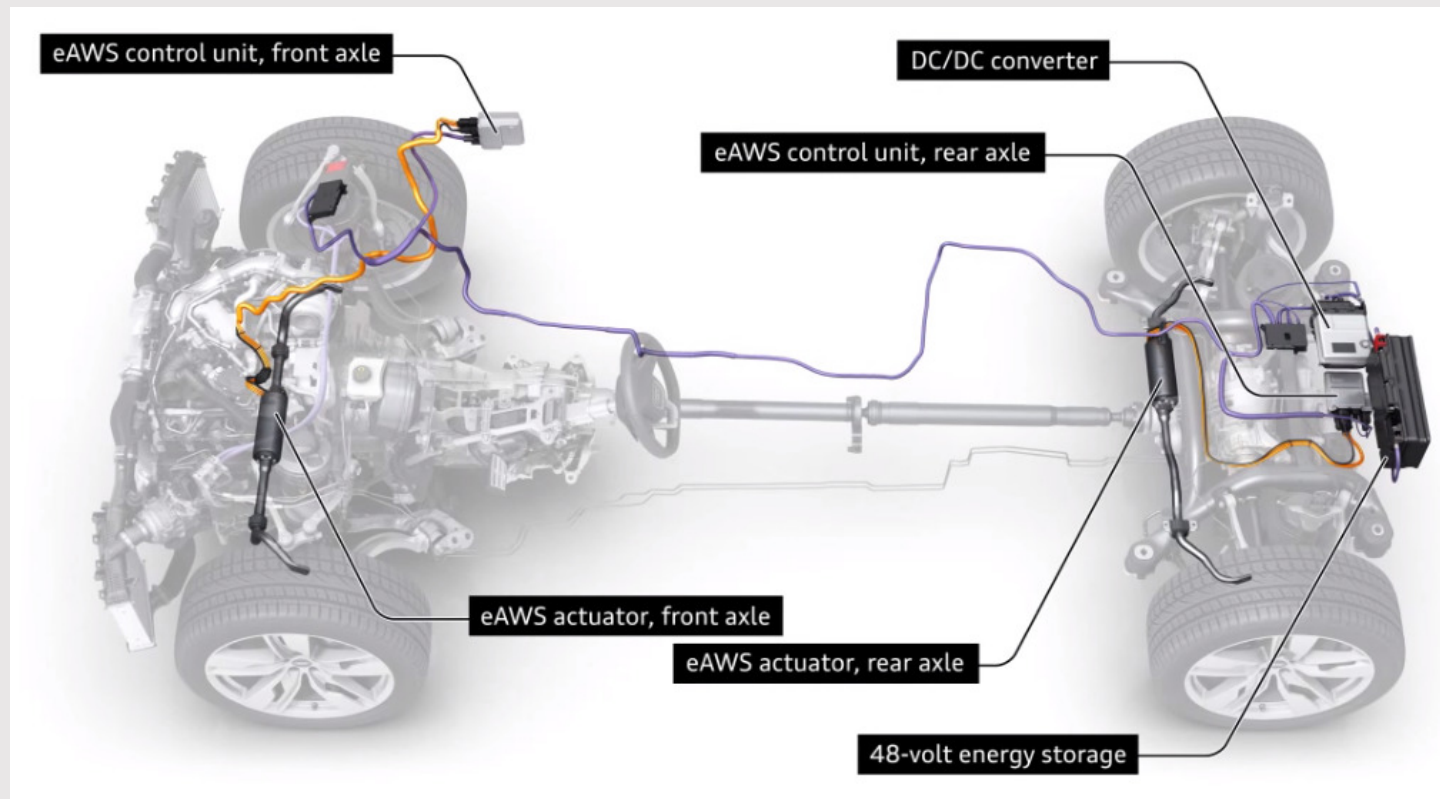
- Valve Control

- <http://lhtech.com/pdf/automation/pneumatic/Goodyear-Air-Spring-Data.pdf>
- https://link.springer.com/chapter/10.1007%2F978-3-658-14219-3_30
- <https://presskit.porsche.de/specials/en/porsche-fahrwerkentwicklung/topic/mehr-performance-mit-mehr-komfort-adaptive-luftfederung.html>
- <http://www.cfm-itbona.com/ITBONA/CFM-Schiller/airsprings.htm>



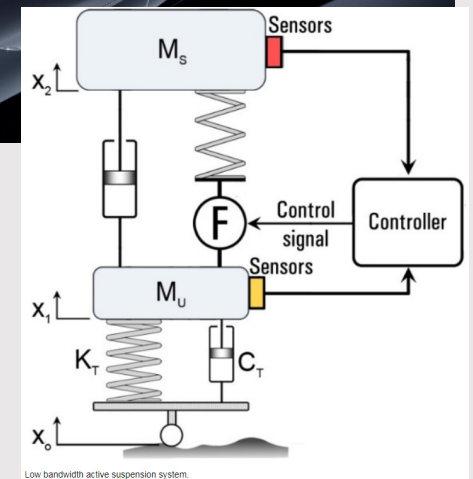
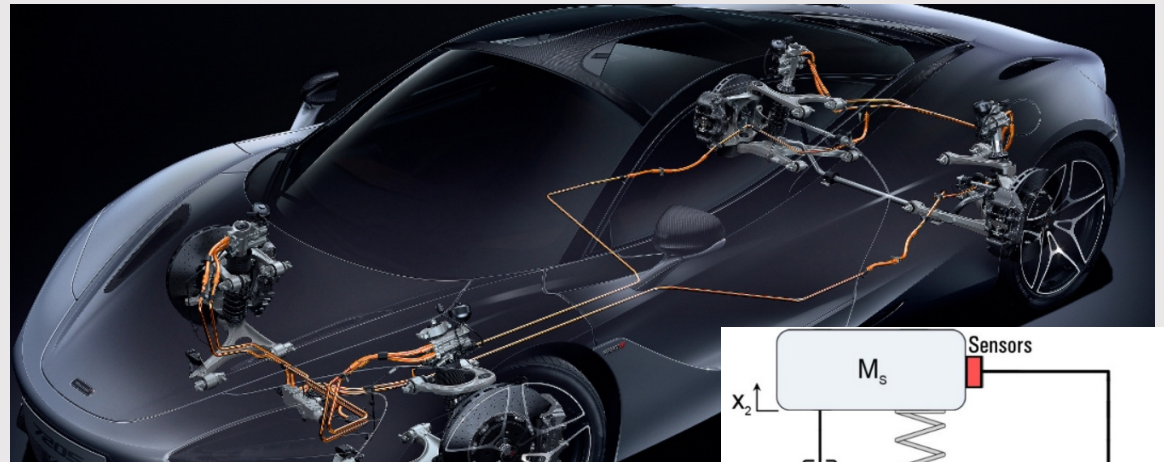
Examples: Active Roll Control

- Comfort vs Roll
- Distribution



Examples: 'Kinetic' + Fully Active Suspensions

- Kinetic – hydraulically linked via valves (pitch, roll)
 - Semi-active (discrete states)
- Fully Active
 - Heave Control
 - Energy?



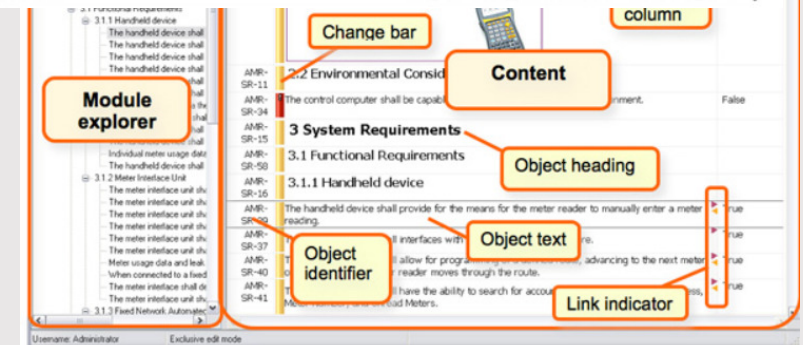
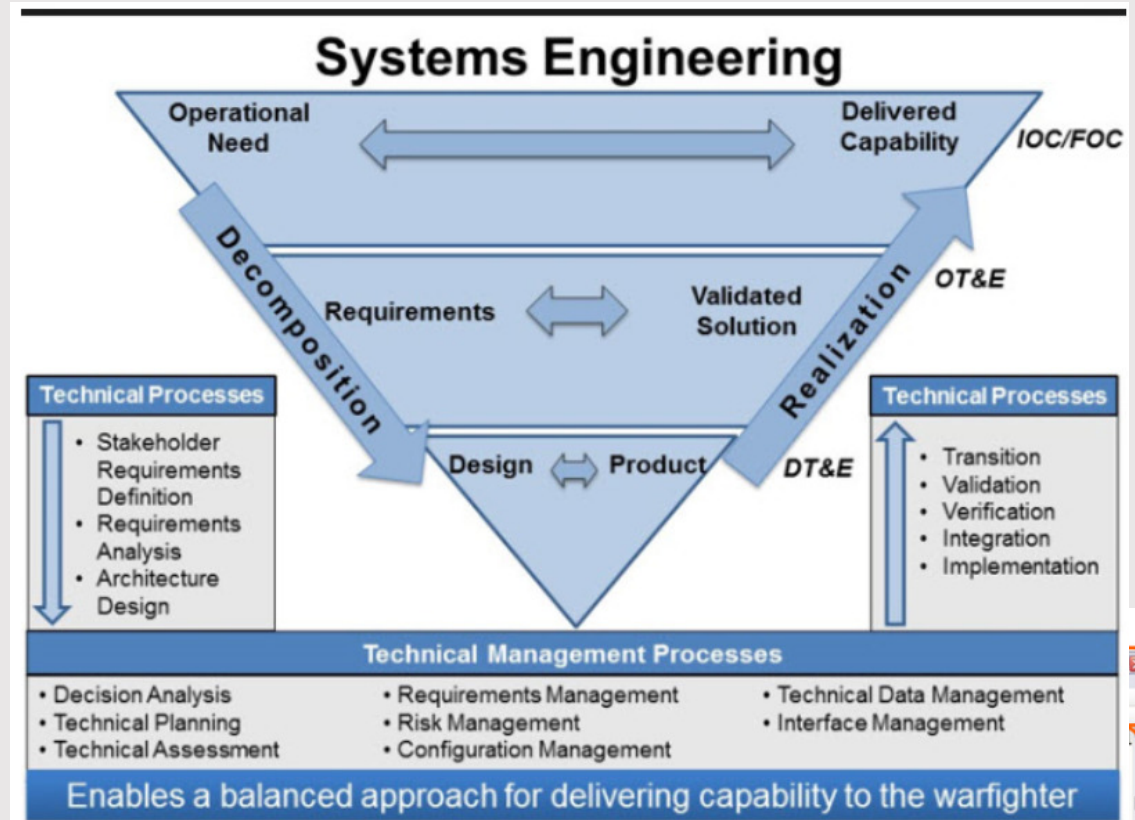
- <https://www.sae.org/news/2018/07/mclaren-720s-semi-active-suspension>
- https://www.tenneco.com/assets/1/7/Kinetic_Brochure.pdf

Controls Development Framework

- PID, State Machines, Control Theory
- Model Development Robustness / Process
- Target ECU Platform
- Systems Engineering
- Functional Safety - ISO 26262
- Automotive-Spice

Systems Engineering

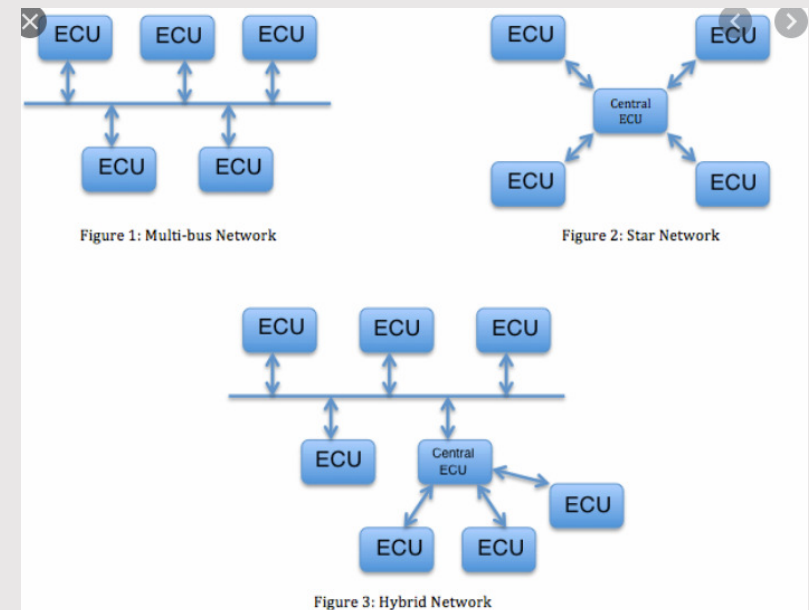
- Systems V
- Requirements
- Test Cases
- Time Consuming
- Change Management
- Validation vs Verification
- Automotive, Aviation, Military
- IBM DOORS / ReqIF
- <http://railengdigest.com/technical-articles/systems/brief-guide-railway-systems-engineering/>
- <https://www.ibm.com/developerworks/rational/library/getting-started-ibm-rational-doors/index.html>
- https://en.wikipedia.org/wiki/Requirements_Interchange_Format



Controls Development Framework

- Diagnostics
 - OBD2 vs OEM systems
- Automotive Electronics
 - Individual or Centralised?
- Networks
 - CANBus (Robust)
 - FlexRay (Deterministic)
 - Ethernet (Fast)

• <https://cecas.clemson.edu/cvel/auto/Buses/Flexray.html>

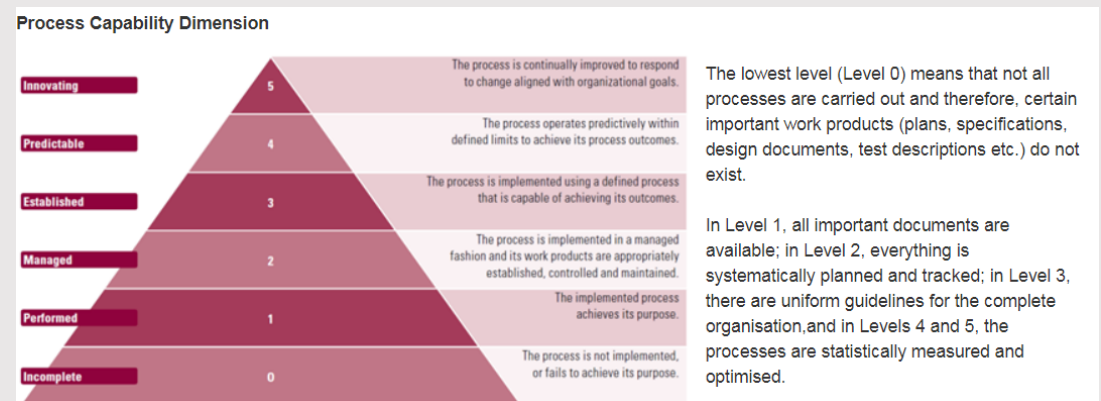


Controls Development Framework

- Functional Safety - ISO 26262
 - Common Language
 - Safety Critical Electronic Systems
 - Hazard Analysis / ASIL rating
 - Mitigation Strategies

- Automotive-Spice

- <https://www.automotive-iq.com/electrics-electronics/articles/what-is-iso-26262>
- <https://www.industryforum.co.uk/resources/blog/automotive-spice-by-vda/>



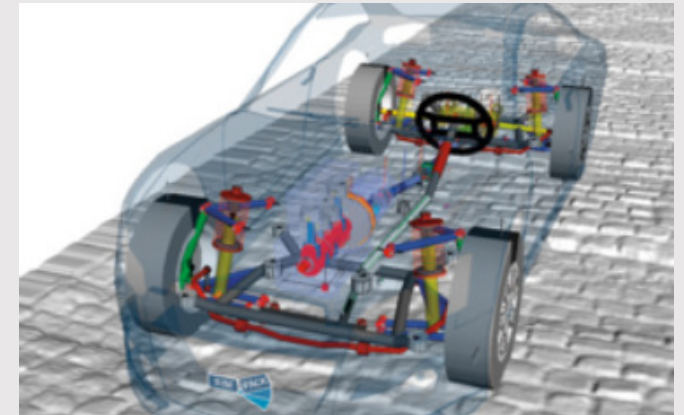
Battery Electric Vehicles

- Mainstream
- Range: 300miles?
- Charging time? 15 minutes per 120 miles?
- High Voltage? 400V? 800V?
- Vehicle Mass?
- Costs / materials availability
- Software Update Over the Air?



Virtual Engineering: Vehicle Dynamics Simulation

- Matlab / Simulink
- Open Loop / Closed Loop
- Multi-Body Systems vs Lookup tables / 1D
- Driving Simulators
- CarMaker Example

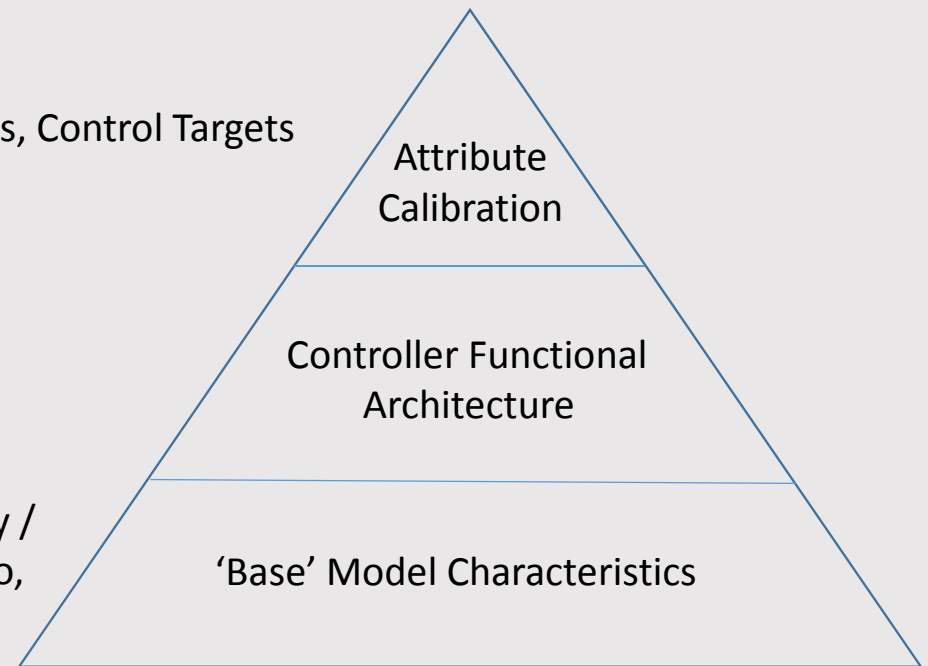


What Is Control System Application?

- Calibration / Tuning
- Testing: Targets; Regulations
- Sign-Off & Documentation

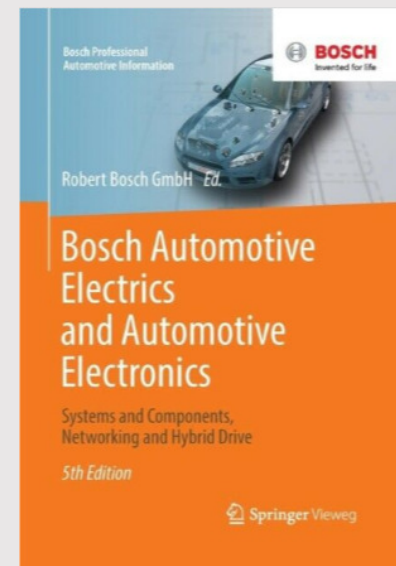
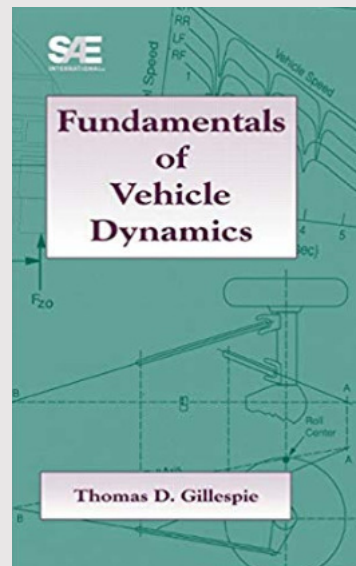
Masses / Inertias, Geometry /
Wheelbase.. / Steering Ratio,
Actuator characteristics

System Gains, Control Targets



- <https://www.youtube.com/watch?v=XMcl4hBWIC8>

Some References



Conclusions, Questions, Return Samples

- Controls Engineers deliver things (SW, Calibration, Documentation)
 - Control Systems: Sensors, Control & Actuation
 - Development Framework, Regulations & Standards (Systems Eng, FS)
 - Wide variety of Engineering Tools (DOORS, Matlab, CarMaker..)
-
- Anything relevant to you? Soft skills or Engineering related?