Die Rechenautomaten haben etwas von den Zauberern im Märchen.
Sie geben einem wohl, was man sich wünscht, doch sagen sie einem nicht, was man sich wünschen soll.

Calculation machines have some of the magicians in the fairy tale. They might give you, what you wish, but they don’t tell you, what you should want.

(Norbert Wiener (1984-1964), Professor at MIT)
How DoE Makes Vehicle Dynamics Simulation Intelligible And Efficient

A bit of magic help in tuning vehicle dynamics

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Background

• Calibrating vehicle chassis parameters is always a compromise and simulation can provide a sensible starting point for real vehicle tuning.

• This is a glimpse at how optimisation techniques can help reach this starting point and make effects of compromise more understandable to the engineer.

• It will be demonstrated by simple examples using limited variables.

• The scenarios are based on settings for a hypothetical rally car where the focus is on optimising vertical ride and tyre grip performance.
Scenario 1
“Flat” Primary Ride (minim pitch disturbance)

- An existing rally car has been fitted with an electric drivetrain.

- Front/rear weight distribution has been fixed but location of the 2 batteries (1 front 1 rear) can be adjusted to adjust the pitch inertia.

- To save money only the rear spring rate is allowed to be changed, Front spring and all dampers are fixed.
The Optimisation Challenge

- The Vehicle’s Dynamics” must make it safe as possible by keeping the wheels well connected to the ground and its responses consistent and predictable.

- Any “Vehicle’s Dynamics” must match the “Driver’s Dynamics” requirements for:
  - Confidence
  - Controllability
  - Agility
  - Speed
  - Comfort

depending on the driving experience required
“Flat” Primary Ride

- To test this the vehicle is driven over a long wavelength bump.

**First Objective**
- At first recovery from the bump, front and rear axle heights should be in phase and of equal amplitude, giving a pitch free attitude.

**Additional Objective**
- minimise pitch velocity over the whole manoeuvre (less driver distraction)
Scenario 1
“Flat” Primary Ride (i.e. minimising pitch)

Characteristics observed to judge:
Reference Condition (not flat ride)
CAMEO – on a steady state TEST BED SYSTEM
Calibration needs reproducible measurements

<table>
<thead>
<tr>
<th>DYNO</th>
<th>ENGINE</th>
<th>ECU</th>
</tr>
</thead>
<tbody>
<tr>
<td>![DYNO Image]</td>
<td>![ENGINE Image]</td>
<td>![ECU Image]</td>
</tr>
<tr>
<td>Control unit (EMCON)</td>
<td>Fuel Consumption (753)</td>
<td>Indicating (Indimaster)</td>
</tr>
<tr>
<td>Emission bench (CEB)</td>
<td>Smokemeter, Opacimeter</td>
<td>Application System</td>
</tr>
</tbody>
</table>

Asap 3

PUMA

ACI

CAMEO
CarMaker as Simulation System and CAMEO:
Task definition

- Definition of the manoeuvre to be optimized:
  - the vehicle is driven over a long wave bump

- Definition of the optimisation target
  - the vehicle has subjectively “flat” primary motion:
    \[
    \text{Minimize } \Delta \text{ Amplitude at } \Delta \text{ time}=0
    \]

- Definition of the factors (variation parameters to be changed)
  - pitch inertia and rear spring rate
Calibration Workflow using CAMEO (Office Environment)

- Create the right manoeuvre in IPG-Carmaker and apply “named values” for the parameters to be varied:
  
  e.g.:

  - Define the formulas for the calculations of the characteristic result values

- Create test plan in respect to Design of Experiment (DoE)
Calibration Workflow using CAMEO (Office Environment)

- Task definition
- Test planning
- Run Simulations
- Modelling
- Optimisation
- Map Generation & Verification
Run the Simulations in direct link between:

**Inputs**
- Rear spring rate
- Pitch Inertia

**Outputs**
- $\Delta$ Time
- $\Delta$ Amplitude
- tyre load variation
- vertical load variation
- max vertical defelction in CG

Test Maneuver
IPG CarMaker

DoE / Optimizer
AVL CAMEO
Run the Simulations in direct link between CAMEO and CarMaker:

**Inputs**
- Rear spring rate
- Pitch Inertia

**Outputs**
- $\Delta$ Time
- $\Delta$ Amplitude
- tyre load variation
- vertical load variation
- max vertical deflection in CG
Calibration Workflow using CAMEO (Office Environment)

- Task definition
- Test planning
- Run test
- Modelling
- Optimisation
- Map Generation & Verification

- Fit the Characteristic result values
e.g.: $\Delta$ time = as $f(\text{pitch inertia and rear spring rate})$

3D-View of the model as $f(2 \text{ Parameters})$

Intersection View of the model as $f(2 \text{ Parameters})$
Calibration Workflow using CAMEO
(Office Environment)

- Minimize $\Delta$ Amplitude
- at $\Delta$ time=0

**Task definition**
- Test planning
- Run test
- Modelling
- Optimisation

**Map Generation & Verification**

---

**Graph:**
- **Y-axis:** $\Delta$ Amplitude
- **X-axis:** $\Delta$ time
- **Data Points:**
  - Rear spring rate: Factor: 1.338, 1548 kg*m^2
  - Pitch inertia: 0.0047202, 0.004836, 0.0044833
Scenario 2
Maximising tyre contact & minimising pitch velocity

- Now what is about the load variations on the tires as well as the overall pitch velocity?

- The team have now been allowed a budget to tune the dampers as well, to
  - minimise pitch velocity over the whole manoeuvre
  - but keep also the flat ride condition!

- These items are now allowed to be optimised
  - rear damper settings (Compression and Rebound)
  - rear springs
  - pitch inertia
So, minimize pitch velocity and keep “flat ride condition” (the picture is just a place holder for the live Demonstration)
Calibration Workflow using CAMEO
(Office Environment)

- Task definition
- Test planning
- Run test
- Modelling
- Optimisation
- Map Generation & Verification

![Graph showing body movement above axle vs time, with different conditions (rear base, front base, rear good, front good).]
Flat ride animation:
Scenario 3
Maximum tyre contact & minimum body acceleration on a bumpy road

- Using the rear spring rate and the pitch inertia from the flat ride both **tyre grip and comfort on rough surfaces** needs to be minimised.
- The team have now been allowed a budget to tune both **front and rear dampers**.
- Engineers need a graphic way to understand the compromise
- Using the data presented as a “Pareto Front” enables them to make an informed assessment of the best compromise
Trade off:
“Tire load variation” $\leftrightarrow$ “body acceleration”
Feedback of the trade off decision into the intersection plot:
Summary

- By combining IPG-CarMaker and AVL-CAMEO we have shown:
  - **In scenario 1)** a “Flat ride condition” was optimized with just adapting pitch inertia and rear spring rate when driving over a long wavelength bump.
  - this “Flat ride condition” was further improved **in scenario 2)** by also adapting the rear damper settings (Compression and Rebound) in order to minimize the overall pitch velocity.
  - and finally in **scenario 3)** – keeping the pitch inertia and the rear spring rate fixed - this settings was further refined to optimize “tire load variation” and “body acceleration”.
  - by Visualizing the trade off behavior, a decision regarding front and rear damper settings (Compression and Rebound) could be made.
Conclusion

- “Computers have some of the magicians in a fairy tale. They give you perhaps, what You wish, but they don’t tell You, what You should want“

  Norbert Wiener (1984-1964), Professor at MIT

→ Task planning

→ Getting a good starting point for development of a real vehicle and making choices about meeting conflicting targets in an engineering challenge

→ identify workable combinations of tunables

and

→ User friendly visualisation of conflicting solutions helps the engineer make more informed judgements for both the virtual and the real vehicle