Design and Development of a New Suspension System for the Caterham SV-R

Presented by: Jay O’Connell, Multimatic Vehicle Engineering Manager
Vehicle Engineering

Multimatic has engineered a number of complete vehicle and chassis systems for both niche road car and race applications.
Caterham SV Suspension

- **Presentation Overview**
  - Project Scope
  - Project Targets
  - Suspension Design
    - Measurement and Modeling of Existing Vehicle
    - New Suspension Target Setting and Optimisation
    - Kinematic Analysis
    - New Design Modeling and Detail Component Design
  - Suspension Development
    - Initial Suspension Set-Up Calculations
    - Dynamic Analysis including virtual 4 post rig
    - Prototype Assembly
    - Rig Testing: K+C and 4-Post Rig Tests
    - Road Evaluation
    - Track testing
  - Results and Conclusions
Caterham SV Suspension

Project Scope

- Caterham Cars Ltd. commissioned Multimatic, Inc. to design and develop new front and rear suspensions for the Roadsport SV model in 2003
- Revise the front steering geometry and replace the outboard spring-damper design with inboard mounted dampers maintaining the same motion ratio
- Replace the de Dion rear suspension with an all new adjustable independent rear suspension
Caterham SV Suspension

Project Targets:

- Improved ride and handling without losing the iconic character of the Caterham Seven
- Improved suspension and steering kinematics
- Increased adjustability (ride height, front ARB, rear camber and toe adjustability)
- Reduced unsprung weight
- Minimise use of new components and level of validation required
Caterham SV Suspension

Measurement of Existing Vehicle

- CMM measurements taken of existing frame and suspension components

Right front suspension  Left rear suspension
Caterham SV Suspension       Measurement of Existing Vehicle

- Chassis compliance was measured through full vehicle torsion testing at MTCE
Caterham SV Suspension Modeling of Existing Vehicle

- Kinematic model of standard car produced in ADAMS and validated based on correlation with K&C results

Caterham SV FRONT
Bump Camber

\[
y = 3.93E-08x^2 - 1.36E-04x^2 + 2.89E-02x + 1.79E-03
\]

\[
y = -3.75E-08x^2 - 1.30E-04x^2 + 2.77E-02x + 8.14E-04
\]
SDRC I-Deas 3D CAD models were created for the existing components and assembled into a full vehicle model.
Front and Rear suspension design targets were set using desired vehicle characteristics, benchmarking and experience.

### Front Targets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caster (deg)</td>
<td>5.0</td>
</tr>
<tr>
<td>Caster trail (mm)</td>
<td>30.0</td>
</tr>
<tr>
<td>KPI (deg)</td>
<td>9.0 to 11.0</td>
</tr>
<tr>
<td>Hub offset (mm)</td>
<td>50.0 to 60.0</td>
</tr>
<tr>
<td>ground offset (mm)</td>
<td>8.0 to 15.0</td>
</tr>
<tr>
<td>Toe (deg)</td>
<td>-0.10</td>
</tr>
<tr>
<td>Camber (deg)</td>
<td>-2.00</td>
</tr>
<tr>
<td>Roll Centre H (mm)</td>
<td>30.0 to 40.0</td>
</tr>
<tr>
<td>RC migration @3°(mm)</td>
<td>-10.0 to 10.0</td>
</tr>
<tr>
<td>Anti-Dive (%)</td>
<td>20.0</td>
</tr>
<tr>
<td>Anti-Squat (%)</td>
<td>-</td>
</tr>
<tr>
<td>Anti-Lift (%)</td>
<td>-</td>
</tr>
<tr>
<td>Bump Steer (deg/m)</td>
<td>-3.0 to -5.0</td>
</tr>
<tr>
<td>Bump Camber (deg/m)</td>
<td>-10.0 to -40.0</td>
</tr>
<tr>
<td>Bump Caster (deg/m)</td>
<td>&lt; 20.0</td>
</tr>
<tr>
<td>Wheel Reces. (mm/m)</td>
<td>&gt; 0.0</td>
</tr>
<tr>
<td>Roll Camber (deg/deg)</td>
<td>0.25 to 0.30</td>
</tr>
<tr>
<td>Roll Steer (deg/deg)</td>
<td>0.04 to 0.075</td>
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<tr>
<td>Ackerman (%)</td>
<td>40.0%</td>
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</table>

### Rear Targets

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caster (deg)</td>
<td>2.0 to 5.0</td>
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<tr>
<td>Caster trail (mm)</td>
<td>5.0 to 25.0</td>
</tr>
<tr>
<td>KPI (deg)</td>
<td>&lt;12.0</td>
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<tr>
<td>Hub offset (mm)</td>
<td>40.0 to 75.0</td>
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<td>ground offset (mm)</td>
<td>-5.0 to 20.0</td>
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<tr>
<td>Toe (deg)</td>
<td>0.17</td>
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<tr>
<td>Camber (deg)</td>
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<tr>
<td>Roll Centre H (mm)</td>
<td>20.0 to 40.0 &gt; Front</td>
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<tr>
<td>RC migration @3°(mm)</td>
<td>5.0 to 15.0 &lt; Front</td>
</tr>
<tr>
<td>Anti-Dive (%)</td>
<td>-</td>
</tr>
<tr>
<td>Anti-Squat (%)</td>
<td>20.0</td>
</tr>
<tr>
<td>Anti-Lift (%)</td>
<td>40.0</td>
</tr>
<tr>
<td>Bump Steer (deg/m)</td>
<td>1.0 to 2.5</td>
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<tr>
<td>Bump Camber (deg/m)</td>
<td>-10.0 to -40.0</td>
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<tr>
<td>Bump Caster (deg/m)</td>
<td>Minimise</td>
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<td>Wheel Reces. (mm/m)</td>
<td>&gt;15.0</td>
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<tr>
<td>Roll Camber (deg/deg)</td>
<td>0.35 to 0.40</td>
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<tr>
<td>Roll Steer (deg/deg)</td>
<td>-0.01 to -0.02</td>
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<tr>
<td>Ackerman (%)</td>
<td>-</td>
</tr>
</tbody>
</table>
Caterham SV Suspension

- Kinematics optimised using ADAMS/Car and ADAMS/Motorsport against baseline targets
- Proposals reviewed and compared against CAD data for design and manufacturing feasibility

**FRONT SUSPENSION**

**Proposal C:**
Objectives: Widen the front track to correspond to the rear one
Constraints: Use the existing upright, hub, lower A-Arm position
Modifications: Hub shifted outboard to match new front track.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TARGET</th>
<th>SV original</th>
<th>Proposal B</th>
<th>Proposal C</th>
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</thead>
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<tr>
<td>Caster (deg)</td>
<td>5</td>
<td>7.7</td>
<td>4.7</td>
<td>4.8</td>
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<td>Caster trail (mm)</td>
<td>30</td>
<td>33</td>
<td>24</td>
<td>24</td>
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<tr>
<td>KPI (deg)</td>
<td>9 to 11</td>
<td>11.2</td>
<td>10.9</td>
<td>10.9</td>
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<td>Hub offset (mm)</td>
<td>50 to 60</td>
<td>100</td>
<td>75</td>
<td>75</td>
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<tr>
<td>ground offset (mm)</td>
<td>8 to 15</td>
<td>61.5</td>
<td>36.5</td>
<td>36.5</td>
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<tr>
<td>Toe (deg)</td>
<td>-0.1</td>
<td>-0.28</td>
<td>-0.33</td>
<td>-0.34</td>
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<tr>
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<td>-2.3</td>
<td>-2.1</td>
<td>-2.1</td>
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<tr>
<td>Camber (deg)</td>
<td>30 to 40</td>
<td>62</td>
<td>32.2</td>
<td>33</td>
</tr>
<tr>
<td>Roll Centre H (mm)</td>
<td>-10 to 10</td>
<td>-0.9</td>
<td>-3.6</td>
<td>-4.1</td>
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<tr>
<td>Anti-Dive (%)</td>
<td>20</td>
<td>72</td>
<td>57</td>
<td>57.6</td>
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<tr>
<td>Anti-Squat (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Anti-Lift (%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bump Steer (deg/m)</td>
<td>-3 to -5</td>
<td>-1.6</td>
<td>-4.0</td>
<td>-4.2</td>
</tr>
<tr>
<td>Bump Camber (deg/m)</td>
<td>-10 to -40</td>
<td>-30</td>
<td>-17</td>
<td>-17</td>
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<tr>
<td>Bump Caster (deg/m)</td>
<td>&lt;20</td>
<td>39</td>
<td>29</td>
<td>29</td>
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<tr>
<td>Wheel Reces. (mm/m)</td>
<td>&gt;0</td>
<td>9</td>
<td>2.2</td>
<td>1.9</td>
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<tr>
<td>Roll Camber (deg/deg)</td>
<td>0.25 to 0.30</td>
<td>0.39</td>
<td>0.22</td>
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<td>Roll Steer (deg/deg)</td>
<td>0.04 to 0.075</td>
<td>0.02</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>Ackerman (%)</td>
<td>40%</td>
<td>32% (1 rev)</td>
<td>33% (1 rev)</td>
<td>32% (1 rev)</td>
</tr>
</tbody>
</table>

*All values valid for ride height 2UP condition with CR500 195/45 R15 tyre.*
Caterham SV Suspension

- ADAMS example: Front Roll Analysis
Caterham SV Suspension

ADAMS example: Rear Roll Analysis
Caterham SV Suspension

- Full chassis and suspension 3D solid modeled in SDRC I-deas
Component design reviewed in partnership with Caterham and their suppliers
Component designs created from 3D hardpoints

- New rear cast upright
Caterham SV Suspension Component Design

- Component designs optimised using load cases generated from the ADAMS analysis

- Topology optimisation of the front rocker
Design verification using FEA on critical components

- ABAQUS stress analysis of the front rocker design under a 5g loadcase
### Caterham SV Suspension Initial Set-Up Calculations

- Initial suspension set-up calculation for spring and bar rates performed using Multimatic software.

#### MTC ride roll & damper v1.1

<table>
<thead>
<tr>
<th>Input</th>
<th>Vehicle information</th>
<th>front</th>
<th>rear</th>
<th>units</th>
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<tr>
<td></td>
<td>Wheelbase</td>
<td>2250.0</td>
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<td>mm</td>
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<td></td>
<td>Track width</td>
<td>1510.0</td>
<td>1410.0</td>
<td>mm</td>
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<tr>
<td></td>
<td>CG height (from ground)</td>
<td>330.0</td>
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<td>mm</td>
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<td></td>
<td>Roll centre height (from ground)</td>
<td>21.0</td>
<td>61.0</td>
<td>mm</td>
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<tr>
<td></td>
<td>Total mass</td>
<td>285.0</td>
<td>355.0</td>
<td>kg</td>
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<tr>
<td></td>
<td>Unsprung mass (per corner)</td>
<td>95.0</td>
<td>35.0</td>
<td>kg</td>
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<td></td>
<td>Loaded tyre radius</td>
<td>250.0</td>
<td>250.0</td>
<td>mm</td>
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<tr>
<td></td>
<td>Tyre vertical rate</td>
<td>100.0</td>
<td>200.0</td>
<td>N/mm</td>
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<td>Bushing wind-up rate (at the wheel)</td>
<td>1.0</td>
<td>1.0</td>
<td>N/mm</td>
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<tr>
<td></td>
<td>Motion ratio (sprung/wheel)</td>
<td>0.79</td>
<td>0.84</td>
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<table>
<thead>
<tr>
<th>Roll and Roll targets</th>
<th>front</th>
<th>rear</th>
<th>units</th>
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</thead>
<tbody>
<tr>
<td>Ride natural frequency</td>
<td>2.11</td>
<td>2.33</td>
<td>Hz</td>
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<tr>
<td>Roll gradient</td>
<td>1.33</td>
<td>deg/g</td>
<td></td>
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<tr>
<td>Maximum lateral acceleration</td>
<td>1.00</td>
<td>g</td>
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<table>
<thead>
<tr>
<th>Vehicle information</th>
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<th>rear</th>
<th>units</th>
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<tbody>
<tr>
<td>Total vehicle mass</td>
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<td>kg</td>
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<tr>
<td>% front mass</td>
<td>45.6</td>
<td>53.4</td>
<td>%</td>
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<tr>
<td>Sprung mass</td>
<td>47.1</td>
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<td>kg</td>
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<tr>
<td>% sprung mass</td>
<td>45.6</td>
<td>54.4</td>
<td>%</td>
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<td>Spring mass CG location</td>
<td>1228.1</td>
<td>1071.9</td>
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<tr>
<td>Total vehicle CG location</td>
<td>1249.0</td>
<td>1048.0</td>
<td>mm</td>
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<tr>
<td>Roll</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ride rate required</td>
<td>18.8</td>
<td>27.5</td>
<td>N/mm</td>
</tr>
<tr>
<td>Wheel centre rate</td>
<td>13.77</td>
<td>31.9</td>
<td>N/mm</td>
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<tr>
<td>Spring rate (metric)</td>
<td>39.4</td>
<td>43.8</td>
<td>N/mm</td>
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<tr>
<td>Spring rate (imperial)</td>
<td>225.0</td>
<td>250.0</td>
<td>lb/in</td>
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<table>
<thead>
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<th>Roll</th>
<th>front</th>
<th>rear</th>
<th>units</th>
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<tbody>
<tr>
<td>Roll moment lever arm</td>
<td>318.77</td>
<td></td>
<td>mm</td>
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<tr>
<td>Roll moment</td>
<td>1472.90</td>
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<td>N/mm</td>
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<tr>
<td>Tyre roll gradient</td>
<td>0.27</td>
<td>deg/g</td>
<td></td>
</tr>
<tr>
<td>Spring mass roll gradient</td>
<td>1.06</td>
<td>deg/g</td>
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<tr>
<td>Total roll rate</td>
<td>1383.03</td>
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<td>N/mm</td>
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<tr>
<td>Total load transfer</td>
<td>1309.42</td>
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<td>Nl/g</td>
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<td>Lead transfer</td>
<td>731.65</td>
<td>633.33</td>
<td>N/g</td>
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<td>Roll rate required</td>
<td>839.89</td>
<td>557.52</td>
<td>N/mm</td>
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<td>Roll rate - no bar (at wheel center)</td>
<td>393.38</td>
<td>583.47</td>
<td>N/mm</td>
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<tr>
<td>Anti-roll bar roll rate</td>
<td>1054.42</td>
<td>1339.14</td>
<td>N/mm</td>
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<tr>
<td>Anti-roll bar contribution</td>
<td>125.65</td>
<td>23.49</td>
<td>%</td>
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<tr>
<td>Roll rate - lever arm</td>
<td>22.39</td>
<td>1.11</td>
<td>N/mm</td>
</tr>
<tr>
<td>Anti-roll bar diameter (solid)</td>
<td>18.0</td>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>Anti-roll bar diameter (tube)</td>
<td>SOLVE</td>
<td>11.1</td>
<td>mm</td>
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<tr>
<td>Anti-roll bar shear stress</td>
<td>0.21</td>
<td>0.11</td>
<td>Mpa</td>
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</table>
Initial damper forces calculated using Multimatic Dynosoft software
Caterham SV Suspension

Virtual 4-Post Rig Analysis

test_fourposts Time= 5.0700 Frame=512
Caterham SV Suspension

- Build support at Caterham’s Dartford, UK factory
Caterham SV Suspension

- Suspension kinematics and compliances measured on single axle K+C rig and compared with ADAMS analysis
Caterham SV Suspension

- Vehicle tuned on MTCE 4-post rig in Thetford, UK using Dave Williams methodologies
Initial road testing at Millbrook conducted by Murray White, Head of Vehicle Development:

“Very Impressive performance out of the box; greatly reduced steering effort, kickback, and rear-end steer over bumps.”

“Limit balance was progressive and adjustable and proved sensitive to anti-roll bar stiffness changes.”

“The yaw center seems about right for a good compromise between agility and stability.”

“Good phasing of the front to rear axle lateral force build up.”
Caterham SV Suspension

- On-track development run and supported by MTCE staff: engineers, technicians and driver

Caterham SV Suspension

- On-track development run and supported by MTCE staff: engineers, technicians and driver

“The new suspension makes the vehicle more stable and easier to drive faster.” – Scott Maxwell, Driver
Caterham SV Suspension

- Program results:
  - Project managed and delivered on time to Caterham
  - Incorporated increased level of adjustability
  - 6 kg reduction in unsprung mass
  - Improved kinematics:
    - lower roll centre both front and rear
    - significant reduction in hub and ground offset
    - Improved wheel recession and front/rear anti-dive/anti-lift balance
  - Ride and handling: the car was very good “right out of the box”. The steering feel and response was improved and the handling was well balanced, progressive and adjustable.
Conclusions:

• Successful integration of target setting, analysis, rig testing and road testing
• Front and Rear suspension systems designed to complement each other
• Modern platform for Caterham future derivatives