International Automotive Congress 2017

epsilon - Small Electric Vehicle with Maximized Safety and Innovative Lightweight Body

Shanghai, November 28th 2017

Institute for Automotive Engineering
Agenda

- Motivation
- Project Overview
- Concept Investigation
- Development
- Demonstrator Vehicle
- Summary
Project Overview
Motivation

- **Urbanisation** is closely connected to the evolution of mobility

- 74% of European population lives in urbanised areas

- Urban population will increase from 3.6 billion to 6.3 billion between 2011 and 2050

- New challenges in terms of congestion as well as pollution and noise emissions

- Shared mobility and services become more important
Agenda

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small Electric Passenger vehicle with maximized Safety and Integrating a Lightweight Oriented Novel body architecture
Project Overview
Consortium

- Exterior and interior prototyping
- Project coordination
  - Concept investigation
  - Exterior & interior design
  - Package
  - Body design (CAE, CAD)
  - Drivetrain layout
  - HMI
- Active crash structures and restraints

- Body structure prototyping
- Full vehicle integration and assembly

- CFRP rear axle
- Drivetrain layout
  - Energy efficiency
  - HVAC

- Integral safety
  - Battery integration
  - Crash testing

- Business case study
  - Chassis design & build
  - Vehicle dynamics tests
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Concept Investigation
Scenario and market analysis – urban mobility

Do you live in a rural or urban area?
- Rural Area: 10%
- Urban Area: 90%

Which is your age group?
- 20-24: 15%
- 25-34: 25%
- 35-44: 30%
- 45-54: 10%
- 55-64: 5%
- 65-74: 5%
- 75-80: 0%

Preferred number of seats
- 2 seats: 70%
- 3 seats: 20%
- 4 seats: 10%

Acceptable recharge time
- 8 hours: 10%
- 5 hours: 15%
- 2 hours: 30%
- 1/2 hour: 45%

Minimum speed
- 60 km/h: 10%
- 90 km/h: 35%
- 130 km/h: 55%

Distance from your home
- <5 km: 70%
- 5-10 km: 30%
- 10-20 km: 0%
- 20-30 km: 0%
- 30-40 km: 0%
- 40-50 km: 0%
- >50 km: 0%

n = 162
Concept Investigation
Scenario and market analysis – urban mobility

- **Commuting** is the main use case for urban individual transport, followed by leisure time activities.
- **Safety** is one of the most important features.
- Low purchase **costs and TCO** are required.
- **Ease of use** (range, recharge time) and **agility** in urban driving with a possible top speed of at least 110 km/h should be realised.
- Despite road space becoming more and more congested, **sufficient space and comfort** remain key attributes.

Minimalistic vehicle concept providing safe & efficient mobility at affordable costs
Concept Investigation

Objectives

- Designing and prototyping the urban small electric vehicle of 2020 - 2025
- Appealing driving performance at affordable costs
- Holistic development and integration of innovative technologies
- Lighter, more energy-efficient and compact than today's sub-compact cars
- Higher safety, transport capacity and comfort than powered two-wheelers
- Closing the gap between ultra light vehicles (L7e) and conventional cars (M1)
Concept Investigation

Package

Concept Specification Sheet

<table>
<thead>
<tr>
<th>References</th>
<th>Renault Twizy</th>
<th>Tazzari Zero</th>
<th>Smart Fortwo E</th>
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<tbody>
<tr>
<td>L: 2335 mm</td>
<td>L: 2880 mm</td>
<td>L: 2695 mm</td>
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<tr>
<td>W: 1225 mm</td>
<td>W: 1560 mm</td>
<td>W: 1559 mm</td>
<td></td>
</tr>
<tr>
<td>H: 1454 mm</td>
<td>H: 1425 mm</td>
<td>H: 1565 mm</td>
<td></td>
</tr>
</tbody>
</table>

| Vehicle Type | Segment     | Seats        | Units per year | SOP            | Technical Specs and Targets |
|--------------|-------------|--------------|----------------|-----------------|
|              | M0, Sub-A   | 2 (M95th) + 1 (F5th) | 50,000         | 2020 - 2025     |

<table>
<thead>
<tr>
<th>Exterior Dimensions</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Width</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Wheelbase</td>
</tr>
<tr>
<td>Front track</td>
</tr>
<tr>
<td>Rear track</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Headroom driver</td>
</tr>
<tr>
<td>Headroom co-driver</td>
</tr>
<tr>
<td>Headroom 2nd row</td>
</tr>
<tr>
<td>Shoulder room front</td>
</tr>
<tr>
<td>Shoulder room rear</td>
</tr>
<tr>
<td>Trunk volume</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Functional Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suitability for car sharing</td>
</tr>
<tr>
<td>Mainly for urban commuting</td>
</tr>
<tr>
<td>Modularity for families</td>
</tr>
<tr>
<td>Easy to use</td>
</tr>
<tr>
<td>Agile in urban environment</td>
</tr>
</tbody>
</table>

References: Smart Fortwo E, E Renault, Tazzari Zero, Zerobil
Concept Investigation
Package

Final Package

Package concept

Drivetrain development

Chassis development

Vehicle concept

BiW development

Cooler
Charger
HV battery
Inverter; DC/DC
Motor
Transmission
Concept Investigation

Package

Final Package

- Inverter/converter
- HVAC-box
- 12V battery
- Radiator and fan
- AC charger
- PTC heater
- E-motor
- McPherson axle
- Hybrid CFRP-metal rear axle
- HV battery
- Transmission
Agenda

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Development
Structural BIW concept

Holistic lightweight design approach

Geometrical lightweight design

- Lightweight design by topology optimisation

Conceptual lightweight design

- Structurally integrated battery
- Structurally integrated rear seat

Material lightweight design

- CFRP-AI-Space-Frame
  - Aluminium
  - CFRP
Development
Structural BIW concept

Body in White

- CFRP-Al-Space-Frame architecture
- CFRP space frame enclosing the passenger compartment
  - Axontex technology by partner Axon
  - LDPE foam cores overbraided with HT carbon fibre
  - Additional braiding process leads to multi-chamber cross section
  - Filling with PU resin by VARTM in a tool
  - Curing in autoclave
- Aluminium extrusion profiles for front, rear and side deformation zones
Development
Structural BIW concept

- A multi material solution, based on CFRP and aluminium
- Non-structural injection moulded outer panels (GFRP for prototype)
Development
Structural BIW concept

Weight target full vehicle: 600 kg

- Body: 210 kg (35%)
- Drivetrain: 96 kg (16%)
- Chassis: 60 kg (10%)
- Electronics: 168 kg (28%)
- Interior: 66 kg (11%)

Weight target body: 210 kg
Final weight: 211 kg

- BIW: 112 kg (53%)
- Doors and closures: 35 kg (17%)
- Exterior: 35 kg (16%)
- Glazing: 8 kg (4%)
- Hang-on parts/brackets: 21 kg (10%)

Weight target full vehicle: 600 kg

Development Structural BIW concept

Weight target body: 210 kg
Final weight: 211 kg

- BIW: 112 kg (53%)
- Doors and closures: 35 kg (17%)
- Exterior: 35 kg (16%)
- Glazing: 8 kg (4%)
- Hang-on parts/brackets: 21 kg (10%)
### Crash load cases

<table>
<thead>
<tr>
<th>#</th>
<th>Crash Test</th>
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<tbody>
<tr>
<td>1</td>
<td>Euro NCAP full width rigid barrier front crash</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>Euro NCAP offset deformable barrier front crash</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>Euro NCAP moveable deformable barrier side crash</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>Euro NCAP side pole crash</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>FMVSS 216 roof test</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>FMVSS 301 offset deformable barrier rear crash</td>
<td>✓</td>
</tr>
</tbody>
</table>
Development
Structural BIW concept

Euro NCAP full width rigid barrier front crash
Development
Passive safety – restraint system layout

- **Driver** restraint system
  - Dummy 50th, ODB 65 km/h

- Dummy 5th, FW 50 km/h (Adaptive load limiter)

- **Passenger** restraint system
  - Dummy 50th, ODB 65 km/h

- Dummy 5th, FW 50 km/h (Adaptive load limiter)

<table>
<thead>
<tr>
<th>Head gap</th>
<th>HIC(_{36\text{ms}})</th>
<th>Cd</th>
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<tbody>
<tr>
<td>40 mm</td>
<td>565</td>
<td>42 mm</td>
</tr>
<tr>
<td>35 mm</td>
<td>350</td>
<td>45 mm</td>
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</table>

<table>
<thead>
<tr>
<th>HIC(_{36\text{ms}})</th>
<th>Neck F(_z)</th>
<th>Neck F(_x)</th>
<th>Neck M(_y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>235</td>
<td>1.58 kN</td>
<td>0.75 kN</td>
<td>13.0 Nm</td>
</tr>
<tr>
<td>64</td>
<td>1.06 kN</td>
<td>0.50 kN</td>
<td>13.0 Nm</td>
</tr>
</tbody>
</table>

(TUG)
Development
Pedestrian protection

- epsilon vehicle
  - 600 kg
  - Rating: 76%

- Reference vehicles
  - 845 - 940 kg
  - Rating: 46 - 73 %
Development

Structural BIW concept

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Euro NCAP full width rigid barrier front crash

[Image of a car crash simulation]
### Front and rear axle

- **McPherson** front suspension and steering system derived from a donor vehicle with minor adaptations.

- An **Omega beam rear axle** has been specifically designed for the epsilon vehicle with the aim of:
  - assuring a good K&C performance
  - weight reduction (37%) with hybrid metal/CFRP solution

1: Middle section (CFRP)
2: Connection with central joint (metal)
3: Connection between middle and side section
4: Side section (metal)
5: Wheel trunk (metal)
6: Connection with the Watt-linkage (metal)
Drivetrain architecture

- At least 150 km driving range
- Less than 80 Wh/km
- Acceleration to 0-100 km/h in < 10 s

High voltage battery

- Integrated power distribution unit
- 110 kg (25% less than liquid-cooled version)
- Three additional electric connectors for fast charging, PTC heater, refrigerant compressor
- Cell arrangement: 102 serial 15 parallel
- Cell type: Panasonic 18650PF
- Voltage (nom.): 367 V
- Energy content: 15.6 kWh (DoD of 75%)
- Discharge current (cont./max.): 150 A /225 A (15s)
Complete drivetrain and HVAC-system on the test rig

- HIL-Testing of complete drivetrain including ECU and HVAC system at test facilities of VIRTUAL VEHICLE
- Coupling real-world drivetrain and cooling system with virtual car, including vehicle body, chassis, driver and road
- Via this HIL-method the driving efficiency and performance is determined showing an achievement of the key criteria:
  - **156 km** driving range @ 90 % SOC to 15 % SOC
  - **76 Wh/km** energy demand
  - **8.9 s** to 100 km/h

- Regenerative braking including adjustable “Pedal-off” braking (drive pedal), regenerative braking torque is further increased if brake pedal is actuated
Development
Exterior design
Agenda

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Demonstrator Vehicle
Prototyping

Prototyping

Body structures

Drivetrain system

Omega beam

+ Parts from donor vehicle

Full vehicle integration
Agenda

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Summary

- The epsilon concept is a prototype of an urban small electric vehicle of 2020 - 2025.
- Specifically designed for the typical transport tasks in urban areas, based on a scenario and market analysis.
- The minimalistic vehicle concept is a safe & efficient urban mobility concept.
- A running prototype vehicle has been built to showcase a new vehicle class to possible customers and stakeholders.

**epsilon**

- Closes the gap between L7e vehicles and conventional cars (M1),
- Is lighter and more energy efficient than today's sub-compact cars,
- Offers higher safety, transport capacity and comfort compared to powered two-wheelers (PTWs) and ultra light vehicles.
Thank you for your attention!

On behalf of the epsilon team
Contact

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