Assessing Automotive Interior Weight Reduction Opportunities Through Innovative Design And Material Utilization

August 24, 2016
Discussion Topics

1. Design approaches that can contribute to interior weight savings

2. Evaluating material options that can be used in interiors to replace traditional options

3. Evaluating the opportunities for a lightweight door

4. Emerging technologies for wiring, glass and plastics that could contribute to interior weight reduction
Lotus Engineering Overview
Lotus Engineering Core Competencies

Lightweight Architectures
- Range extender
- Engine control
- Omnivore

Driving Dynamics
- Bespoke Platforms
- Lightweight Concepts
- Lotus Platforms

Efficient Performance
- H&EV
- HMI systems
- Lotus controllers

Combined Offerings
- Whole Vehicle Programs
- Total Hybrid Drivetrain

Electrical and Electronic Integration

EEI Products and Technologies
- Attribute Development
- Active Dynamics
- Active Noise Control

EP Products and Technologies

LA Products and Technologies

DD Products and Technologies
2017 Lotus Evora 400 – U.S. Certified

- 0 – 60 MPH: 4.1 seconds
- Top speed: 186 MPH
- Braking*: 60 – 0 MPH: <105 feet
- Lateral acceleration*: >0.95 g’s
  * estimated

Quotes From Press Day Reviewers (Gingerman Raceway, MI)

- “It is, quite simply, the best street car I’ve ever driven on track, bar none.”¹
- “No car in this class inspires this sort of immediate and absolute confidence.”²
- “This is a road car with the soul of a GT3 racer”²
- “On the road, the Evora is astoundingly easy to live with.”³
- “Porsche has nothing on Lotus in terms of quality, luxury, or style.”³
- “The car is absolute magic on the track.”⁴
- “The 2017 Evora 400 is a great car on the track and a great car off the track”⁵

¹. http://jalopnik.com/the-lotus-evora-400-is-the-best-track-car-i-have-ever-d-1784855962
Lotus – Not Just Sports Cars

New Cutting Edge Technology Engineering Solutions

Returning to Motorsports

Variations on Lightweight Engineering
1. Design Approaches That Can Contribute To Interior Weight Savings
1.1 Design Approaches
1.1.1 Key Features To Consider When Designing A Vehicle Interior

- Appearance
- Ergonomics
- Build Quality
- Material Quality
- Function
- Comfort
- Noise Isolation
- Control feel

1973 Lotus Elan+2
2017 Lotus Evora 400
1.1.2 Typical Design Approach For a New Vehicle Interior

- Select “off the shelf” previously used hardware
  - Seats
    - Frames
    - Cushions
  - Structural elements
  - Controls
  - Instruments

- Select “off the shelf” previously used materials

- Utilize proven safety hardware
  - Air bags
  - Seat belts
  - Retaining systems
1.1.3 Key OEM Considerations For a New Vehicle Interior

- Minimize tooling costs
- Minimize piece costs
- Minimize assembly plant impact
- Minimize MVSS risks
- Minimize new technology risks
  - Materials
  - Manufacturing
  - Joining

Evora 400 Interior
1.1.4 An Alternative Approach To Vehicle Interior Engineering

- Utilize more expensive, stronger structural materials
  - But use much less material

- Make the Class A surface the primary instrument panel structure
  - Eliminate secondary reinforcements

- Integrate components to eliminate/minimize redundant functions

- Minimize tooling, fixturing, joining & assembly costs

- Reduce mass to minimize/eliminate the need for robotic handling

- Replace mechanical hardware with electrical/electronic systems

- Replace material with air
1.2 Assessment of Typical Interior Sub-System Masses
1.2.1 Typical Interior Sub-System Masses

- Seats, IP and Trim comprise over 70% of the interior mass
- These are the primary focus area for this interior mass reduction study

<table>
<thead>
<tr>
<th>Baseline Interior (Typical)</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seats</td>
<td>97.9</td>
<td>39.1%</td>
</tr>
<tr>
<td>Instrument Panel</td>
<td>28.5</td>
<td>11.4%</td>
</tr>
<tr>
<td>Console</td>
<td>8.7</td>
<td>3.5%</td>
</tr>
<tr>
<td>Insulation (FOD)</td>
<td>6.2</td>
<td>2.5%</td>
</tr>
<tr>
<td>Trim</td>
<td>54.8</td>
<td>21.9%</td>
</tr>
<tr>
<td>Controls</td>
<td>22.9</td>
<td>9.1%</td>
</tr>
<tr>
<td>Safety</td>
<td>17.9</td>
<td>7.1%</td>
</tr>
<tr>
<td>HVAC &amp; Ducting</td>
<td>13.7</td>
<td>5.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>250.6</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>
1.2.2 Interior Sub-System: Seats

- Two front seats comprise half of the seat system mass (20% of interior mass)

<table>
<thead>
<tr>
<th>Seats - Front</th>
<th>Kg</th>
<th>%</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Adjuster (Passenger = Manual)</td>
<td>9.7</td>
<td>36.1%</td>
<td>6.0</td>
<td>25.9%</td>
</tr>
<tr>
<td>Frame Structure</td>
<td>7.2</td>
<td>26.8%</td>
<td>7.2</td>
<td>31.0%</td>
</tr>
<tr>
<td>Cushion</td>
<td>4.3</td>
<td>16.0%</td>
<td>4.3</td>
<td>18.5%</td>
</tr>
<tr>
<td>Seat Back</td>
<td>3.3</td>
<td>12.3%</td>
<td>3.3</td>
<td>14.2%</td>
</tr>
<tr>
<td>Safety</td>
<td>1.6</td>
<td>5.9%</td>
<td>1.6</td>
<td>6.9%</td>
</tr>
<tr>
<td>Headrest</td>
<td>0.8</td>
<td>3.0%</td>
<td>0.8</td>
<td>3.4%</td>
</tr>
<tr>
<td>Total</td>
<td>26.9</td>
<td>100.0%</td>
<td>23.2</td>
<td>100.0%</td>
</tr>
<tr>
<td>Front Seat Total:</td>
<td>50.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.2.3 Interior Sub-System: Instrument Panel

- Cross car beam and IP fascia make up about 60% of the IP assembly

<table>
<thead>
<tr>
<th>Component</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Car Beam</td>
<td>9.68</td>
<td>34.0%</td>
</tr>
<tr>
<td>IP Fascia</td>
<td>6.19</td>
<td>21.7%</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>6.6</td>
<td>23.2%</td>
</tr>
<tr>
<td>Storage Compartments</td>
<td>3.44</td>
<td>12.1%</td>
</tr>
<tr>
<td>Dashboard Covers</td>
<td>1.77</td>
<td>6.2%</td>
</tr>
<tr>
<td>Air Vent</td>
<td>0.82</td>
<td>2.9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>28.5</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
1.2.4 Interior Sub-System: Trim

- Trim panels and carpeting make up the majority of the interior trim mass.

<table>
<thead>
<tr>
<th>Trim Parts</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panels</td>
<td>19.2</td>
<td>35.0%</td>
</tr>
<tr>
<td>Carpeting</td>
<td>12.2</td>
<td>22.3%</td>
</tr>
<tr>
<td>Parcel Tray</td>
<td>3.9</td>
<td>7.1%</td>
</tr>
<tr>
<td>Insulation</td>
<td>4.7</td>
<td>8.6%</td>
</tr>
<tr>
<td>Console</td>
<td>8.6</td>
<td>15.7%</td>
</tr>
<tr>
<td>Headliner</td>
<td>3.4</td>
<td>6.2%</td>
</tr>
<tr>
<td>Misc. Int. Components</td>
<td>2.8</td>
<td>5.1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>54.8</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
1.3 Case Study: Icon A5 Light Sport Aircraft Interior
1.3.0 Acknowledgements – Icon A5 LSA (Light Sport Aircraft) Engineering and Design Team

The Icon A5 Design team consisted of:

Klaus Tritschler – VP Design
Dong Tran – Lead Designer
Alex Tannen – Design Support
Amanda Koh – Alias Sculpter

Lotus was honored to work with this talented team as well as numerous other members of the Icon Aircraft engineering and design team.
1.3.1 A Unique Design Approach – Icon A5 LSA

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft
1.3.2 Very Different Transportation With A Common Goal

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft

Icon A5 LSA

Lotus Exige

Making People Smile Every Time They Go For A Ride
1.3.3 Drive or Fly – A Hanger is Optional

Interior and Exterior Styling by Icon Aircraft
1.3.4 A5s Out Having Fun

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft
1.3.5 Playing in The Water

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft
1.3.6 End of The Day

Interior and Exterior Styling by Icon Aircraft
1.3.7 Moving On

Interior and Exterior Styling by Icon Aircraft
1.4 Icon A5 Light Sport Aircraft Interior Engineering
1.4.1 Typical Light Sport Aircraft Interiors

- Cirrus LSA Aircraft

[Images of Cirrus LSA Aircraft interiors and exterior]
1.4.2 Typical Light Sport Aircraft Interiors

- Cessna 162 Skycatcher
1.4.3 Production Icon A5 Interior

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft
1.4.4 A5 Interior Development: From Styling Concept to Production


Interior and Exterior Styling by Icon Aircraft
1.4.5 Lotus A5 Interior Engineering

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
Interior and Exterior Styling by Icon Aircraft
1.4.6 Material Properties

- Carbon fiber is about 30% lighter than aluminum and is >7x stronger

<table>
<thead>
<tr>
<th>Material</th>
<th>Density(lb/in^3)</th>
<th>Ult. Strength(ksi)</th>
<th>Modulus(ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>epoxy</td>
<td>0.044</td>
<td>4,200</td>
<td>500,000</td>
</tr>
<tr>
<td>IM7 (PAN)</td>
<td>0.064</td>
<td>747,000</td>
<td>40,000,000</td>
</tr>
<tr>
<td>M46J (PAN)</td>
<td>0.066</td>
<td>611,000</td>
<td>63,300,000</td>
</tr>
<tr>
<td>K139 (PITCH)</td>
<td>0.077</td>
<td>540,000</td>
<td>110,000,000</td>
</tr>
<tr>
<td>K13D (PITCH)</td>
<td>0.077</td>
<td>580,000</td>
<td>140,000,000</td>
</tr>
<tr>
<td>Boron</td>
<td>0.083</td>
<td>580,000</td>
<td>56,600,000</td>
</tr>
<tr>
<td>Steel</td>
<td>0.287</td>
<td>200,000</td>
<td>30,000,000</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.099</td>
<td>80,000</td>
<td>11,500,000</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.158</td>
<td>150,000</td>
<td>16,000,000</td>
</tr>
<tr>
<td>Balsa Wood</td>
<td>0.0029</td>
<td>2,300</td>
<td>250,000</td>
</tr>
<tr>
<td>Spruce Wood</td>
<td>0.025</td>
<td>13,700</td>
<td>1,740,000</td>
</tr>
</tbody>
</table>
1.4.7 Icon A5 Interior Mass

- Icon A5 interior mass is more than 4x lighter than the adjusted baseline passenger car interior mass (90.0 kg)

<table>
<thead>
<tr>
<th>Icon A5 Interior</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seats</td>
<td>6.038</td>
<td>29.9%</td>
</tr>
<tr>
<td>Instrument Panel</td>
<td>4.306</td>
<td>21.3%</td>
</tr>
<tr>
<td>Trim</td>
<td>9.843</td>
<td>48.8%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>20.187</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

- Adjusted baseline automotive mass for above systems: 90.0 kg
  - Seat mass: 50.1 kg (2 front seats)
  - IP mass: 12.5 kg (70% of total IP mass less instruments)
  - Trim: 27.4 kg (50% of total trim)
1.5 Icon A5 Light Sport Aircraft Seat Design
1.5.1 Icon A5 Interior – Seat Mass

- Mass per seat (with cushions): 3.019 kg

<table>
<thead>
<tr>
<th>Icon A5 Seats</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Structure</td>
<td>4.752</td>
</tr>
<tr>
<td>Seat Cushions</td>
<td>1.286</td>
</tr>
<tr>
<td>Total (2 seats)</td>
<td>6.038</td>
</tr>
</tbody>
</table>

- Baseline automotive seat masses: Driver - 26.9 kg; Passenger – 23.2 kg
- Mass advantage: > 8x lighter
1.5.2 ICON A5 Seat Design

Seat – RH, LH

- Fixed seat back angle
- Fixed fore-aft mounting
- A5 utilizes adjustable pedals
- 3 kg per seat with cushions/cloth

Styling and CAD by ICON Aircraft
1.5.3 Can A Lightweight, Fixed Back Seat Be Comfortable?

‘Forget your Maybachs and Rolls-Royce Phantoms.

The most comfortable car seat in the world could just be
in the little Lotus Elise’

Source: The Daily Telegraph

- Foam Thickness: < 35mm
- Composite structure
- Fixed seatback angle
- Fore-aft adjustment
- No height adjustment
1.5.4 Solution For Back Pain?
1.6 Icon A5 Light Sport Aircraft IP Design
1.6.1 Icon A5 Interior – IP Components

Styling and CAD by ICON Aircraft
1.6.1 Icon A5 Interior – IP Load Paths

- Icon A5 IP has no metal reinforcements
- Console has no metal reinforcement
- Show surface is the primary structure
### 1.6.2 Icon A5 Interior – IP Mass

#### Icon A5 IP mass advantage: >3x lighter

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Icon A5 Instrument Panel</td>
<td></td>
</tr>
<tr>
<td>IP Cross Beam</td>
<td>1.052</td>
</tr>
<tr>
<td>Top IP Panel - LH</td>
<td>0.200</td>
</tr>
<tr>
<td>Center IP Beam</td>
<td>0.446</td>
</tr>
<tr>
<td>Top IP Panel - RH</td>
<td>0.298</td>
</tr>
<tr>
<td>Instrument Cluster Support</td>
<td>0.385</td>
</tr>
<tr>
<td>IP Access Panel</td>
<td>0.095</td>
</tr>
<tr>
<td>Garmin Enclosure</td>
<td>1.020</td>
</tr>
<tr>
<td>Compass Enclosure</td>
<td>0.054</td>
</tr>
<tr>
<td>Instrument Bezel Trim</td>
<td>0.075</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.496</strong></td>
</tr>
</tbody>
</table>

- Baseline automotive IP mass: 12.5 kg (17.8 kg * 70%)
  - 21.4 kg - 3.6 kg for instruments = 17.8 kg
1.6.3 Icon A5 Interior – IP Structure Comparison

- Icon A5 IP cross beam is the show surface
  - 1.052 kg mass

- Baseline automotive equivalent mass:
  - Cross car beam: 9.68 kg
  - Show surface (Dashboard): 6.19 kg
  - Total: 15.87 kg
  - Size adjusted: 11.11 kg (70%)

- Icon A5 IP assembly is >10x lighter

<table>
<thead>
<tr>
<th>Instrument Panel</th>
<th>Kg</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Car Beam</td>
<td>9.68</td>
<td>34.0%</td>
</tr>
<tr>
<td>IP Fascia</td>
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<td>21.7%</td>
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</tr>
<tr>
<td>Storage Compartments</td>
<td>3.44</td>
<td>12.1%</td>
</tr>
<tr>
<td>Dashboard Covers</td>
<td>1.77</td>
<td>6.2%</td>
</tr>
<tr>
<td>Air Vent</td>
<td>0.82</td>
<td>2.9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>28.5</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
1.7 Icon A5 Light Sport Aircraft Interior Trim Design
### 1.7.1 Icon A5 Interior – Hard Trim Mass

<table>
<thead>
<tr>
<th>Icon A5 Hard Trim Parts</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Console (part of fuselage structure)</td>
<td>0.000</td>
</tr>
<tr>
<td>Throttle Bezel Trim</td>
<td>0.311</td>
</tr>
<tr>
<td>Center Console Bezel</td>
<td>0.101</td>
</tr>
<tr>
<td>Aft Bulkhead Trim Panel</td>
<td>0.960</td>
</tr>
<tr>
<td>Rear Cockpit Side Closeout - RH</td>
<td>0.464</td>
</tr>
<tr>
<td>Rear Cockpit Side Closeout - LH</td>
<td>0.591</td>
</tr>
<tr>
<td>Rear Load Floor</td>
<td>1.907</td>
</tr>
<tr>
<td>Side Trim Panel - RH</td>
<td>0.810</td>
</tr>
<tr>
<td>Side Trim Panel - LH</td>
<td>0.810</td>
</tr>
<tr>
<td>Floor Panels</td>
<td>2.297</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.251</strong></td>
</tr>
</tbody>
</table>
1.7.2 Icon A5 Interior – Hard Trim Components

Styling and CAD by ICON Aircraft
## 1.7.3 Icon A5 Interior – Soft Trim Mass

<table>
<thead>
<tr>
<th>Icon A5 Soft Trim Parts</th>
<th>Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seat Cushions</td>
<td>1.286</td>
</tr>
<tr>
<td>Knee Cushions</td>
<td>0.036</td>
</tr>
<tr>
<td>Console Armrest Trim</td>
<td>0.236</td>
</tr>
<tr>
<td>Side Armrest Cushions</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.592</strong></td>
</tr>
</tbody>
</table>

Styling and CAD by ICON Aircraft
1.7.4 Icon A5 Interior – Soft Trim (less seat trim)

Interior soft trim (less seat trim): 0.304 kg
1.7.5 Icon A5 Interior – Combined Hard & Soft Trim Mass

- Baseline automotive hard & soft trim mass: 27.4 kg (54.8 kg /2)
- Less carpeting and insulation: 8.5 kg (16.9 kg/2) = 27.4 kg – 8.5 kg = 18.9 kg
- Icon A5 hard & soft trim: 8.6 kg
- Potential mass advantage: >2x

Lotus Elise/Exige Chassis & Interior

Styling and CAD by ICON Aircraft
2. Evaluating Interior Material Options
2.1 Automotive Interior Material Overview

- Traditional Interior Materials
  - Plastic
  - NVH treatments
  - Foam
  - Steel
  - Aluminum
  - Magnesium

- Non-traditional Interior Materials
  - Carbon fiber
  - Air
2.2 Automotive Interior Material Selection Guidelines

- Use air to replace material
  - Active noise cancellation
  - Foamed plastics
  - Open air designs
  - Ultra-thin seat backs

- Eliminate redundant materials
  - Make foam the primary seat spring
  - Replace metal cross car beam with a composite based structural IP

- Utilize multi-material structures combining ferrous, non-ferrous and composite materials, e.g., seat frames

- Utilize HSS/AHSS to create a seat frame that contributes to enhanced body stiffness
3. Evaluating The Opportunities For A Lightweight Door
3.1 Traditional Door Assembly

- High parts count
- Low level of component integration
- High percentage of stamped steel parts
- Welded assemblies
- Significant material scrap
3.2 Non-Traditional Door Assembly

- Low parts count
- High level of component integration
- Low percentage of stamped steel parts
- Adhesively bonded assemblies
- Minimal material scrap
3.3 Lightweight Door Concept – Structural Elements

- Magnesium frame (cast)
  - Integrated side impact beams
  - Incorporates AHSS impact beams
  - Minimal scrap material

- Thermoplastic outer
  - Minimal scrap material

- Molded composite integrated door module
  - Integrated window module
  - Replaces door inner reinforcements
  - Replaces separate door trim panel
  - Structural contributor
3.3 Lightweight Door Concept – Trim Elements

- Soft touch bolsters
- Soft touch lower trim panels
- Molded map pocket modules
- Structural door module serves as part of interior trim
4. Emerging Technologies For Wiring, Glass And Plastics That Could Contribute To Interior Weight Reduction
4.1 Wiring – Material Basics

- Material density:
  - Copper: 8900 kg/m³
  - Aluminum: 2700 kg/m³

- Delphi claims a 47% mass reduction & lower cost for its aluminum cable systems
4.2 Wiring Alternatives

• Use wireless communication to replace normally hard wired functions
  • Focus: Non-safety related areas
    • Communication
    • Secondary switches

• Utilize the human body as a transmission path
  • Red Tacton is a Human Area Networking technology, which is under development, that uses the surface of the human body as a safe, high speed network transmission path.\(^1\)
  • It is completely distinct from wireless and infrared technologies as it uses the minute electric field emitted on the surface of the human body.\(^1\)

• Potential Mode of Operation
  • The seat position and steering wheel height adjust to match the driver just by sitting in the car.\(^2\)
  • The driver’s home is set as destination in the car navigation system.\(^2\)
  • The stereo plays the driver’s favorite songs.\(^2\)

---

4.3 Glass Overview

• Replace glass with silicate treated polycarbonate
  • Fixed glass application

• Reduce glass thickness
  • Corning® Gorilla® Glass
    • > 30% lighter than conventional automotive glass
    • Usage: windshields, sidelites, sunroofs and backlites
      • 2017 Ford GT applications: windshield inner, backlite and acoustic barrier

• Minimize glass area
  • Maintain vision angles

https://www.ford.com/performance/gt/?searchid=237083766|1414258640|78130292949&s_kwcid=AL!2519!10!8027995531!78130292949&ef_id=UwziGQAAASQBL2Ra:20160821224556:s
4.4 Plastics Overview

- Replace material with air to reduce mass and cost
  - MuCell
  - 3M™ Glass Microspheres

- MuCell benefits:
  - Reduced sink: 1:1 rib ratio
  - Lower tonnage presses
  - Potential to reduce parent material thickness

- 3M™ Glass Microsphere benefits:
  - Higher filler loading
  - Improved flow
  - Reduced warpage
  - Improved dimensional stability

http://multimedia.3m.com/mws/media/431692O/3mtm-glass-microspheres-for-the-automotive-market.pdf?fn=GlassMicrospheresAuto.pdf