ENGINEERING

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

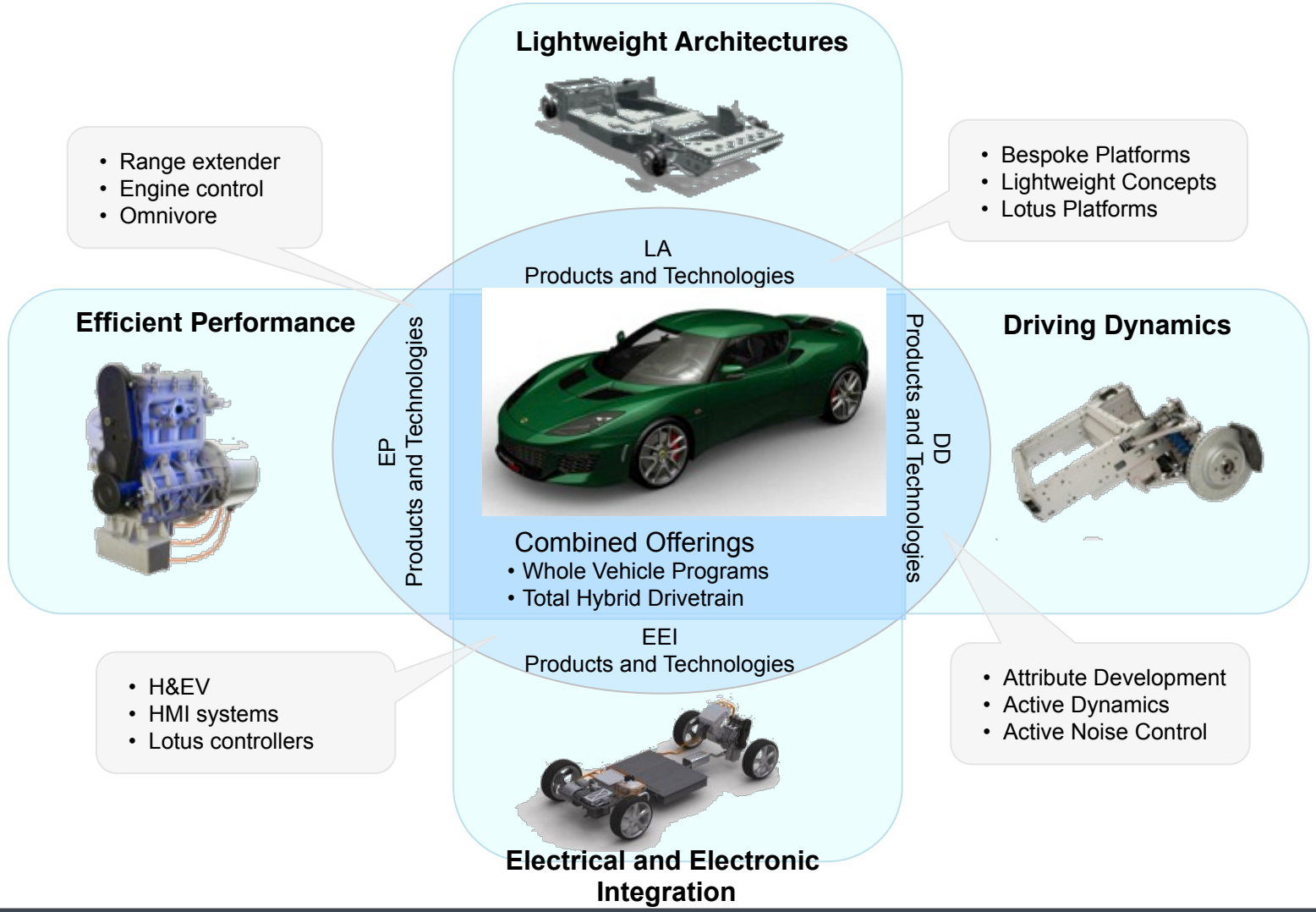
4. Emerging technologies for wiring, glass and plastics that could contribute to interior weight reduction

ENGINEERING

Lotus Engineering Overview

05/09/2013

Lotus Engineering Core Competencies



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]

ENGINEERING

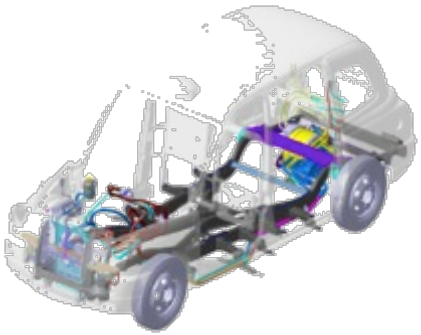
1. http://jalopnik.com/the-lotus-evora-400-is-the-best-track-car-i-have-ever-d-1784855962
2. http://www.roadandtrack.com/new-cars/road-tests/a30266/lotus-evora-400-track-test/
3. http://www.automobilemag.com/news/2017-lotus-evora-400-first-drive/
4. http://www.motortrend.com/cars/lotus/evora/2017/lotus-evora-400-first-drive-review/
5. http://autoweek.com/article/car-reviews/2017-lotus-evora-400-first-drive-welcome-back

Lotus – Not Just Sports Cars

ENGINEERING

New Cutting Edge Technology Engineering Solutions






Returning to Motorsports


Variations on Lightweight Engineering




ENGINEERING

1. Design Approaches That Can Contribute To Interior Weight Savings

ENGINEERING

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

ENGINEERING

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

Baseline Interior (Typical)		**Kg**	**%**
Seats		97.9	39.1%
Instrument Panel		28.5	11.4%
Console		8.7	3.5%
Insulation (FOD)		6.2	2.5%
Trim		54.8	21.9%
Controls		22.9	9.1%
Safety		17.9	7.1%
HVAC & Ducting		13.7	5.5%
Total		**250.6**	100.0%

1.2.2 Interior Sub-System: Seats

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

Seats - Front	Kg	%	Kg	%
				(vs. Driver Side)
	Driver	Driver	Passenger	Passenger
Power Adjuster (Passenger = Manual)	9.7	36.1%	6.0	25.9%
Frame Structure	7.2	26.8%	7.2	31.0%
Cushion	4.3	16.0%	4.3	18.5%
Seat Back	3.3	12.3%	3.3	14.2%
Safety	1.6	5.9%	1.6	6.9%
Headrest	0.8	3.0%	0.8	3.4%
Total	26.9	100.0%	23.2	100.0%
Front Seat Total:	50.1			

1.2.3 Interior Sub-System: Instrument Panel

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

Instrument Panel	Kg	%
Cross Car Beam	9.68	34.0%
IP Fascia	6.19	21.7%
Instrumentation	6.6	23.2%
Storage Compartments	3.44	12.1%
Dashboard Covers	1.77	6.2%
Air Vent	0.82	2.9%
Total	28.5	100.0%

1.2.4 Interior Sub-System: Trim

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

Trim Parts		Kg	%
Panels		19.2	35.0%
Carpeting		12.2	22.3%
Parcel Tray		3.9	7.1%
Insulation		4.7	8.6%
Console		8.6	15.7%
Headliner		3.4	6.2%
Misc. Int. Components		2.8	5.1%
Total		54.8	100.0%

ENGINEERING

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

Icon A5 LSA

Lotus Exige

Making People Smile Every Time They Go For A Ride

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

1.3.3 Drive or Fly – A Hanger is Optional

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
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

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

1.3.7 Moving On

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

ENGINEERING

1.4 Icon A5 Light Sport Aircraft Interior Engineering

1.4.1 Typical Light Sport Aircraft Interiors

- Cirrus LSA Aircraft

http://www.bing.com/images/search?q=Cirrus+Light+Sport+Aircraft&FORM=IRMHRS#!?q=Cirrus+Light+Sport+Aircraft&view=detailv2&&id=5BE691B4CC747973E564A3D9631A754D1C5576E5&selectedIndex=3&ccid=Ovchf7%2bx&simid=608002838617590231&thid=OIP.M3af7217fbfb1189d2d6ad8073b44816eo0&mode=overlay

1.4.2 Typical Light Sport Aircraft Interiors

- Cessna 162 Skycatcher

http://www.bing.com/search?q=cessna+162+skycatcher+interior&qs=n&form=QBRE&pq=cessna+162+skycatcher+interior&sc=0-30&sp=-1&sk=&cvid=7321D5396DC04051AB5826BFDA4A5ACD

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

Concept

Production

Photos Courtesy of Icon Aircraft: http://iconaircraft.com/news/photos
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

Material		Density(lb/in^3)	Ult. Strength(psi)	Modulus(psi)
epoxy		0.044	4,200	500,000
Carbon Fiber-				
	IM7 (PAN)	0.064	747,000	40,000,000
	M46J (PAN)	0.066	611,000	63,300,000
	K139 (PITCH)	0.077	540,000	110,000,000
	K13D (PITCH)	0.077	580,000	140,000,000
Boron		0.083	580,000	56,600,000
Steel		0.287	200,000	30,000,000
Aluminum		0.099	80,000	11,500,000
Titanium		0.158	150,000	16,000,000
Balsa Wood		0.0029	2,300	250,000
Spruce Wood		0.025	13,700	1,740,000

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)

Icon A5 Interior		**Kg**	**%**
Seats		6.038	29.9%
Instrument Panel		4.306	21.3%
Trim		9.843	48.8%
Total		**20.187**	100.0%

- 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)

ENGINEERING

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

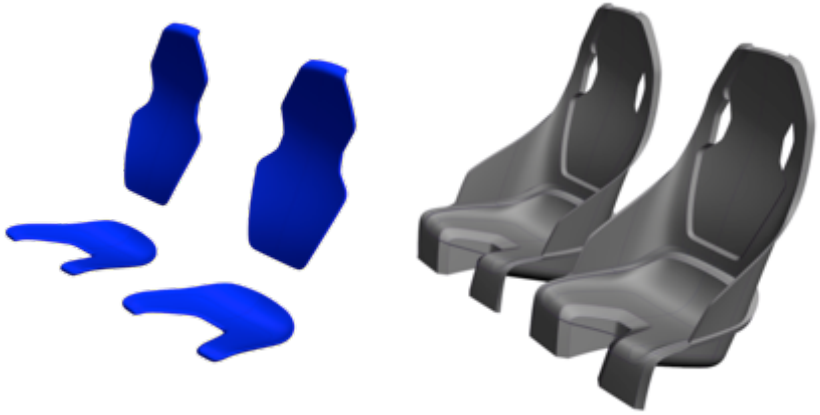
Icon A5 Seats		Kg
Seat Structure		4.752
Seat Cushions		1.286
Total (2 seats)		6.038

- 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



1.5.3 Can A Lightweight, Fixed Back Seat Be Comfortable?

- Foam Thickness: < 35mm
- Composite structure
- Fixed seatback angle
- Fore-aft adjustment
- No height adjustment

'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

1.5.4 Solution For Back Pain?

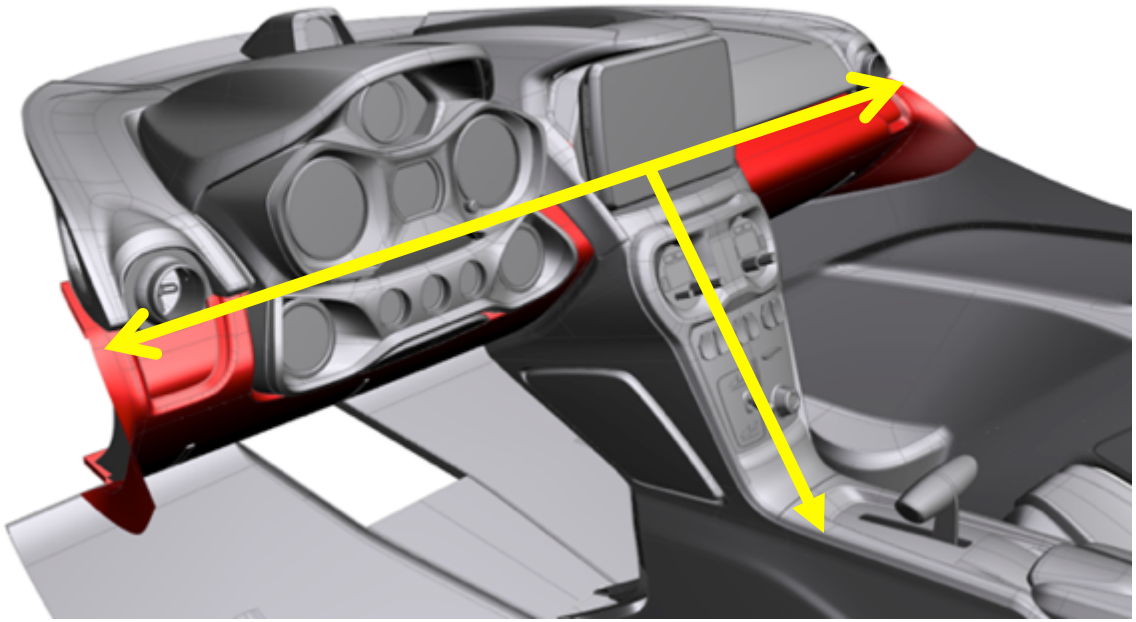
ENGINEERING

1.6 Icon A5 Light Sport Aircraft IP Design

1.6.1 Icon A5 Interior – IP Components

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

Icon A5 Instrument Panel		Kg
IP Cross Beam		1.052
Top IP Panel - LH		0.200
Center IP Beam		0.446
Top IP Panel - RH		0.298
Instrument Cluster Support		0.385
IP Access Panel		0.095
Garmin Enclosure		1.020
Compass Enclosure		0.054
Instrument Bezel Trim		0.075
Total		3.496

- 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

Instrument Panel	Kg	%
Cross Car Beam	9.68	34.0%
IP Fascia	6.19	21.7%
Instrumentation	6.6	23.2%
Storage Compartments	3.44	12.1%
Dashboard Covers	1.77	6.2%
Air Vent	0.82	2.9%
Total	28.5	100.0%

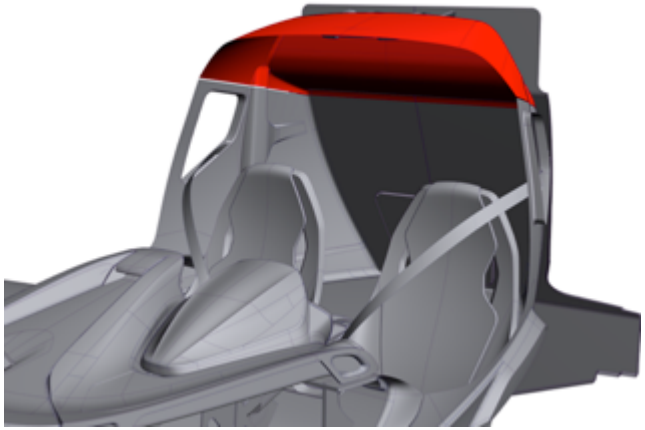
ENGINEERING

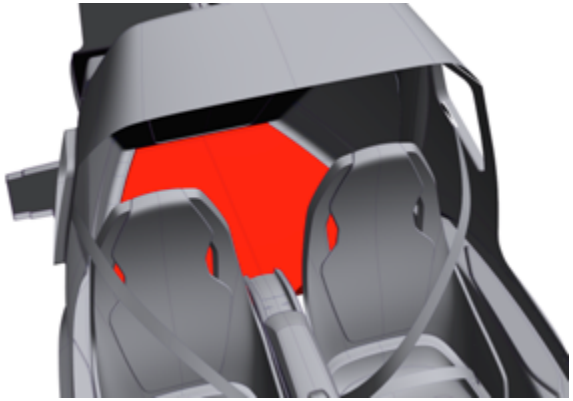
1.7 Icon A5 Light Sport Aircraft Interior Trim Design

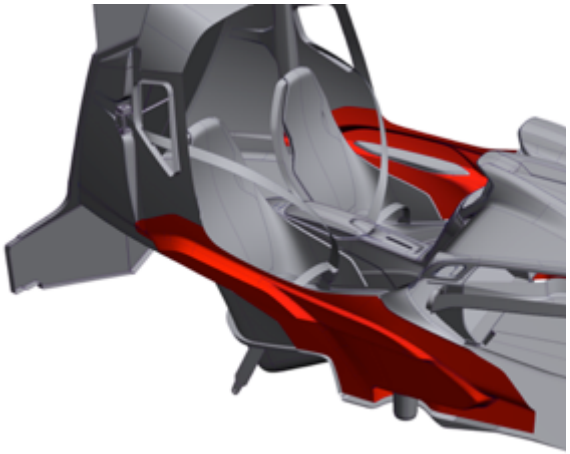
1.7.1 Icon A5 Interior – Hard Trim Mass

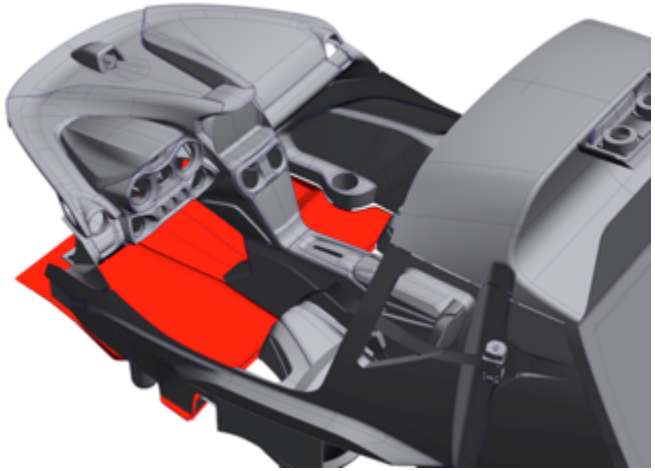
Icon A5 Hard Trim Parts		Kg
Console (part of fuselage structure)		0.000
Throttle Bezel Trim		0.311
Center Console Bezel		0.101
Aft Bulkhead Trim Panel		0.960
Rear Cockpit Side Closeout - RH		0.464
Rear Cockpit Side Closeout - LH		0.591
Rear Load Floor		1.907
Side Trim Panel - RH		0.810
Side Trim Panel - LH		0.810
Floor Panels		2.297
Total		8.251

1.7.2 Icon A5 Interior – Hard Trim Components



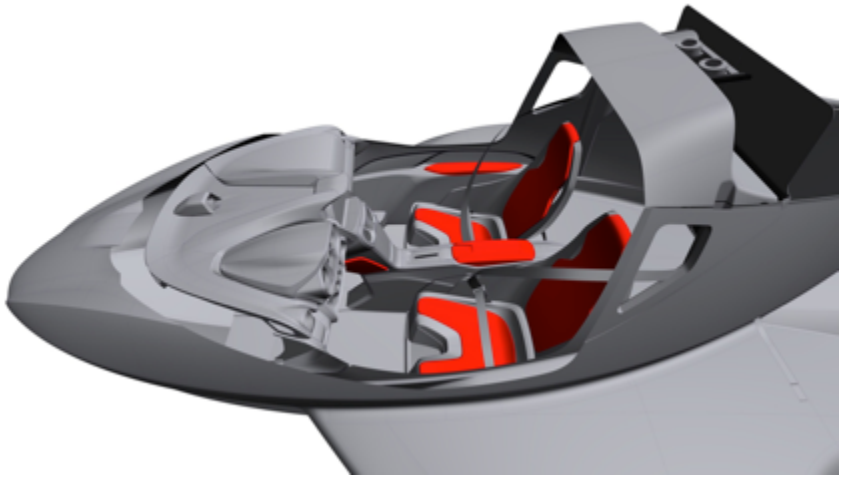






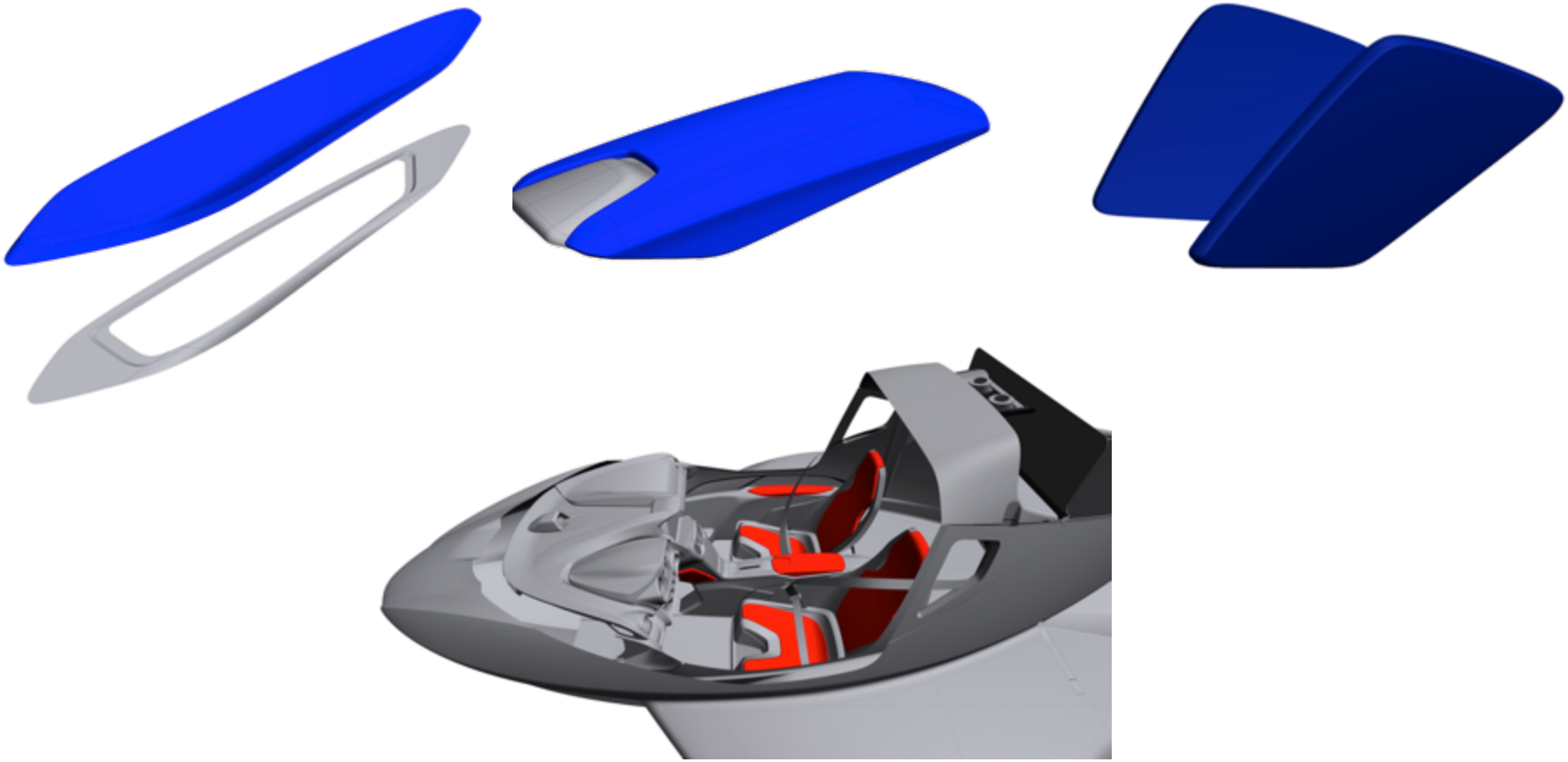
1.7.3 Icon A5 Interior – Soft Trim Mass

Icon A5 Soft Trim Parts		Kg
Seat Cushions		1.286
Knee Cushions		0.036
Console Armrest Trim		0.236
Side Armrest Cushions		0.034
Total		1.592



1.7.4 Icon A5 Interior – Soft Trim (less seat trim)

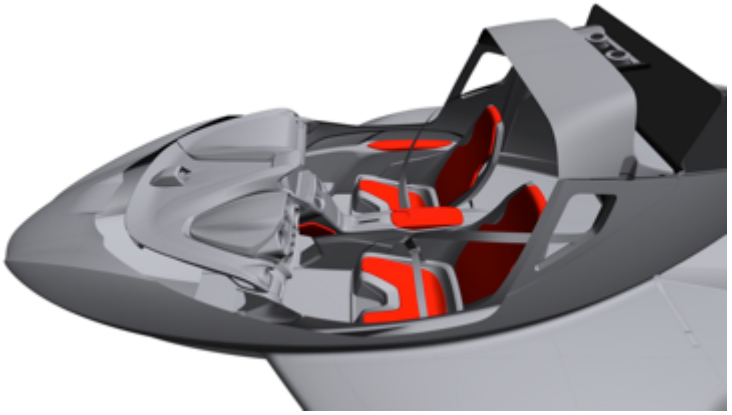
Interior soft trim (less seat trim): 0.304 kg



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



ENGINEERING

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

Lotus Exige S Cupholder

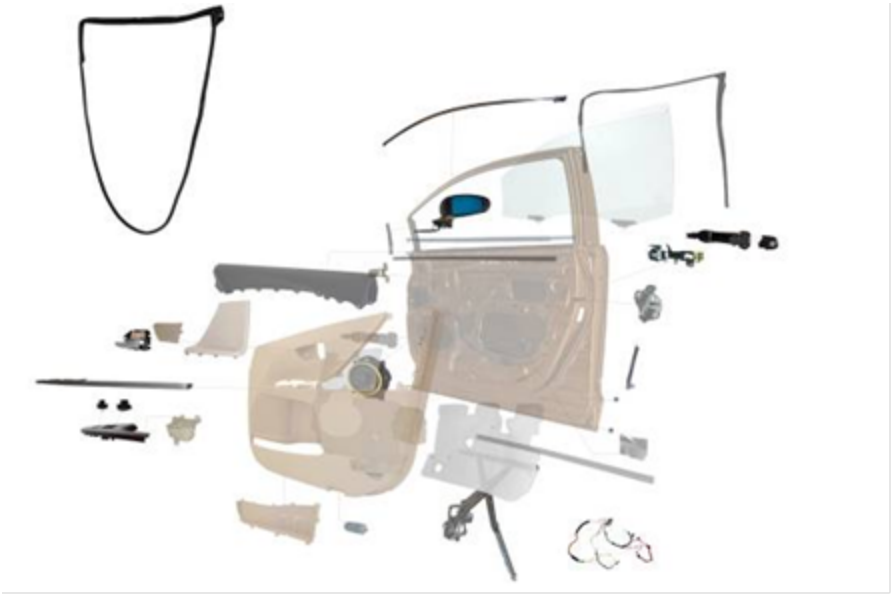
Lightweight Seat Concept

ENGINEERING

3. Evaluating The Opportunities For A Lightweight Door

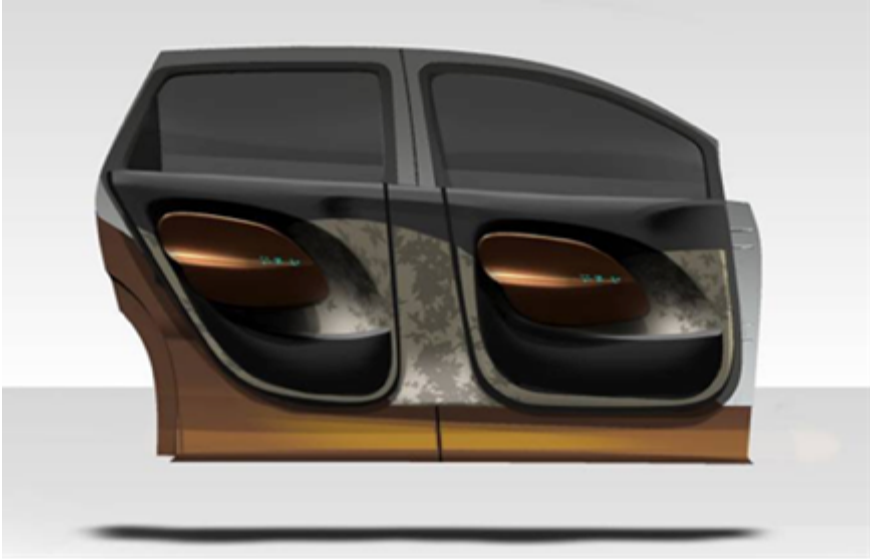
3.1 Traditional Door Assembly

- 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

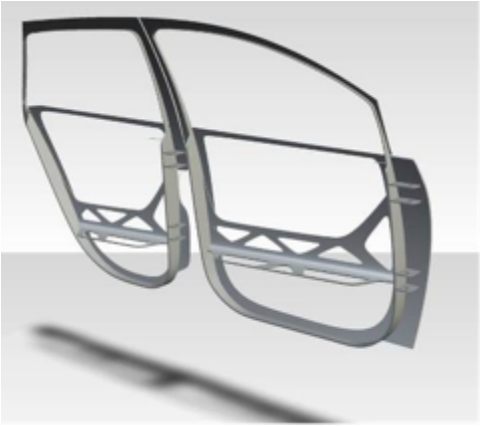


3.3 Lightweight Door Concept – Structural Elements

- 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

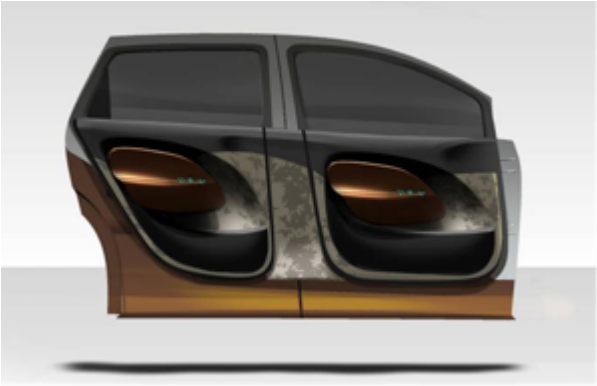


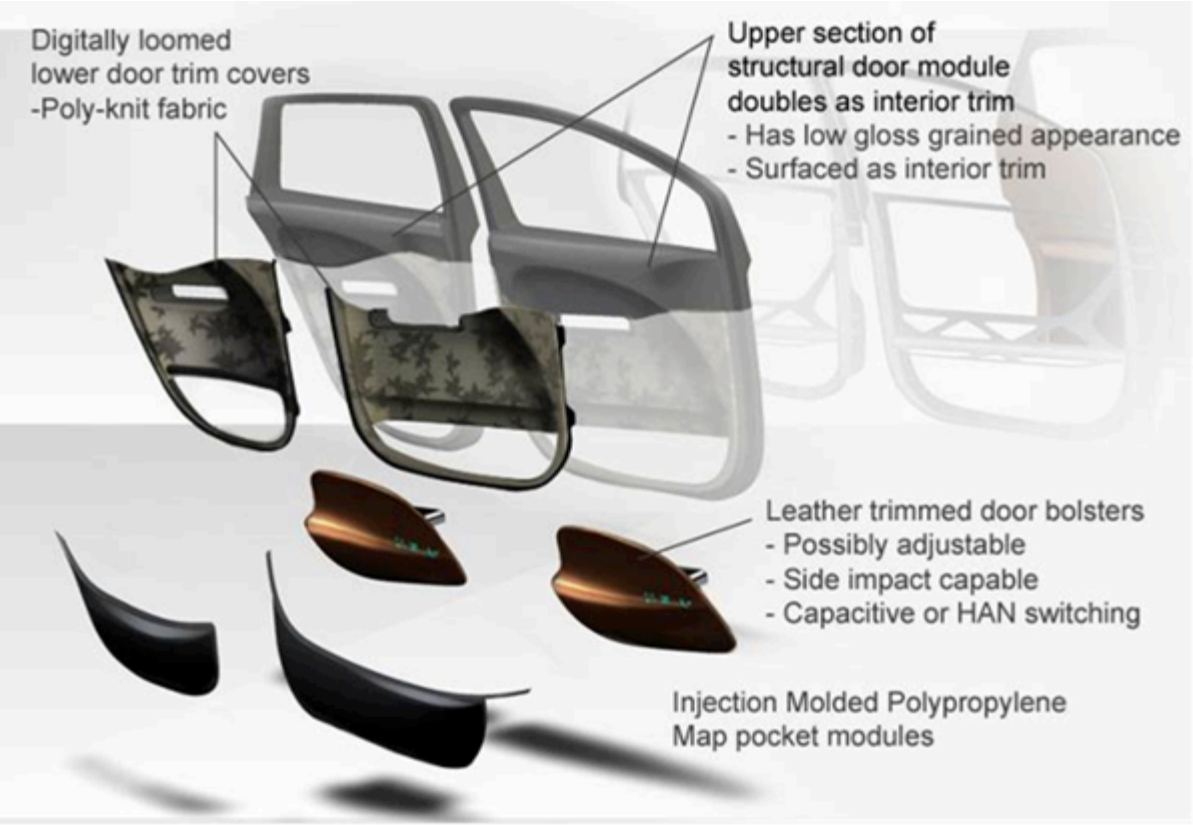
Cast Magnesium Frame

Integrated Door Module

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





ENGINEERING

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

Metal	*Density* *(kg/m³)*	*Melting point* *(°C)*	*Thermal conductivity* *(W/m°C)*	*Coefficient of linear expansion at 20°C (μm/m/°C)*
Aluminium	2700	660	220	23.0
Brass	8450	950	130	16.7
Bronze	8730	1040	67	17.3
Cast iron	7250	1300	54.5	9.0
Copper	8900	1083	393.5	16.7
Lead	11 400	327	33.5	29.1
Monel metal	8600	1350	25.2	14.0
Nickel	8900	1453	63.2	12.8
Silver	10 500	960	420	18.9
Steel	7850	1510	50.2	11.1
Tin	7400	232	67	21.4
Tungsten	19 300	3410	201	4.5
Zinc	7200	419	113	33.0
Cobalt	8850	1490	69.2	12.4
Molybdenum	10 200	2650	13	4.8
Vanadium	6000	1750	—	7.75

Delphi Aluminum Cables

http://www.bing.com/images/search/?q=Density+of+Common+Metals+Chart&id=3F7CD9599114F639F6BE9FF6687BFE39A0F5F34B&FORM=BRQONH#!/images/search?q=Density+of+Common+Metals+Chart&view=detailv2&&id=3F7CD9599114F639F6BE9FF6687BFE39A0F5F34B&selectedIndex=0&ccid=%2bBPD8xXA&simid=608013657652791096&thid=OIP.Mf813c3f315c0b31862ed79cfdd88d1dcH0&mkt=de-DE&ajax=1

http://delphi.com/manufacturers/auto/ee/cables/cable-al/

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]

1. https://www.scribd.com/doc/50074166/Redtacton-IEEE-Report
2. https://www.scribd.com/doc/83679469/Red-Taction-ppt-free-download
3. https://prezi.com/ecp9dattbpkv/human-area-network/

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

http://www.corning.com/gorillaglass/worldwide/en/applications/automotive.html

http://www.corning.com/gorillaglass/worldwide/en/news/news-releases/2015/12/ford-gt-first-production-vehicle-to-use-lightweight-corning--gor.html

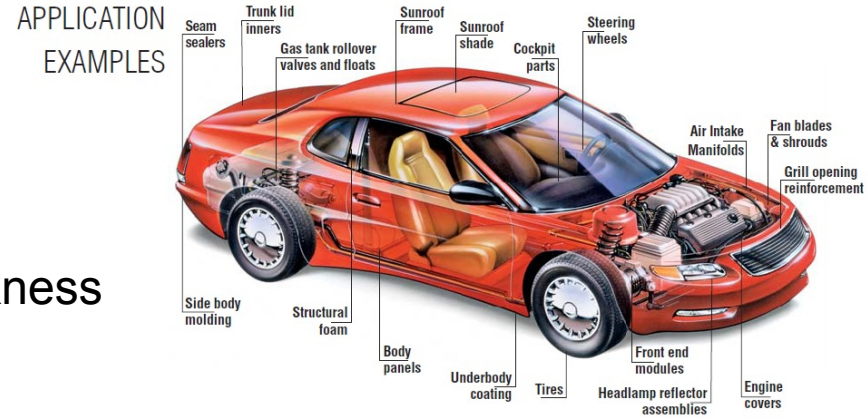
https://www.ford.com/performance/gt/?searchid=237083766|1414258640|78130292949&s_kwcid=AL!2519!10!8027995531!78130292949&ef_id=UwziGQAAASQBL2Ra:20160821224556:s

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



3M™ Glass Microspheres

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

Thank You

ENGINEERING

Please reply to: Gregory E. Peterson

Job title: Senior Technical Specialist

Telephone: 248-508-0292

Email: gregg.peterson@lotus-usa.com

Website: lotuscars.com/engineering

UNITED KINGDOM
Potash Lane
Hethel, Norwich
NR14 8EZ
Phone +44 (0) 1953 608423
Eng-uk@lotuscars.com

USA
1254 N. Main Street
Ann Arbor
MI 48104
Phone +1 734 995 2544
Eng-usa@lotuscars.com

CHINA
7th Floor, New Jinqiao Tower
No. 28 New Jinqiao Road, Pudong
Shanghai. PR CHINA 201206
Phone +86 (21) 5030 9990
Eng-china@lotuscars.com