FIA Technical Conference
Focus on Mass Reduction and Power Density

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September 12, 2018
About AAM

Nearly $7B PRO FORMA SALES

Over 700 CUSTOMERS

Over 25,000 ASSOCIATES

17 COUNTRIES

Over 90 LOCATIONS

Over 17 ENGINEERING CENTERS

Over 75 MANUFACTURING FACILITIES
Diverse Product Portfolio

DIVERSE & INNOVATIVE product portfolio that serves the global automotive market

**DRIVELINE | ≈ $4.0B**
- Rear and front axles
- Rear drive modules
- Power transfer units
- Driveshafts
- Transfer cases
- Electric drive units

**METAL FORMING | ≈ $1.5B**
- Ring / pinion gears
- Axle / transmission shafts
- Differential gears
- Transmission gears
- Suspension components

**POWERTRAIN | ≈ $1.1B**
- Transmission module and differential assemblies
- Aluminum valve bodies
- Vibration control systems
- Connecting rods
- VVT products

**CASTING | ≈ $900M**
- Axle carriers
- Differential cases
- Steering knuckles
- Control arms
- Turbo charger housings
- Brackets
Advancing Technologies

**EcoTrac®**
Disconnecting AWD System

**VecTrac™**
Torque Vectoring RDM

**e-AAM™**
Hybrid & Electric Drive Systems

**QUANTUM™**
Lightweight Axle Technology

**TracRite®**
Portfolio of Traction Enhancing Differentials

**Sylent™**
Lightweight, Tunable Foam-Wrapped Liner
EcoTrac® Disconnecting AWD Systems

EcoTrac® - utilizes electronics and connectivity to improve Fuel Economy, Safety, and Performance

KEY ATTRIBUTES

- First to market technology
- Disconnects at the power transfer unit (PTU), causing the driveshaft to stop spinning
- Automatically engages when it senses AWD traction requirement
- Benefits:
  - Improved vehicle fuel economy
  - Improved vehicle handling
- System Components:
  - Disconnecting PTU
  - Multi-piece driveshaft
  - Rear drive module with electronic control unit
  - Torque transfer device
e-AAM™ Hybrid & Electric Drivelines

**e-AAM™** - AAM is well positioned to benefit from the global trend of electrification

**KEY ATTRIBUTES**

- **Power Density** - compact design allows for easy integration for multiple vehicle platforms
- **Torque Vectoring** - maximum traction and ride control for enhanced safety and stability
- **Modularity** - Modular solutions for passenger cars / CUVs
- **Benefits:**
  - Improves fuel efficiency up to 30% and reduces CO₂ emissions
  - Improved vehicle performance and drive quality
  - Improved handling and stability
QUANTUM™ Technology

KEY ATTRIBUTES

- Industry first technology along with a revolutionary design
- Significant mass reduction (up to 35%)
- In combination, additional efficiency and weight reduction can deliver 1% to 1.5% improved vehicle fuel economy
- Scalable across multiple applications—without loss of performance or power
- Streamlined manufacturing process for key driveline components.
Regulations & Market Forces

- **Mega Trends**
  - Globalization and urbanization
  - Environmental
  - Electrification and Autonomous Vehicles

- **Legislative Requirements**
  - Global fuel efficiency
  - Tailpipe emissions
  - Safety

- **Competitive Performance**
  - Cost
  - Weight, efficiency and power density
  - Performance & NVH
Next Generation Powertrains

North America, Europe, and China Volumes in Units

2025 BEV Adoption @ 5.7%

64.9% of Vehicles contain ICE engines

Source: Average of Plante Moran and Ricardo/Schlegel und Partner Projections
Key Material Trends for Automotive

- Increased use of ultra high strength steel for structural components around the “safety cage” to prevent intrusion
- Aluminum use for chassis and exterior panels is increasing
- Fiber reinforced plastics (glass and carbon) for structural components are still several years away from high volume production
- Optimized microstructure and metal forming is enabling metamorphic designs for mass reduction.
- Multi Material solutions providing excellent optimized mass and structural improvements
## Emerging Manufacturing Processes

### Enablers for Growth

<table>
<thead>
<tr>
<th>Enablers for Growth</th>
<th>3D Printing</th>
<th>High Pressure Thin Walled Aluminum Die Casting</th>
<th>Resin Transfer Molding</th>
<th>Warm Form Aluminum</th>
<th>Hot Formed Steel</th>
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</thead>
<tbody>
<tr>
<td>Reduce Cycle Time</td>
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<td>Increase Equipment Capacity</td>
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<td>Reduce Equipment Cost</td>
<td>Increase Equipment Capacity</td>
<td>Standardization of Operating Barometers</td>
<td>Increase Equipment Capacity</td>
<td>Reduce Cycle Time</td>
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</tr>
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<td>Reduced Material Costs</td>
<td>Develop Supply Chain for CFRP</td>
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### Graph

- **Mature** Processes
- **Short Term** Processes
- **Long Term** Processes

### Processes
- **3D Printing**
- **High Pressure Thin Walled Aluminum Die Casting**
- **Resin Transfer Molding**
- **Warm Form Aluminum**
- **Hot Formed Steel**

### Barometers
- Increase Equipment Capacity
- Reduce Cycle Time
- Reduce Equipment Cost
- Reduced Material Costs
- More R&D Needed
- Develop Supply Chain for CFRP
# Materials and Mass Reduction Expectations

<table>
<thead>
<tr>
<th>Material</th>
<th>Material Replaced</th>
<th>Mass Reduction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>Steel, Cast Iron</td>
<td>60 – 75%</td>
</tr>
<tr>
<td>Carbon Fiber Composites</td>
<td>Steel</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Aluminum Matrix Composites</td>
<td>Steel, Cast Iron</td>
<td>40 – 60</td>
</tr>
<tr>
<td>Aluminum</td>
<td>Steel, Cast Iron</td>
<td>40 – 60</td>
</tr>
<tr>
<td>Titanium</td>
<td>Alloy Steel</td>
<td>40 – 55</td>
</tr>
<tr>
<td>Glass Fiber Composites</td>
<td>Steel</td>
<td>25 – 35</td>
</tr>
<tr>
<td>Advanced High Strength Steels</td>
<td>Mild Steel, Carbon Steel</td>
<td>15 – 25</td>
</tr>
<tr>
<td>High Strength Steel</td>
<td>Mild Steel</td>
<td>10 – 15</td>
</tr>
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</table>

*Source: US Department of Energy*
AAM Forging Solutions For Power Density and Lightweighting
**Net Forged Hypoid Gears**
- Process Flow: Forge – Heat Treat - Lap
- Unconventional tooth geometry
  - Micro-geometry unachievable with cutting provides improved pattern control and reduced sensitivity to positioning and misalignment
  - Optimized root geometry and webbing
  - Allows for optimized balance between strength and gear efficiency
- 5-axis milling of forge tools (AGMA 2009 quality 3)
- Test results support significant fatigue life increase (2X)

**OrRoC Net Forged Straight Bevel Gears**
- “Forge-Only” gear geometry that is neither Octoid nor Revacycle
- Geometry delivers higher contact ratio gears, eliminates undercuts, enables coarser pitch gears
- Reduces both bending and contact stress
- Enables some 4 pinion designs to be reduced to a 2 pinion OrRoC design

<table>
<thead>
<tr>
<th>PART TYPE</th>
<th>RING GEAR TORQUE (Nm)</th>
<th>AVERAGE LIFE (Cycles)</th>
<th>B10 LIFE (Cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FACE MILLED</td>
<td>1,350</td>
<td>43,517</td>
<td>35,733</td>
</tr>
<tr>
<td>FORGED</td>
<td>1,350</td>
<td>88,115</td>
<td>59,909</td>
</tr>
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</table>
AAM has developed a process and installed capacity to forge high strength one-piece axle tubes with reduced wall thickness.

- Two 60” stroke 3-station 2500 ton mechanical presses have been installed in Malvern OH, Silao MX,
- Additional 400T hydraulic draw press installed April 2017 for draw operation
- Initial application: 2020 Full Size Truck Platform
Axle Tube Forging Process

- Single piece forging from billet
- Eliminates friction weld and associated processes
- 3 or 4 forging station dependant on part geometry
- Steel chemistry conducive to welding of brackets
- Increased Yield Strength when compared to traditional axle tubes
- Opportunity to reduce wall thickness, reduce mass

AAM Patent Pending
- Strength properties affected by temperature during final operation
- Target temperature for maximum yield strength while maintaining elongation requirement
- Temperature controlled processing to maintain consistency
- 25 lbs. overall system mass reduction possible on typical DW application

**Yield Strength (MPa)**

- Temperature Range
- Forged Tube Min Target YS
- Current Process Min Target YS
Conformal and non conformal structures hold potential to enable novel gear geometries and significant mass optimization.

Directional ribbing for torque and load force distribution.

Higher strength materials yielding potential for improved power density and mass reduction.

Thin wall and lattice based structures hold potential for novel mass reduction.
AAM Technology Collaboration
Cooperative Institutional Alignment LIFT
LIFT, operated by the American Lightweight Materials Manufacturing Innovation Institute (ALMMII), is a public-private partnership to develop and deploy advanced lightweight materials manufacturing technologies, and implement education and training programs to prepare the workforce.

7 Technology Pillars of Advanced Development

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<tr>
<td>MELTING</td>
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<tr>
<td>THERMO-MECHANICAL PROCESSING</td>
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<tr>
<td>POWDER PROCESSING</td>
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<tr>
<td>AGILE LOW-COST TOOLING</td>
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<td>COATINGS</td>
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<tr>
<td>JOINING</td>
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<tr>
<td>ICME</td>
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LIFT is building a technology portfolio serving the military and commercial transportation sectors.

All projects have applications crossing at least two transportation sectors.

LIFT projects are prioritized by large Industry partners with input from government agencies to ensure commercialization plans are in place.

Increasing value of weight reduction & decreasing units/year.
Priority metal classes and its alloys are: Advanced High-Strength Steels, Titanium, Aluminum and Magnesium

Technology development needs have been grouped into 6 pillars:
- Melt processing
- Powder Processing
- Thermo-mechanical processing
- Low Cost, Agile Tooling
- Coatings
- Joining and Assembly

In addition, there are crosscutting themes:
- Integrated Computational Materials Engineering (ICME)
- Design
- Life-cycle analysis
- Validation/Certification
- Cost modeling
- Supply chain
- Corrosion
- Ballistic/Blast
LIFT Microstructure Simulation Development
Modeling material behavior during forging and as-received state of part

- Location-specific microstructure & composition of Al-Li H-forging
- Texture & grain morphology shown to vary significantly through forging thickness

Texture components – through thickness

Grain morphology – through thickness

- Dynamic recrystallization evolves with deformation
- Precipitate content quantified and effect on hardening

TEM analysis

Dislocation dynamics simulation

Dynamic recrystallization
LIFT Microstructure Simulation Development
Micromechanical Testing for Model Calibration

Background

- **Goal** – Experimentally measure single crystal moduli of AA2070 to aid in the development of crystal plasticity models
- **Challenge** – single crystals of AA2070 for conventional stiffness measurement techniques are not readily available

Approach

- Employ micromechanical testing techniques to probe individual grains (single crystal) from a polycrystalline coupon

1. Identify crystal orientation of individual grains in polycrystalline AA2070 with Electron Backscatter Diffraction (EBSD)
2. Use focused ion beam (FIB) micro-machining to fabricate a compression pillar & rail shear specimen within a single grain
3. Use nano-indenter outfitted with a flat punch tip to perform micro-compression & -shear experiments measuring elastic moduli
Crystal plasticity model based on large deformation formulation

Plastic deformation proportional to slip shear rates

Texture evolution driven by rate-dependent plastic deformation

Cauchy stress - function of lattice rotation (texture evolution)

Slip rate driven by resolved shear stress, hardening, dislocation density, & temperature

LIFT Microstructure Simulation Development
Plasticity model developed for prediction in Al-Li forging

Decompose deformation gradient

Solve kinematics in terms of crystal slip

Texture evolution

12 octahedral {111}<110> slip systems
Traditional Blacksmithing Evolved into Large, Dedicated Machines with Expensive Tooling.

Machine

Sensors

Thermal

Tool

Positioning

ICME

Simulation and ICME

Heating and Cooling

Sensors

Position

High Value Component with local Microstructure and Shape
LIFT Forging Simulation of H-beam forging process
Achieved accurate prediction of forged texture

Forging process
- Cast ingot →
- AB upset →
- Draw & step preform →
- Closed-die forge

Forging simulation
- All major texture components predicted (incl. Goss)

Additional insights
- Rotation of pole figure accurately predicted
Develop Physics Based Predictive Models
Objective to improved Die Performance

- Crack propagation
- Transient Fatigue
- Damage interaction

- Time/sequence
- Manufacturing Process
- Ingot
- Phases, particles
- Melt
- Microstructure
- Forging
- Heat Treatment
- Residual Bulk stress
- Residual Surface stress
- Installation, Performance
- ThermoCalc, ANSYS, ABAQUS

Constitutive Material Model
\[ \sigma = f(\varepsilon, T, \ldots) \]

ThermoCalc, ANSYS, ABAQUS, DEFORM

Microstructure, Materials properties, transient loading and history

CUTPRO...

Empirical Models
  \[ \downarrow \]
  Improve Fidelity
  \[ \downarrow \]
  Advanced Physics Based Models
Summary and Conclusions
Mass reduction and power density continues to be a priority in several industrial segments.

Global Government Mandates necessitate aggressive lightweighting to achieve Co2 / Ghg targets.

Multi-material solutions and new manufacturing processes are yielding positive solutions.

New ICME tools are providing excellent predictive modeling in both material and process.

Improved TMP technologies are enabling improved material and process capabilities.

Advanced coating and nanomaterials will augment lightweighting benefits to cross industries.

Cross industry collaboration with Academia and Institutions are yielding excellent value.

Improved materials, process controls and ICME capabilities in forging is creating unique solutions.
THE POWER TO PUT EXCELLENCE IN MOTION

THANK YOU