White Paper

From 200 to 200,000

Challenges in Advanced Air Mobility Market Scaling

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Innovation by Chemistry

Introduction

The Vertical Flight Society currently counts more than 400 entrants in the advanced air mobility (AAM) industry, with more entering every week. This rapidly developing market holds the potential to significantly disrupt air transportation as we know it, basically reinviting how we travel by air through increasing our use of aircraft to travel shorter distances, reduce travel times, lower aircraft emissions, and further reduce carbon footprints.

Defined by NASA as an air transportation system "using revolutionary new aircraft that are only just now becoming possible," the AAM industry has been in various stages of concept and initial development for years. However, it has recently gained momentum with significant investment from venture capital, private equity, SPACs, automotive companies, legacy aerospace OEMs, and tech companies.

AAM's potential to manufacture large quantities of components and full vehicles is considerable. As manufacturers of these aircraft tackle the challenges of bringing a successful AAM aircraft to market, it is vital to consider early on how to cost-effectively boost production from a few hundred units to many thousand while meeting stringent FAA and EASA standards and regulations.

Solutions for Today and Tomorrow

A NEW MANUFACTURING FRONTIER

The AAM industry is coming into focus as a merging of traditional aerospace and automotive industries. Legacy OEMs in both arenas are entering the field alongside progressive technology companies seeking to merge the best of both worlds. Visionaries in the industry foresee the public embracing a vehicle with the familiar comforts of a car and the convenience of air travel. Engineers are tackling how to make such a vehicle reality.

One hurdle is regulation. Aerospace is the most regulated transportation industry, with stringent standards governing everything from the materials and processes for manufacture to performance, crashworthiness, and operation. Automobiles on the other hand face far fewer regulations, especially in terms of materials and processes. While specific regulations governing AAM vehicles and their manufacture are still evolving and maturing around the world, the industry expects aerospace-level standards to govern AAM oversight.

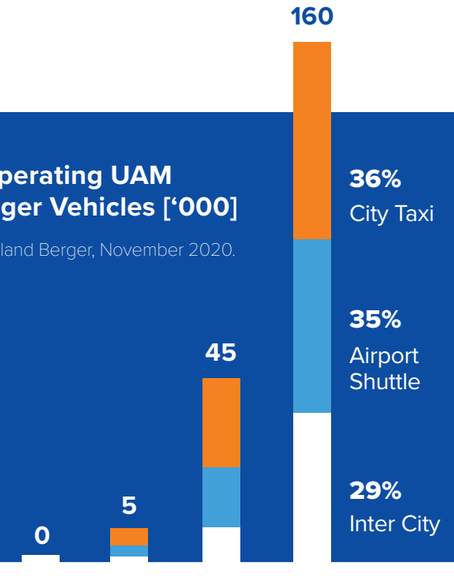
Another hurdle is scaling. Scaling for total commercial aircraft, from small airplanes and helicopters to business and commercial jets, has traditionally hovered between 1,000 and 2,000 units a year. Automobiles are completely different, with total global production in this industry topping 70 million cars a year, more than 14,000 a day.

AAM growth estimates vary widely, yet the volume of aircraft is expected to quickly outpace traditional aerospace with anywhere from 15,000 to 200,000 units expected by 2035.

In some cases, traditional aerospace materials and processes will be ideal for AAM, while others cannot meet scaling demands. At the same time, mass production processes and materials ideal for the automobile industry currently fall far short of FAA and EASA requirements.

Operating UAM Passenger Vehicles ['000]

Source: Roland Berger, November 2020.



The challenge for AAM companies is how to meet these anticipated production volumes at the different stages of market growth with the right materials and processes and within international regulations and standards.

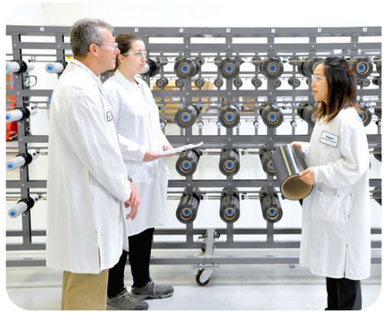
The Right Partner

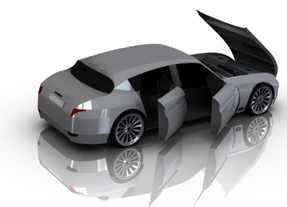
MEETING THE CHALLENGE THROUGH PARTNERSHIP

To meet this challenge, it is vital OEMs and component manufacturers partner with a material manufacturer early in the design process and maintain that close partnership throughout the lifecycle of the aircraft. Ideally, this supply partner should have demonstrated experience in aerospace and automotive industries with a deep portfolio of tested and proven materials, which will lend to a more wholistic view of potential design and material solutions. Partnering with a material supplier with expansive capabilities early on will enable better material selection from prototyping through to high volume production and can save considerable time and cost.

With a full understanding of your design and production goals, your material supply partner will help identify the most successful and cost-effective path by recommending materials and processes that will meet requirements and standards at early stages of prototyping, which can then efficiently shift to limited and mid-volume production before smoothly entering high-volume production.

This partnership extends well beyond a first production run. As opportunities to improve the aircraft arise, your materials partner will help identify the best way to achieve them. Conversely, as the rapidly evolving materials industry develops and certifies new products, your supplier will keep you on the cutting edge of the latest materials and processes.





Composite material choices, and perhaps even more importantly, the fabrication processes for each, directly affect production rates.

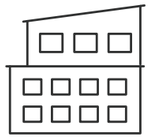
From Prototype to High-Rate Production

PRESS / STAMP FORMING

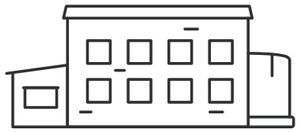
COMPRESSION MOLDING

OOA / ATL / AFP

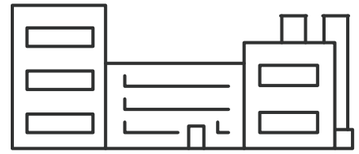
HAND LAYUP / AUTOCLAVE / OVEN



2-20
Prototype
Limited Production



200-2K
Low to Moderate
Rate Production



20K-200K
High-Rate
Production

The Right Products

THE RIGHT PRODUCTS AND THEIR FABRICATION PROCESSES

In order to understand the changes in materials and processes needed as product volumes increase and the value your supplier can lend to manufacture, let's look at advanced composite materials for structural components as an example. Due to their superior strength, light weight, and variety, advanced composite materials are common today in both aerospace and automotive applications. For those same reasons, they are essential to the success of an AAM vehicle. How manufacturers approach using these materials will have a significant impact on that success.

Composite material choices, and perhaps even more importantly, the fabrication processes for each, directly affect production rates.

When it comes to aerospace structures, there are essentially two fundamental fiber reinforced polymer chemistries to choose from for AAM vehicles in the advanced composites category: thermoset and thermoplastic.

Both chemistries come in a variety of forms when reinforced with continuous fiber (such as carbon or glass), including uni-directional tapes, woven prepregs and long-chopped fiber bulk molding compounds, however it is the polymer science that impacts the processing methodology and overall capacity for volume production from converting the material into a final component or structure.

Thermosets are ideal for prototyping and early production in terms of cost, production, and design flexibility. Thermosets have been used in aviation for over 40 years and have data sets and databases that can aid in design and certification. Currently the industry is building prototypes for AAM vehicles with FAA-approved thermoset composites.

Thermosets are less expensive to procure and are typically processed at lower build rates than thermoplastics, allowing companies to modify designs through the prototype process at a minimal cost impact. They do not necessarily require metal tooling, allowing for composite tooling that can be more economically created in the prototyping process.

The Right Products

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Thermosets are more amenable to manual layup than thermoplastics and can be used in a large number of fabrication process options. However, they do require relatively long autoclave and oven curing processes. These processes allow versatility and support complex shapes, making them ideal for prototypes and first productions, but quickly become very expensive with higher volumes. While there are rapid molding systems and processes for thermosets used today in the automotive industry, they do not meet aerospace standards for flight critical and structural aerospace components.

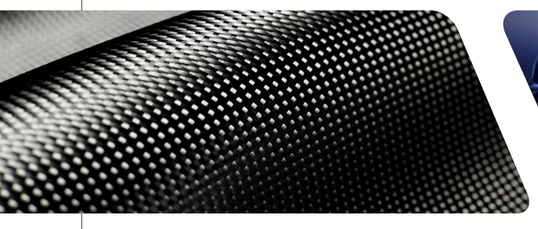
Once scaling builds, thermoplastics become far more economical, allowing rapid and high-level production. Thermoplastics can be rapidly formed in minutes, and further enhanced with integration of functionality and design features through injection overmolding, often in a single step. While initial costs for these materials are higher than thermosets, this is offset by their ability to be rapidly processed in high volumes through automation, and part consolidation, providing overall large-scale cost savings.

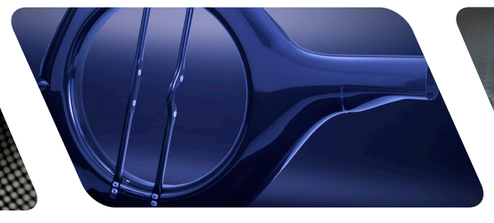
Another major benefit of thermoplastics is their ability to be welded together, creating a strong uncompromised complete structure comparable to laminate strengths. What's more, welding processes are fast, thereby increasing assembly production rates.

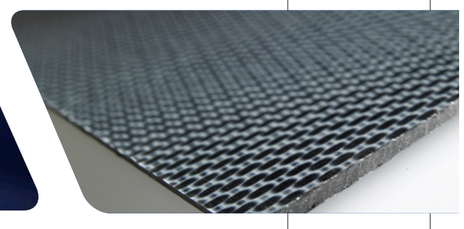
Thermoplastics and thermosets both support fast, high-scale automated production processes including automated tape layup (ATL) and automated fiber placement (AFP). However, thermoplastics give an added degree of high-rate production when continuous compression molding (CCM), which produces a fully consolidated laminate in one operation, is followed by rapid stamp forming. With a production rate on the order of 4,000 inches per minute or 100 meters per minute, thermoplastic AFP followed by vacuum bag only consolidation can expedite the overall fabrication process as well. Additionally, thermoplastic AFP enables the possibility of a fully consolidated laminated part in-situ, albeit at speeds that still need some development. For smaller parts, long discontinuous fiber compression molding has improved cycle times compared to thermosets. The process employed depends largely on the material used and the complexity of final part, yet each allows rapid high scale production of high-quality parts.

In addition to increasing output, thermoplastics also offer significant benefits including room temperature storage, increased durability, the ability to be reformed, and exceptional waste-reducing and cost-saving recyclability. With many processes available depending on the type of part being made, thermoplastics overall provide very good flexibility and versatility at high manufacturing rates.

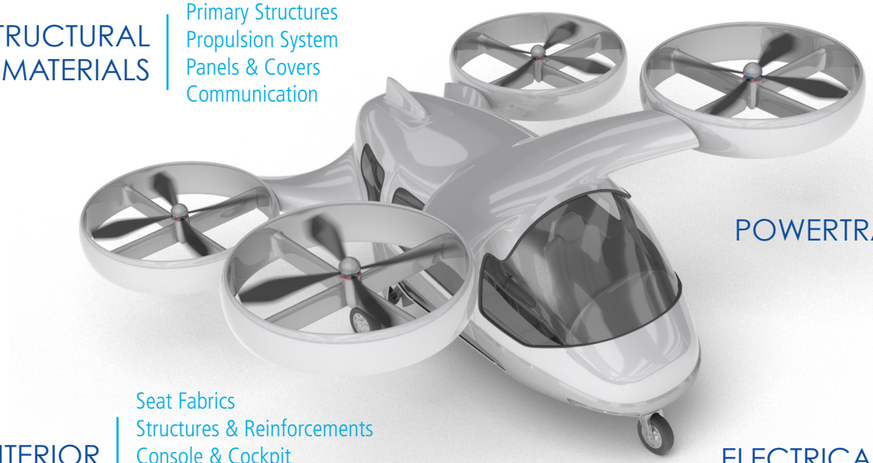
A skilled and well-equipped materials supply partner and its knowledgeable team of materials engineers will help an AAM manufacturer navigate complex material and process choices. Your partner will, help craft a plan from prototype through high volume production, recommending materials and processes every step of the way for a streamlined, cost-effective approach from day one.







Toray Material Portfolio for eVTOLs



EXTERIOR
- Platform Protection
- Millimeter-Wave Radar
- Window Film
- Front Bumber
- Sensor Covers

STRUCTURAL MATERIALS
- Primary Structures
- Propulsion System
- Panels & Covers
- Communication

POWERTRAIN
- Battery Racks/Boxes
- Thermal Management
- Electrical Cases
- Bus Ring/Bar
- Filter & Cords
- Drive Motor Insulator
- DC/DC Converter
- Battery Separator Film
- Motor Insulating Film

INTERIOR
- Seat Fabrics
- Structures & Reinforcements
- Console & Cockpit
- Trims & Covers
- Lighting

ELECTRICAL
- ECU Case
- Current Sensor
- Touch Panel
- Display
- IR Sensor

Automotive + Aerospace Product Experience Tailored for eVTOL Needs

Experience Heritage

MARKET EXPERIENCE AND HERITAGE

Due to the merged nature of AAM, borrowing from both aerospace and automotive legacies, companies can also experience considerable time and resource savings by partnering with a comprehensive material supplier with a strong pedigree in both industries.

A comprehensive material supplier with significant experience in aerospace will have compiled various databases on their materials to demonstrate FAA qualification. The typical coupon level cost for full FAA qualification of a material can cost close to $2 million and take several years. The cost and timing increase with the complexity of the part. Selecting a materials supplier with an extensive existing database of testing and qualification for its materials not only provides engineers support in selecting the ideal material, but also saves considerable time and money in the qualification process.

A materials supplier with experience in both aerospace and automotive will be familiar with both industries' needs, processes, and challenges. Knowing from extensive experience what materials best support flight critical parts and what materials perform best for other systems and designs allows a materials supplier to reliably consult and support AAM OEM and component manufacturers.

A MATERIAL FOR EVERY USE

In today's advanced technological age, there is an ever-expanding variety of lightweight and durable materials ideal for every component on tomorrow's AAM vehicles. Partnering early with a supplier with the capability of supplying everything from composites, engineering plastics, battery separating films, fibers, and textiles, to optical plastic fibers, inks, and pastes for advanced sensors and displays will further position an AAM company for success.

Unrivaled Material Portfolio

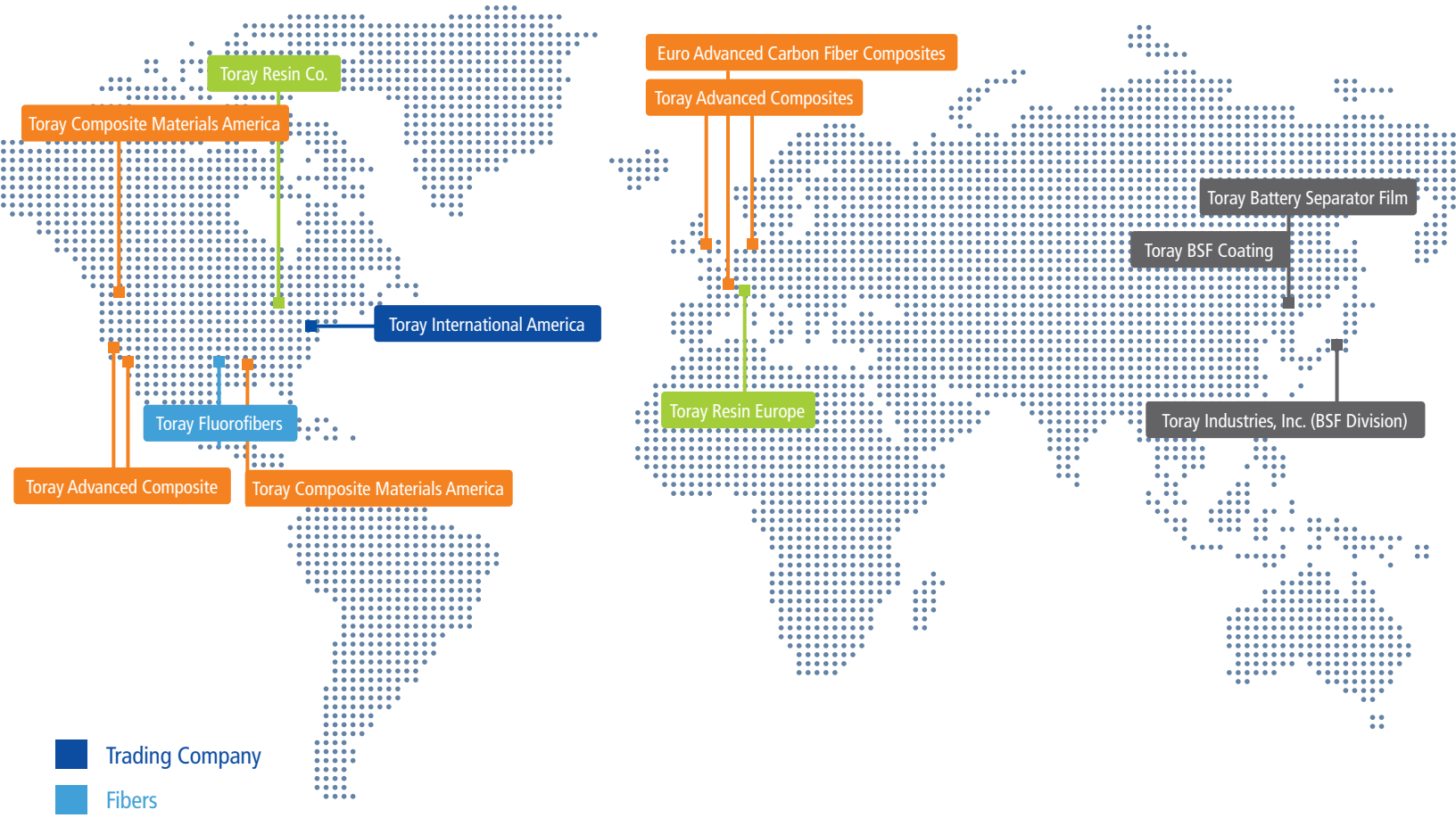
TORAY INDUSTRIES SUPPPORTS AAM

Since 1926, Toray has been on the cutting edge of advanced material development and production to support established and emerging industries with superior advanced materials. Toray's extensive aerospace and high-performance automotive experience, broad portfolio of proven high-caliber materials, and comprehensive databases allow us to partner early in the design phase with AAM manufacturers, providing support and material guidance from prototype to high volume production, and beyond.

Toray's expansive thermoset and thermoplastic composite portfolio supports structural applications at any production rate.

Toray also produces a vast selection of non-structural materials such as textiles for seat fabrics and interior trims, optical fiber for lighting, films for windows and batteries, inks for sensors, resins for motors and cases, and fibers for bearings and bushings. These non-structural materials have had decades of success in automotive and business jet applications around the world.

Toray is fully committed to helping AAM manufacturers succeed at any rate of manufacturing and growth. Our partnerships with leading companies are an example of our ability to enable the path from prototype to high-rate production. To learn more about Toray's materials for AAM applications visit our website at www.uam.toray.



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