A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Federal Aviation Administration

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Joint Centers of Excellence for Advanced Materials

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

CECAM center of excellence for composites and advanced materials

JAMS Technical Review

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Agenda

- Research Team
- Research Questions
- Research Process Overview
- Literature Review
- Industry Engagement
- Key Findings
- Future Research Areas

Introduction

- **ASSURE A53** – Advanced Materials and Processes Survey for AAM and UAS Aircraft
- **Lead Principal Investigator**: Gerardo Olivares, NIAR AVET
- **ASSURE Researchers**
  - **NIAR AVET**: Luis Gomez, Aswini Kona Ravi, Akhil Bhasin
  - **MSU ACI**: Christopher Bounds (Co-PI), Wayne Huberty, Matthew Roberson
- **Other FAA Personnel** – Katie Constant-coup, Hector Rea, Cindy Ashforth, James Reynolds
- **Industry Partnerships/Other Collaborations** – Raw material suppliers, Original Equipment Manufacturers (OEMs), tier one suppliers, Subject Matter Experts (SMEs).

Research Background, Approach and Objectives

Background

- Novel advanced material systems are at the core of emerging markets such as Advanced Air Mobility (AAM) and Unmanned Aircraft Systems (UAS).
- The existing FAA guidance for certification of composite structures are defined for traditional continuous fiber reinforced thermoset composite materials.
- Established the need for analyzing the existing manufacturing & certification standards and develop new standards for AAM and UAS aircraft if necessary.

Approach

- To conduct literature research and collaborate with industry partners to identify the new material systems that are being used in UAS & AAM vehicles.

Projected Benefit of Research

- Documentation of the industry’s adoption of novel advanced materials and processes.
- Understand the major differences between the advanced and the existing materials that already have certification guidelines.

Research Questions

Research Question #1 **Are there any new or unique composite or other advanced materials used in AAM and UAS vehicles that are not in use in traditional aircraft or rotorcraft?**

- Identify all the composite and other advanced material systems.
- Identify all the advanced manufacturing applications.
- Includes all the primary, secondary structural and non-structural applications.

Research Question #2 **Are there any new or unique applications of existing composite materials?**

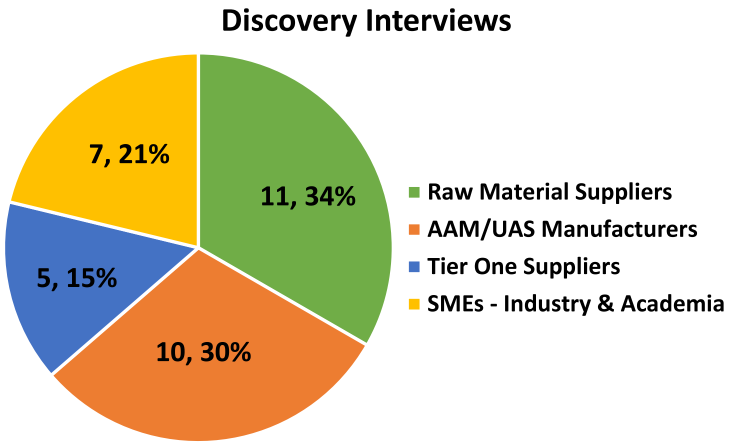
- To analyze materials intended for traditional aircraft applications to AAM and UAS vehicles.
- Document if the following advanced materials are in use:
    - Thermoplastics – if so, their applications? Purpose of deviating from traditional materials?
    - Ceramic matrix composites, hybrid structures.
- Document the joining methods – fastened, bonded, welding?
- Document the repair and inspection criteria.

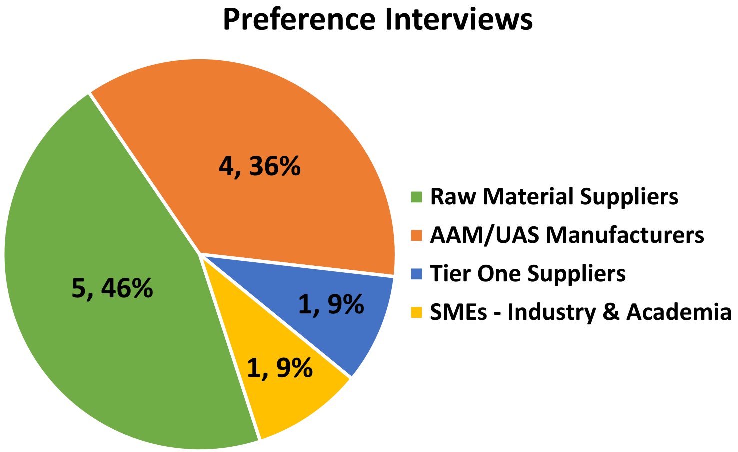
Research Question #3 **Are there any material characteristics that are uniquely critical for AAM and UAS vehicles that are not included in material databases for traditional aviation applications?**

- Address if the existing public material databases are adequate for UAS and/or AAM applications.

Research Process Overview

- **1.0 Literature Review**
- **2.0 Industry-based Survey:** Conducted using New Product Blueprinting, a commercially available market survey software.
  - **2.1 Discovery Phase** – 33 interviews.
  - **2.2 Preference Phase** – 11 interviews.





AAM Literature Review – Research Question #1

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Literature Review (AAM) – RQ#1

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Joby Aviation

[1][2]

- Carbon fiber thermoset prepregs
- Automated Fiber Placement (AFP)
- AM: Titanium – Safety Critical Components
- Future: Thermoplastics

Vertical Aerospace

[3]

- Primary & Secondary Structures: Solvay MTM45-1
- Future: Out Of Autoclave (OOA), AFP, thermoplastics.

Novotech

[4][5]

- Primary: Solvay MTM45-1, CYCOM 5320-1
- AFP, Resin fiber infusion
- Future: Thermoplastics.

Lilium

[6][7][8]

- Qualified carbon fiber composites: fuselage, wings & flaps.
- Low-rate production: hand layup, autoclave cure
- Future: AFP, OOA, AM, thermoplastics.

Volocopter

[1]

- Qualified carbon fiber and resin composites: entire airframe, rotor blades and seats.
- Full-rate production: OOA

Pipistrel

[9]

- Epoxy based prepregs
- Hand layup, room temperature cure, occasional OOA.
- Future: more OOA, automated fabrication.

Literature Review (AAM) – RQ#1

Xpeng HT Aero

[12]

- Carbon fiber sheet molding compound

– seat frame & control panel.

- Carbon fiber components – cockpit seats, mechanical arm and other structural interior and exterior parts.
- AB Pillar: combination of compression molding and autoclave cure.

Wisk

[1]

- Qualified fiber and resin: all primary structures
- Hand layup with OOA
- Future: automated technologies.

Lift

[13][14]

- Carbon fiber airframe
- Pylon: titanium, additively manufactured.

ElectraFly

[10][11]

- Metal gears to be replaced with 3D printed composite parts.
- Partnered with Impossible Objects (CBAM 3D printer).

Alakai

[15]

- Carbon fiber airframe and landing skids.

Jaunt Air Mobility

[16]

- Thermoplastics: primary aircraft structure, wings, outside body, rudders, stabilzers.
- Thermoplastic airframe substructure: compression molded from chopped fiber composites.
- Primary and secondary structures: hot press forming.
- Thermoplastic welded structures: induction welding.
- Conventional thermosets: rotor blades.

Literature Review (AAM) – RQ#1

Presented below are some of the high-rate applicable advanced materials and processes suitable to the AAM industry:

- **Cycom EP2750 [17]:**
  - Highly drapable toughened epoxy prepreg specifically designed for compression molding processes.
  - AAM applications: bulkheads, ribs, fuselage sections, brackets and clips.
- **Toray 2700 [18]:**
  - Adaptable for automation and high rate production processes.
  - Can be used in compression molding of high-volume small parts such as aircraft clips, molded brackets and wing ribs, while larger parts may be processed via out-of-autoclave (OOA) and vacuum bag only (VBO).
- **Tailored Universal Feedstock for Forming (TuFF) [19][20]:**
  - Manufacturing process - Discontinuous fiber feedstock.
  - Highly aligned discontinuous carbon fiber preform in ply format.
  - Stamped to make complex parts. Stretch formable.
  - Tensile properties equivalent to continuous fiber composites.
  - Compatible with any type of fiber with nearly all polymers (thermoplastics and thermosets). [IM7, T800, pitch carbon fiber, recycled carbon fiber, PEI].

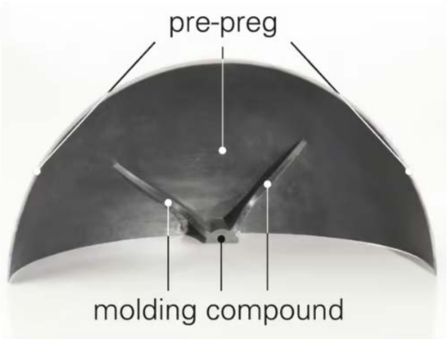
TuFF Stamp Formed Part [19]

Literature Review (AAM) – RQ#1

Presented below are some of the high-rate applicable advanced materials and processes suitable to the AAM industry:

- **Faster curing prepregs – Hexcel [ACMA AAM Composite Technology Days (21)]:**
  - Reducing cure time of well-established primary structure prepregs.
  - Improving performance of industrial grade fast curing prepregs.
  - Studies on 8552 system for 10-25% shorter cure times
    - Compression molding – 30 mins with similar mechanical performance as autoclave.
- **Hybrid prepreg – molding compound [ACMA AAM Composite Technology Days (21)]:**
  - Co-molding, co-curing of continuous fiber reinforced prepreg and molding compound.
  - Specifically designed for compression molding processes.
  - Phenolic, snap cure phenolic, vinyl ester resin systems. Epoxy system in development.
  - Shorter cure cycle times.

EnableX™ from Norplex-Micarta [22]



Literature Review (AAM) – RQ#1

Presented below are the research programs focused on the design and development of propellers for the AAM industry:

- **Smart rotors [23]:**
  - Ultra-efficient propeller and rotor blades specific to hybrid and electric aircraft and drones.
  - Development of technologies such as automated preforming with dry fibers.
- **Braided thermoplastic propellers [24]:**
  - Triaxial braiding for complex geometry structures such as propellers.
  - Novel manufacturing process that combines bladder molding with commingled thermoplastic and carbon fiber reinforcements.
  - Reduced cure times when compared to typical thermoset epoxy resins.
  - DigiProp Dowty propellers research program for evolving aircraft applications and next-generation platforms.

DigiProp prototype thermoplastic composite propeller blade [24]

AAM Industry Survey – Research Question #1

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AAM Industry Survey [Material Suppliers] – RQ#1

Identify all the composite and other advanced material systems, manufacturing processes and their applications.

- Legacy, certified, aerospace-grade composite material systems - primary & secondary structural applications.
  - Qualified materials in public material databases.
  - Most companies want to be first to market.
- Change in material selection when the market evolves and matures into high production rates.
  - Most aircraft OEMs are opting for thermosets to begin with and plan on switching to high production rate materials and processes.
- High-rate applicable materials – snap cure thermosets, thermoplastics.
- Manufacturing processes: Autoclave cure, out-of-autoclave processes, resin infusion processes, snap cure processes, automated fiber placement, automated tape laying, compression molding, injection molding, stamp forming, thermoset press cure, rapid clave.

AAM Industry Survey [OEMs] – RQ#1

AAM OEM	Current Materials	Current Fabrication Processes	Current Use of Thermoplastics	Future Materials & Processes
OEM A	UD thermosets available in public material databases such as NCAMP, CMH-17.	Hand layup, autoclave cure. No OOA & AM.	Limited to brackets.	Snap cure & thermoplastics; Press cure, Resin infusion.
OEM B	Thermosets available in public material databases; snap cure is of interest.	OOA, oven curing, VARTM. No autoclave. AM - for internal non-structural use.	None.	-
OEM C	Snap cure resins. AM - critical components using titanium.	High pressure RTMs, SQRTM. AM.	Research ongoing. Processes of interest: Overmolding, stamp forming, CCM.	Evaluating discontinuous fiber for secondary structures.
OEM D	Thermosets available in public material databases.	AFP.	Limited use for now.	Would be heavily reliant on thermoplastics.
OEM E	Traditional thermosets & thermoplastics.	Hand layup, AFP, ATL. No AM.	Brackets.	Snap cure & thermoplastics (PEEK & Ultem 9085 being evaluated).
OEM F	Thermosets available in public material databases. AM - propellers, structural components (have not decided the AM processes).	Injection molding is of interest. Open to different processes.	Still looking into thermoplastics.	In prototyping phase and deciding on the current M&P.
OEM G	Thermoplastics.	No autoclave.	Primary and secondary structures.	-
OEM H	Primary: Al & other conventional metals. Secondary: qualified composites.	-	-	-

AAM Industry Survey [Tier One Suppliers] – RQ#1

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Identify all the composite and other advanced material systems, manufacturing processes and their applications.

- Many aspects discussed in the previous two sections with the interview results from material suppliers and OEMs were repeated by the tier-one suppliers.
- Most companies are currently using standard thermoset prepreg materials.
    - This is expected to shift to thermoplastics, fast curing thermosets.
- Continuous fiber thermoplastics would be of interest due to their high performance and toughness.
    - Combination of processes – continuous fiber with over molding of short fiber composites.

AAM Industry Survey [Subject Matter Experts] – RQ#1

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Identify all the composite and other advanced material systems, manufacturing processes and their applications.

- The interviews with the SMEs contained some of the key points discussed in the previous sections, such as high-production rate-related issues and the need for more qualified high-rate applicable materials such as thermoplastics, snap cure thermosets.
- The materials and processes might not be very unique or different from the traditional aerospace industry, but industrialization might be one of the key differences.
  - Legacy process systems are labor dependent. Push for automation with minimal touch labor and faster, efficient processes.
  - In-process checks to monitor product quality along the manufacturing stages.

sUAS Literature Review – Research Question #1

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sUAS Literature Review – RQ#1

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Identify all the composite and other advanced material systems, manufacturing processes and their applications.

- **DJI:** Primary structure – magnesium alloy (AZ91D), injection molding; arms – PA66+30%GF, injection molded; propellers – GF composites [25].
- **Quantum Systems:** Airframe – elapor foam molded with carbon fiber; Mounts are additively manufactured [26][27].
- **Parrot:** Primary structure – polyamide based glass fiber material system; AM – selective laser sintering [28].
- **Cobra:** Central body – polyvinylchloride foam sandwich shell with expanded polystyrene foam rib [29].
- **Skydio:** Airframe – Carbon, glass fiber composites using Additive Molding technology (region specific material property optimization) [30].
- **MI-DRONE:** Aerospace grade carbon fiber material; automated tape placement, induction welding [31].
- **Applied Aeronautics:** Airframe - carbon, glass fiber composites, honeycomb; carbon fiber – wing spars, interior shelving, landing gears [32].

UAS Industry Survey – Research Question #1

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

sUAS Industry Survey – RQ#1

Identify all the composite and other advanced material systems, manufacturing processes and their applications.

Material Suppliers

- Small UAS is a low cost platform without the certification burden.
- Lower mechanical performance materials as compared to traditional aircraft are often used.
- One material supplier said that emphasis is on manufacturing methods and less on innovation in material systems.
- One material supplier mentioned that due to the production requirements of an OEM, they chose thermoplastics.
  - They used qualified material in case of any future certification requirements.

OEMs

- "Using qualified materials has become important, in case of FAA regulations" – sUAS OEM.
- One OEM mentioned multi-injection molding is a key fabrication process in building their drone. Carbon fiber composites – central body and wings; aluminum-composite hybrid materials – motor support structures. In future, to integrate qualified thermoplastic materials.
- Advanced materials: Carbon/glass fiber composites, polycarbonate, aluminum, magnesium alloys; expanded polypropylene foam, chopped fiber composites.
- Fabrication Processes: Compression molding, injection molding, multi-material injection molding, continuous additive manufacturing, additive manufacturing with topology optimization.

Large UAS Industry Survey [OEMs] – RQ#1

Identify all the composite and other advanced material systems, manufacturing processes and their applications.

- Materials: Quick cure thermosets, thermoplastics.
- Not restricted to traditional manufacturing processes.
- Fabrication Processes: Infusion, VARTM, SQRTM.
- Increased use of AM.
- Topology optimization.

AAM Literature Review – Research Question #2

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Research Question #2

Are there any new or unique applications of existing composite materials?

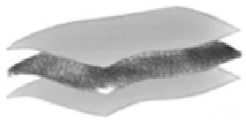
- To analyze materials intended for traditional aircraft applications to AAM and UAS vehicles.
- Document if the following advanced materials are in use:
  - Thermoplastics – if so, their applications? Purpose of deviating from traditional materials?
  - Ceramic matrix composites, hybrid structures.
- Document the joining methods – fastened, bonded, welding?
- Document the repair and inspection criteria.

In the following slides, we will present the results from the literature review and the industry surveys (OEMs, Tier One Suppliers, Material Suppliers and Subject Matter Experts (SMEs).

Literature Review [AAM] – RQ#2

Presented below are the bonding applications suitable to the AAM industry:

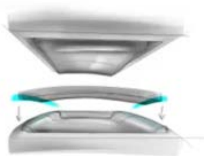
- **Multi-material Joining Technology [33]:**
  - Robotic ultrasonic-welding process. Spot and continuous welds.
  - A thermoplastic coupling layer (catalyst) is applied directly to the thermoset material and cured (heat and pressure) to activate the surface.
  - For the subsequent assembly, injection-molded brackets or stiffening elements can be integrated via welding or over molded directly onto the part.



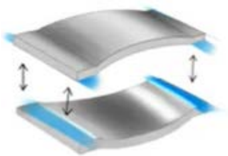
Cutting and preparation of fabric

Stacking and preforming fabric

Lay-up Conexus-layer in joining areas



Moulding and curing under heat and pressure



Joining areas

Continuous welding process

*KTM E-Technologies [33]

Literature Review [AAM] – RQ#2

Presented below are the bonding applications suitable to the AAM industry:

- **FusePly^{TM} [34][35]:** epoxy-based film that is designed to co-cure with a prepreg and create a chemically active surface.
  - Combination of co-cure bonding and secondary bonding methodologies.
  - End product - Bonded structures joined by chemical bonds.
- **AeroPaste® [34]:** structural paste adhesives.
  - Room to high temperature adhesives.
  - Designed for out-of-autoclave structural bonding.
  - For rapid assembly and automation of metal and composite structures.

AAM Industry Survey – Research Question #2

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Industry Survey [Material Suppliers] – RQ#2

Novel Material Systems

- Applications of existing aerospace grade material systems to remain the same for AAM aircraft.
- Emphasis on novel materials with similar performance as legacy materials but with a different process window.
- Solvay EP2190, EP2750, Toray 2700 - new toughened epoxy systems.

Thermoplastics

- Material suppliers offer a wide portfolio for primary & secondary structural applications.
- Proportion of thermoplastics to grow as rate requirements grow.
- Capabilities such as welding could help reduce weight and play an important role to meet high production rate requirements.
- The major challenge with thermoplastics are scalability and processing temperatures.

Joining Methods, Ceramic Matrix Composites (CMCs), and Hybrid Materials

- Secondary bonding - thermosets; welding - thermoplastics.
- Limited to no use of CMCs and hybrid materials.

Industry Survey [AAM/sUAS - OEMs] – RQ#2

Novel Material Systems

- OEMs are looking to go with more proven processes and materials such as materials available in public material databases.

Thermoplastics

- There is currently limited to no use of thermoplastics for primary structures. Likely to change in future.
- Applications – bracketry, enclosures, clips, interior components, secondary structures.
- Limited qualified thermoplastic materials in public databases.
- Thermoplastic materials – PEEK, PAEK, Nylon, PEKK, PPS, PPA.

Additive Manufacturing (AM)

- AM is being considered by OEMs to make clips, brackets, and smaller UAS aircrafts.
- Limited AM materials in public databases.

Repair and Inspection Criteria

- The criteria for AAM have not yet been defined, but it would likely follow the practices of the traditional aircraft industry.
    - Frequency of inspection likely to be higher.
- Small UAS is less limited by materials due to a lower certification burden and less stringent repair and inspection criteria.

AAM Industry Survey – Research Question #3

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Research Question #2

Are there any material characteristics that are uniquely critical for UAS and AAM vehicles that are not included in material databases for traditional aviation applications?

- Address if the existing public material databases are adequate for UAS and/or AAM applications.

Properties
Elevated Temperatures
Interlaminar Fracture Properties
Delamination Growth
Toughness on Corners
CTE
Liquid Flow Field Properties
Electrostatic Discharge
Chemical Compatibility
Dynamic Properties
Durability of Welded Structures
Fire, Smoke, and Toxicity
Dielectric Constant
Creep
Heat Deflection Temperature
Insulation and Firewalls
Electromagnetic Properties
Gas and Liquid Gas Permeability
Compression After Impact

Materials
Thermoplastics
Additive materials
Stamp formable thermosets
AFP materials
Honeycomb
Braided materials
Paste Adhesives like Aeropaste
Compression Molding materials
Materials that support high-production rate environment

Key Findings & Future Research Areas

A53 – Advanced Materials and Processes Survey for AAM and UAS Aircraft

Key Findings – AAM

Advanced Air Mobility Industry

- Advanced material systems in use and planned to be in use –
  - Thermoset material systems (Solvay® MTM45-1, Cycom® 5320-1).
  - Snap cure resins.
  - Thermoplastic material systems.
- Fabrication processes in use and planned to be in use in AAM –
  - Hand layup, autoclave cure, AFP, ATL.
  - RTM, VARTM.
  - AM.
  - CCM, stamp forming, overmolding.
- Applications of existing traditional aviation material systems for short-term programs. The material selection and manufacturing techniques may change once production rates increase.
- Joining methods: limited fasteners, secondary bonding for thermosets, and welding for thermoplastics.
- Repair & inspection criteria: similar to traditional aviation; inspection frequency could be higher.

Key Findings – UAS

Small Unmanned Aircraft Systems (under 55 lbs 14 CFR 107)

- Advanced material systems in use and planned to be in use in small UAS –
  - Carbon/glass fiber composites, polycarbonate, aluminum, magnesium alloys; expanded polypropylene foam, chopped fiber composites.
- Fabrication processes in use and planned to be in use in small UAS –
  - Compression molding, injection molding, multi-material injection molding, continuous additive manufacturing, additive manufacturing with topology optimization.
- Repair & inspection criteria: had no stringent criteria in place until recently; companies keen on designing repairable drones.

Unmanned Aircraft Systems Industry (over 55lbs 14 CFR TBD)

- Limited input from 2 OEMs.
- Rapid cure thermosets, thermoplastics, AM.
- Infusion, VARTM, SQRTM.
- AM with topology optimization.
- These manufacturers will likely have similar material, and manufacturing usage as AAM OEMS.

Future Research Areas

1) Near-term research for materials and processes that are clearly on the short-term horizon for UAS/AAM. These would include the materials in the NCAMP database that can be processed in various ways, i.e., Toray 2700, PAEK/PEEK materials (both discontinuous and continuous fibers).
2) Comparing and contrasting various processing techniques, i.e., VARTM, RTM, press, thermoset vs. thermoplastic, etc.
3) Investigate chopped fiber systems structures, processing, and controls for safe implementation and regulation.
4) Understanding how AM can be safely implemented for primary AAM and UAS aircraft structures.
5) The effects of the electrical propulsion system in advanced materials (Heat, Flammability, and Electromagnetics).

Questions?

References

1. https://www.compositesworld.com/articles/composite-aerostructures-in-the-emerging-urban-air-mobility-market
2. https://evtol.com/features/joby-aviation-dassault-systemes-additive-manufacturing/
3. https://www.compositesworld.com/news/solvay-vertical-aerospace-expand-on-uam-agreement
4. https://www.compositesworld.com/news/solvay-supplies-composites-adhesives-technical-support-to-novotech-seagull-aircraft-development
5. https://novotech.it/seagull/
6. https://www.3dprintingmedia.network/lilium-raises-35-million-for-upcoming-vtol-taxi/
7. https://lilium.com/newsroom-detail/carbon-composites-and-the-lilium-jet
8. https://www.compositesworld.com/news/lilium-selects-aciturri-for-evtol-fabrication
9. https://www.compositesworld.com/news/pipistrel-accepts-orders-for-nuuva-series-evtol-aircraft-
10. https://www.compositesworld.com/news/electrafly-analyswift-win-us-air-force-sttr-grants
11. https://evtol.com/news/electrafly-uammi-additive-manufacturing/
12. https://www.compositesworld.com/news/hrc-manufactures-cfrp-parts-for-xpeng-ht-aeros-x2-evtol-aircraft
13. https://evtol.news/lift-hexa/
14. https://www.materialise.com/en/industries/aerospace-aeronautics/interviews/lift-aircraft
15. https://www.compositesworld.com/news/alakai-technologies-launches-hydrogen-powered-evtol
16. https://evtol.news/news/stamping-out-air-taxis
17. https://www.solvay.com/en/product/cycom-ep2750
18. https://www.compositesworld.com/products/toray-composite-materials-america-launches-flexible-adaptive-2700-prepreg-system
19. https://www.udel.edu/udaily/2020/july/tuff-material-center-for-composite-materials/
20. https://www.ccm.udel.edu/research/program-highlights/tuff/#:~:text=TuFF%20(Tailored%20Universal%20Feedstock%20for%20Forming)%20consists%20of%20a%20highly,to%20make%20high%20performance%20composites.

References

21. ACMA AAM Composite Technology Days
22. https://www.norplex-micarta.com/structural-materials/enablex/
23. https://www.compositesworld.com/news/development-of-dry-fiber-preforms-and-other-technologies-for-smart-rotors
24. https://www.compositesworld.com/news/digiprop-positions-dowty-propellers-and-its-customers-for-sustainable-next-generation-platforms
25. http://californium.in/2018/08/22/how-its-made-dji-mavic-air/#:~:text=The%20alloy%20used%20for%20the,structural%20metals%20in%20the%20world
26. https://www.shapeways.com/blog/archives/42225-quantum-systems-3d-printing-drones-to-endure-the-force-of-flight.html
27. https://geomatika-smolcak.hr/wp-content/uploads/2021/08/System-Description-Trinity_MRO.pdf
28. https://www.windform.com/case-studies/3d-printed-structure-parrot-bebop-2-drone-functional-prototype/#:~:text=Parrot%20has%20developed%20the%20final,based%20glass%20reinforced%20composite%20material
29. https://cobrainter.com/assets/downloads/Cobra-CS-VETAL-Aug21-v2.pdf
30. https://www.skydio.com/blog/skydio-adds-arris-additive-molding-composites-x2-drone-thermal-autonomous/
31. https://www.compositesworld.com/news/eirecomposites-manna-and-nuig-to-develop-carbon-fiber-composite-drone-airframe
32. https://www.appliedaeronautics.com/far
33. https://www.compositesworld.com/news/ctc-gmbh-and-ktm-e-technologies-develop-innovative-joining-technologies-for-urban-air-mobility
34. https://www.bigmarker.com/gardner-business-media-inc-w1/Bonding-and-Surfacing-Technologies-for-Urban-Air-Mobility-UAM?utm_bmcr_source=web
35. https://www.solvay.com/en/brands/fuseply