AEROSPACE NEEDS IN LOW COST AGILE MANUFACTURING

AEROSPACE COMPOSITES FORUM - JULY 2022

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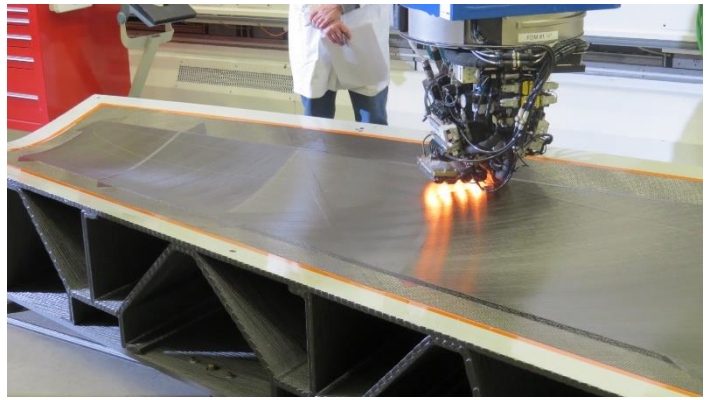
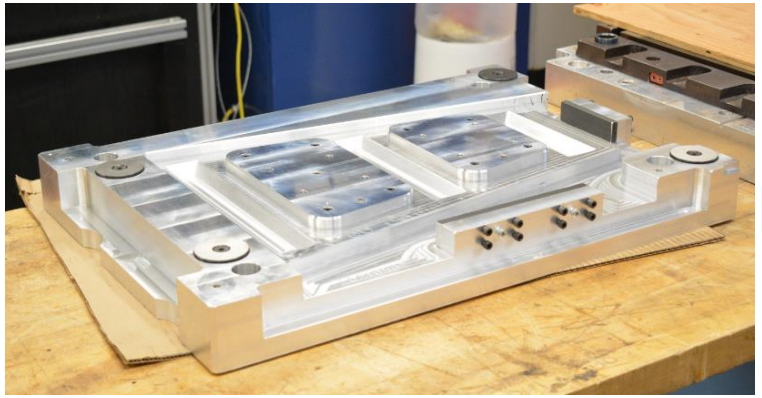
LOCKHEED MARTIN

LOW COST TOOLING

- Low Production Volumes Demands Tooling Innovation
- Cost of invar and composite tooling typically exceed $1500/sq ft
  - Smaller match mold tools are more costly
- Need cycle times in weeks rather than months
- LCAA requirements enable less durable materials
- Polymer tooling enables lower costs with durability sacrifice
  - BAAM tooling for larger scale parts
  - Polymer tools for compression molding



BAAM Tooling for WiSDM Wing Skins

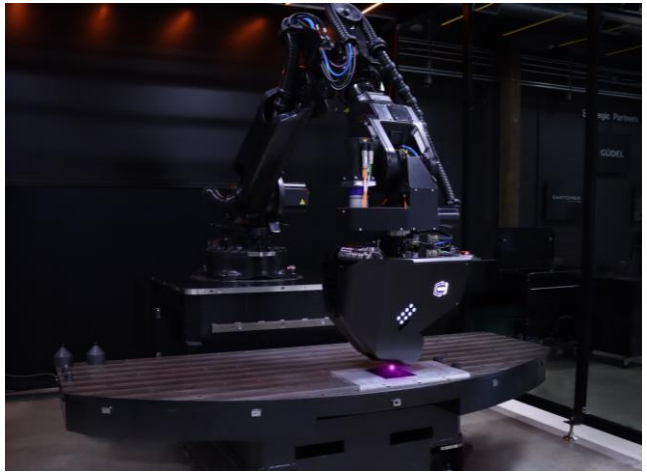


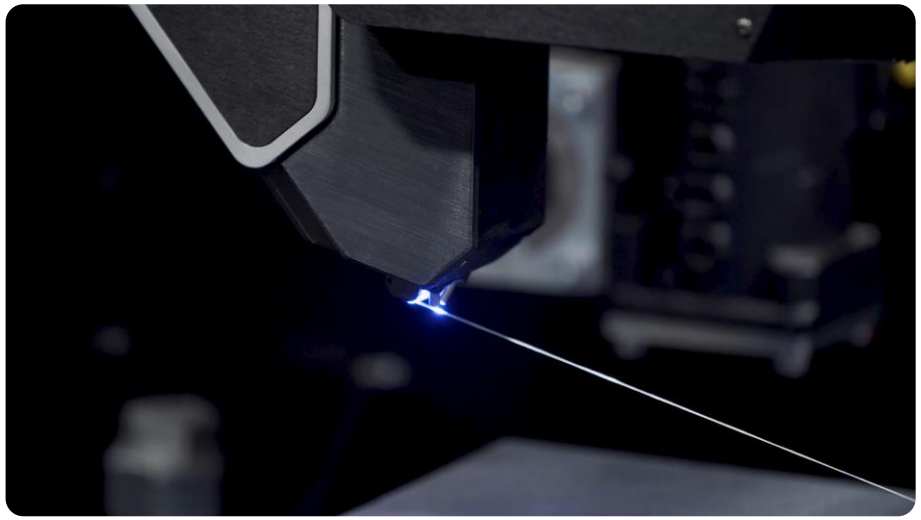
Metallic Tooling for Compression Molded Stiffeners

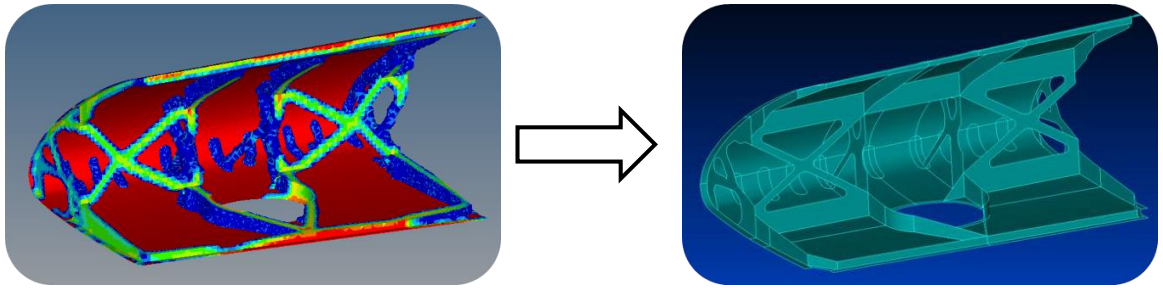
Polymer Tooling for Compression Molded Stiffeners

TOOL-LESS MANUFACTURING - AM

- Continuous Fiber Additive is a Breakthrough Opportunity
- Additive Manufacturing with continuous fiber materials offers cure-on-the-fly with high performance potential
- Thermoplastics require annealing for crystallinity
- Continuous Fiber 3D (CF3D) UV curable TS
  - WiSDM Spar Fabrication
    - 1st application of CF3D on any “real” part design
  - Manufacture of topology optimized composite designs
  - Multifunctional material applications







Current application of topology optimized designs requires CAD interpretation for realism

CF3D Images and Video Courtesy of Continuous Composites

DETERMINATE ASSEMBLY

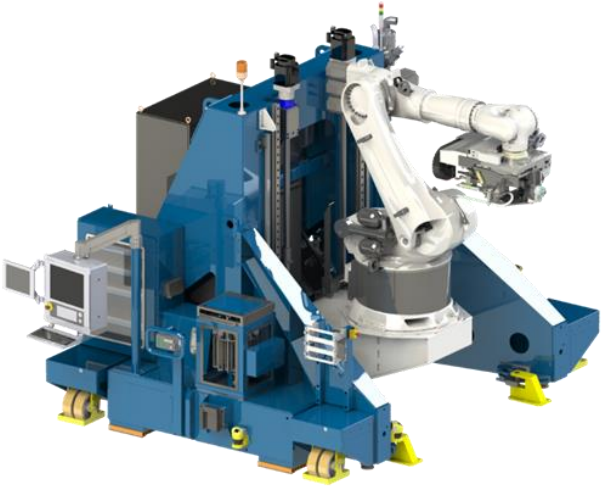
- A design and build philosophy that shortens assembly spans, minimizes tooling required, compress factory floor footprint, steepen learning curve, and reduces assembly labor
- Determinant Assembly enables initial holes put in structural parts to be at their final diameter
  - Hole positions are coordinated between parts in an assembly to allow fastener install, eliminate the need for most assembly tooling, and remove the need to post process the holes during assembly
  - Benefits include toolless assembly, no step up drilling, no destack, no debur, and no finish touch up
- Savings in labor and assembly spans up to 50%

Current Build Process for C-130J Skull Cap

DA Build Process for C-130J Skull Cap

AUTOMATED TRIM, DRILL AND FASTENING

- **Automation Reduces Production Labor and MRB Costs**
- **Advances in mobile industrial robotics has increased accuracy to compete head-to-head with traditional machine tool system**
- **Rapid end effectors swap**
- **A single robotic system can perform trim, drill, and fastening**
  - **Lessens capital cost, reduces the factory floor footprint, and expands the flexibility of the asset.**
- **Integration with robotics with mobile platforms expands the system capability without the need for dedicated "monument" machinery on the factory floor**

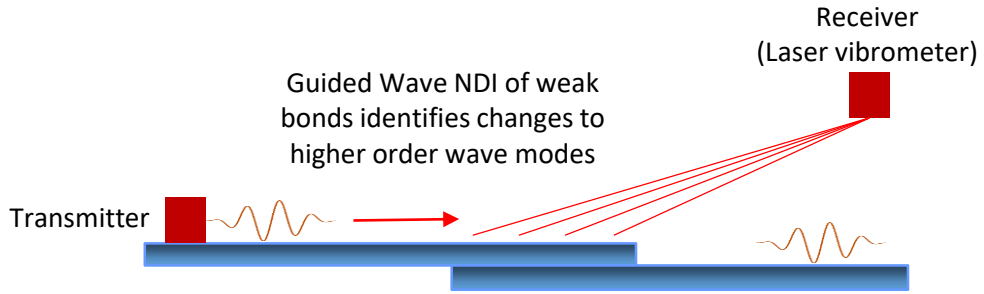


COBRA - Combined Operations: Bolting & Robotic AutoDrill

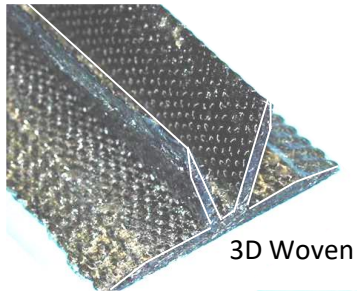
COBRA used on ~8000 X-59 holes @ 100 holes/hr with 45 mins to reposition to next drill station

CERTIFIED BONDED ASSEMBLIES

- **Finding the "Kissing Bond" Non-destructively**
  - **Bonded assemblies offer a low cost solution for prototype and low production volume air vehicles**
  - **Certifying bonded assemblies is challenged by an inability to identify "kissing bonds" nondestructively**
  - **Recent developments in guided wave NDI and cohesive zone modeling is showing promise**
- **Low Cost Pi Preforms/Joints**
  - **3D woven Pi preforms offer robust performance in co-bonded assemblies**
  - **LM retains innovative tooling approaches which control cost and provide uniformity in co-bonded Pi joints**



Dreamchaser OV-1 during final assembly (courtesy of Sierra Nevada)



3D Woven Pi

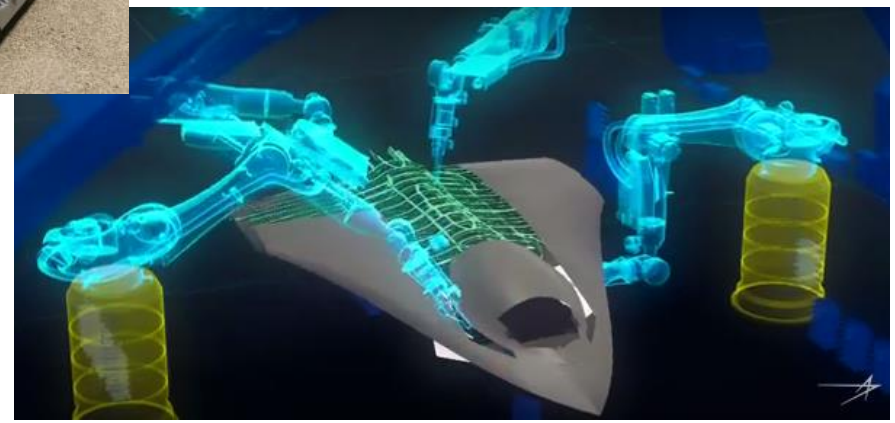
LM "D-Box" co-bonded with 3D woven Pis

AUTOMATION AND DIGITAL TRANSFORMATION

- **Automation**
  - Reduced touch labor
  - Robotic solutions for mundane tasks
  - Quality uniformity
  - Adapting to production surges
  - Reduced volume and rate cost dependance
  - Accelerated in-process & post-process inspection
- **Digital Transformation**
  - Reduced design to build cycle times through digital simulation and tool connectivity
  - Enabled model based engineering through machine learning and AI integration Enhanced machine accuracy
  - Design for manufacturing
  - Cost loop process control

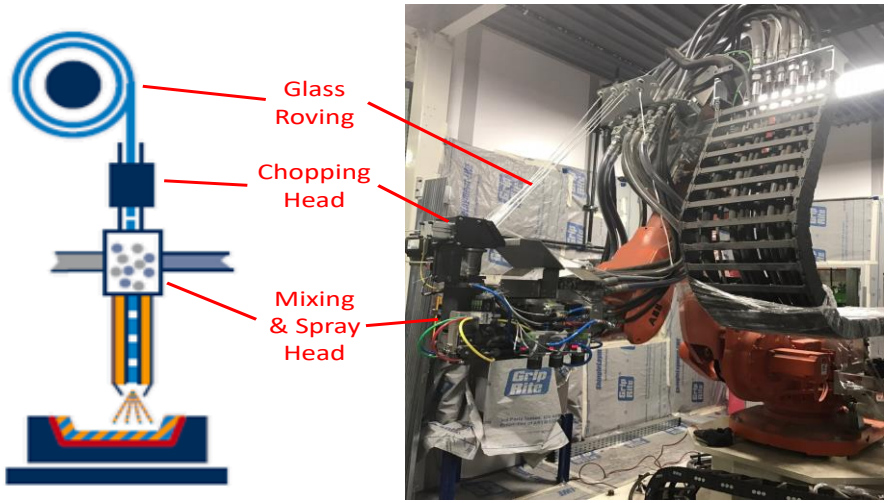
Blind Fastener Prep Robot automates highly manual processes for the F-35

Automated Fiber Placement enables large scale composite manufacture for LM ADP wing skins

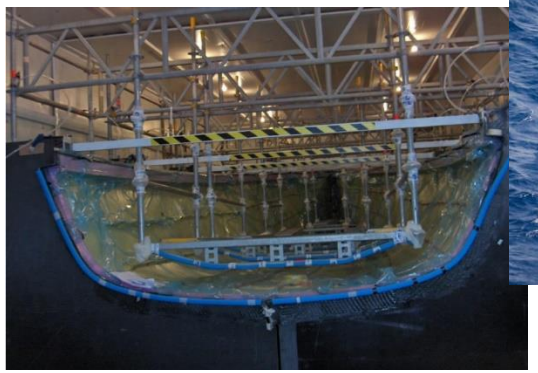


LEVERAGING INNOVATION FROM AUTOMOTIVE, ETC.

- **Limit Performance Sacrifices while Achieving Dramatic Cost and Cycle Times Savings**
  - **Discontinuous fiber composites permit low cost compression molding and injection molding processes**
  - **Can properties be improved to expand application to structural components?**
- **Using Aerospace Materials with Non-Aerospace Processes**



Long Fiber Injection (image and video courtesy of Romeo RIM)



Resin infusion for marine structures (courtesy of M-Torres)

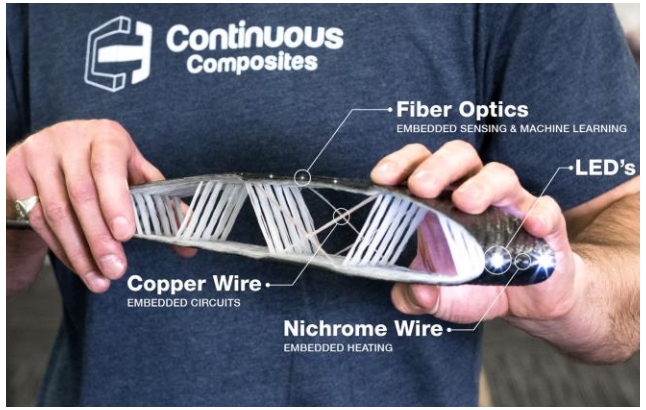
RapidClave® (courtesy of Globe Machine Manufacturing)

LOWER COST MATERIALS

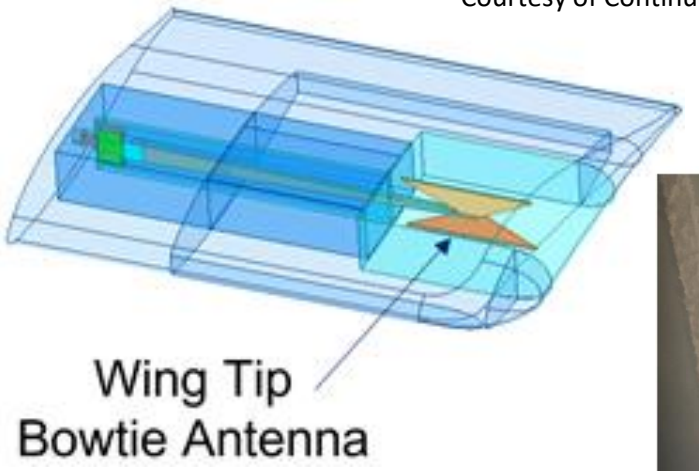
- Streamline Material Qualification Testing
  - Digital tools for B-basis allowables estimation
  - Estimated design values for preliminary design work
  - Final design values are then derived using targeted testing and further analytical and statistical analyses
  - Qualification by analysis for additional material forms from same fiber and resin
- Reduce Aero Acceptance Test Requirements
- Processes that Bypass Prepregging
- Room Temperature Storage
- Recycled Raw Material
- Commercial Grade Carbon Fibers with Larger Filament Counts

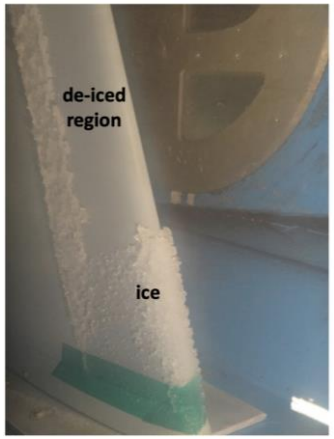
MULTIFUNCTIONAL MATERIALS & STRUCTURES

- **Alternative fibers for multifunctional capabilities**
  - **Structural health monitoring**
  - **Temperature sensing**
- **Structurally Embedded Antennas**
  - **Integrated RF components reduce drag and improve integration**
  - **Fully additive process enables agile, rapid developme and deployment.**
  - **Low loss dielectrics and fully conductive discrete patterns increase RF performance**
- **Nanofillers**
  - **Enhanced mechanical performance**
  - **Transverse thermal & electrical conductivity**
  - **Active deicing**
  - **Low energy curing**



Courtesy of Continuous Composites





Ice tunnel testing of CNT composites.
(courtesy of MIT NECST)

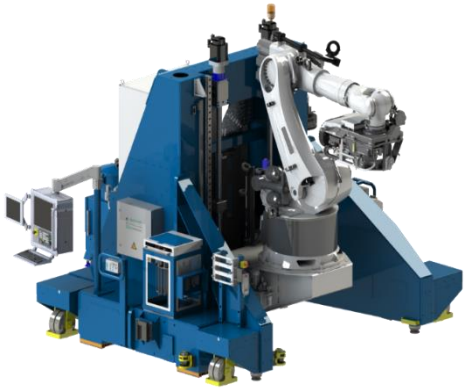
THE FACTORY OF THE FUTURE

- One of a kind 208K sq. ft. facility paving the way for the Digital Thread
- CFD guided design of HVAC systems
- Online condition monitoring of critical assets
- Ability for quick turn manufacturing reconfiguration
- Life Cycle Cost analysis providing blend of maintainability and energy efficiency

THE FACTORY OF THE FUTURE

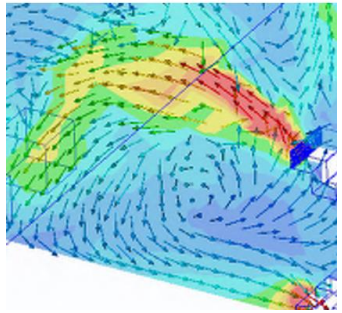
Flexible Factory Floor

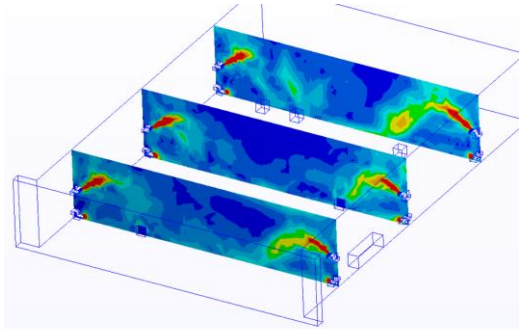
- No stanchions or fixed monuments
- Widely distributed utilities in subterranean trenches
- Enabling rapid reconfiguration for process improvements or new programs



Precise Temperature Control

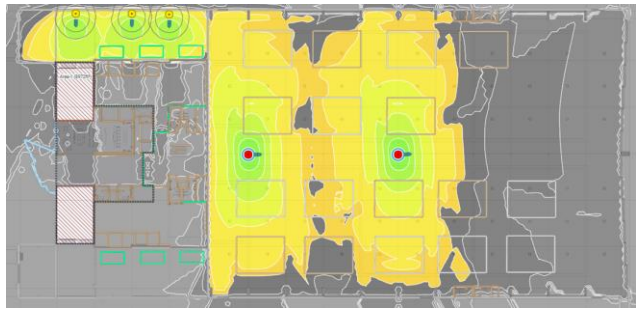
- Provide determinate assembly capabilities
- Allows sourcing of parts from geographically diverse suppliers
- First known full scale Metallic/Composite DA facility





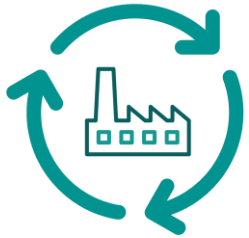
Wireless Connectivity for Manufacturing Assets

- Provides Industry 4.0 capabilities and enhances the digital thread
- Creates economical means of data capture
- Increases ability to make information based decisions across all functions



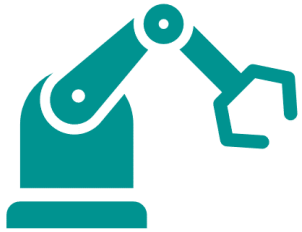
3 Critical Components – Flexible, Intelligent & Adv. Manuf.

- These components enable the factory to operate as a digitally connected OneLM factory
- Equipment and information systems utilizing artificial intelligence and technology
- Creates a more automated, flexible, predictive, and interoperable production system to deliver high quality, affordable, and rapid solutions to our customers.



The Flexible Factory

The Intelligent Factory



Advanced Manufacturing Technology