Title of Grant / Cooperative Agreement:	18-ULI2Step-B-0060, Composite Manufacturing Technologies for Aerospace Performance at Automotive Production Rates
Type of Report:	Final Research Performance Progress Report
Name of Principal Investigator:	JOHN W GILLESPIE JR
Period Covered by Report:	09/01/2020-06/30/2025
Name and Address of recipient's institution:	UNIVERSITY OF DELAWARE 100 Discovery Blvd, 10Th Floor Star Tower NEWARK DE 19713
NASA Grant / Cooperative Agreement Number:	80NSSC20M0164

Reference 14 CFR § 1260.28 Patent Rights *(abbreviated below)*
The Recipient shall include a list of any Subject Inventions required to be disclosed during the preceding year in the performance report, technical report, or renewal proposal. A complete list (or a negative statement) for the entire award period shall be included in the summary of research.

Subject inventions include any new process, machine, manufacture, or composition of matter, including software, and improvements to, or new applications of, existing processes, machines, manufactures, and compositions of matter, including software.

Have any Subject Inventions / New Technology Items resulted from work performed under this Grant / Cooperative Agreement?	No ◉	Yes ○
If yes a complete listing should be provided here: Details can be provided in the body of the Final Research Performance Progress Report		

Reference 14 CFR § 1260.27 Equipment and Other Property (abbreviated below)
A Final Inventory Report of Federally Owned Property, including equipment where title was taken by the Government, will be submitted by the Recipient no later than 60 days after the expiration date of the grant. Negative responses for Final Inventory Reports are required.

Is there any Federally Owned Property, either Government Furnished or Grantee Acquired, in the custody of the Recipient?	No ◉	Yes ○
If yes please attach a complete listing including information as set forth at § 1260.134(f)(1).		

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Reference 14 CFR § 1260.22 Technical publications and reports (December 2003)
Reports shall be in the English language, informal in nature, and ordinarily not exceed three pages (not counting bibliographies, abstracts, and lists of other media).

A Final Research Performance Progress Report is due within 120 days after the expiration date of the grant, regardless of whether or not support is continued under another grant. This report shall be a comprehensive summary of significant accomplishments during the duration of the grant.

Final Research Performance Progress Report Request
09/01/2020-06/30/2025

ULI2 Step-B-0060, Composite Manufacturing Technologies for Aerospace Performance at Automotive Production Rates

NASA Grant Number 80NSSC20M0164

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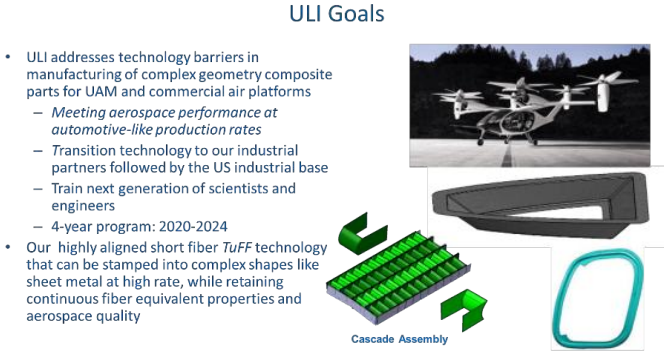
Executive Summary

National Aeronautics and Space Administration (NASA) University Leadership Initiative selected a team led by the University of Delaware Center for Composite Materials (UD-CCM) to address technology barriers and education/workforce training needs in composites manufacturing technologies providing aerospace performance at automotive production rates for the Urban Air Mobility (UAM) and commercial air platforms. Our program started on September 1, 2020 and ended June 30, 2025. This summary highlights our major accomplishments in research, technology development and education and workforce training.

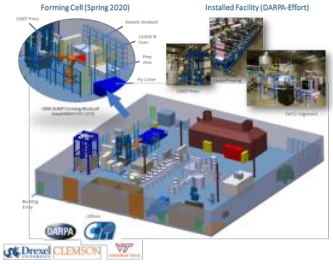


Our Team: Our team consists of UD-CCM as the lead organization with core team members from the composite supply chain from material suppliers, part manufacturers (Joby Aviation, Spirit AeroSystems and Advanced Thermoplastic Composites). Our academic partner is Southern University (SU).

Our ULI Focuses on the NASA Grand Challenge for UAM: UAM is an on-demand mobility (ODM) transportation vehicle for small package delivery to air taxis, is next frontier in air transportation. Projected total number of air taxis exceed 850,000 in the US alone. With higher production volumes studies have identified the need for next generation automated manufacturing methods to meet production rates and cost targets while retaining the ultralightweight performance offered by composites.

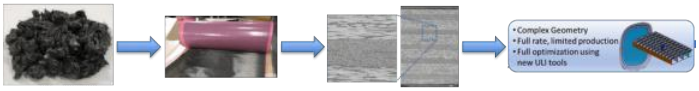
Our ULI Approach: Our project builds on UD-CCM's revolutionary highly aligned short fiber technology (called *TuFF* or Tailorable universal Feedstock for Forming) that can be formed into complex shapes at high rate, while retaining continuous fiber equivalent properties and aerospace quality. UD-CCM has developed a pilot line that converts short fibers into unidirectional prepreg and blanks that are stretch formed in a single step into complex aerospace parts. This pilot line was used to make all materials for the program as well as to develop and demonstrate new tooling and automated processing approaches that are transitioned to our industry team members for part trials at the facilities.

TuFF Integrated Manufacturing Facility



UD-CCM's 9000 Sqft *TuFF* Integrated Manufacturing Facility (Funded by DARPA)

- Fibers to Parts under One Roof will be used for ULI tasks
- Training for HBCU faculty and student internships
- Technology Demonstrations with the UAM Industry Supply Chain for Material, Process and Product Development at Rate

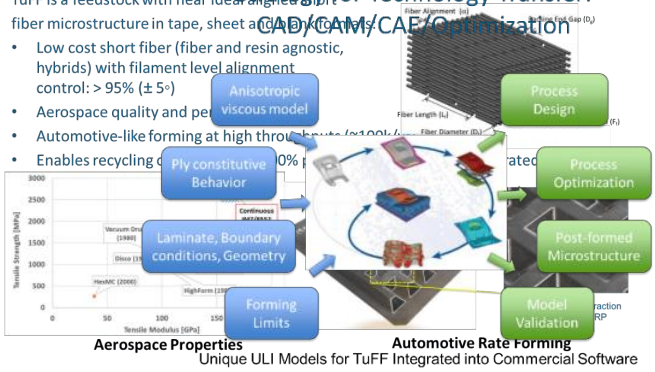


What is ***TuFF***?

TuFF is a feedstock with near ideal aligned short fiber microstructure in tape, sheet and [illegible]

- Low cost short fiber (fiber and resin agnostic, hybrids) with filament level alignment control: > 95% (± 5◦)
- Aerospace quality and per[illegible]
- Automotive-like forming at high throu[illegible]
- Enables recycling [illegible]

Strategy for Technology Transfer: CAD/CAM/CAE/Optimization



Unique ULI Models for TuFF Integrated into Commercial Software

Research and Technology Highlights: Our overall vision was to leverage existing commercial software for CAD/CAM/CAE for composites, focus our research task on the identified technology gaps and integrate the key results (material models and material databases) to enable design of materials, forming processes and part design using TuFF composites. Our ULI program is organized into eight technical tasks. Major research highlights are given below. Of particular note is the creation of the first aligned short carbon fiber TuFF material using LM-PAEK thermoplastic matrix developed to meet the material specific needs of Joby and Spirit aerospace parts. In addition, this program developed new stretch-steering of TuFF tape in automated tape placement machines providing 100-fold improvement of minimum steering radius compared to current state-of-the art enbabling complex geometry UAM parts to be fabricated and topology optimization to provide additional weight savings.

Research Highlights

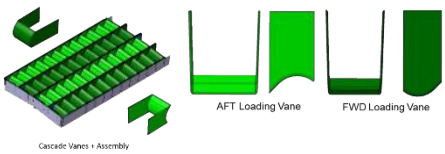
- ❑ Tailored Universal Feedstock (TuFF): New Materials
  - ✓ World's Strongest Short Fiber Composite
  - ✓ Equivalent Aerospace Material Properties
  - ✓ Superior Fatigue Properties
  - ✓ Any combination of fibers and resins
  - ✓ Demonstrated on 3mm IM7 carbon fiber with thermoplastic and thermoset matrices
- ❑ New TuFF based manufacturing methods
  - ✓ High rate forming: Stretch, stamp, bladder
  - ✓ Laser Assisted Tape Placement: Stretch Steering
  - ✓ New Test Methods and Constitutive Models

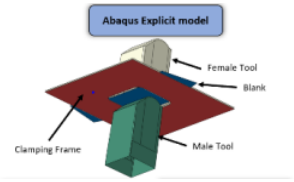
Technology Highlights

- ❑ Automotive Rates Demonstrated by Spirit
  - ✓ Cascade Vane Parts (1,200 parts per aircraft)
  - ✓ 5 minute cycle times (10-20x reduction)
- ❑ New Simulation Capabilities Implemented in ABAQUS and Aniform commercial software
- ❑ Successful Transitions
  - ✓ Pilot facility (fibers to parts) for scale-up
  - ✓ NSF and SERDP (recycling/sustainability)
  - ✓ ONR and AFRL on DOD applications

Our program also had many technology highlights through our collaboration with our industrial partners. Spirit Aerospace using our *TuFF*/LM-PAEK materials demonstrated at their facility a 10-20x reduction in cycle time. Five minutes cycle times on a cascade vane part satisfies forecasted production rates (432,000 vanes/year). Repeatability of the stamp forming process was proven out on complex Joby parts for their eVTOL vehicle. Constitutive models for *TuFF* forming were developed and implanted into commercial software ABAQUS and Aniform to provide industry with the needed tools to design and manufacture *TuFF* parts at high rate of production. In addition, the simulation software, material databases, tooling and forming capabilities are being used in multiple government programs ranging from basic reseaerch funded by NSF and SERDP to DoD applications funded by ARFL and ONR.

› Spirit identified Thrust Reverser Cascade as a candidate part
› Thermoplastic stamp forming of TuFF composite for cascade components
- 432,000 vanes would be required each year
- 5 min cycle times required to meet production rate





Spirit Thermoplastic Stamp Forming Cell

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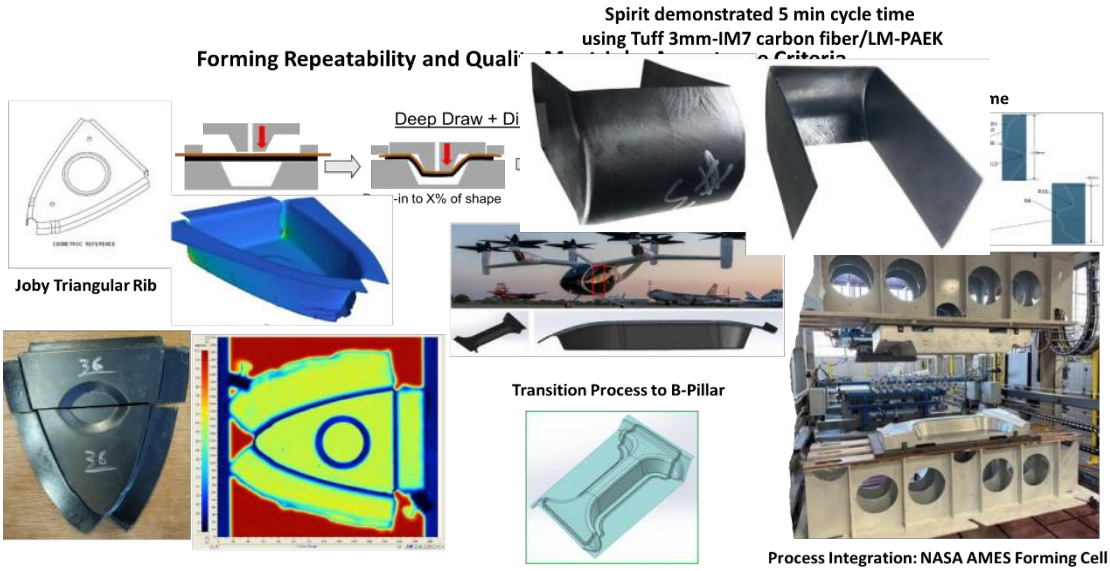

ULI Website
https://www.ccm.udel.edu/research/program-highlights/nasa-university-leadership-initiative-uli/

Education/Workforce Training and Outreach Highlights

During our ULI program, we have held monthly technical meeting with \NASA, held annual program reviews that were open to the public and actively participated in NASA annual meeting (such iMaginAviation). Our total reviews attendance exceeded 500 people. On site tours and lab demonstrations were given. Our program has generated many presentations and publications. To promote dissemination of our ULI accomplishments to the composite's community, we established a public website for our ULI (where all past presentations, reports, publications and other activities are posted.

Our ULI had significant education and outreach activities at both UD-CCM and our HBCU partner (SU) in Baton Rouge, LA. More than 2500 K-12 students from local middle and high school students participated in class room activities and summer research projects. Similar activities were offered at UD-CCM for local middle and high school students as well as summer research projects. Four summer interns were also hired and spent the summer at NASA Langley working on composite projects. UD-CCM also hosted interns from SU to conduct research on self-healing composites. Our ULI students are participated in NASA's annual IMAGINAVIAITION Conferences (representing our ULI virtually to more than 1000 attendees) as well as having our students interviewed by NASA to share their research experiences on our ULI and to share recommendations with other students. Both UD-CCM and SU also participated in NASA Watch parties that expanded outreach to a much greater student audience. UD-CCM and SU invited to NASA Aeronautics Day on the Hill to represent our ULI to program managers and staffers.

Education/Workforce Training Highlights

- ❑ More than 2,500 K-12 students engaged
- ❑ More than 1,000 ULI attended IMAGINAVIATION Conferences and Watch Parties
- ❑ More than 500 people attended annual ULI reviews
- ❑ Four summer internships at NASA Langley
- ❑ ULI supported 14 faculty and 80+ students
- ❑ More than 75 papers and presentations
- ❑ Dedicated ULI website established