

Optimizing the Design of Structural Joints for Use in Composite UAV Structures

Zachary Norris

Mentor: Dr. Takahashi

School for Engineering of Matter, Transport, and Energy (SEMTE)



How can joints used in the composite structure of a small unmanned aerial vehicle (UAV) be further optimized given the unique operational constraints of such aircraft? How may these developments relate to prolonging the operational life of the aircraft?

Project Motivation...

The structural design of small UAVs remains a largely underexplored area of aircraft design. Building on previous research completed in the Spring of 2022, this project seeks to address the dominant failure mode observed in previous destructive testing. As such, new testing frameworks were explored. Following this, Finite-Element Modeling was used to design sample joints that may be implemented into the structure of an analog UAV.

Testing Procedure...

The primary area to be explored was shear failure of structural epoxy under bending moment loads. As such, the configurations tested were...

- **Solid Joint – Nominal Offset** was used as the control geometry, representing the strongest geometry from previous testing
- **Solid Joint – 1/16" Offset, No Fiberglass** was used as a test geometry, exploring if more glue volume fixed shearing issues
- **Solid Joint – 1/16" Offset, Internal Fiberglass** was used as a test geometry, exploring if internal fiberglass fixed shearing issues
- **Solid Joint – Nominal Offset, External Fiberglass** was used as a test geometry, testing if external fiberglass fixed shearing issues

The following were controlled for all of the performed tests...

- **RockWest 1" Composite Square Stock** was used as the composite structure, based on legacy use in small UAVs
- **Aeropoxy ES6209 Structural Adhesive** was used as the binding epoxy, based on its ability to bond metals, thermoplastics, and thermoset materials; this was updated since the Spring semester
- **Overture PETG Filament (Double Wall Thickness, 60% Infill)** was used to create structural joints, based on legacy use in small UAVs
- **3 in² Bonding Area** was used for all tests, based on both legacy use in small UAVs and maximum material use with the limited carbon fiber

Failure Mode to Address...

Failure of Bonding Epoxy in Shear

The dominant failure mode observed was of the bonding structural epoxy in shear. In this failure, the structural epoxy would show signs of strain during the loading, leading to a relatively large deformation at the joint, ultimately leading to a failure of the composite structural member in compression. In this failure, the joint was often left intact.



Destructive Testing Data...

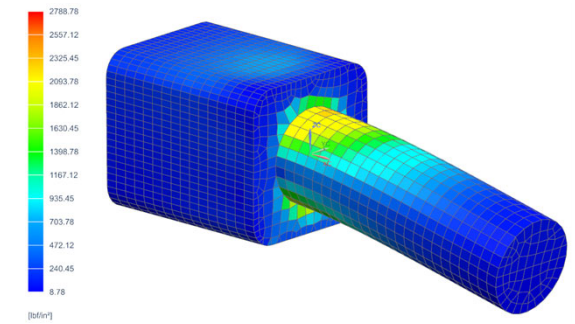
Index No.	Config.	Failure Moment	Type
1	Solid, Nominal	41.2 ft*lbf	Epoxy
2	Solid, Nominal	43.02 ft*lbf	Joint
3	Solid, 1/16", No Fiberglass	15.5 ft*lbf	Epoxy
4	Solid, 1/16", No Fiberglass	20.64 ft*lbf	Epoxy
5	Solid, 1/16", Internal Fiberglass	45.36 ft*lbf	Joint
6	Solid, 1/16", Internal Fiberglass	35.02 ft*lbf	Epoxy
7	Solid, Nominal, External Fiberglass	52.51 ft*lbf	Epoxy
8	Solid, Nominal, External Fiberglass	63.68 ft*lbf	Joint

Data Indicates...

The ultimate strength of the jointed structure is driven by the quality of the processing during the construction of the joint. Despite this, there are some findings from the data above. Increased clearance between the joint and the carbon fiber structure does not increase epoxy volume as much of it runs away during curing. Similarly, internal fiberglass does little to improve the strength, as the fiberglass itself has nothing to 'grab onto' given the smooth internal surface of the carbon fiber. External fiberglass seems to be promising as the rough exterior allows the fiberglass to bond and carry some shear load.

Finite Element Approach...

In addition to the destructive testing, some basic FEM analysis was completed on a sample jointing configuration for use in a small UAV, pictured below:



Conclusion...

Overall, the destructive testing completed points to the finding that careful processing of carbon fiber joints, utilizing structural epoxy on the inner face of the joint combined with fiberglass on the exterior of the joint is able to most reliably create jointed geometry. This testing has also revealed that failure of both the joints and the epoxy matrix is characterized by high-deformations, which ultimately offer a useful point of inspection for pre- and post-flight procedures.

Questions for Future Research...

1. What failure modes are dominant when similar tests are performed on non-planar structural geometries?
2. What numerical approaches can be developed for systems that integrate multiple jointed structural members?
3. What surface treatments for autoclaved carbon fiber result in the best surface adhesion for structural epoxies?