An overview of the development and qualification of a carbon fiber composite drive shaft system is presented as a summary of the design approach, material characterization and article test. As part of the UH-60M upgrade program, weight reductions have been achieved through the implementation of composite materials for airframe and dynamic systems applications. The introduction of an all composite tailcone precipitated the requirement for a compatible composite tail rotor drive shaft to provide a suitably matched coefficient of thermal expansion. Improvements in manufacturing technology in recent years have enabled the expansion of composite laminates into the domain of dynamic components with critical load and precision balance requirements. This effort utilized proven manufacturing methods to produce a composite structure with highly controlled properties to successfully replace the legacy metallic component. Triaxial braid architecture was selected as the structural reinforcement for the design to address the components physical, mechanical and ballistic requirements. Resin transfer molding was chosen as the manufacturing method using CYCOM 890 resin to the meet stringent dimensional tolerances of a dynamic component. Component qualification testing was conducted to ensure that the dynamic response, mechanical properties and ballistic tolerance of the shaft met the existing system requirements. This research was partially funded by Army ManTech under contract Number DAAH23-2-C-R002. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation herein. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied of the Army ManTech office or the U.S. Government.

Introduction

Dynamic components for rotorcraft applications have traditionally been fabricated as an assembly of metallic subcomponents, typically made from Aluminum and Titanium. These materials have a proven history of meeting the specific strength, stiffness and damage tolerance criteria established for a range of applications. The need for a composite drive shaft for the new UH-60MU aircraft was driven by the requirement that the thermal expansion coefficient of the tail rotor drive shaft match that of the newly developed composite tailcone to avoid excessive bearing stress at extreme thermal excursions. A trade study of alternative materials and design configurations resulted in the conclusion that replacing the aluminum shaft tube of the legacy design with a composite detail with the same expansion coefficient as the tail cone was the lowest risk, lowest cost approach. A triaxial braid architecture was selected for the fiber reinforcement due to the demonstrated ballistic tolerance derived from the interlocking of the braided yarn. Resin transfer molding was chosen as the method of manufacture to address the requirement for the highly controlled dimensions and tolerances that are typical of dynamic components. The remainder of the assembly design was altered as little as possible to limit the impact of the new design on existing components and manufacturing requirements.

The program was structures with a standard building block approach to sequentially develop the drive shaft design and analysis as well as the material data requisite to support the structural substantiation and qualification of the drive shaft. A conceptual design was developed based on existing mechanical data for braided structures and projected design allowables. In parallel, coupon level mechanical testing was conducted on both environmentally conditioned and unconditioned laminate flat panels using the selected architecture. This initial coupon effort was followed by the fabrication of risk reduction sub-element test articles representative of the drive shaft design. These articles were subjected to element level testing to assess mechanical performance and physical attributes. The test data was fed back into the structural analysis and the results were used as the basis for the structural substantiation of the final design. Finally, the
qualification of the drive shaft will be based on the results of mechanically testing a series of full scale of test articles and flight test trials.

Supplier Selection
An industry wide survey of suppliers was conducted to identify the best candidates to perform the two distinct operational phases of drive shaft manufacture; fabrication of the composite tube and the assembly and balancing of the overall shaft component. Because of the diverse requirements of the two phases, two independent suppliers were selected for the respective operations.

Composite molding suppliers were identified as candidates based on their known capacity to manufacture parts using the resin transfer molding process and capability to construct the required braid preform. Three candidates were identified as possessing the appropriate resources to fabricate production shafts and were solicited to provide quotes for material characterization test panels and sub-element test articles.

Responses for the fabrication of composite shafts were analyzed based on technical capabilities, history of performance and recurring production cost projections. Based on this review, EDO-Fiber Innovations of Walpole MA was selected from the suppliers solicited to provide the drive shaft articles and all the composite specimens required to support the material characterization testing.

A review of drive shaft assembly suppliers currently qualified to deliver dynamic components for use in Sikorsky aircraft led to the selection of Goodrich Corporation of Rome NY as the best candidate within the United States. They were selected as the supplier for the assembly and balancing of the completed drive shaft components based on their demonstrated capabilities and past business relationship with Sikorsky Aircraft.

Conceptual / Preliminary Design
A conceptual design of the drive shaft was developed to a sufficient level of fidelity to serve as the basis of the initial structural analysis. Additionally, the preliminary design served to define interface requirements and establish a drawing tree of next assembly configurations.

The task approach started with the thorough definition of requirements and loads for the drive shaft based on the legacy component as well as additional requirements influenced by the introduction of the composite tube. A study was conducted to evaluate the theoretical mechanical properties of several candidate braid architectures that meet specific manufacturability criteria. The braid architecture was selected based on its analytically projected torsional stiffness and compressive strength. The over-all design layout and rough dimensioning were developed for two shaft assemblies, based on the requirements and a derived set of preliminary material allowables. This design was verified by initial hand calculations and finite element analysis (FEA), taking into consideration torsional stiffness, natural frequency, and load capability.

The configuration of the new shaft assemblies contains the following components and features, as shown in the exploded assembly views in Figures 1 and 2.

- Composite Tube
- End Fittings
- Inner Liner
- Blind mechanical fasteners
- Adhesive at interfaces
- Dynamic balance using weighted tape on tube ID

Figure 1 – Exploded Assembly View of Shaft

Figure 2 - Detail of Typical End Assembly
An analysis of the preliminary design was conducted to
demonstrate the equivalency of the new composite
design to the legacy metallic component in terms of
structural capability and dynamic response. The
preliminary design of the drive shaft components was
presented for review at the TRDS preliminary design
review (PDR) held in Huntsville on May 31, 2006 and
shown at that time to meet all of the requirements
identified for the assembly.

Materials Characterization / Risk Reduction

Material Testing
The objective of this task was to establish a set of
application specific materials design allowables based
on the mechanical properties of the selected laminate
derived from coupon and element test data.

An approach was selected to provide allowables that
incorporate an “A” basis statistical conservatism factor,
while not expanding the test program to a scope
typically associated with the full qualification of a new
material for all applications. To achieve this goal a
hybrid methodology was developed. The approach
utilized a single batch of data developed for the specific
fiber and braid architecture employed in the drive shaft
design in conjunction with a five batch qualification
data base developed by Cytec Engineered Materials for
the 890 resin system with a five harness satin fabric
reinforcement. The braid data established mean
strength and modulus data for the drive shaft material at
various environmental conditions, while the
qualification data base provided a means of assessing
batch to batch variability through the development of an
“A”-basis reduction factor.

A series of standard ASTM static and fatigue coupon
tests were conducted at the National Institute for
Aviation Research (NIAR) in accordance with a
detailed test plan. The specified tests and conditions
are summarized in Tables 1 and 2.

Table 1 – Coupon Static Test Matrix

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Orientation</th>
<th>- 65 °F Ambient</th>
<th>RT Ambient</th>
<th>180 °F Wet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlaminar shear</td>
<td>ASTM D 2344</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Compression Modulus &amp; Strength</td>
<td>ASTM D 6641</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>±45-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>OH Tension Strength</td>
<td>ASTM D 5766</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td>NTP*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±45-deg NTP*</td>
<td>6</td>
<td>6</td>
<td>NTP*</td>
</tr>
<tr>
<td>Tension Modulus &amp; Strength</td>
<td>ASTM D 3039</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td>NTP*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>±45-deg NTP*</td>
<td>6</td>
<td>6</td>
<td>NTP*</td>
</tr>
<tr>
<td>Shear Mod &amp; Strength</td>
<td>ASTM D 7078</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>OH Comp Strength</td>
<td>ASTM D 6484</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>±45-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Bolt Bearing</td>
<td>ASTM D 5961</td>
<td>90-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Compression After Impact</td>
<td>NASA 1092</td>
<td>0-deg NTP*</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

* No Test Planned

Table 2 - Fatigue Test Matrix

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Orientation</th>
<th>Plies</th>
<th>RTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression - Compression</td>
<td>ASTM D6484</td>
<td>± 45°</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>In-Plane Rail Shear</td>
<td>ASTM 7078</td>
<td>0°</td>
<td>4</td>
<td>12</td>
</tr>
</tbody>
</table>
Additionally, extended environment testing including fluid exposure and elevated temperature dry properties was conducted by Cytec Engineered Materials. This testing was performed on laminates with a five harness satin fabric reinforcement and the CYCOM 890 resin system and served to augment the existing data base developed during the qualification of that material system. The test results confirmed that the limiting design condition is represented by the elevated temperature wet properties derived from the braid testing. The data collected were used to generate a complete set of design allowables. The allowables were developed by applying a statistical reduction factor to the mean test data reduced from the single batch coupon testing summarized above. The factor was derived by establishing the ratio of the mean data to A-basis statistical values from a multi-batch qualification of the CYCOM 890 resin system previously conducted by Cytec Engineered Materials.

Risk Reduction Testing

In addition to the coupon testing, a series of sub-element risk reduction tests were conducted to evaluate the fundamental performance of the selected material and architecture in a form as similar as possible to the drive shaft actual article design. In addition to the testing of representative element articles an evaluation of repair processes was conducted on flat laminate specimens with a construction matching that of the drive shaft.

The approach to develop this preliminary data involved the use existing tooling to mold composite tubes with the four ply construction of the preliminary design and of a suitable length to provide representative data. Testing was conducted to evaluate the mechanical, electrical and ballistic performance of the design in accordance with individual Sikorsky test plans for each of the three test types. Additionally, conventional bolt bearing testing was conducted to verify the efficacy of repair procedures. Each of the sub-element test activities is summarized below.

Mechanical Testing

Torsional testing of five sub-element specimens was conducted at NIAR testing laboratory in accordance with a detailed test plan. The testing included a static survey and overload test conducted on a single specimen and fatigue testing at multiple load levels conducted on four additional specimens.

The static torque test was conducted to verify the composite drive shaft design parameters such as: torsional spring rate, limit load and ultimate load capabilities. A single test specimen was subjected to the design limit load and the ultimate load. The test specimen successfully passed both test conditions, finally fracturing at a torque level of 2.2 times the design ultimate load.

The fatigue test data is summarized as an S-N plot in Figure 3. Analysis of the data showed that an “as manufactured” test specimen would have a 30,000 hour fatigue life and flawed test specimens (with impact damage commensurate with the selected threat criteria) would have approximately a 10,000 hour fatigue life.

Figure 3 - Sub-Element Fatigue Test Data
Electrical Testing
The electrical testing of two sub-element specimens was conducted at Lightning Technologies Inc. of Pittsfield Massachusetts in accordance with a detailed test plan.

A Zone 3 current conduction test was conducted on two specimens with end fittings, fasteners and bonded joints representative of the production assembly. This test confirmed that the system has sufficient current carrying capability in the event of a lightning strike. The test data was analyzed and a teardown of the specimen was conducted to evaluate the response of the drive shaft to lightning strike.

The risk reduction test article exposed to the higher current level of the two tested was visually examined after undergoing the current conduction test to identify any degradation to the areas and features most affected by the electrical current flow due to a lightning strike. Evidence of arcing was limited to the areas surrounding fasteners. This is consistent with the fact that the conductance path was from the composite laminate through the fastener and into the end fitting surrounding the composite that served as the grounding point.

The integrity of the assembly and laminate were evaluated in the areas exhibiting the greatest evidence of degradation and concluded to represent the worst case effects from the strike. A cross section of the specimen was taken through six fastener locations at one end of the part to expose the interfaces between the fasteners and the composite and between the composite and the fitting (see Figure 4).

Ballistic Testing
The ballistic testing of three sub-element articles was conducted at the Army Research Laboratory’s ballistic test facility at Aberdeen, MD in accordance with a detailed test plan.

Each subsequent article was quasi-statically tested, with load applied prior to the ballistic strike and continued and increased after the strike to assess the strain response of the damaged article and its residual ultimate strength.

All shots were slicing edge shots along the top of the test articles, designed to remove as much material as possible. Two of the test articles were shot at 45-degree angles off the shaft axis, and one was shot with 0-degree obliquity to the shaft axis.

The three articles were shot under an initial load, which encompasses approximately 93% of the flight spectrum, and is representative of the most likely load should a ballistic impact occur in the field. From this initial state, the load was increased incrementally until the article failed to carry load.

The second test was a 45 degree impact representative of an actual shot condition and determined to be the limiting test case. The results of the impact are shown in Figure 5. The load at failure equaled approximately 72% of the required load.
The third test was a shot at 0 degree obliquity to the shaft axis. The first shot was off target high, resulting in damage that didn’t completely slice through all layers of the shaft. A lower second shot was on target and removed the proper amount of material achieving the desired slice out of the top of the test article. The article was incrementally loaded to failure at a level which equaled approximately 90% of the required design load.

The test demonstrated that the shaft in its current configuration can meet the load levels for all conditions, with the exception of the Hover Turn maneuver, which is approximately 1.6 times more severe than any other load case. Strain gauge and inclinometer data was gathered from the testing, and used to correlate to finite element models for use in determining the projected capacity of the drive shaft. As a result of the ballistic test data analysis, the design of the drive shaft was modified to include two additional braid plies, increasing the basic configuration of the shaft to six plies, with nine plies in the reinforced ends.

**Damage / Repair**
In conjunction with the material characterization effort, inspection criteria and methods were developed and documented as part of the manufacturing requirements. NDI procedures were evaluated in an effort coordinated between Sikorsky Quality Assurance and a Sikorsky qualified inspection laboratory. A full immersion pulse echo ultrasonic C-scan inspection method was selected for use on the composite drive shaft tubes. An inspection standard for the various laminate configurations present in tube structure was established through the inclusion of interlaminar defects in a sub-element shaft article. The subject article was scanned by an approved NDI supplier, resulting in the establishment of an inspection methodology, technical parameters and acceptance criteria.

In a parallel effort, an evaluation of repairable defects and damage was carried out with testing conducted on a specific repair method for limited manufacturing defects. An evaluation was conducted on the type and extent of damage that would be deemed acceptable for dynamic component with critical balance requirements. It was determined that any structural damage to the laminate leading to fiber breakage or interlaminar failure would not be considered repairable, due in large part to the fact that the addition of patch material would have an unacceptable impact on dynamic performance and balance. Limited delaminations at the edges of holes and part trim were identified as the sole case where sufficient remediation of the laminate could be achieved without functional degradation.

To evaluate the repair of local delamination, damage was induced at fastener holes through the use of aggressive drilling methods. The damage was repaired by applying a low viscosity resin, Loctite EA956, to the affected area and curing with surface cauls to restore the laminate. The specimens were tested to compare their fastener bearing strength to a baseline pristine specimen and confirmed that the restoration of the required mechanical strength could be achieved through this repair method.

**Detailed Design and Analysis**
During the course of the program the final detailed design of the drive shaft components, upper level assemblies and installation requirements were developed. As part of the design task, a detailed structural analysis was conducted to substantiate the design configuration.

The design of the part was conducted using CATIA v5, with all necessary components parametrically modeled. The final design incorporated the increased wall thickness associated with the addition of two braid plies identified as necessary to meet the ballistic requirement. Configuration management activities were also undertaken as part of the design effort to account for part characteristics, parts lists, and aircraft effectivity. The final design was presented at a CDR, summarizing the designs compliance with each of the identified requirements. Figure 6 summarizes the key design criteria and the performance of the composite shaft in comparison to the legacy metallic article.
Comparison with Metallic Shaft

<table>
<thead>
<tr>
<th>Property</th>
<th>Composite</th>
<th>Metallic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal Bending Stiffness</td>
<td>1.26</td>
<td>1.00</td>
</tr>
<tr>
<td>First Bending Frequency (rpm)</td>
<td>1.04</td>
<td>1.00</td>
</tr>
<tr>
<td>Fatigue</td>
<td></td>
<td>+0.29</td>
</tr>
<tr>
<td>Torsional Strength (in-lb)</td>
<td>1.5</td>
<td>1.00</td>
</tr>
<tr>
<td>Torsional Stiffness (in-lb/deg)</td>
<td>1.34</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Figure 6 – Drive Shaft Design Performance

Subsequent to the CDR several limited changes to the design were implemented to address producibility concerns. Foremost of these was the addition of sacrificial fiber layers in these attachment areas to allow for secondary machining of the interface surfaces where the composite shaft bonds to the end fittings. The secondary machining was determined to be an advantageous approach to attaining the geometric profile and run out tolerances that were deemed to exceed the capacity of a net molding approach.

As part of the design task, a structural substantiation and analysis was conducted using a range of methodologies as applicable. The approach for substantiation of the composite driveshaft relied upon proven rotor component development and includes detailed structural analysis, building block testing, and full-scale qualification testing. The driveshaft was analyzed using transmission design rules and equations, detailed finite element analysis, and strength allowables accounting for damage, environment and fatigue. A coupon and sub-element building block test program was employed to verify the design and modeling practices. Finally, the assembled composite driveshaft will be subjected to a series of flaw tolerant static, fatigue, and ballistic strength tests as part of the UH-60M upgrade program.

The structural analysis included focused efforts in several specific areas including: static analysis of the joint between the composite shaft and Titanium fittings, a mechanical analysis of the shaft, evaluation of torsional buckling, bearing and ballistic capacity, a dynamic response analysis and a fatigue analysis of the composite tube based on flaw tolerance test and model data.

A finite element model was utilized to perform detailed stress analysis of the shaft, as well as the flange joint; specifically including the Titanium flange, Titanium liner, and composite shaft. The flange geometry and thickness remain identical to the legacy metallic shaft. Therefore, the analysis focused primarily on the composite tube to metallic flange attachment. The 3D finite element model employed is shown in Figure 7.

A non-linear solution was executed using the finite element model to determine torsional buckling capability. This analysis showed bucking occurred at 14.5 degrees of twist and produced a margin of +0.90. The stress results at the buckling load were compared with shear strength allowables producing a margin of +0.70. Therefore it was concluded that material failure would occur prior to shaft buckling, but at a load level significantly above the ultimate load condition defined for the design.

The drive shaft system was analyzed for dynamic response using the Sikorsky shaft dynamic computer program (SHAFDY). As a starting point the HH-60J model was used as a basis for the composite drive shaft model and to compare to legacy metallic drive shaft results. The composite properties utilized were based on the design allowables for the 180°F wet condition. The analytic result for the 6 layer braid was based on the shaft diameter and thickness established in the final design. The first frequency of the composite shaft is close to, yet slightly higher than the aluminum component and meets the design requirement.

A ballistic finite element model was developed with risk reduction geometry and ballistic damage, as shown in Figure 8. The analysis results correlated well with shear strain to failure coupon data. The analysis was repeated with both five and six layers of braid. The analysis showed that the six braid layers were needed to meet ballistic damage tolerance and load requirements.
Finally, a fatigue analysis was performed on the composite shaft. The dominant fatigue loading of the shaft produces shear stress. The analysis involved determination of peak shear stresses in the composite shaft using the joint finite element model. The fatigue strength was calculated using stress amplitude vs. life (S/N) curves from coupon testing. In this evaluation both low-cycle fatigue and high cycle fatigue were considered based on Ground-Air Ground cycles and max vibratory loading, respectively. The analysis employed a flaw tolerance approach in which the S/N curve was adjusted for manufacturing defects and mechanical impact damage. The fatigue strength of the composite shaft was established based on worst case stresses and exposed impact regions. Therefore, the taper region in vicinity of flange was considered in this analysis. As an independent check, the fatigue strength is supported with risk reduction composite tube testing. The shear stress results from the FEA model were below the fatigue stress allowables derived from coupon and risk reduction tests as shown in Figure 9.

Figure 9 - Correlation of Coupon and Risk Reduction Fatigue Testing

Full Scale Manufacturing

Full Scale component manufacturing was initiated in February of 2007 with contracts being placed with EDO Fiber Innovations and Goodrich Corporation. Manufacturing activities were supported with the release of material and process specifications to control the procurement of the fiber and resin products as well as the dry fiber preform construction and RTM manufacturing process. The drive shaft preform is braided directly on the tooling mandrel with additional fabric reinforcement plies added in the attachment areas, as shown in Figure 10.
The completed preform with the tooling mandrel is transferred to a closed mold with end registration features to ensure the correct alignment of the preform details with the tooling cavity. The mold was fabricated from tool steel and is of a self clamping design using a perimeter bolting system to react the internal RTM resin pressure. The RTM process is conducted with the tool fixtured vertically in a convection oven with close loop controls driven by thermocouples monitoring the tool temperature. The tool and oven set up are shown in Figure 11.

After molding the part is trimmed to length and the end surfaces that interface with the Titanium fittings are ground to precise diametric and run out tolerances. Subsequent to the composite processing operations and NDI procedure, the parts are transferred to the Goodrich facility for assembly. The assembly operations consist of bonding the end fitting to the shaft, installing blind fasteners and balancing. The bonding of the shaft is achieved using Magnobond 6380 while the components are constrained in a precision fixture to ensure the axial alignment and final length of the assembled detail, as shown in Figure 12.

After bonding the end fittings and inner liners in place, the assembly is drilled and blind fasteners are wet installed with a polysulfide sealant as pictured in Figure 13.

The completed assembly is then dynamically balanced, inspected, primed and stenciled to finalize manufacturing operations. A completed shaft is shown in Figure 14 prior to priming.
Full Scale Testing

The qualification test plan for the full-scale drive shaft includes static deflection and torsion testing, pristine and defect fatigue testing, ballistic and electrical testing. The testing of the drive shaft assemblies began in the fourth quarter of 2007 with static testing conducted at NIAR. A bend test was conducted to verify the response of the shaft was consistent with the result of the analysis. Torsional static testing was performed on a pristine article in the test fixture shown in Figure 15.

The article was loaded and unloaded in torsion as part of a static survey to generate stress/strain plots for the evaluation of torsional stiffness and linear strain response. With the confirmation that these properties matched the analytical prediction; the article was loaded sequentially to limit, ultimate and finally failure. The failure mode was the fracture of the spline fitting on the Titanium stub shaft as shown in Figure 16. This fracture occurred at 3.6 times the design limit load. The composite shaft, bond line and fastener installation was inspected, revealing no damage resulting from the static loading.

The fatigue test plan includes the testing of a single pristine article and five defect/damage articles. The fatigue torsion load is based on ground-air-ground load levels with acceleration factors for temperature and moisture. The defect/damage articles have been manufactured with ¼ inch diameter fluoropolymer film incorporated into the laminate at the highest stress locations to simulate manufacturing flaws. Additionally, the articles have been impacted with 10 foot-pounds of energy at two locations to induce delaminations representative of anticipated potential “in service” damage. As of this writing one fatigue article and one pristine article have successfully sustained more than 200,000 cycles, which represents the criteria to clear the drive shaft assembly the for introduction of into flight testing operations.

The remainder of the fatigue testing will continue in parallel with the flight test. The current indication is that the damaged drive shaft will be qualified for unlimited life. The remainder of the testing, including ballistic tolerance and lightning strike will be conducted concurrently with the ongoing fatigue test program, with all testing scheduled for completion in late April of 2008.

Conclusion

The composite tail rotor drive shaft development program was successfully concluded with the release of a final design and all necessary supporting specifications. The program results were transitioned to the UH-60 program, which has continued the qualification effort with the procurement and testing of flight hardware. The ManTech drive shaft effort successfully produced a functional design and developed a set of design allowables for a new material.
on an aggressive schedule using streamlined methodologies and parallel efforts. As a result, a robust, flaw tolerant and producible design capable of meeting all of the requirements, while achieving a weight savings, was delivered for insertion into the tailcone qualification plan on schedule. The results of the qualification testing that have been conducted to date indicate that the composite shaft and end fitting attachment method introduced as a result of this program will not reduce the performance of the tail drive system, while at the same time reducing weight and providing a cost effective solution to the challenge of CTE compatibility with the composite tailcone structure.

Acknowledgements

I would like acknowledge the following organizations for their contributions to the successful execution of this program; EDO Fiber Innovations, Goodrich Corporation, National Institute for Aviation Research at Wichita State. I would also like acknowledge the following Sikorsky Team members for their contributions; Thomas Carstensen and Brian Witte (Program Management), Bruce Eidinger (Design), Jeffery Schaff (Structures) Alex Vygoder (Ground Test), JinKyu Choi (Materials & Process), David Baranowski (Manufacturing Engineering) and Suzi DeGarmo (Ballistics). Finally, I would also like to acknowledge that this effort was made possible through the support of the United States Army’s Manufacturing Technology (ManTech) program under the program management of Michelle Ozier.