Final Report

Award Number:	N00421-18-2-0006
Title of Proposal:	Mach-Scaled Swept-Tip Blades for High-Speed Tiltrotors
Prime Applicant:	University of Maryland
Type of organization:	Other Educational
Technical contact:	Anubhav Datta Department of Aerospace Engineering 3125 Glenn L Martin Hall College Park, MD 20742 Phone: 301-405-1130 Fax: 301-314-9001 datta@umd.edu
Administrative contact:	Danette Boone Office of Research Administration 3112 Lee Building College Park, MD 20742 Phone: 301-405-6269 Fax: 301-314-9569 oraa@umd.edu
Amount of effort:	$80,000 / year (total $160,000)
Place of performance:	College Park, MD
Period of performance:	10/01/2017 – 09/30/2018
Award type requested:	Grant
Proposal validity period:	120 days
DUNS number:	79-093-4285
Taxpayer ID number:	52-6002033
CAGE code:	0UB92

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
11/09/2020	FINAL	10/01/2017-9/30/2018

4. TITLE AND SUBTITLE

Mach-Scaled Swept-Tip Blades for High-Speed Tiltrotors

5a. CONTRACT NUMBER

N004211820006

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Sutherland, James; Datta, Anubhav

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

UNIVERSITY OF MARYLAND
3112 LEE BLDG 7809 REGENTS DRIVE
COLLEGE PARK, MD 20742-5141

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

NAVAL AIR WARFARE CENTER AD (PAX)
2.5.17
21983 BUNDY ROAD, BLDG 441
PATUXENT RIVER, MD 20670

10. SPONSOR/MONITOR'S ACRONYM(S)

NAWCAD

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Year-1 effort developed the mold and fabrication process for the blades. The blades have 2.375-ft radius, 3.1-in chord, -37 degrees twist, 20 deg sweep back 0.8-1.0R, VR-7 airfoil profiles, D-spar, all composite +/-45 deg weave of IM7/8552. Three sets of blades were built-straight, twisted, and twisted-swept. Year-1 (this proposal) completed straight, and twisted.

15. SUBJECT TERMS

Tiltrotor blades. Composite rotors. Mach-scale XV-15. Whirl-flutter. Aeromechanics.

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU	4	Anubhav Datta
					19b. TELEPHONE NUMBER *(Include area code)*
					(650) 678-8520

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATE COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33315-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report. e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

Table of Contents

Executive Summary:

The objective of this proposal was to design, fabricate, and characterize, highly twisted (-30° to -45°) and swept (20° back) composite tilt rotor blades. The swept tip is the novel and new basic research component. Comprehensive analysis performed by the US Government and Academia in the last decade have shown the potential of swept tip blades in extending whirl flutter boundary. Swept tip blades can be also contribute positively to DoD's vision of 2X speed of Future Vertical Lift (FVL). The intent is to follow-up this seed program with wind-tunnel testing of the blades at Maryland Tiltrotor Rig (MTR) at the Glenn L Martin wind tunnel. The project tracked all its milestones and completed all deliverables. The twisted blades were designed, fabricated, and characterized.

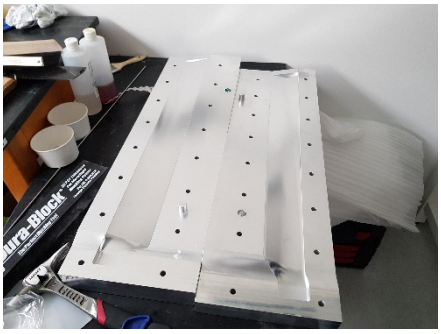
Planned Project Schedule and Milestones:

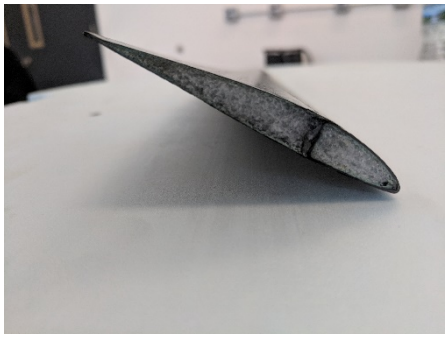
The planned schedule and milestones in the original proposal are copied below for reference. The 2018 plans were completed.

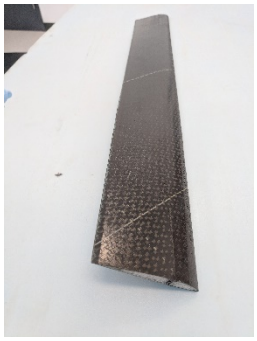
2018: Design, fabrication, property characterization of **twisted blades**
2019: Design, fabrication, property characterization of **twisted and swept blades**
2020-2022: Wind-tunnel tests on UMD tilt rotor rig for performance, loads, and whirl flutter. Note that this is part of our over-all roadmap, not part of this proposal.

Year 1 Accomplishments:

The Year-1 effort (10/01/2017 – 09/30/2018) tracked its milestones. The student took 6 graduate classes – 3 on rotorcraft: Aerodynamics, Dynamics I, Stability & control; and 3 on Composite Structures, Structural Dynamics, and Computational Methods. The research conducted and principal results were documented in AIAA Conference Paper at SciTech 2019 Dynamics Specialists Conference Session on Next-Generation Tiltrotors [1]. Figures 1 and 2 summarize its final products. Figure 1 shows the baseline composite D-spar twisted blade (-40° from root cut-out to the tip) built in-house as part of this project. Figure 2 shows a new gimballed hub being developed as part of ONR DURIP. The two parts are now being prepared for integration. Thus this NAWC-AD project is in perfect sync within the over-all tiltrotor research program. Characterization of the blades (3-blades built so far) for stiffness, inertial and modal properties, and validation with in-house CAD/meshing/FEA analysis is on-going. The swept-tip blade effort is also on-going. Figure 1c shows a 4-axis Tormach milling machine procured as part of this project. It will be essential for fabricating blade molds, root inserts, swept tip spars, and embedded sensor decks, all in-house, by the graduate student – an important long term investment for cost reduction and hands-on student training.







(a) Twisted mold **(b) D-spar section view** **(c) twisted blade**

Figure 1: Composite tiltrotor blade; twist -45°, radius 2.5 feet, profile VR-7, D-spar.

(a) isolated blade **(b) blade and gimbal hub** **(c) 4-axis Tormach mill**

Figure 2. Tiltrotor blade shown with parts of the new gimballed hub.

Papers & Productivity:

One abstract was submitted to AIAA conferences.

1. Tsai, F., Sutherland-Foggio, J., and Datta, A., "Design of a New Tiltrotor Test Facility at the University of Maryland," abstract submitted to AIAA SciTech 2019, DSC Session on Next-Generation Flutter-Free Tiltrotors, 7-11 January, San Diego, CA, 2019.