Acoustic Testing of the Tiltrotor Test Rig in the National Full-Scale Aerodynamics Complex 40- by 80-Foot Wind Tunnel

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ABSTRACT

The Tiltrotor Test Rig (TTR) was tested in the National Full-Scale Aerodynamics Complex (NFAC) 40- by 80-Foot Wind Tunnel from 2017 to 2018. The rotor system can be configured in airplane mode, with the rotor plane perpendicular to the wind flow, and in helicopter mode, with the rotor plane parallel to the wind flow. Four microphones were placed around the TTR: two on the wind tunnel floor and two on struts. The primary goal of the test was to understand the operational capabilities of the TTR, while also acquiring research data as available. Limited measurements of the blade vortex interaction (BVI) noise of the TTR rotor were taken to not only understand the acoustic testing capabilities of the TTR in the NFAC 40- by 80-Foot Wind Tunnel, but to also compare to previous tests and to be used for future validation studies. In particular, data will be compared to measurements of an XV-15 rotor previously acquired in the NFAC 80- by 120-Foot Wind Tunnel.

INTRODUCTION

The Tiltrotor Test Rig provides the Department of Defense (DoD) and National Aeronautics and Space Administration (NASA) with a new national test capability to conduct technology development, testing and evaluation of new large-scale proprotors for performance, control, loads, and stability in the National Full-Scale Aerodynamics Complex (NFAC). The TTR is unique because it allows for the universal testing of various rotors instead of having specific configurations for each type of rotor (Ref. 1). The TTR is designed to be used in both the NFAC 40- by 80- and 80- by 120-foot NFAC wind tunnels. The TTR is a rig that is able to rotate on the test-section turntable and fly at various angles from airplane mode to helicopter mode, from 0- to 100-deg shaft tilt angles. Separate publications to be presented at this conference are included in the references (see (Ref. 2) and (Ref. 3)).

Test Objectives

The primary acoustic goal of the TTR test was to measure rotor the noise at various Blade Vortex Interaction (BVI) flight conditions in order to understand the acoustic testing capabilities of the TTR in the NFAC 40- by 80-Foot Wind Tunnel, to compare to previous tests and to provide data for future validation studies. The scope of the acoustic data collection was to measure BVI noise of the TTR rotor in helicopter mode, which can be characterized as noise between the tenth through fiftieth blade passing frequency (BPF) harmonics. BVI harmonics were above 100 Hz, and thus within the acoustic liner absorption capability (Ref. 4).

TEST HARDWARE

The rotor tested on the TTR was a 3-bladed research rotor derived from the right-hand rotor of the Leonardo (Agusta-Westland) 609 rotor (Ref. 1). The basic parameters of the test, inducing rotor dimensions, are shown in Table 1.

The TTR is a horizontal axis rig mounted in the wind tunnel on a three-strut support system that rotates on the test-section turntable. The turntable can either face the rotor into the wind at high speed (up to 300 knots) for airplane mode or fly edgewise

Table 1. TTR Bell Model 699 parameters in the NFAC 40- by 80-Foot Wind Tunnel (Ref. 1).

Parameter	Value	Unit
Radius	13	feet
Number of Blades	3	N/A
RPM (helicopter mode)	565	rot/min
RPM (airplane mode)	477	rot/min
Maximum Speed	300	knots

Table 2. Microphone positions for the TTR test in the NFAC 40- by 80-Foot Wind Tunnel and XV-15 tests in the NFAC 80- by 120-Foot Wind Tunnel.

Wind Tunnel Model	Year	Mic #	X/R	Y/R	Z/R	Distance (R)	Azimuth (deg)	Elevation (deg)
NFAC 80- by 120-Foot XV-15	1996	1*	0.00	-0.58	-1.82	1.91	90	-18
	1996	2*	0.00	-0.75	-1.82	1.97	90	-22
	1996	3*	0.00	-1.11	-1.82	2.13	90	-31
	1996	4*	0.00	-1.46	-1.82	2.33	90	-39
	1996	5	-4.87	-2.82	-2.05	5.99	157	-28
	1996	6	-3.60	4.20	-2.05	5.90	150	-45
NFAC 80- by 120-Foot XV-15	1999	1*	-0.20	-1.80	-0.35	1.84	120	-77
	1999	2*	-0.20	-1.80	-0.54	1.89	110	-72
	1999	3*	-0.20	-1.80	-0.74	1.95	105	-67
	1999	4*	-0.20	-1.80	-0.93	2.04	102	-62
	1999	5*	-0.20	-1.80	-1.12	2.13	100	-58
	1999	6*	-0.20	-1.80	-1.31	2.24	99	-54
	1999	7*	-0.20	-1.80	-1.51	2.36	98	-50
	1999	8*	-0.20	-1.80	-1.70	2.48	97	-46
	1999	9	-4.89	-2.05	-2.82	6.01	150	-20
NFAC 40- by 80-Foot TTR	2018	1	-1.85	-2.15	-1.07	3.03	150	-45
	2018	2	-0.92	-2.46	-1.07	2.84	131	-60
	2018	3	-2.66	-1.12	-1.54	3.27	150	-20
	2018	4	-2.15	-1.54	-1.54	3.06	144	-30

* Denotes microphones on traverse, where X/R is closest distance to the center of the hub.

at low speed (up to 120 knots) for helicopter mode, or at any angle in between. The TTR is designed for use in both the 40- by 80- and 80- by 120-Foot Wind Tunnels. The NFAC 40- by 80-Foot Wind Tunnel test section walls are treated with acoustically absorbent material to reduce reflections that can contaminate the noise field. This provides an absorptivity of greater than 90-percent at frequencies above approximately 100 Hz (Ref. 4).

Acoustic instrumentation

For acoustic measurements in the NFAC 40- by 80-Foot Wind Tunnel, four microphones were placed around the TTR. Special consideration was given to the placement of the microphones such that they did not affect the inflow to the rotor in airplane mode and transition.

Microphones 1 and 2 were mounted on 5.625 ft. struts and Microphones 3 and 4 were flush-mounted to the test section floor. Table 2 shows the microphone positions with respect to the center of the TTR rotor in helicopter mode. The x-direction is positive in the streamwise direction, positive z-direction is upward, and positive y-direction is the cross-flow direction toward the test section door. Microphones 1 and 2 were positioned to capture BVI and Microphones 3 and 4 captured the more in-plane BVI hotspots. The microphones in the test section are shown in Figure 1. Additionally, Figure 2 shows an overhead and side view of the microphone locations.

Two different tests were performed in the NFAC 80- by 120-Foot Wind Tunnel in 1996 (Ref. 5) and 1999 (Refs. 6, 7). The test in 1996 had six microphones, as shown in Table 2. Microphones 1 through 4 were placed on a traverse under the rotor to capture BVI, while microphones 5 and 6 were placed to capture in-plane BVI. The test in 1999 had nine microphones, also shown in Table 2. Microphones 1 through 8 were placed on a traverse under the rotor to capture BVI, while microphone 9 was placed to capture in-plane BVI.

In order to compare measurements from the NFAC 40- by 80-Foot Wind Tunnel to the 1996 and 1999 NFAC 80- by 120-Foot Wind Tunnel tests, microphone elevations and azimuthal angle are equivalent (see Table 2). Microphone 3 from the NFAC 40- by 80-Foot Wind Tunnel is placed at an elevation and azimuthal angle of 150 and -20 degrees, which corresponds approximately to the location of microphone 5 from 1996 and microphone 9 from 1999 in the NFAC 80- by 120-Foot Wind Tunnel. Microphone 1 from the NFAC 40- by 80-Foot Wind Tunnel is placed at an elevation and azimuthal angle of 150 and -45 degrees, which corresponds approximately to the location of microphone 6 from 1996 in the NFAC 80- by 120-Foot Wind Tunnel. The propagation distance is accounted for by the inverse-square law (Ref. 8).

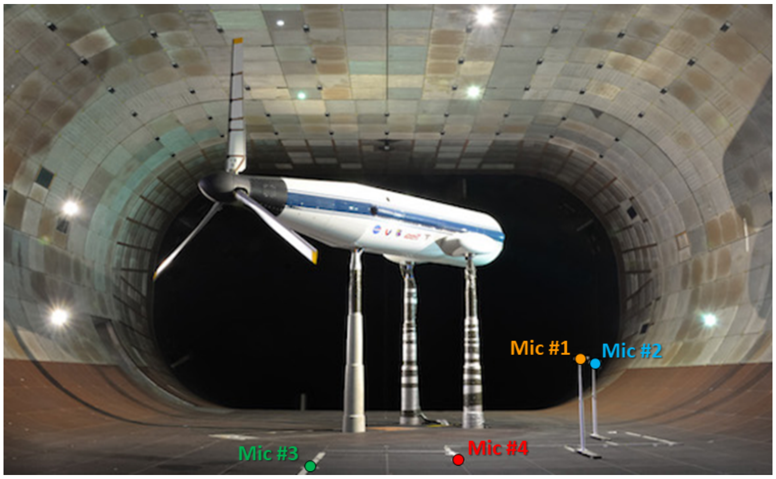

Fig. 1. TTR microphone locations in the NFAC 40- by 80-Foot Wind Tunnel test section.

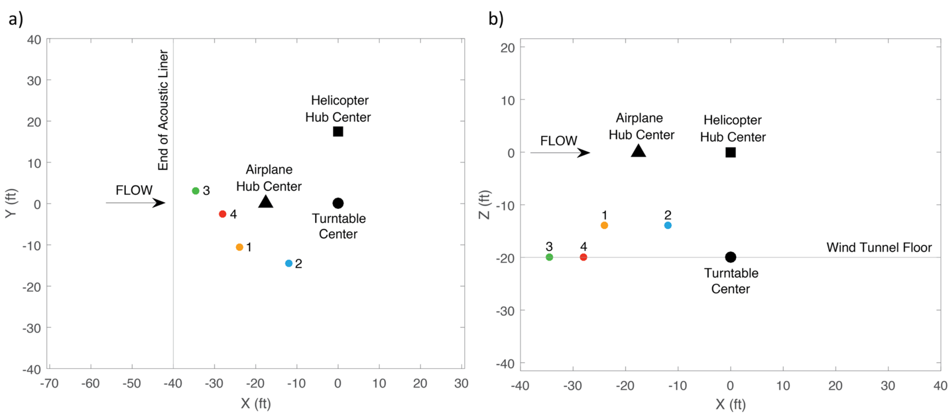

Fig. 2. TTR microphone locations in the NFAC 40- by 80-Foot Wind Tunnel a) XY an db) XZ plane.

DATA ACQUISITION

All TTR acoustics data was acquired with the NFAC's data system. Analog feed from the four microphones was routed from the test section into the acoustics station in the computer room where the microphone power supply (G.R.A.S. 12AG 8-Channel Power Module), the DEWETRON TrendCorder, and the near real-time display were located. For TTR testing, each microphone channel had to be set to high-pass. The high-pass filter in each channel is a 3-pole Butterworth filter with a 1 dB cut-off at a frequency of 20 Hz. This filter is for reducing unwanted low-frequency signals, e.g. caused by wind-induced noise on the microphone. The gain was changed accordingly and recorded on the near real-time display computer, which is connected to the NFAC DDAS data system. Two different power supplies are needed for each type of microphone. The microphone conditioner served as a power supply for the microphones and also provided gain-control for each of the microphone's output signal. Acoustic time history data (in volts) was subsequently digitized by the DDAS at a sampling rate of 2048 points per revolution for 128 revolutions. Calibration of all four microphones was conducted weekly in order to ensure microphone data quality.

TEST CONDITIONS

The scope of acoustic testing includes a sweep of shaft angle (α_s) at an advance ratio (μ) of 0.125 and 0.150 and a blade loading coefficient (C_T/σ) of 0.075. Upon completion of this sweep, data will be analyzed in order to identify the shaft angle that yields the peak BVISPL. The shaft angle identified will be used in subsequent advance ratio and blade loading coefficient sweeps. The identified shaft angle is not shown in this abstract.

Precision required of the shaft angle placement (implemented through the wind tunnel turntable yaw angle) during the test was governed by the sensitivity of the BVI to shaft angle. BVI sensitivity to the shaft angle is not constant, but rather a function of the specific microphone location and the shaft angle itself, generally being the smallest in the neighborhood of the shaft angle

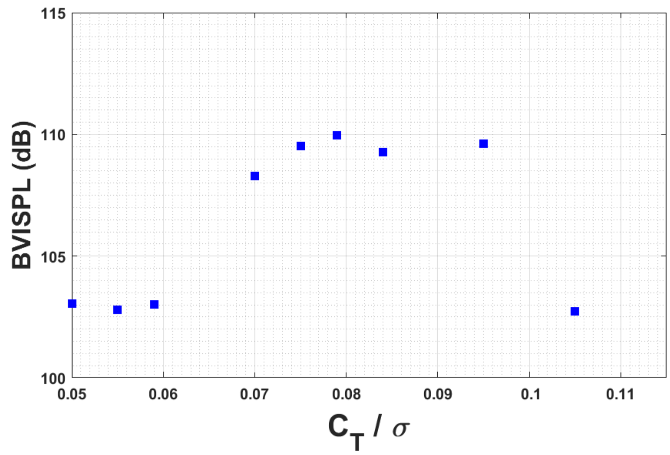

Fig. 3. TTR in the NFAC 40- by 80-Foot Wind Tunnel BVISPL verses C_T/σ for a flight condition of μ = 0.125, and α_s = 0° for microphone 3.

for the peak BVI. The desired shaft angles to be measured for the TTR are from -6° to +12° at 3° increments. Once completion of the test in the NFAC 40- by 80-Foot Wind Tunnel, measurements will be further analyzed beyond the scope of this abstract.

Background Noise

Background noise (acoustic tares) due to wind noise over the microphones and tunnel drive system were acquired with the rotor hub spinning and test hardware without blades. The background noise accounts for the combination of wind noise over the test hardware, microphones, mechanical and hydraulic TTR pump and motor noise, and tunnel drive noise.

Sample Data

Initial analysis of the TTR acosutic data has been performed. The BVI sound pressure level (BVISPL) was used to analyze trends for various flight conditions, including an advance ratio and thrust sweep. Preliminary plots show geometric angle of attack; corrected angle of attack will be provided in the final paper. Further analysis will be done for the final paper.

A thrust sweep at an advance ratio of 0.125 and α_s of 0° was performed, see Figure 3 for variation in BVISPL for microphone 3. An increase in BVISPL increases from a C_T/σ of 0.05 to 0.08 and decreases after the peak BVI (110 dB) condition. BVI sound pressure levels were determined by bandpass filtering the data from 10th through 50th blade harmonic. The peak BVI time history for the filtered and unfiltered measurements are shown in Figure 4.

An advanced ratio (μ) sweep from 0.12 to 0.20 was performed for a constant α_s of -15° at a C_T/σ of 0.051, see Figure 5. An increase in the advance ratio resulted in an increase in BVISPL for all four microphones.

DATA TO BE PRESENTED IN THE FINAL PAPER

- Discussion of TTR testing limitations.
- Further analysis of NFAC 40- by 80-Foot Wind Tunnel TTR acoustic data.
- Comparison of NFAC 40- by 80-Foot Wind Tunnel to NFAC 80- by 120-Foot Wind Tunnel XV-15 data.

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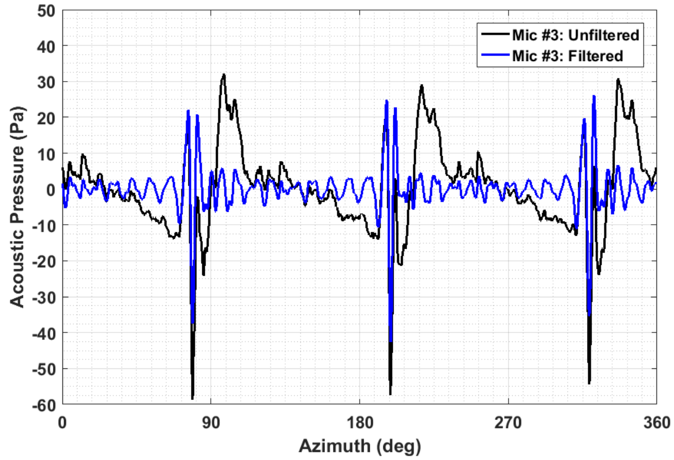

Fig. 4. TTR in the NFAC 40- by 80-Foot Wind Tunnel microphone 3 unfiltered and filtered at peak BVISPL condition from thrust sweep for a flight conditions of μ = 0.175 and α_s = 0°.

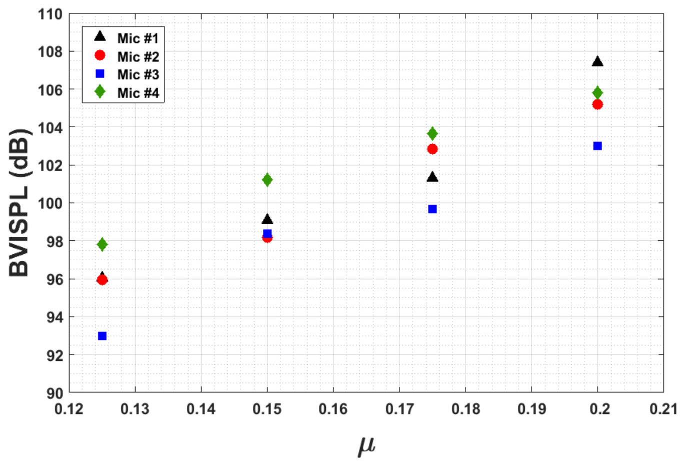

Fig. 5. TTR in the NFAC 40- by 80-Foot Wind Tunnel BVISPL verses advance ratio for a flight condition of μ = 0.12 to 0.20, C_T/σ = 0.051 and α_s = -15°.

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