Acoustics Reflections of Full-Scale Rotor Noise Measurements in NFAC 40- by 80-Foot Wind Tunnel

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Introduction

The 40- by 80-Foot Wind Tunnel at NASA Ames Research Center at Moffett Field, CA first opened in 1944, is a unique national facility capable of full-scale rotor acoustics testing. Since the upgrade[1,2] in 1998 to a deep sound absorbing panel, several full-scale rotor models entries have taken advantage of the large anechoic space to perform high-fidelity, controlled testing of new low noise rotor designs[3,4].

The improved acoustic liner[1,2] is 42 inches deep except in certain shallow areas over structural beams, turntable apparatus, and the diffuser inlet. At most locations in the 40- by 80-Foot test section, the liner consists of modular 4- by 4-foot panels that have a nominally 68%-open perforated steel sheet diffusion-bonded to fine wire mesh screen and supported by an open grating. The deep acoustic lining for the test section was designed to provide sound absorption (Fig. 1a) of about 94% to 97% between 100 Hz to 2,500 Hz. The floor turntable absorbs only 78% of the acoustic energy below 315 Hz, because of shallower depth due to structural elements required for model support.

For full-scale rotor noise testing, the "poor" panel absorption characteristics at low frequencies (below 100 Hz) pose a challenge to the ability to acquire accurate rotor noise measurements at the first few Blade Pass Frequency (BPF) harmonics. Strong reflections from wall surfaces introduce distortions that prohibit delineation of the "true" low frequency rotor noise radiation patterns and characteristics. In addition, low absorbency of the panels in the test section enclosure leads to strong standing wave patterns that can spatially amplify measured noise amplitudes at discrete (modal) frequencies[5] associated with the geometry of the wind-tunnel test section. As shown in Fig. 1b, results from a noise calibration study[6] demonstrated the inability to make far-field noise measurements in the test section.

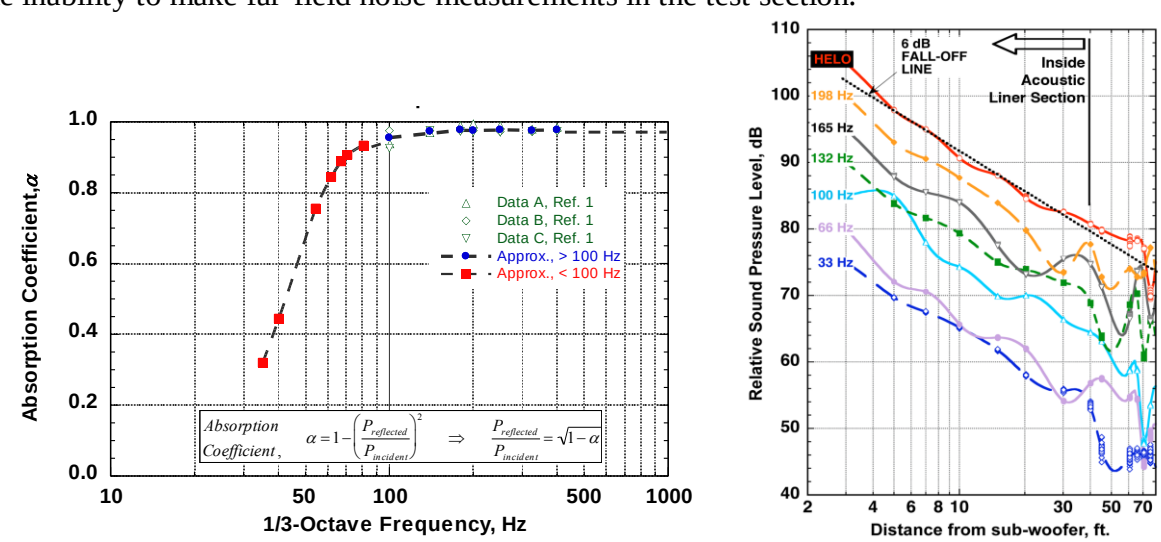


Fig. 1. Sound absorption characteristics of 42-inch acoustic panel and assessment of low frequency sound measurement in the NFAC 40- by 80-Foot Wind Tunnel.

While these issues are formidable, conventional use of multiple rotor revolutions-averaging can alleviate some of these standing-wave issues, provided that the modal frequencies do not coincide with the rotor harmonic frequencies. Unfortunately, the same technique cannot address reflection issues as the distortions occur at the same frequencies as the direct rotor noise.

Objective & Technical Approach

The objective of current research is to identify the extent of acoustic time history distortions due to wind tunnel wall reflections. Acoustic measurements from the recent full-scale Boeing-SMART rotor test (Fig. 2) will be used to illustrate the quality of noise measurement in the NFAC 40- by 80-Foot Wind Tunnel test section.

Results will be compared to PSU-WOPWOP predictions obtained with and without adjustments due to sound reflections off wind tunnel walls. Present research assumes a rectangular enclosure as shown in Fig. 3a. The Method of Mirror Images[7] is used to account for reflection sources and their acoustic paths by introducing mirror images of the rotor (i.e. acoustic source), at each and every wall surface, to enforce a no-flow boundary condition at the position of the physical walls (Fig. 3b). While conventional approach evaluates the "combined" noise from both the source and image rotor at a single microphone position, an alternative approach is used to simplify implementation of PSU-WOPWOP for this reflection analysis. Here, an "equivalent" microphone position is defined with respect to the source rotor for each mirror image that effectively renders the reflection analysis to be a one rotor, multiple microphones problem. This alternative approach has the advantage of allowing each individual "equivalent" microphone, representing the reflection pulse from the associated wall surface, to be adjusted by the panel absorption coefficient illustrated in Fig. 1a. Note that the presence of parallel wall surfaces requires an infinite number of mirror images (Fig. 3c) to satisfy the no-flow boundary conditions. In the present analysis, up to four mirror images (per wall surface) are accounted to achieve convergence in the predicted time histories.

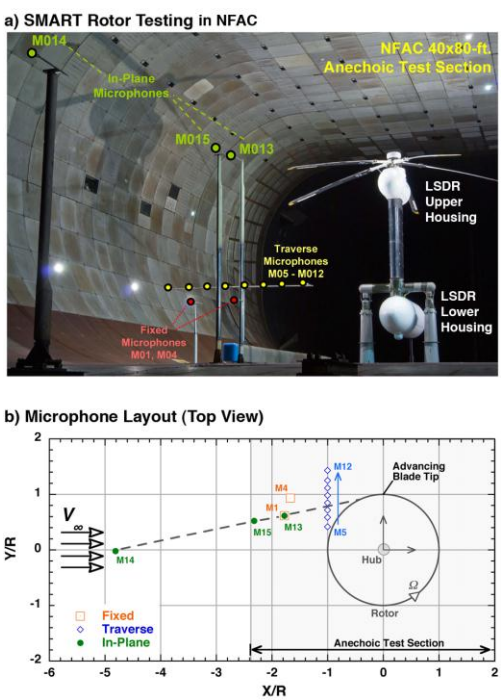


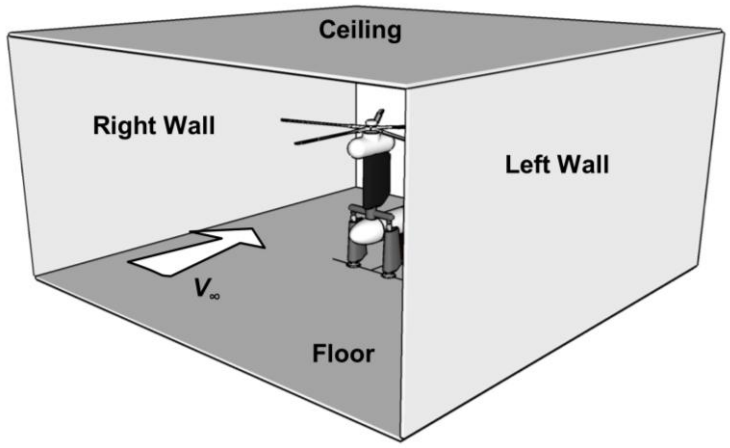
Table 1a. Hub-Centered Microphone Position wrt. Horizon

XH Positive towards aft of the rotor
YH Positive towards starboard
ZH Positive up

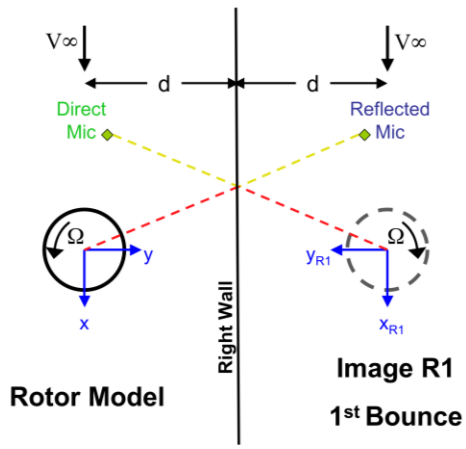
Mic. No.	XH, ft	YH, ft	ZH, ft	rH,ft	rH/R	ΨH, deg	ΘH, deg.	
M1	-29.67	10.27	-17.94	36.16	2.14	160.9	-29.7	FIXED MICS
M4	-27.92	15.59	-17.87	36.63	2.16	150.8	-29.2	
M5	-16.73	6.97	-15.13	23.61	1.39	157.4	-39.9	TRAVERSE MICS @ ASA POS. = -200
M6	-16.73	9.79	-15.13	24.59	1.45	149.7	-38.0	
M7	-16.73	12.02	-15.13	25.56	1.51	144.3	-36.3	
M8	-16.73	14.17	-15.13	26.64	1.57	139.7	-34.6	
M9	-16.73	16.42	-15.13	27.90	1.65	135.5	-32.8	
M10	-16.73	18.67	-15.13	29.28	1.73	131.9	-31.1	
M11	-16.73	20.90	-15.13	30.75	1.82	128.7	-29.5	
M12	-16.73	23.92	-15.13	32.88	1.94	125.0	-27.4	
M13	-29.67	10.27	-5.34	31.85	1.88	160.9	-9.7	IN-PLANE MICS
M15	-38.77	8.73	-7.13	40.38	2.39	167.3	-10.2	
M14	-80.36	-0.33	-14.84	81.72	4.83	180.2	-10.5	

Fig. 2. Schematics of full-scale Boeing-SMART Rotor in NFAC 40- by 80-Foot Wind Tunnel and installed microphone positions

a) Box enclosure



b) Mirror image system – single wall surface



c) Mirror image system – parallel wall surfaces

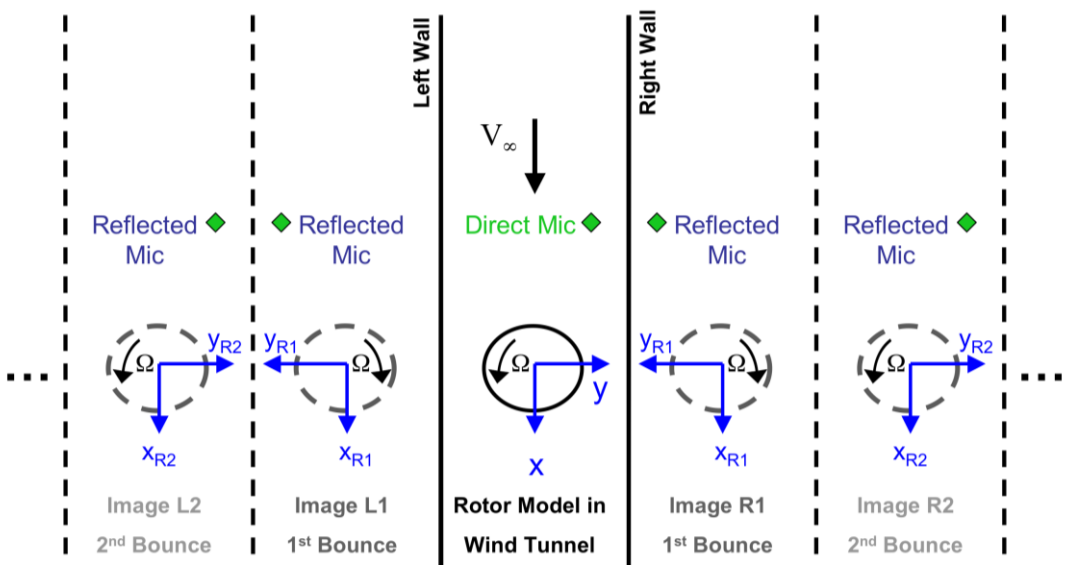


Fig. 3. Application of the Method of Mirror Images: a) rectangular (box) enclosure, b) single surface with one image, c) parallel surfaces with infinite images

Preliminary Results and Discussion

The Boeing-SMART acoustic test data for microphone 13 and 14 (Fig. 2) will be used for the initial analysis. Preliminary results shown in this abstract correspond to measured acoustic time histories for a test condition (NFAC Run 57, Point 68) at advance ratio of 0.299 (123 kts), corrected shaft tilt of –9.1 degrees, advancing tip Mach number of 0.808 and rotor thrust-to-solidity ratio of 0.0749.

Predicted time histories associated with reflections from the right/left walls and from the ceiling and floor are shown in Fig. 4. Reflection pulses at different microphone locations have different contributions from each individual wall surface. For microphone 13, the dominating surface appears to be the ceiling/floor pair, while for microphone 14, all four surfaces are of equal importance. As indicated by Fig. 4, the total reflections are also different with respect to microphone positions, with microphone 14 showing larger reflections than 13. This would suggest a poorer signal-to-noise ratio at microphone 14 since the sensor is also further away from the rotor source.

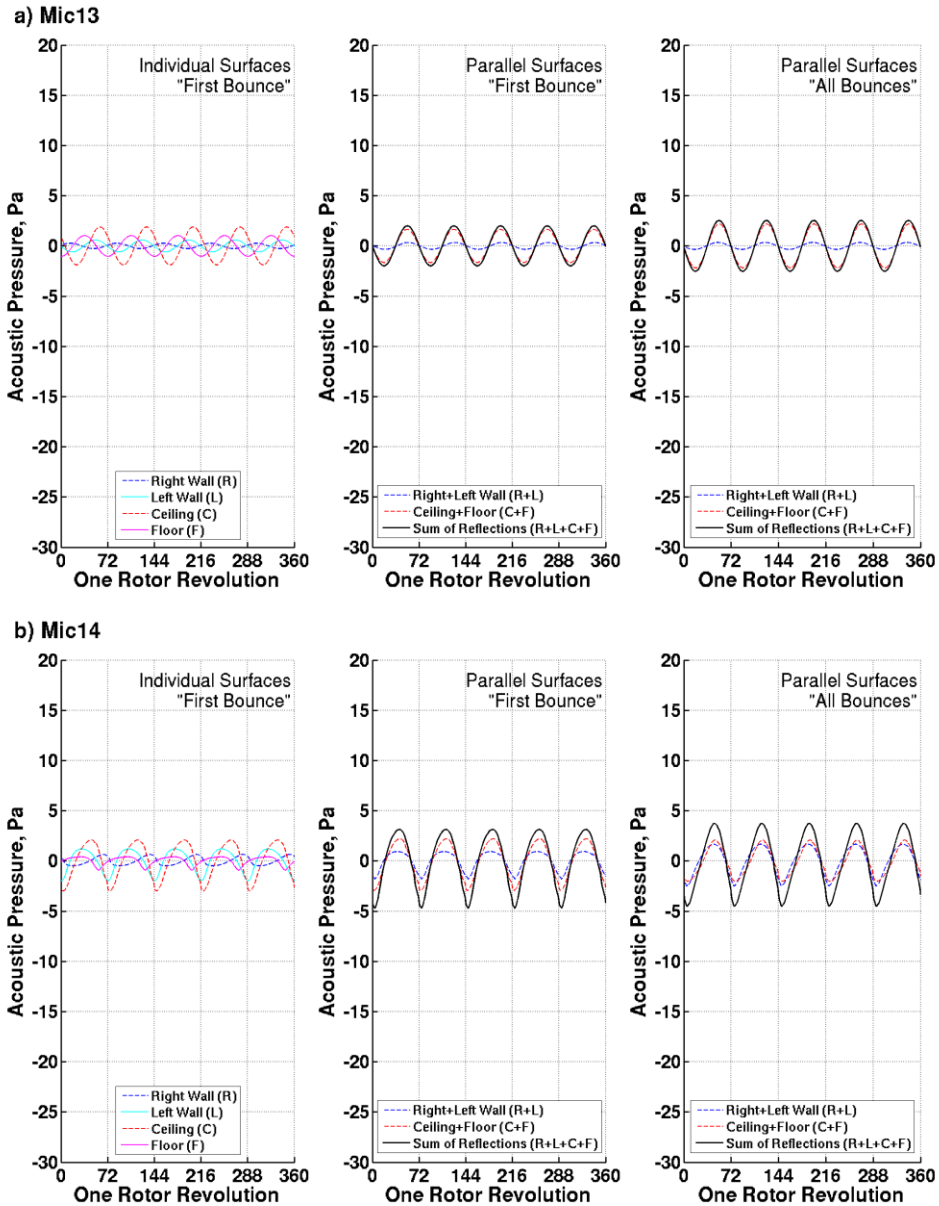


Fig. 4. Predicted reflections pulses from wall surfaces for microphones 13 and 14.

Incorporating these predicted reflections to conventional PSU-WOPWOP predictions (simulating a rotor in the free-field) are shown in the Fig. 5. It is apparent that wall reflections introduce additional distortions to the time histories not present in free-field simulations. In addition, these distortions are consistent with acoustic time histories measured in the wind tunnel. The authors will extend this analysis to other test measurement points and provide an overall assessment of the acoustic data quality of the 40- by 80-Foot Wind Tunnel test section.

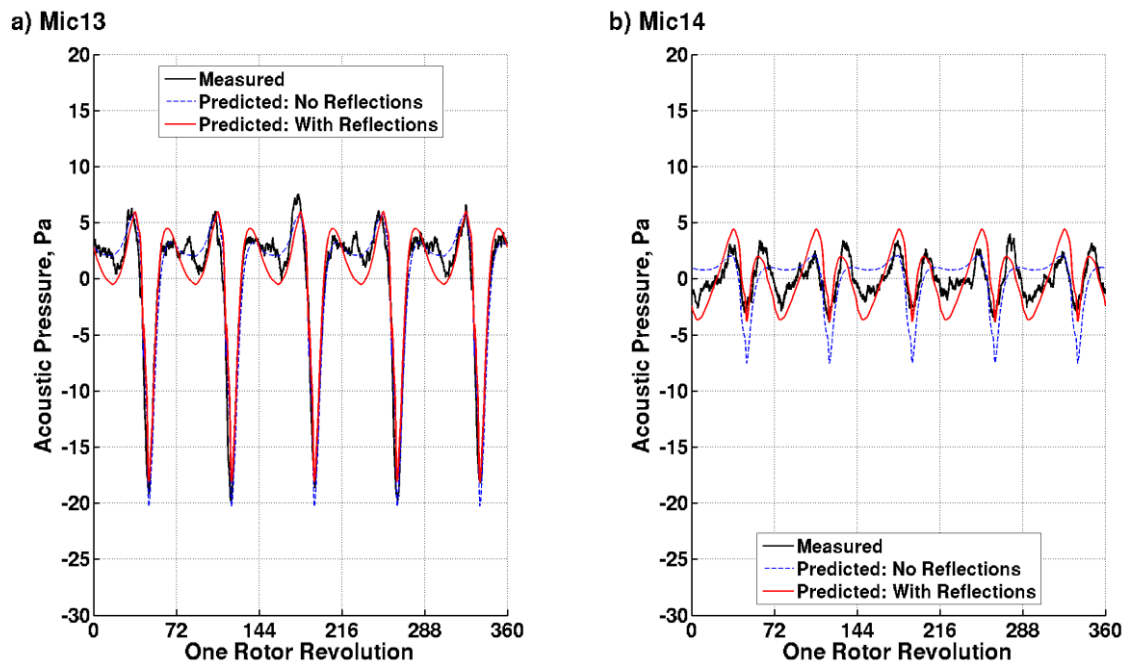


Fig. 5. Predicted time histories with and without reflections for microphones 13 and 14.

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