Acoustic Performance of Novel Fan Noise Reduction Technologies for a High Bypass Model Turbofan at Simulated Flight Conditions

David M. Elliott, Richard P. Woodward, and Gary G. Podboy
Glenn Research Center, Cleveland, Ohio

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to *help@ sti.nasa.gov*

- Fax your question to the NASA STI Help Desk at 443–757–5803

- Telephone the NASA STI Help Desk at 443–757–5802

- Write to:
  NASA Center for AeroSpace Information (CASI)
  7115 Standard Drive
  Hanover, MD 21076–1320

Acoustic Performance of Novel Fan Noise Reduction Technologies for a High Bypass Model Turbofan at Simulated Flight Conditions

David M. Elliott, Richard P. Woodward, and Gary G. Podboy
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

April 2010

Acoustic Performance of Novel Fan Noise Reduction Technologies for a High Bypass Model Turbofan at Simulated Flight Conditions

David M. Elliott, Richard P. Woodward, and Gary G. Podboy
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

Two novel fan noise reduction technologies, over the rotor acoustic treatment and soft stator vane technologies, were tested in an ultra-high bypass ratio turbofan model in the NASA Glenn Research Center's 9- by 15-Foot Low-Speed Wind Tunnel. The performance of these technologies was compared to that of the baseline fan configuration, which did not have these technologies. Sideline acoustic data and hot film flow data were acquired and are used to determine the effectiveness of the various treatments. The material used for the over the rotor treatment was foam metal and two different types were used. The soft stator vanes had several internal cavities tuned to target certain frequencies. In order to accommodate the cavities it was necessary to use a cut-on stator to demonstrate the soft vane concept.

Nomenclature

OTR	over the rotor
OAPWL	overall acoustic power level
ADP	Advanced Ducted Propulsor
FeCrAlY	Iron-Chromium-Aluminum-Yttrium alloy
CoNiCrW	Cobalt-Nickel-Chromium-Tungsten alloy
TEB	Trailing edge blowing
BPF	Blade passage frequency
rpm	revolutions per minute
OASPL	overall sound pressure level
SPL	sound pressure level
dB	decibel
Hz	Hertz
PSD	Power spectral density
rpmc	corrected revolutions per minute

I. Introduction

As part of the NASA Fundamental Aeronautics Program's Subsonic Fixed Wing Project, two novel fan noise reduction techniques were investigated for noise attenuation in turbofan engines. These consisted of over the rotor (OTR) acoustic treatment and soft stator vane. Both concepts had been investigated in earlier test programs in a low-speed, very low-pressure ratio research fan at the NASA Glenn Research Center's Aeroacoustic Propulsion Laboratory (Ref. 1). Both had demonstrated significant noise reduction potential, with OTR showing 4 dB reduction in the fan inlet overall noise power level, and the soft vane showing 2 dB reduction in aft acoustic power levels. As a follow on, it was decided to test both concepts in a higher bypass ratio model with a pressure ratio more indicative of actual turbofan engines. The motivation for the use of the OTR is that placing treatment over the rotor should allow for attenuation of rotor self noise. The OTR could also have an additional use as part of a fan blade containment system. While a Cobalt-Nickel-Chromium-Tungsten (CoNiCrW) alloy was used in earlier tests, it was decided to try an Iron-Chromium-Aluminum-Yttrium (FeCrAlY) alloy for this test as well. In

all, three OTR configurations were tried. The motivation behind the use of soft vane is that by integrating tuned internal cavities in the design of the vane, the soft stators may attenuate rotor-stator interaction noise. To accommodate the cavities, it was necessary to use a larger vane than would have been possible with the baseline cut-off stator. Therefore, a cut-on stator with nearly half the vane count and twice the chord and thickness as the baseline stator was designed and used for this purpose. For the sake of comparison, a low-count solid stator vane pack was also tested, as was the baseline cut-off stator. Sideline microphones and hot film sensors were used to determine the effectiveness of the OTR and soft stator vane technologies. These results will be discussed in this paper.

II. Test Hardware

The Pratt & Whitney Advanced Ducted Propulsor (ADP) was chosen as the model fan testbed for this test. The ADP is representative of an ultra high bypass ratio, low tip speed turbofan engine. The fan used for the OTR portion of the test was the Trailing Edge Blowing (TEB) fan, which has internal passages inside the rotor blades to allow the blowing of air from its trailing edge (Ref. 2). The blowing capability of this fan was not used for this test. This fan was chosen due to its relatively thick blade outer edge, which in turn allows a non-concave rub strip to be used. It was thought that this would simplify the fabrication of the metal foam rotor treatments. The TEB fan is made of composite material as opposed to titanium. This fan is 55.9 cm (22 in.) in diameter and there are 18 rotor blades with a simulated core having 63 inlet vanes and 16 support struts downstream of the inlet vanes. The blade tip gap to the casing treatment was approximately 0.076 cm (0.030 in.). The fan used for the soft stator testing is the ADP Fan 1. This fan is similar in aerodynamic performance to the TEB fan but without the hollow passages for the blowing (Ref. 3). In the baseline configuration, the ADP has a hard casing treatment and 45 solid short chord vanes (i.e., a cut-off design). The blade tip gap to the casing treatment for Fan 1 was approximately 0.140 cm (0.055 in.). For this test, three different OTR treatments were tried, a double depth exposed FeCrAlY, a double depth FeCrAlY with perforate cover sheet, and a double-depth CoNiCrW with perforate cover sheet. The overall design intent for the OTR treatments was to give attenuation for as wide a frequency range as possible. For the stator vane portion of the test, a 25 hard long chord stator set and a 25 soft long chord stator set were tried. Note that both represent a cut-on stator design. The 25 hard stator set was used to investigate the change in acoustics from a cut-off to cut-on stator design. The soft stator set was hollow with tuned internal cavities. The tuned cavities were exposed to the exterior of the vane by a mesh perforate covering the suction side of the vane. The soft stator vanes were designed for 2xBPF (blade passage frequency). A picture of the model fan as installed in the NASA Glenn Research Center's 9- by15-Foot Low-Speed Wind Tunnel is shown in Figure 1. The FeCrAlY treatment with no rubstrip is shown in Figure 2 and the perforate covering the metal foam rubstrips is shown in Figure 3. A photograph of the soft stator vanes as installed in the ADP model is shown in Figure 4.

III. Data Acquisition

This test was conducted in the NASA Glenn Research Center's 9- by15-Foot Low-Speed Wind Tunnel (Refs. 4 to 6). All data was taken at a wind tunnel flow of 0.1 Mach in order to provide flight clean-up. Data was acquired at corrected model speeds of 62, 76.6, 86, 95.4, and 100 percent. The 62, 86, and 100 percent speeds correspond to the rating conditions of approach, cutback, and takeoff, respectively. This corresponds to 5425, 7525, and 8750 corrected rpm's.

A. Sideline Acoustics

Sideline acoustic measurements were obtained using a traversing microphone probe at a 2.24 m (88-in.) distance on a track parallel to the fan axis. Data were taken at 48 positions on the traverse at 2.5° intervals ranging from 27.2° to 134.6° relative to the inlet of the model along the flow axis. The emitted

angles of the traversing probe at 0.1 Mach number correspond to the range 24.6° to 130.6°. To obtain more angular extent, three fixed microphone probes were placed in the rear of the test section that correspond to measured angles of 140°, 150°, and 160°. At 0.1 Mach these angles transform to 136.4°, 147.2°, and 158.1° emission angles, respectively. The microphones used were 0.635 cm (1/4-in.) in diameter. Data were taken at a sampling rate of 200 kHz in order to get a frequency range of up to 50 kHz or greater. This would permit increasing later data to full scale values. Corrections to the data have been made for microphone response, bullet nose receptivity, atmospheric attenuation and spherical spreading. All far-field data shown will be corrected to 30.48 cm (1 ft) lossless. The accuracy of the data system is on the order of ±1 dB.

B. Hot Film

A hot-film probe was used to obtain detailed flow field measurements in order to determine to what extent a porous liner changes the flow downstream of the tip of the fan relative to a conventional, nonporous liner. Separate surveys were conducted with the perforate cover sheet double CoNiCrW and the baseline hardwall liners installed in the model. Figure 5 shows a photograph of the hot-film probe installed in the NASA Fan model upstream of the stator vanes. The measurements were obtained by translating the probe to 25 equally-spaced radial locations in an axial plane 5.66 cm (2.23 in.) downstream of the tip trailing edge. Each radial survey covered approximately the outer half of the fan bypass duct; the outer and innermost measurement locations were 0.15 cm (0.06 in.) and 6.63 cm (2.61 in.) from the outer case, respectively. The hot-film measurements were made using a dual-sensor, TSI model 1246-20, cross-film probe. The cross-film designation stems from the x-pattern formed by the two cylindrical hot-film sensors when viewed from a direction above and perpendicular to the two parallel planes containing the sensors. Since these two planes are very close together (separated by only about 1 mm) the two sensors which form the x-pattern can be thought of as lying in one plane. A cross-film probe allows the flow angle in this plane and the flow speed to be measured. The hot-film data presented in this report were obtained using a probe which had the x-pattern oriented radially, therefore this probe was used to measure the radial flow angle and the flow speed.

IV. Results

When testing the OTR treatments with a perforate cover sheet, an interesting phenomenon occurred. In this instance damage was done to the composite blade tip and edge. The blade tip was worn away and the edge became serrated. The serrations in the blade edge seemed to match up with the holes in the perforate cover sheet. This damage is shown in Figure 6. At this time it is speculated that the cause of this is high pressure air being jettisoned from the treatment through the perforate cover sheet holes and thus eroding the blades. It was possible to repair the blades, although it could not be guaranteed that the blades were restored to the exact original condition. Another consequence of the damage was that later runs using the OTR and perforate cover sheet were done more cautiously. In some later runs with OTR and perforate cover sheet, only the lower fan speeds were obtained, primarily the CoNiCrW metal foam. It should also be noted that the blade tip gap was changed to also try and minimize the blade deterioration. The results discussed in this paper will have a 0.030 in.-tip gap for the OTR analysis and a 0.050in.-tip gap for the Soft Stator comparisons.

A. Sideline Acoustic Results

1. Over the Rotor Treatment Comparisons

It is beneficial to examine actual sound pressure level (SPL) spectra results to get an idea of what the treatments are doing with respect to frequency. Figure 7 shows SPL in terms of power spectral density (PSD) versus frequency of the hardwall and three OTR treatments at 62 percent speed and 41° emission

angle. The first thing to note for this plot is the increase in noise for the exposed FeCrAlY configuration, especially in the lower frequency range. There is no consistent result regarding BPF tones, but there does appear to be a lower noise signature for the OTR treatments in the high frequency broadband. Figure 8 shows the 62 percent speed at the aft angle of 128°. There is no discernable difference in the hardwall versus perforate cover sheet OTR treatments, however once again the exposed OTR treatment shows a higher noise level at low frequency. Figures 9 and 10 show the spectral results at 86 percent speed for the inlet angle of 33° and the aft angle of 128°, respectively. The 33° emission angle was shown as opposed to the previous 41° angle data to get a wider perspective of what the inlet results are. The results are similar to the 62 percent speed with the exposed OTR treatments being noisier in the lower frequency range while the perforate cover sheet OTR treatments exhibit a slight advantage in broadband at higher frequencies for the inlet.

To get a better idea of what the overall noise changes from configuration to configuration are, it is advantageous to look at the overall sound pressure level (OASPL) versus angle for the different speeds. These OASPL values are for the 1 to 50 kHz range in order to remove low frequencies where the 9- by 15-Foot Low-Speed Wind Tunnel is non-anechoic. Figures 11 through 15 through show the OASPL directivities for different speeds. Once again it is seen that the exposed OTR treatment is noisier than the other configurations. For the 76.6 and 86 percent speeds, over an inlet angle range of 20° to approximately 50° there is reduction on the order of 2 dB on OASPL basis for the perforate cover sheet OTR treatments. The perforate cover sheet OTR treatments do not show a difference relative to the baseline in other angle ranges.

Overall Power Levels can be used to get a good summary of how effective the OTR treatments are. Figure 16 shows OAPWL versus speed for the different configurations. Like the OASPL values, these power levels are for the 1 to 50 kHz range. This plot shows the small advantage on the order of 1 dB for the perforate cover sheet OTR treatments for the intermediate speeds of 76.6 and 86 percent. The higher noise level of the exposed OTR treatment at all speeds is shown to be on the order of 1 dB.

2. Soft Stator Vane Comparisons

During the testing of the 25 hard and soft stator vanes, it was discovered that an extraneous tone and its harmonics were present in the 9- by 15-Foot Low-Speed Wind Tunnel at 86 percent speed. This tone does not appear to be fan or model related. It has been speculated to be drive rig valve noise. The presence of the extraneous noise overwhelms the results for the 86 percent speed and thus they will not be used extensively. Figures 17 through 20 show example spectral results of the soft stator. One notable aspect of these results is the reduction in high frequency broadband above 6 kHz by going successively from the 45 vane hard stator to the 25 vane hard stator and finally to the 25 vane soft stator configurations. This result is on the order of 1 dB for the 45 hard vane (i.e., cut-off design) to 25 hard vane (i.e., cut-on design) change, and somewhat less from the 25 hard vane to 25 soft vane configuration. The 1 dB reduction is due entirely to the change from the cut-off stator to a cut-on stator. The smaller reduction shows what the benefit of the soft stator cavities entails. There is much tradeoff for the BPF tones and no configuration shows a decided advantage in this area, although the 100 percent speed 31° emission angle data and to a lesser extent 100 percent speed 130° emission angle data show the disadvantage of abandoning the cut-off design since there is an increase in most of the lower BPF tones. As for the OTR results, integrating over all angles gives OAPSL directivity for each speed and these are shown in Figures 21 through 24. At 62 percent speed, an advantage of approximately 1 dB is seen for the change from 45 hard stators to 25 hard stators, and another approximately 1 dB going to the 25 soft stators for the inlet quadrant. This reduction is not as wide spread in the aft quadrant, in fact, in some angle regions no benefit is seen. At 76.6 percent speed the results are different in that the inlet shows no advantage for the 25 soft stators as compared to the 45 hard stators while there is a penalty for the 25 hard stators. There is a noise penalty for both of the 25 vane stators in the aft quadrant at the 76.6 percent speed. At 95.4 percent speed, there is conflicting results depending on what angle range is examined and no configuration shows an overall advantage. Lastly at 100 percent speed it appears the 25-stator

configurations show a penalty on the order of 3 to 4 dB at the peak noise angle of 130°. Referring back to the inlet PSD spectra for 100 percent speed shows that there is much more tonal energy for the 25 hard stator configuration. These tones show up as non-BPF tones especially around the 4 to 6 kHz range. This phenomenon can sometimes be associated with blade-to-blade variation, but since the same rotor was used for all 3 stator packs, this tonal noise is probably excited by the different stator vane configuration. In general it appears that the 25 hard vane and 25 soft vane provide most of their advantage at the lower speed. Figure 25 shows OAPWL for the three configurations versus speed. The low speed advantage of the 25 vane configurations can be seen at the low speed. For the other speeds where useful data exists, it should be noted that while the 25 hard stator configuration has a small noise penalty relative to the 45 hard stator, the soft vane technology brings the noise level back down to the 45 stator level. This fact could be useful for when cutoff needs to be abandoned for non-noise reasons. Then the soft stator technology could be utilized to lower the noise cutoff levels.

B. Hot Film Results for Over the Rotor Treatment

Hot-film results obtained with the fan operating at 62, 86, and 100 percent speed are provided in Figures 26 to 28, respectively. Each figure shows a comparison between the flow fields developed downstream of the fan tip with the hardwall and perforate cover sheet double CoNiCrW liners installed in the model. Color contour plots of mean flow speed (in. ft/s), mean radial flow angle (in degrees, with positive outward), the standard deviation of the flow speed (in. ft/s), and turbulence intensity (a percentage, determined by dividing the standard deviation of the flow speed by the mean flow speed) are provided for each of the six fan speed/liner combinations. The view depicted is from downstream looking upstream at the "average passage" flow occurring in the axial plane of the measurements; the rotor blades would rotate clockwise in this view. The approximate locations of the tip vortices are depicted by the black dots overlaid on top of the radial flow angle contour plots. As shown, the center location of the tip vortex was assumed to coincide with the circumferential location of the abrupt change in radial flow angle in the tip region of the blade passage.

A comparison of the data obtained at the different fan speeds indicates that the changes in the tip flow which result from switching from the hardwall to the perforate cover sheet liner becomes more significant as the fan speed increases. At low fan speed (Fig. 26), the mean flow speed, the standard deviation of the flow speed, and the turbulence intensity changed very little when the hardwall liner was replaced by the perforate cover sheet liner. The primary effect of the perforate cover sheet liner was to cause a slight change in the circumferential location of the tip vortex. The tip vortex was found to be further away from the blade from which it was created when the perforate cover sheet liner was installed in the model. This may indicate that the tip vortex "releases" from the blade sooner (i.e., at an axial location closer to the leading edge of the blade) when a porous as opposed to a hardwall liner is installed outboard of the fan tip. A similar change in the circumferential location of the tip vortex is also seen in the 86 and 100 percent fan speed data (see Figs. 27 and 28). At these higher speeds this change is also accompanied by a change in both the mean flow speed and the unsteadiness of the flow downstream of the fan tip; the mean flow speed decreases and both the unsteadiness (turbulence intensity) and the thickness of the turbulent region along the outer surface of the fan duct increase when the perforate cover sheet as opposed to the hardwall liner is installed in the model. These changes become more dramatic as the rotor speed increases from 86 to 100 percent speed. These changes are thought to result from the flow of air in and out of the holes in the perforate cover sheet liner. The increased turbulence along the outer wall of the fan duct is likely to lead to increased rotor/stator interaction broadband noise which would tend to counteract the noise attenuation effects of the perforate cover sheet liner. In order for the perforate cover sheet liner to result in a net decrease in broadband noise, it must attenuate more noise than would be created by this increase in turbulence.

V. Conclusion

While some implementation problems did arise during this test, the potential viability of OTR and soft stator technology was shown. The OTR configurations with perforate covering showed a slight attenuation in inlet broadband noise. They also showed some OASPL reduction on the order of 1 to 2 dB for two intermediate model speeds of 76.6 and 86 percent This translates to an OAPWL reduction of 1 dB at these two speeds. There was very little difference at the other three speeds tested. The OTR treatment with no perforate cover sheet was actually noisier at most conditions when compared to the hardwall baseline. This was generally on the order of 1 dB. While the perforate cover sheet OTR treatments did not give the noise reductions seen in earlier tests, this test showed the concept in a higher speed higher-pressure ratio device. The phenomenon of blade erosion when the OTR with perforate cover sheets were used needs to be investigated more fully in the future to determine the exact mechanism causing this. It has been noted in other tests that the use of a metal blade or the incorporation of OTR treatment into the rubstrip in a different manner may alleviate this problem.

The 25 count stator vane configurations did show high frequency broadband noise reduction as compared to the 45 count stator vanes over a wide frequency range. The 25 soft stator vane configuration had more of this broadband noise reduction than the 25 hard stator configuration. The reduction of the 25 soft stator configuration relative to the 25 hard stator configuration was on the order of 1 dB. The 25 stator vane hardware did show some inlet noise reduction at the lowest speed, but at the higher speeds the addition of tonal energy negated the inlet advantage seen at the lower speed. The low speed inlet noise reduction produced by the 25 stator vanes was on the order of 1dB. An important aspect of the soft stators is that the noise level was reduced to near the 45 stator vane configuration for the higher speeds. This is very useful if a cutoff stator design needs to be abandoned for non-noise reasons. In this situation the soft stator vanes can reduce the noise of a cut-on stator set closer to a cutoff stator set.

The hot film data generally gave an explanation as to why the OTR treatments did not attenuate noise well at the higher speeds. The flow speed and turbulence intensity downstream of the fan change very little at low speeds when going from a hardwall to OTR treatment. At higher speeds, changes in mean flow speed and turbulence intensity along with an increase in the thickness of the turbulent region may be adding to rotor/stator interaction noise thereby offsetting any reduction from the OTR treatment. Flow in and out of the perforate cover sheet holes may be causing the changes at higher speeds.

References

1. Sutliff, D.L. and Jones, M.G., "Foam-Metal Liner Attenuation of Low-Speed Fan Noise," AIAA Paper 2008–2897, Aug. 2008.
2. Woodward, Richard P., Fite, E. Brian, and Podboy, Gary G., "Noise Benefits of Rotor Trailing Edge Blowing for a Model Turbofan," AIAA–2007–1241, January, 2007.
3. Jeracki, R.J., "Comprehensive Report of Fan Performance from Duct Rake Instrumentation on 1.294 Pressure Ratio, 806 ft/sec Tip Speed Turbofan Simulator Models," NASA/TM—2006-213863, Feb. 2006.
4. Dahl, M.D., and Woodward, R.P., "Comparison Between Design and Installed Acoustic Characteristics of the NASA Lewis 9-by 15-Foot Low-Speed Wind Tunnel Acoustic Treatment," NASA TP–2996, Apr. 1990.
5. Dahl, M.D., and Woodward, R.P., "Background Noise Levels Measured In the NASA Lewis 9- by 15-Foot Low-Speed Wind Tunnel," NASA TP–3274, Nov. 1992.
6. Woodward, R.P., and Dittmar, J.H., "Background Noise Levels Measured in the NASA Lewis 9- by 15- Foot Low-Speed Wind Tunnel," NASA TM–106817/AIAA–95–0720, 1995.

Figure 1.—The Advanced Ducted Propulsor model as installed in the NASA Glenn Research Center's 9- by 15-Foot Low-Speed Wind Tunnel. Microphones are visible at left.

Figure 2.—The FeCrAlY metal foam OTR treatment with no perforate cover sheet as installed in the ADP model.

Figure 3.—A metal foam OTR treatment with perforate cover sheet installed in the ADP model.

Figure 4.—The soft stator vanes behind the rotor in the ADP model.
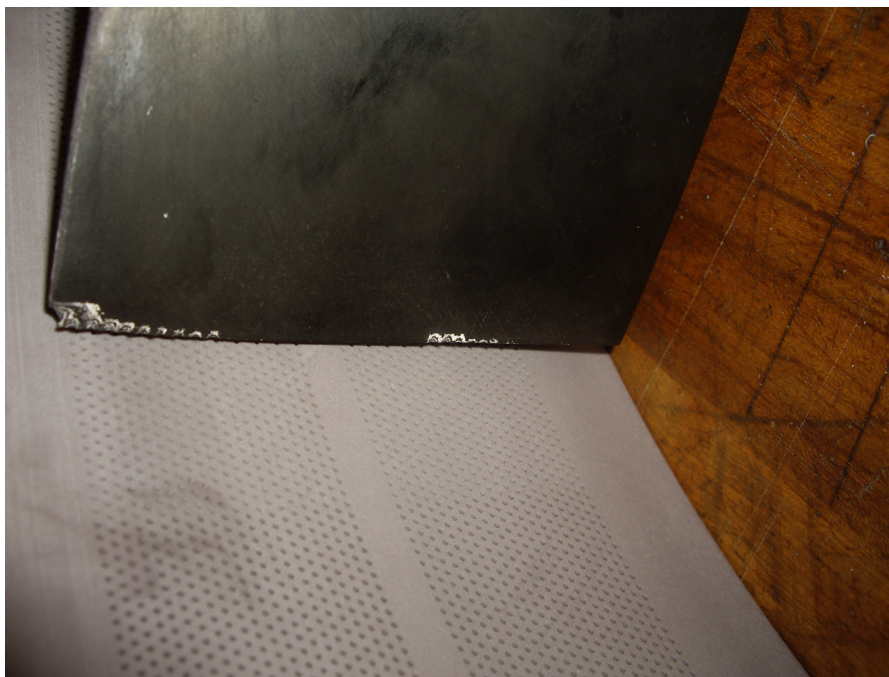
Figure 5.—Photograph of a hot-film probe installed in the NASA Fan model.

Figure 6.—Damage on the composite blade which coincides with the holes in the perforate covering the metal foam OTR treatment.
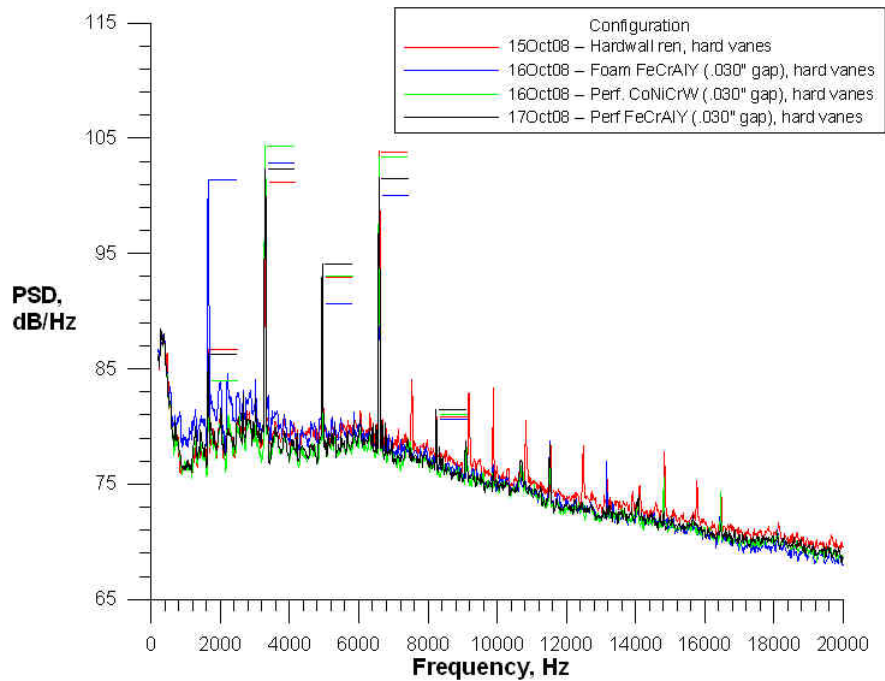
Figure 7.—Hardwall and OTR treatments, PSD versus frequency at 62 percent model speed and 41° emission angle, 0.030 in. blade tip gap and 45 hard stator vanes.
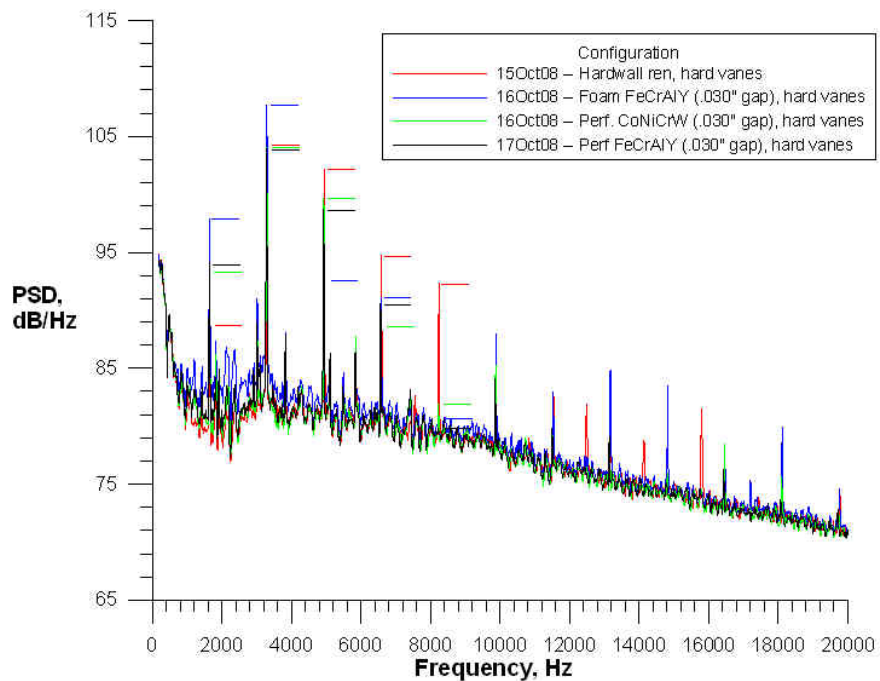
Figure 8.—Hardwall and OTR treatments, PSD versus frequency at 62 percent model speed and 128° emission angle, 0.030 in. blade tip gap and 45 hard stator vanes.
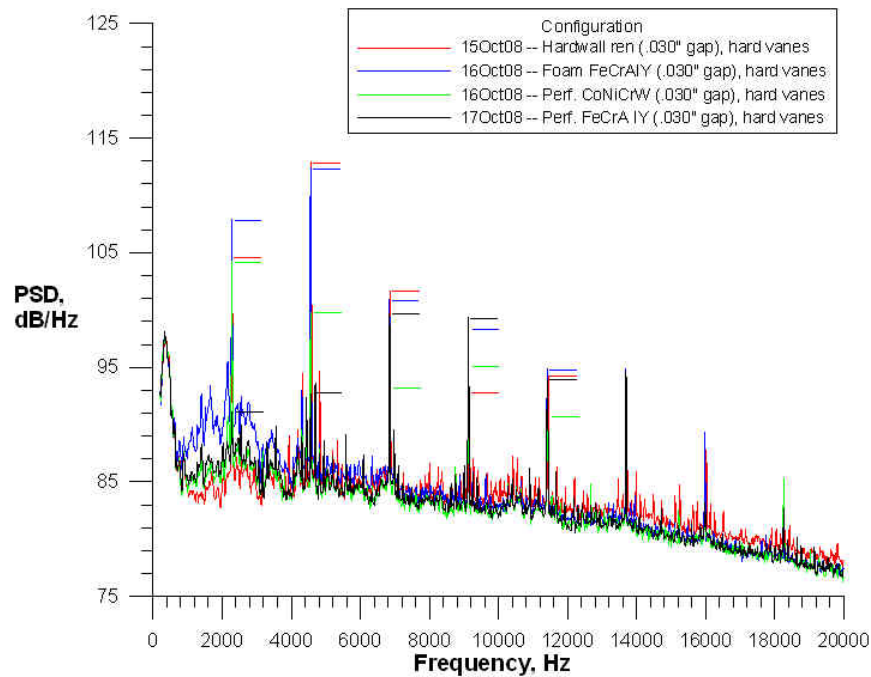
Figure 9.—Hardwall and OTR treatments, PSD versus frequency at 86 percent model speed and 33° emission angle, 0.030 in. blade tip gap and 45 hard stator vanes.
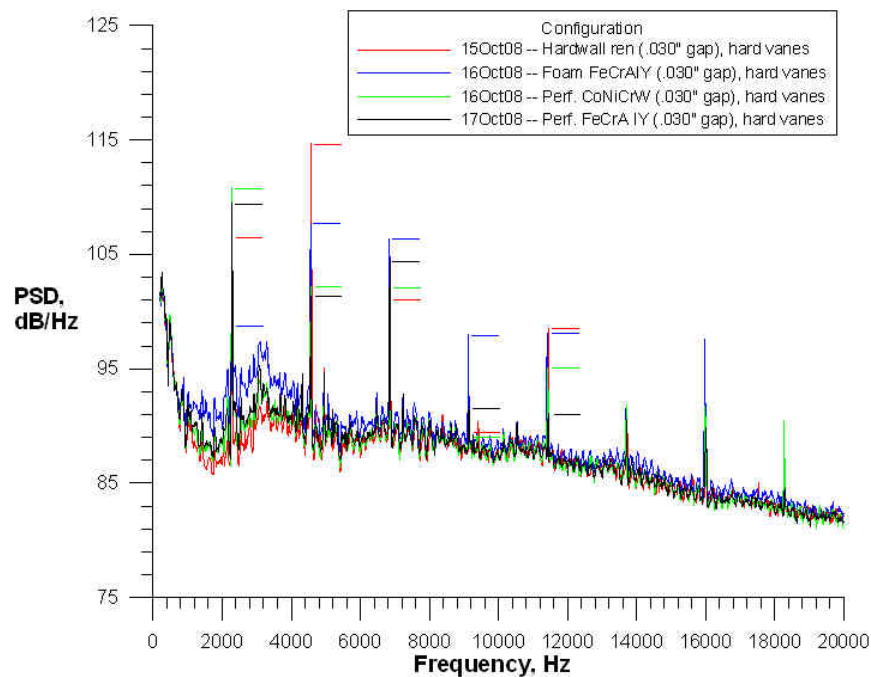
Figure 10.—Hardwall and OTR treatments, PSD versus frequency at 86 percent model speed and 128° emission angle, 0.030 in. blade tip gap and 45 hard stator vanes.
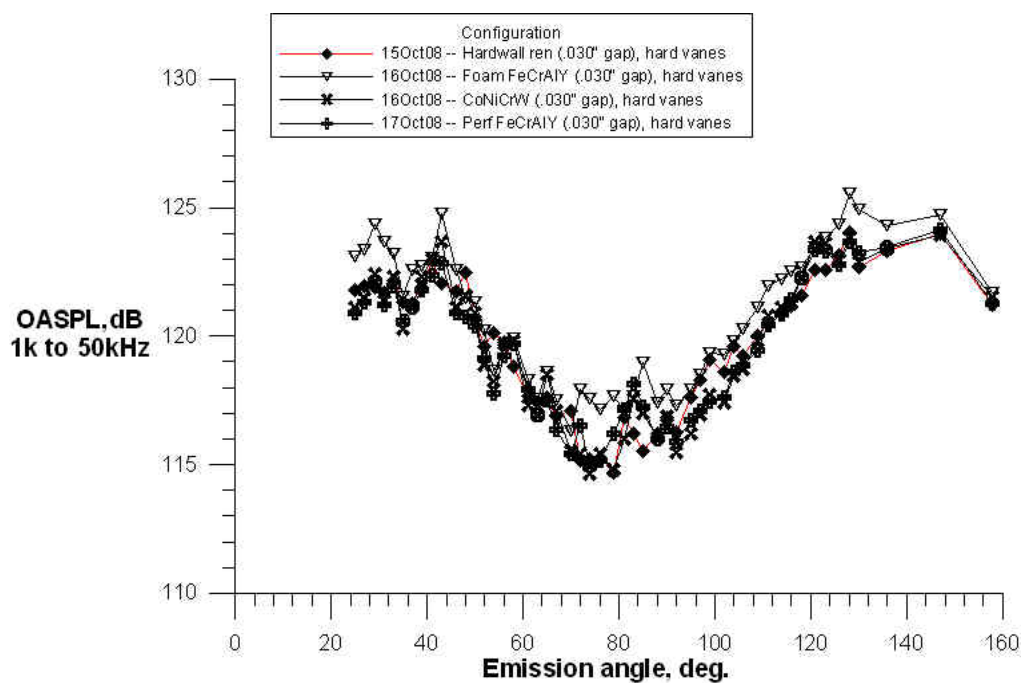
Figure 11.—Hardwall and OTR treatments, OASPL versus emission angle at 62 percent model speed, 0.030 in. blade tip gap and 45 hard stator vanes.
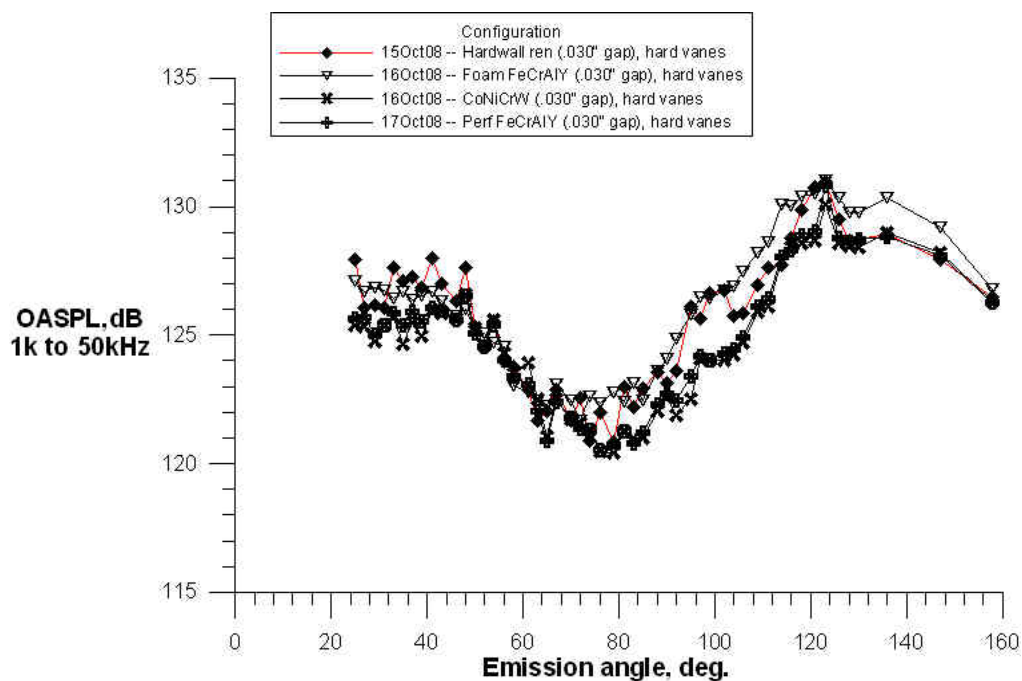
Figure 12.—Hardwall and OTR treatments, OASPL versus emission angle at 76.6 percent model speed, 0.030 in. blade tip gap and 45 hard stator vanes.
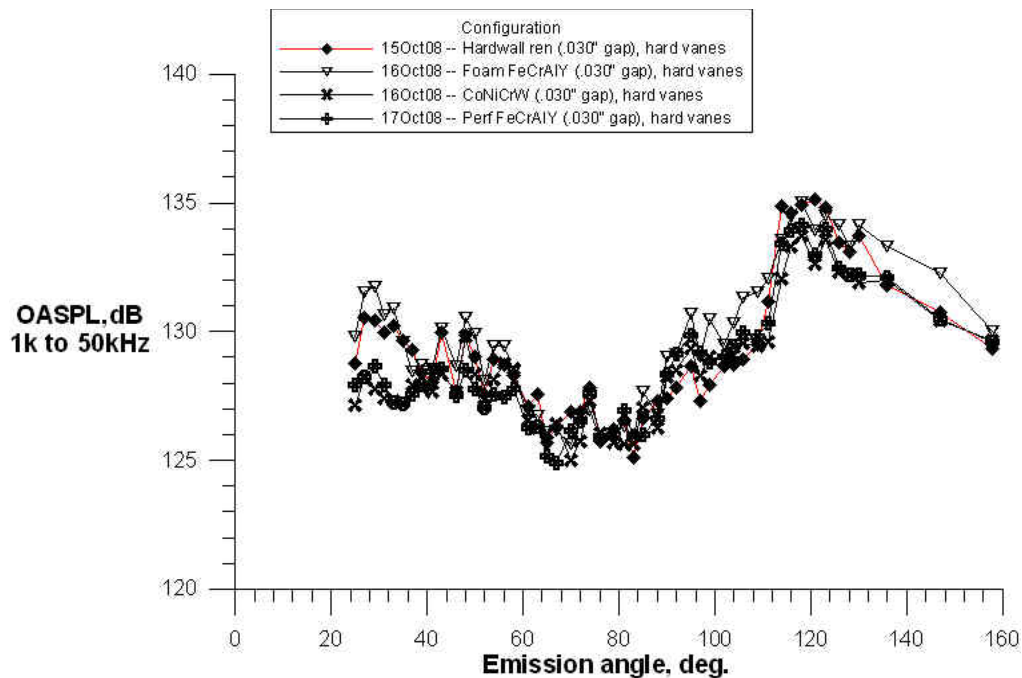
Figure 13.—Hardwall and OTR treatments, OASPL versus emission angle at 86 percent model speed, 0.030 in. blade tip gap and 45 hard stator vanes.
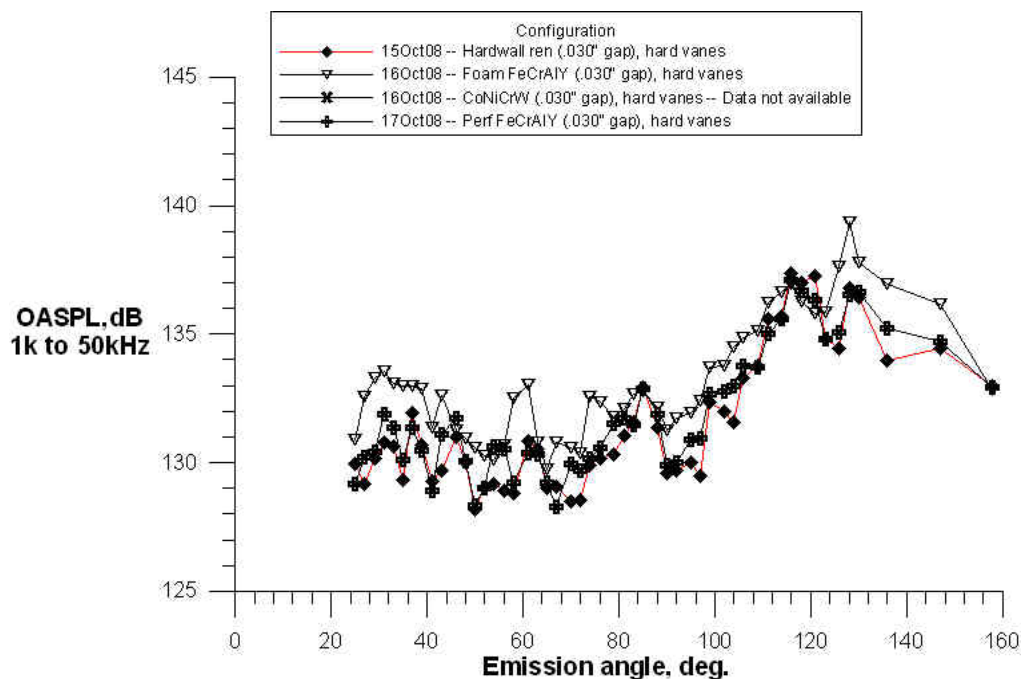
Figure 14.—Hardwall and OTR treatments, OASPL versus emission angle at 95.4 percent model speed, 0.030 in. blade tip gap and 45 hard stator vanes.
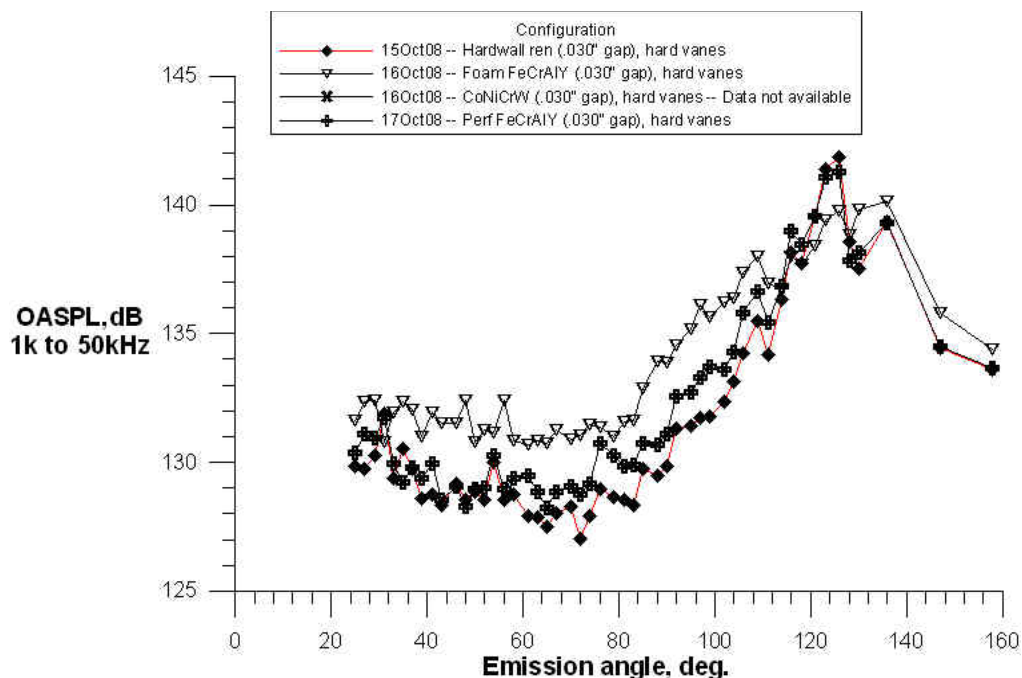
Figure 15.—Hardwall and OTR treatments, OASPL versus emission angle at 100 percent model speed, 0.030 in. blade tip gap and 45 hard stator vanes.
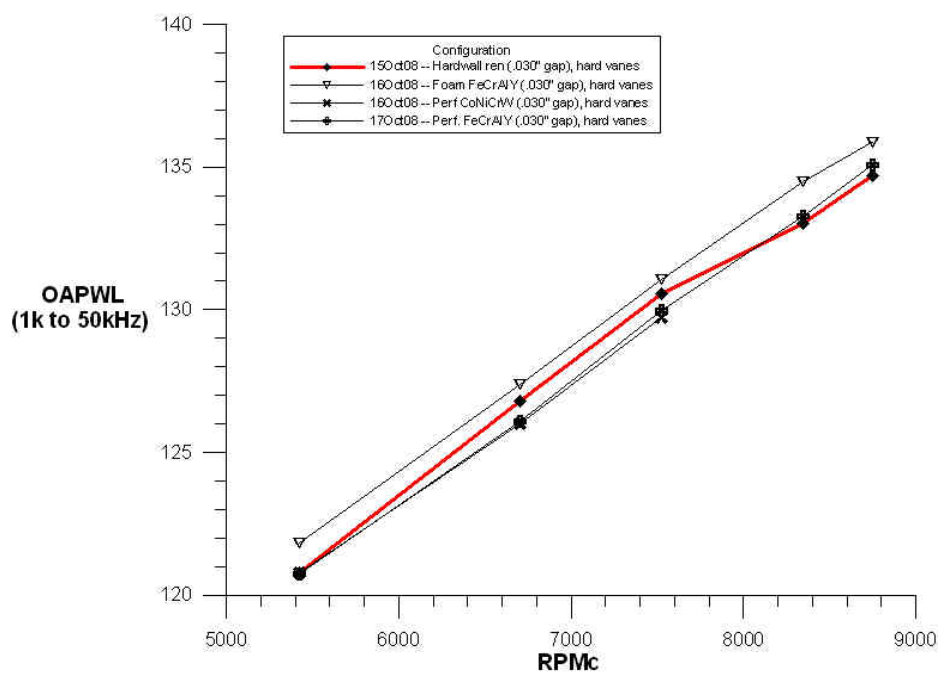
Figure 16.—Hardwall and OTR treatments, OAPWL versus corrected rpm (rpmc), 0.030 in. blade tip gap and 45 hard stator vanes.
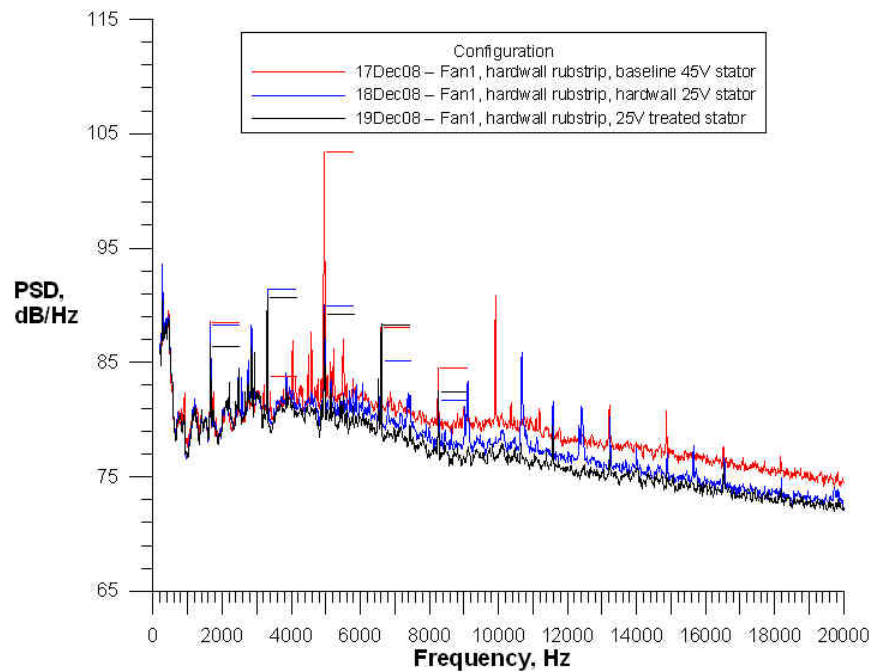
Figure 17.—Comparison of three stator configurations, PSD versus frequency at 62 percent model speed and 31° emission angle, Fan 1, hardwall rubstrip.
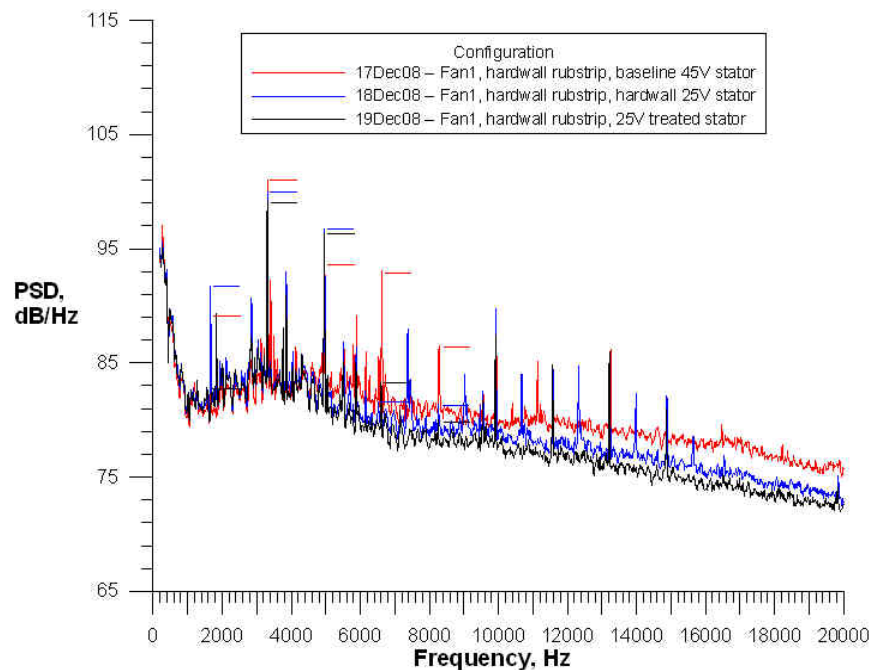
Figure 18.—Comparison of three stator configurations, PSD versus frequency at 62 percent model speed and 130° emission angle, Fan 1, hardwall rubstrip.
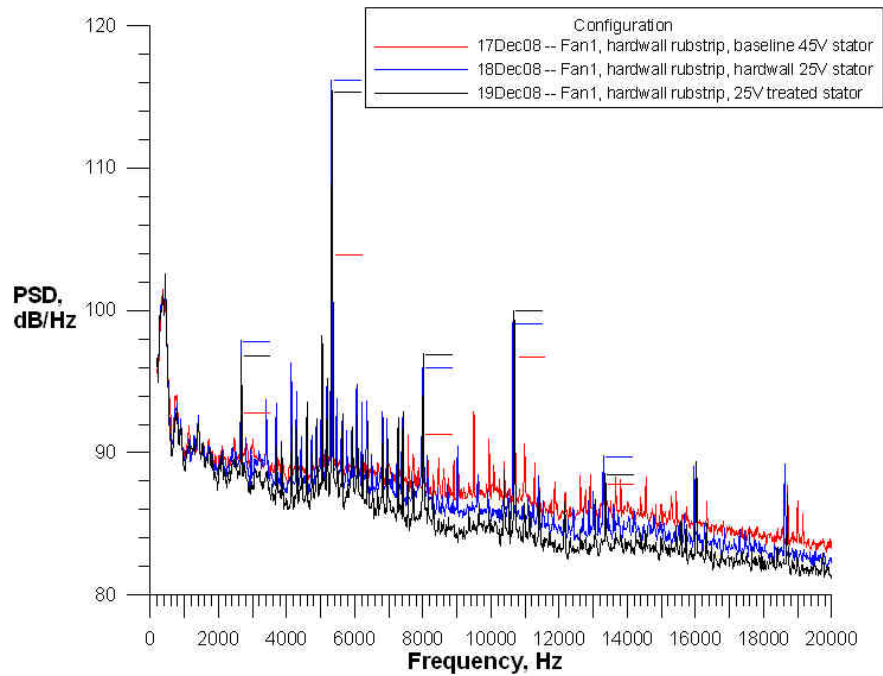
Figure 19.—Comparison of three stator configurations, PSD versus frequency at 100 percent model speed and 31° emission angle, Fan 1, hardwall rubstrip.
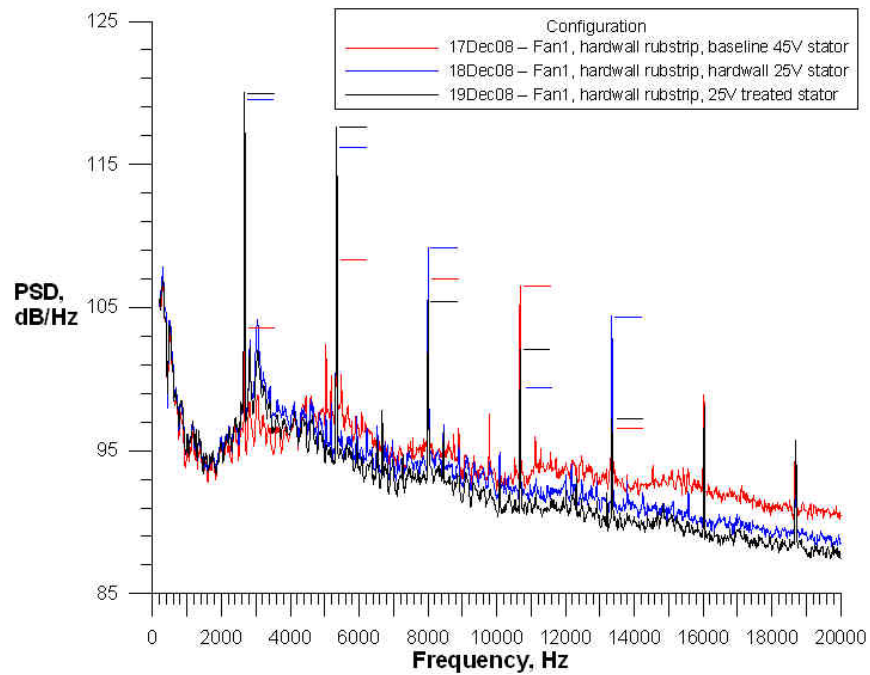
Figure 20.—Comparison of three stator configurations, PSD versus frequency at 100 percent model speed and 130° emission angle, Fan 1, hardwall rubstrip.
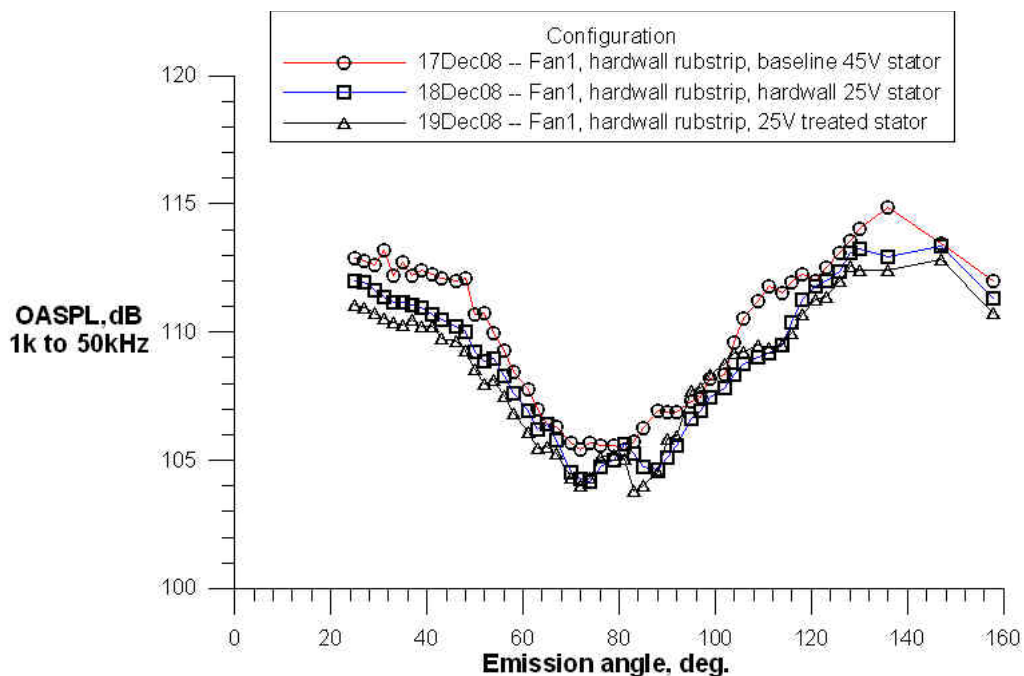
Figure 21.—Comparison of three stator configurations, OASPL versus emission angle at 62 percent model speed, Fan1, hardwall rubstrip.
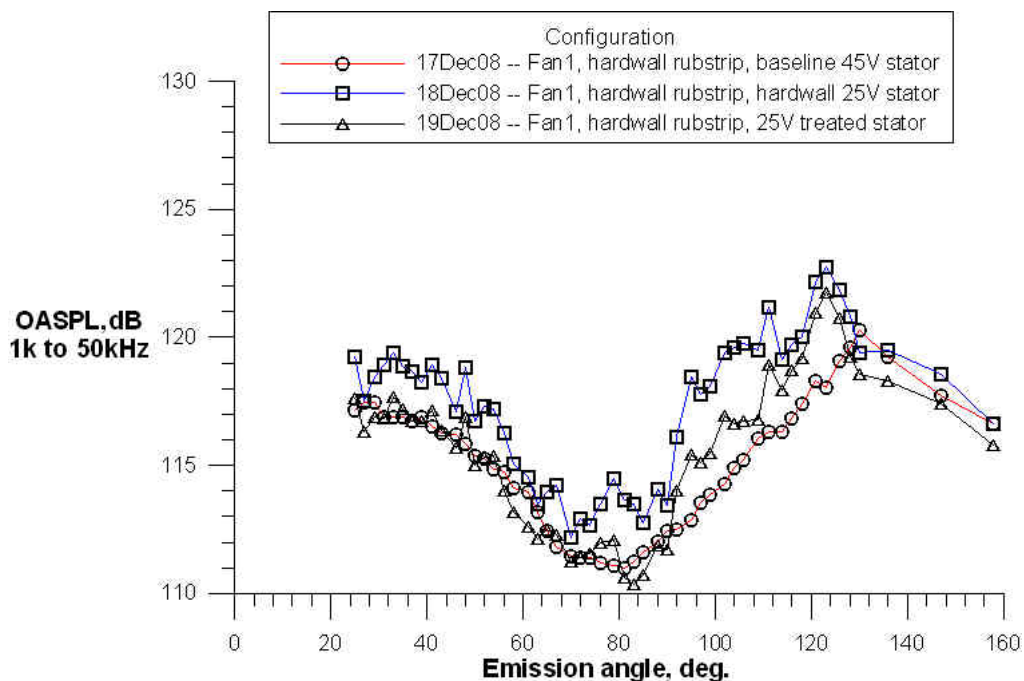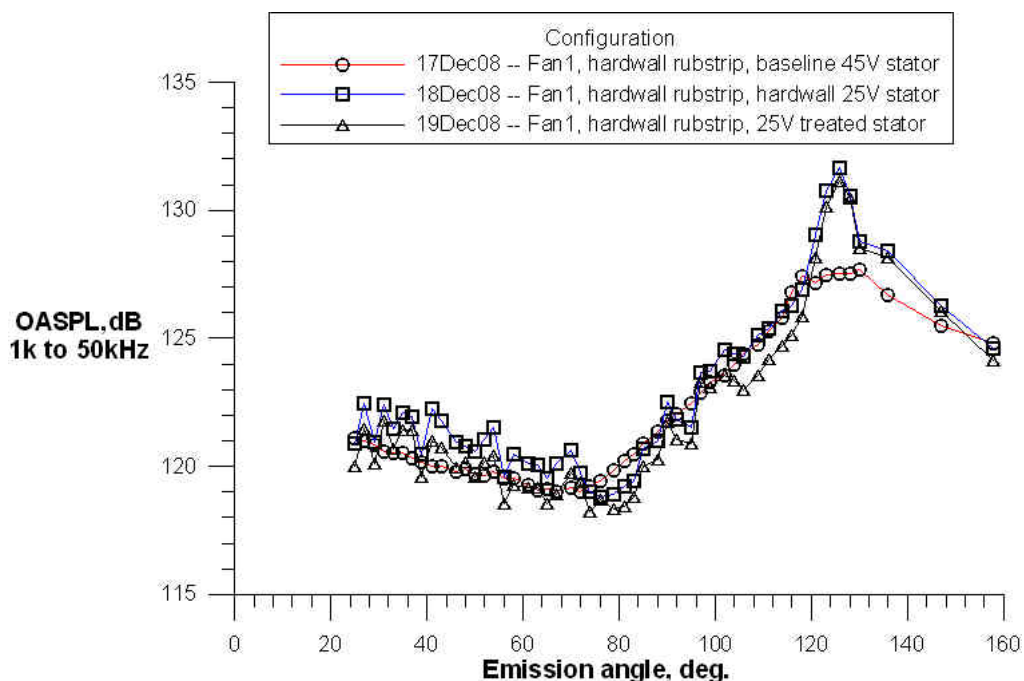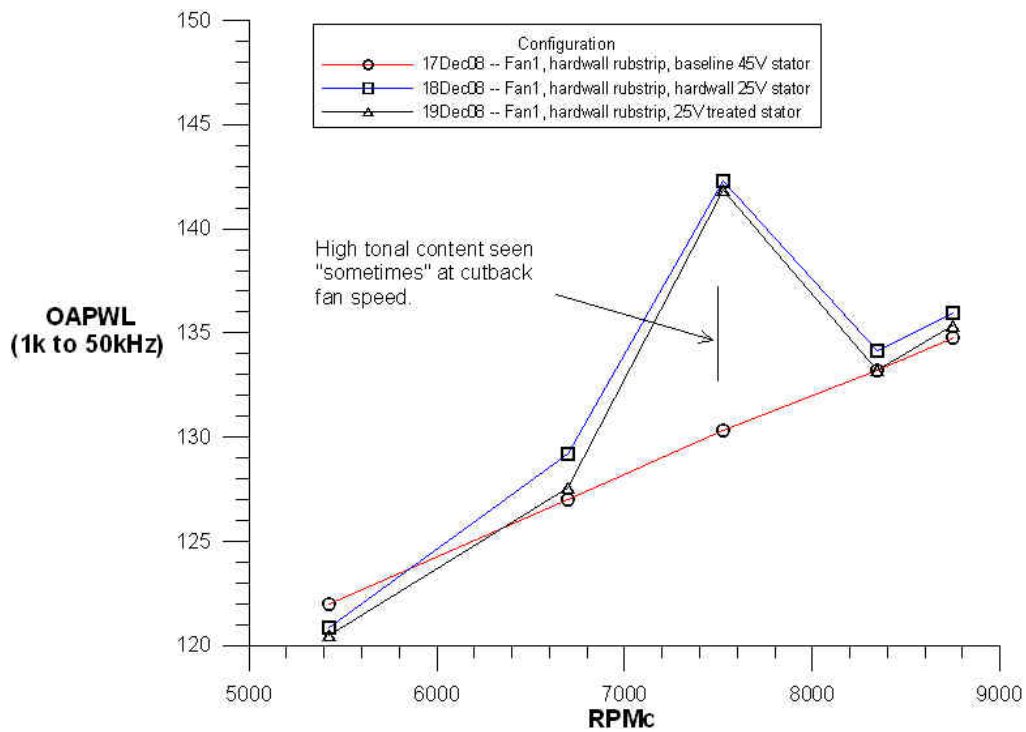

Figure 22.—Comparison of three stator configurations, OASPL versus emission angle at 76.6 percent model speed, Fan1, hardwall rubstrip.
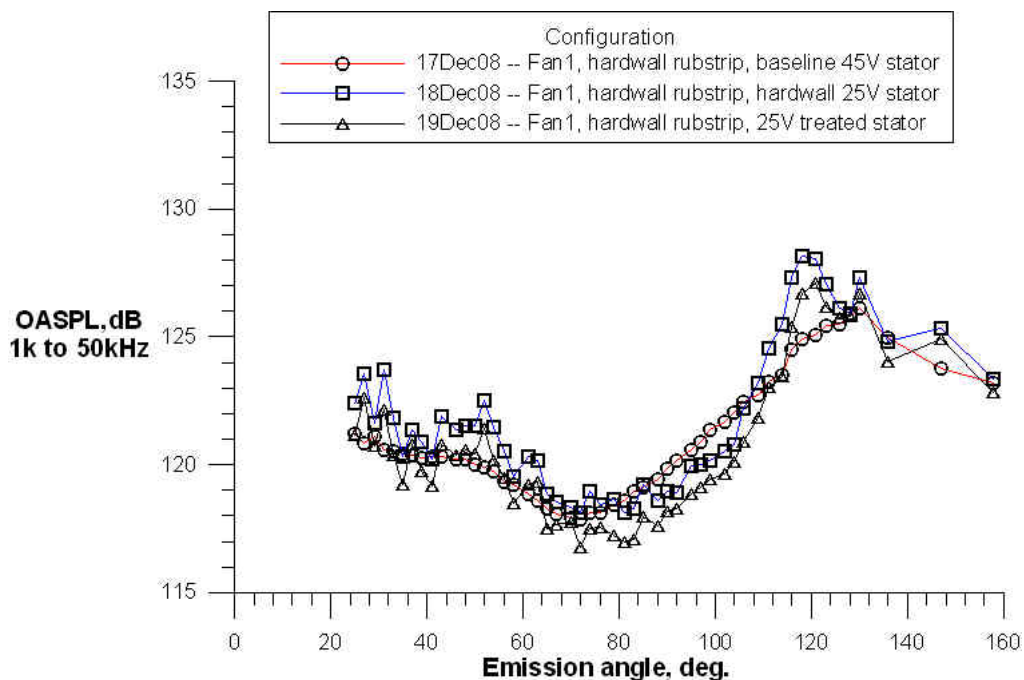
Figure 23.—Comparison of three stator configurations, OASPL versus emission angle at 95.4 percent model speed, Fan1, hardwall rubstrip.

Figure 24.—Comparison of three stator configurations, OASPL versus emission angle at 100 percent model speed, Fan1, hardwall rubstrip.

Figure 25.—Comparison of three stator configurations, OAPWL versus corrected RPM, Fan1, hardwall rubstrip.
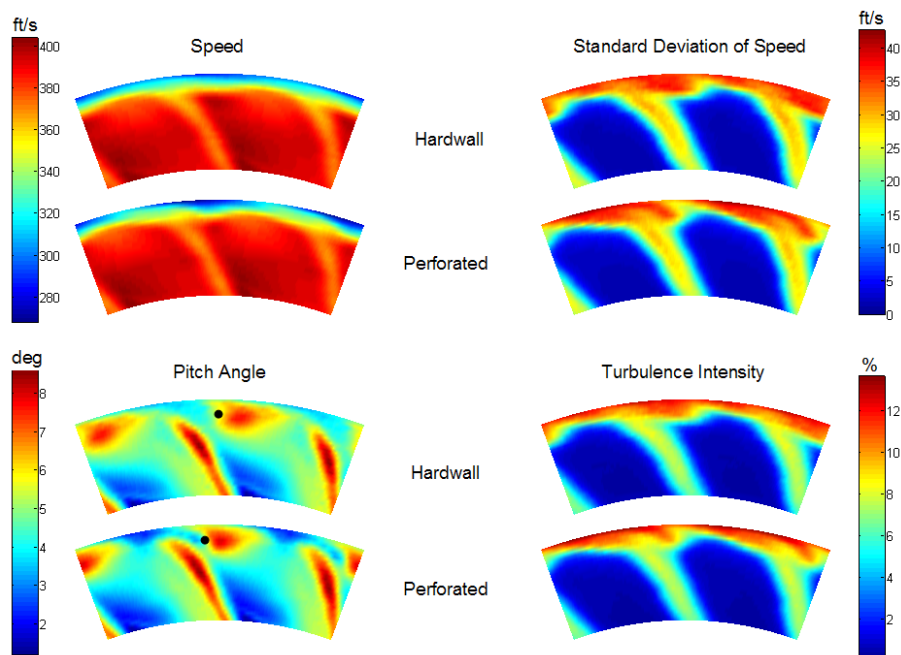
Figure 26.—Comparison of tip wake flows measured at 62 percent speed with hardwall and perforate cover sheet double CoNiCrW liners.
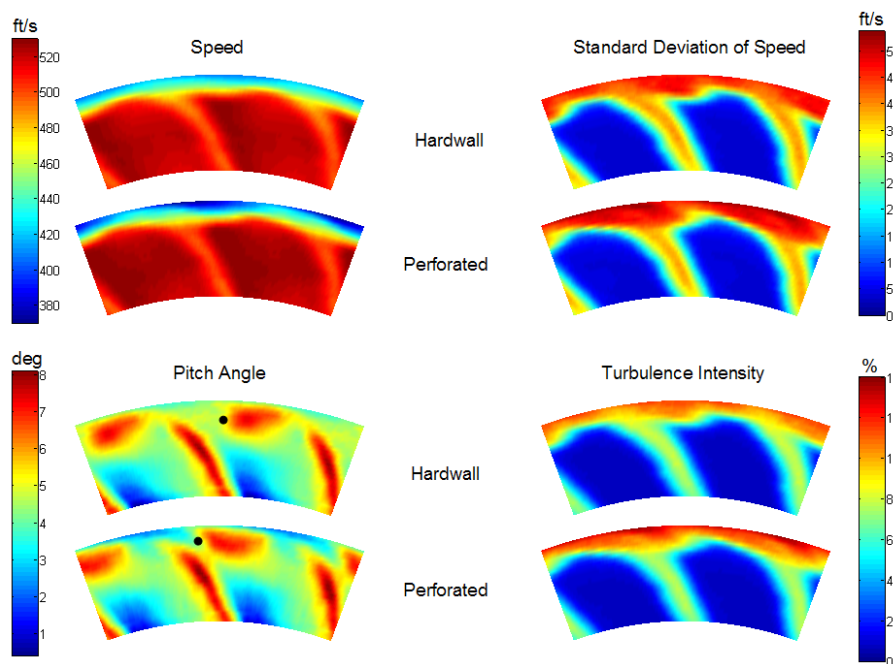
Figure 27.—Comparison of tip wake flows measured at 86 percent speed with hardwall and perforate cover sheet double CoNiCrW liners.
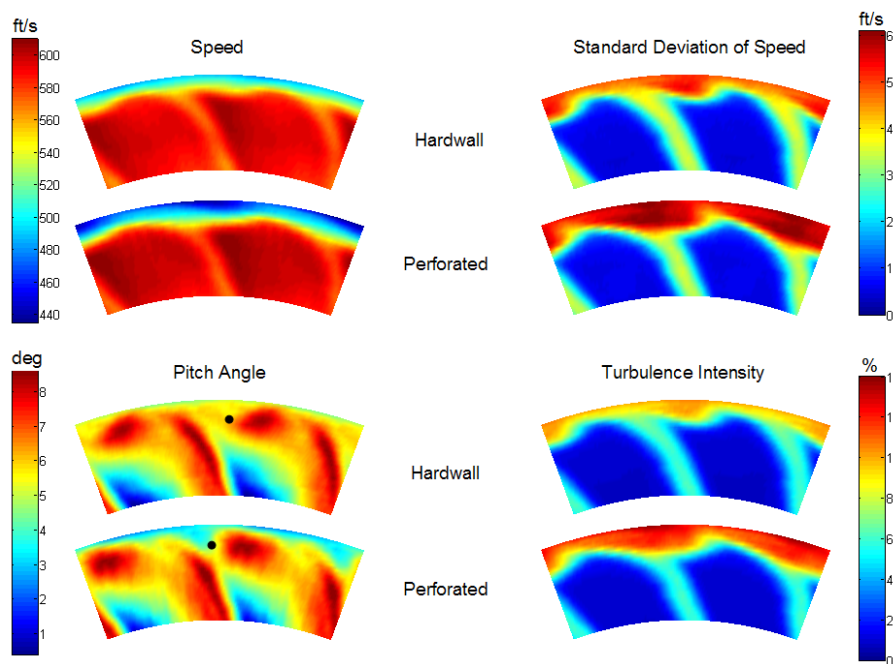

Figure 28.—Comparison of tip wake flows measured at 100 percent speed with hardwall and perforate cover sheet double CoNiCrW liners.

1. REPORT DATE *(DD-MM-YYYY)* 01-04-2010	2. REPORT TYPE Technical Memorandum		3. DATES COVERED *(From - To)*
4. TITLE AND SUBTITLE Acoustic Performance of Novel Fan Noise Reduction Technologies for a High Bypass Model Turbofan at Simulated Flight Conditions			**5a. CONTRACT NUMBER**
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Elliott, David, M.; Woodward, Richard, P.; Podboy, Gary, G.			**5d. PROJECT NUMBER**
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER WBS 561581.02.08.03.18.02
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191			**8. PERFORMING ORGANIZATION REPORT NUMBER** E-17102
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001			**10. SPONSORING/MONITOR'S ACRONYM(S)** NASA
			11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2010-215841

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Category: 71
Available electronically at http://gltrs.grc.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Two novel fan noise reduction technologies, over the rotor acoustic treatment and soft stator vane technologies, were tested in an ultra-high bypass ratio turbofan model in the NASA Glenn Research Center's 9- by 15-Foot Low-Speed Wind Tunnel. The performance of these technologies was compared to that of the baseline fan configuration, which did not have these technologies. Sideline acoustic data and hot film flow data were acquired and are used to determine the effectiveness of the various treatments. The material used for the over the rotor treatment was foam metal and two different types were used. The soft stator vanes had several internal cavities tuned to target certain frequencies. In order to accommodate the cavities it was necessary to use a cut-on stator to demonstrate the soft vane concept.

15. SUBJECT TERMS
Aeroacoustics; Acoustic attenuation; Acoustic measurement; Aircraft noise; Engine noise

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON STI Help Desk (email:help@sti.nasa.gov)
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	26	**19b. TELEPHONE NUMBER** *(include area code)* 443-757-5802