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The Potential Benefits of Advanced Casing Treatment for Noise Attenuation in Utra-High Bypass Ratio Turbofan Engines

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ABSTRACT

In order to increase stall margin in a high-bypass ratio turbofan engine, an advanced casing treatment was developed that extracted a small amount of flow from the casing behind the fan and injected it back in front of the fan. Several different configurations of this casing treatment were designed by varying the distance of the extraction and injection points, as well as varying the amount of flow. These casing treatments were tested on a 55.9 cm (22 inch) scale model of the Pratt and Whitney Advanced Ducted Propulsor in the NASA Glenn 9x15 Low Speed Wind Tunnel. While all of the casing treatment configurations showed the expected increase in stall margin, a few of the designs showed a potential noise benefit for certain engine speeds. This paper will show the casing treatments and the results of the testing as well as propose further research in this area. With better prediction and design techniques, future casing treatment configurations could be developed that may result in an optimized casing treatment that could conceivably reduce the noise further.

1 INTRODUCTION

An advanced rotor casing treatment was tested as part of an advanced liner test on the Pratt and Whitney Advanced Ducted Propulsor (ADP) model. This casing treatment extracted a small amount of flow from behind the fan and injected it forward of the fan. The primary purpose of the casing treatment was to increase stall margin and no acoustic attenuation objectives were considered. The Pratt and Whitney ADP model represents an ultra-high bypass engine where the design bypass ratio is 13 to 1. During the testing, two different fan designs were used. The fans had the same pressure ratio at design speed, but one fan operated at a lower tip speed. A number of different advanced casing treatment configurations were also tested. The advanced casing treatment configurations differed by moving the flow extraction and insertion points as well as changing the amount of flow. Acoustic measurements were taken on the different advanced casing treatments to determine their noise signature relative to a model configuration that did not have any casing treatment. This series of tests took place in the NASA Glenn Research Center 9x15 Low Speed Wind Tunnel[1].

2 TEST APPARATUS AND PROCEDURE

2.1 Pratt and Whitney Advanced Ducted Propulsor Model

The Advanced Ducted Propulsor model is 55.9 cm (22 inches) in diameter and was tested with a low speed fan design referred to as Fan 2. Fan 2 was a second iteration fan design and had a

10% lower tip speed than the previous fan design. Fan 2 also had the same pressure ratio as the previous fan design and was therefore more highly loaded. The ADP Fan 2 had 18 rotor blades and there was a simulated passive core with 63 inlet vanes and 16 support struts downstream of the inlet vanes. During the design of Fan 2, the number of fan exit guide vanes was chosen to minimize the cumulative Effective Perceived Noise Levels at the three design speeds of Sea Level Takeoff (SLTO), cutback and approach. This resulted in 51 fan exit guide vanes being used in conjunction with Fan 2. The takeoff, cutback and approach conditions for Fan 2 are 230, 203 and 130 meters per second (756, 667 and 425 feet per second) respectively. The Fan 2 tip speeds for takeoff, cutback, and approach correspond to corrected speeds of 7875, 6950 and 4425 rpm. A photograph of the ADP model in the NASA Glenn 9x15 Low Speed Wind Tunnel is shown in Figure 1.

Figure 1: Pratt and Whitney Advanced Ducted Propulsor in the NASA Glenn 9X15 Low Speed Wind Tunnel.

2.2 ACOUSTIC MEASUREMENTS

Far-field acoustic measurements were obtained using a traversing microphone probe at a 2.24 meter (88-inch) sideline to the model. Data were taken at 48 positions on the traverse at 2.5 degree intervals ranging from 27.2 degrees to 134.6 degrees relative to the model rotor plane of rotation. All acoustic data was obtained at 0.1 Mach number. The emitted angles of the traversing probe at 0.1 Mach number correspond to 24.6 degrees to 130.6 degrees. To obtain more angular resolution, 3 fixed microphone probes were placed in the rear of the test section to correspond to measured angles of 140, 150 and 160 degrees. At 0.1 Mach these angles transform to 136.4, 147.2 and 158.1 degrees respectively. The microphones used were 0.635 cm (1/4-inch) in diameter. Data was taken in two bursts at different sampling rates in order to obtain 0 to 8 kHz and 0 to 80 kHz spectra. The bandwidth of the 0 to 8 kHz spectra is 5.9 Hz and the bandwidth of the 0 to 80 kHz spectra is 59 Hz. Corrections to the data have been made for microphone

response, cable response, bullet nose receptivity, filter response, atmospheric attenuation and spherical spreading. Due to the filtering characteristics of the system, the confidence of data above 50 kHz is not great, therefore only data below 50 kHz will be used. All data shown will be corrected to 30.48 cm (1 foot) lossless.

3 ADVANCED CASING TREATMENT

As mentioned earlier, the casing treatment in this test entry was primarily used in order to increase stall margin. The casing treatment worked passively and pulled a small amount of flow off from the trailing edge vicinity of the fan blade. This flow was then injected at the leading edge vicinity of the fan blade. There was no attempt to design the treatment in order to change the acoustic signature. Noise measurements were taken simply to characterize the casing treatment and document what effect, if any, the treatment had on the acoustics of the model. When quickly analyzing the effects of the casing treatment on the flow within the duct of the model, it is apparent that a small amount of boundary layer may be removed downstream of the fan. This may have a benefit of reducing the blade tip vortex somewhat, thereby reducing its effect of impinging on the stator vane. However, there is also the possibility that the injection flow from the casing treatment upstream of the fan may induce an inlet disturbance. While one effect may have a potential noise benefit, the other effect may have a noise penalty. If an effective or optimized balance is reached, there could be an overall noise advantage.

Five different casing treatment configurations were tested during this entry. These configurations consisted of the baseline casing treatment (ACT-A), a casing treatment in which the injection flow point was moved further upstream (ACT-B), a casing treatment in which the flow extraction point was moved further downstream and the flow was increased to a maximum amount (ACT-C), a casing treatment in which both flow extraction and injection points were moved downstream and upstream respectively (ACT-D), and a casing treatment where the extraction and injection points were moved downstream and upstream with the flow increased to the maximum value (ACT-E). These casing treatment configurations are shown in Figure 2.

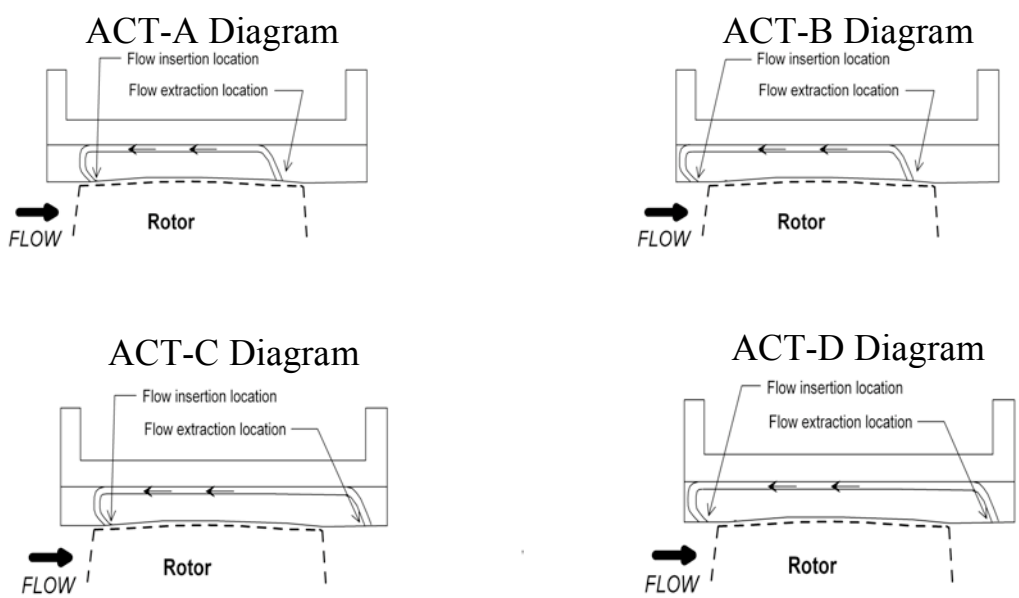

Figure 2: Advanced Casing Treatment (ACT) configurations used with Advanced Ducted Propulsor (ADP) Fan 2 model. The ACT-E configuration is similar to ACT-D but with an increased flow rate through the passage.

4 TEST RESULTS

4.1 Power Levels

While all the advanced casing treatments increased the stall margin by at least 3%[2], the acoustics of the casing treatments were of interest since added noise would be unwanted. An all hard wall nacelle was used as a baseline acoustic reference. Overall power spectra and levels will be examined first, in order to utilize the entire directivity of the data acquired. The sound power level spectra of the hard wall configuration versus the base ACT-A and aft extraction with max flow ACT-C configurations for the takeoff condition of 8750 rpmc is shown in Figure 3. From these data it can be seen that these two ACT configurations have a noise penalty. The casing treatment configurations have higher noise levels for much of the broadband and blade passage tones. This is also seen in the overall power levels for these configurations where the hard wall overall power level (OAPWL) is 135.2 dB compared to 135.5 dB for ACT-A and 135.8 dB for ACT-C. Figures 4, 5, and 6 show the hard wall nacelle compared to the ACT-B, ACT-D, and ACT-E configurations respectively. In each of these comparisons the advanced casing treatment does not introduce any noise penalty. There is actually a noise benefit of approximately 1 dB in the 2000 to 5000 Hz range for broadband noise. There is also a slight reduction of 1 to 2 dB for some orders (nBPF) of the blade passing tone noise. OAPWL numbers were also calculated for these spectra in order to determine if there is an overall benefit of the casing treatments for these configurations. The OAPWL calculations are 134.9, 134.8, and 134.9 dB for the ACT-B, ACT-D, and ACT-E configurations respectively. Each of these configurations has a lower OAPWL value compared to the 135.2 dB of the hard wall configuration. The best configuration at takeoff appears to be the ACT-D configuration where the extraction and injection points were moved outward with base flow amount. This configuration reduced the OAPWL of the reference hard wall by 0.4 dB. While this is not a large number, as pointed out earlier, this result shows an acoustic benefit for a primarily aerodynamic modification.

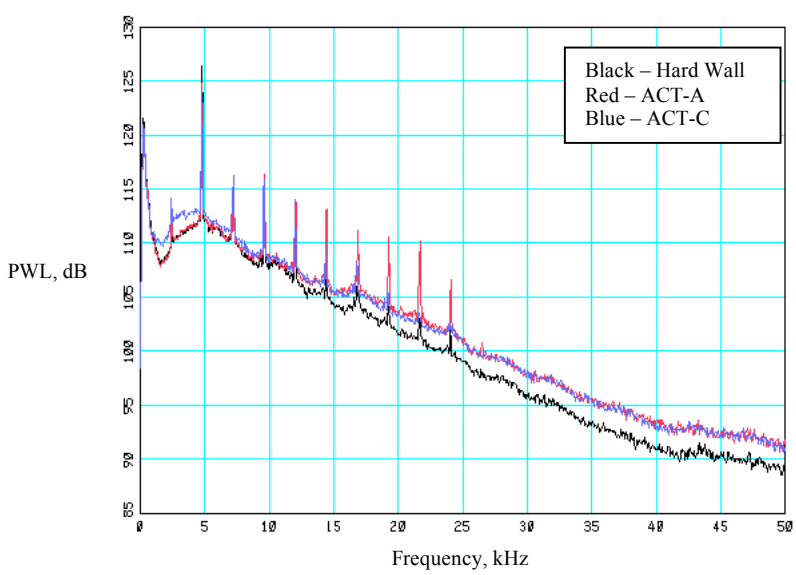

Figure 3: PWL of baseline hard wall versus ACT-A and ACT-C for takeoff condition.

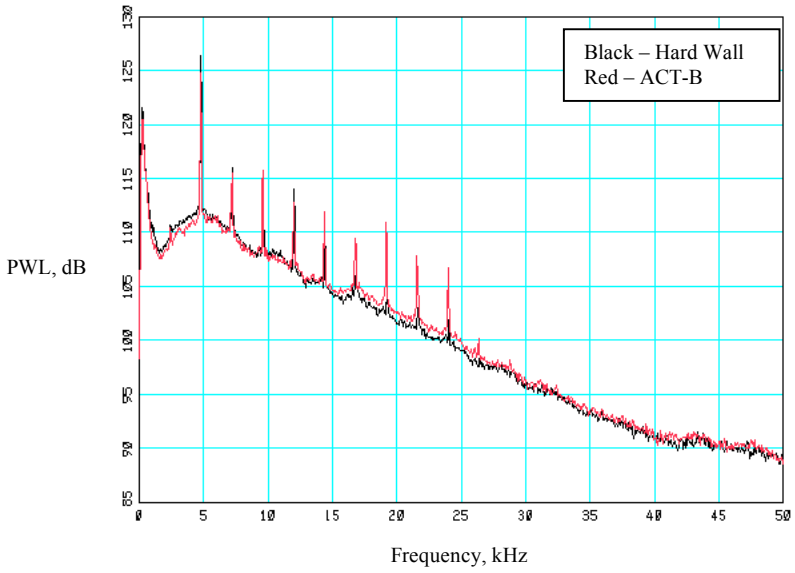

Figure 4: PWL of baseline hard wall versus ACT-B for takeoff condition.

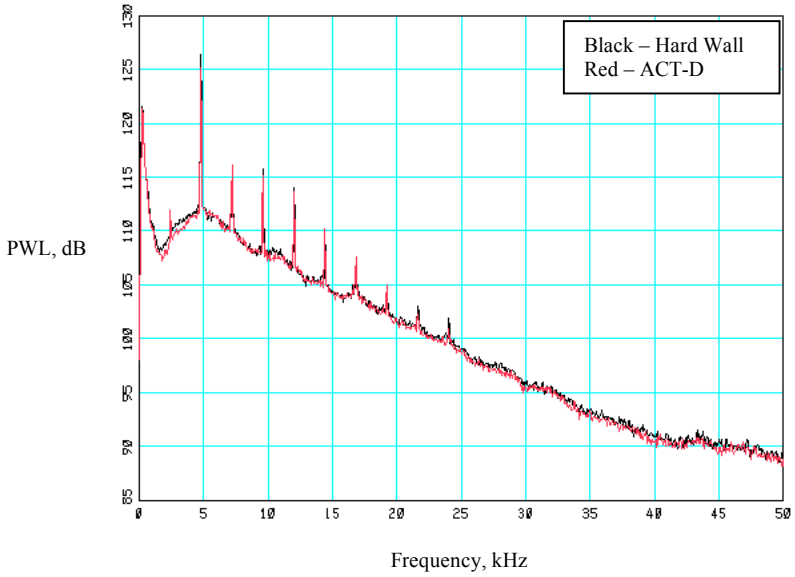

Figure 5: PWL of baseline hard wall versus ACT-D for takeoff condition.

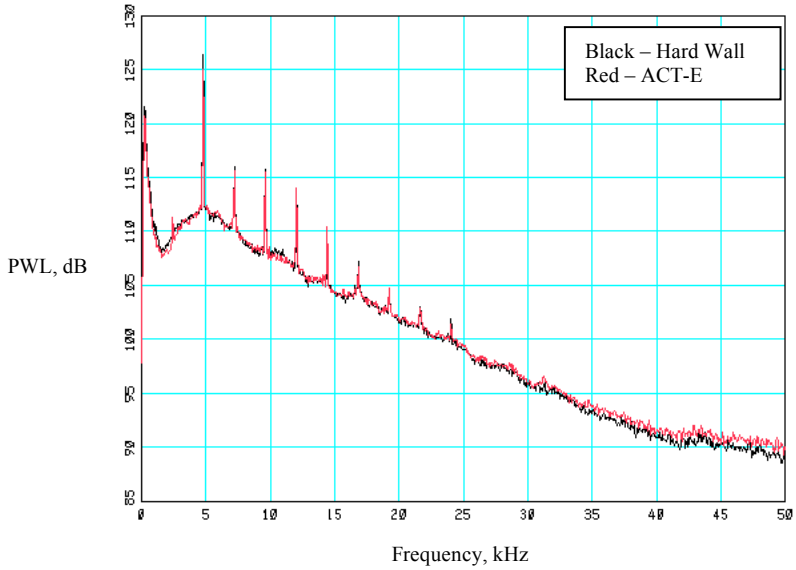

Figure 6: PWL of baseline hard wall versus ACT-E for takeoff condition.

The approach condition of 5425 rpmc was also investigated to get an idea of how the casing treatment performed at a lower fan speed. The power level spectra of the hard wall versus the ACT-A and ACT-C configurations are shown in Figure 7. As in the takeoff condition, the broadband and blade passage tones are higher for these two casing treatments. This is once again shown in the OAPWL numbers of 119.2 dB for the hard wall versus 119.7 and 120.0 dB for ACT-A and ACT-C respectively. The ACT-C configuration in which the flow extraction point is moved further downstream with maximum flow is the noisier configuration at both the low and high speed conditions. It is possible that this configuration does not effectively pull off any of the blade tip vortex downstream of the fan. The hard wall versus ACT-B, ACT-D, and ACT-E PWL spectra are shown in Figures 8, 9, and 10 respectively. The ACT-B configuration shows some high frequency broadband reduction as well as some blade passage tone reduction. The best noise reduction once again appears to come from the ACT-D configuration where there is a slight amount of broadband noise reduction from 15 kHz on up. This configuration also shows some blade passage tone reduction similar to the ACT-B configuration. Lastly the ACT-E configuration shows some blade passage tone reduction similar to what was observed for ACT-B and ACT-D, but there doesn't appear to be much difference in the entire broadband noise. The OAPWL numbers for the ACT-B, ACT-D, and ACT-E configurations are 119.2, 119.0, and 119.0 dB respectively. When compared to the hard wall value of 119.2 dB, once again the ACT-D configuration has the lowest noise signature at approach. This difference in OAPWL is only 0.2 dB, less reduction than what was observed at the higher speed point. Interestingly the ACT-E configuration has a lower OAPWL than the ACT-B configuration at the approach condition, just the opposite of the takeoff speed results.

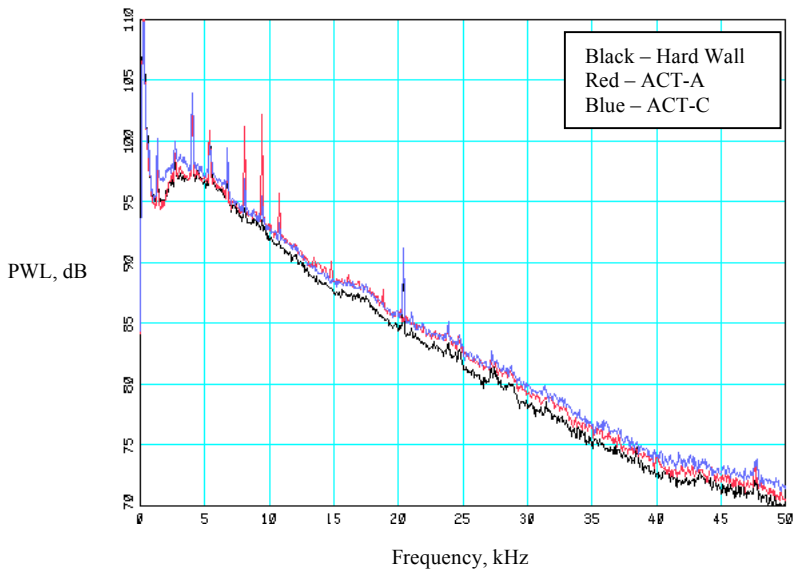

Figure 7: PWL of baseline hard wall versus ACT-A and ACT-C for approach condition.

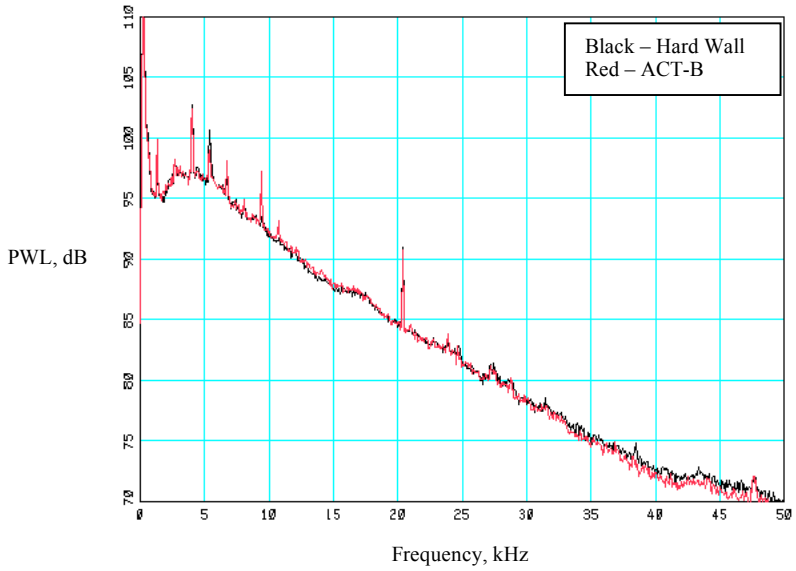

Figure 8: PWL of baseline hard wall versus ACT-B for approach condition.

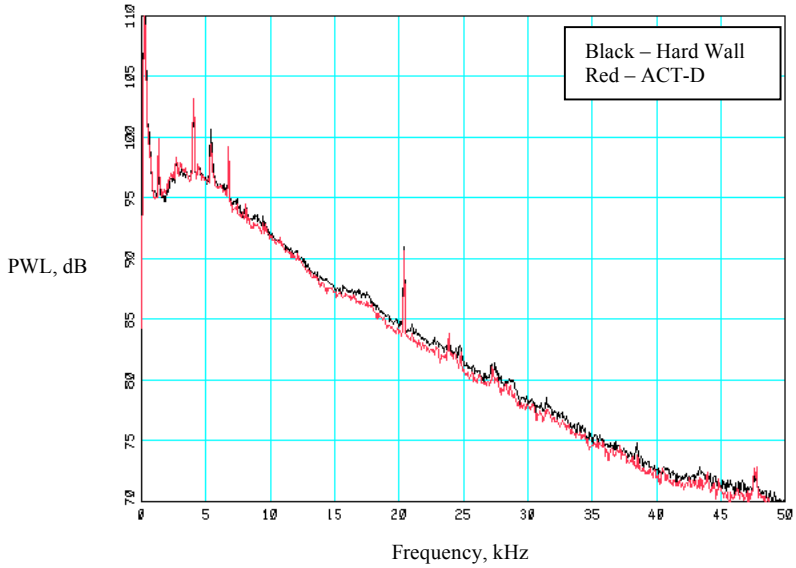

Figure 9: PWL of baseline hard wall versus ACT-D for approach condition.

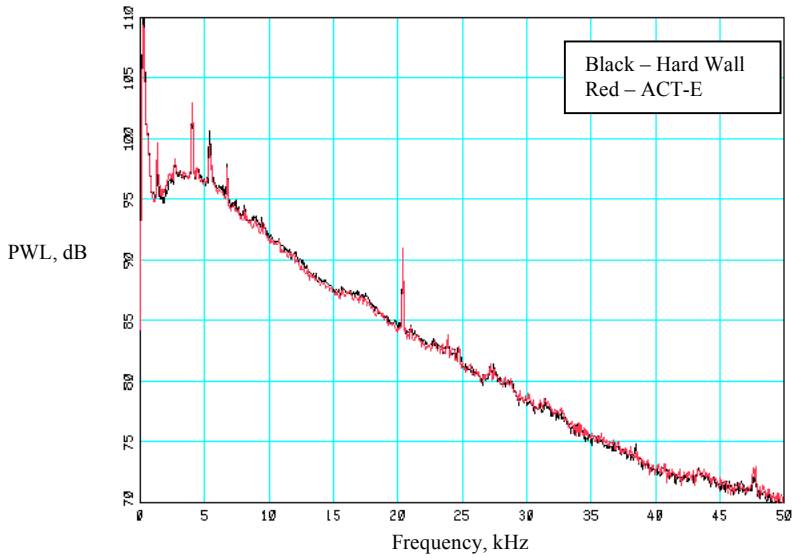

Figure 10: PWL of baseline hard wall versus ACT-E for approach condition.

4.2 Sound Pressure Level Spectra

While the power level spectra and OAPWL values integrate all of the sideline data for a given speed, sound pressure level (SPL) spectra can give a detailed indication of the noise at a particular sideline angle. The SPL spectra of the baseline hard wall versus the ACT-D configuration at 136 degrees for the takeoff condition is shown in Figure 11. This figure shows that the casing treatment is not affecting the noise at this downstream angle to a large degree. The broadband levels as well as most of the blade passage tones are essentially unchanged by the tip treatment. Figure 12 shows the baseline hard wall versus the ACT-D configuration at 36

degrees for takeoff fan speed. The casing treatment has a greater effect on the noise at this upstream angle than was observed at 136 degrees. Most of the blade passage tones are lower by as much as 3 dB. While the overall broadband noise levels are similar, there appear to be some ranges where the noise level with casing treatment is slightly lower than for the hard wall.

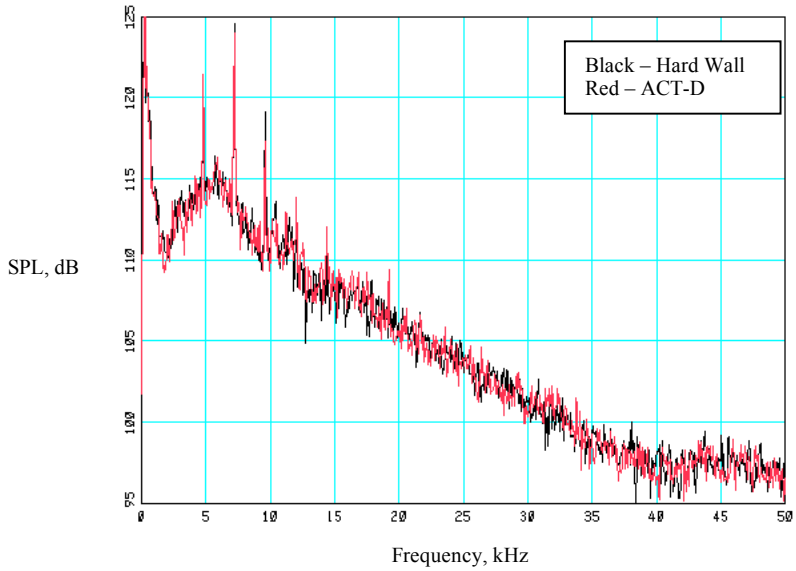

Figure 11: SPL of baseline hard wall versus ACT-D at 136 degrees for takeoff.

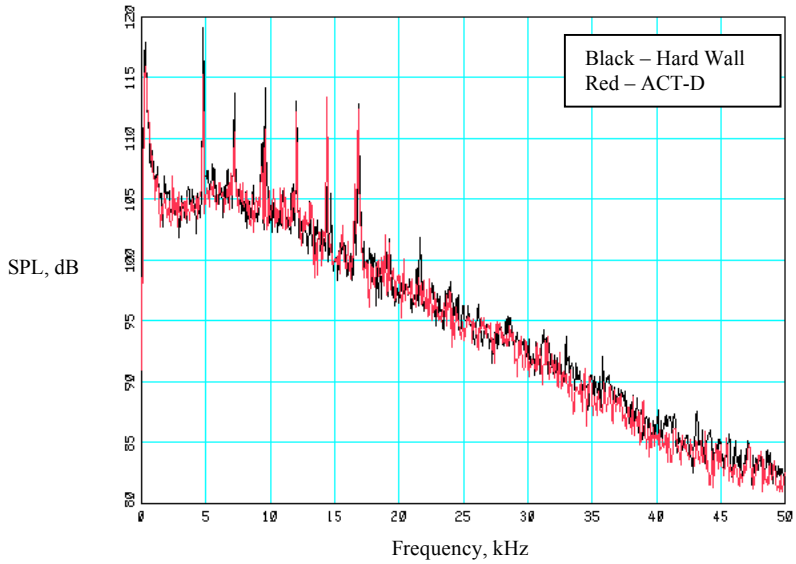

Figure 12: SPL of baseline hard wall versus ACT-D at 46 degrees for takeoff.

4.3 Effective Perceived Noise Levels

Another metric that is commonly used in characterizing noise is Effective Perceived Noise Level (EPNL). EPNL uses Noy weighting for annoyance levels and then generates a flyover noise level. A 6.5 scale factor was used since the ADP was intended for use on large aircraft. The

EPNL values calculated are simple tone corrected values - that is they were not flown on a specific aircraft. The values are for a 457 meter (1500 foot) flyover at 0.1 Mach. The EPNL values for the hard wall and ACT-E configuration are shown in Table 1. The ACT-E configuration was chosen in order to demonstrate the minimum amount of noise reduction expected for a configuration that reduces the noise at both takeoff and approachBy varying . As seen in Table 1, the ACT-E configuration is 0.2 EPNdB quieter at approach and 0.5 EPNdB quieter at takeoff. A 0.5 dB reduction in EPNL is a significant amount in today's low noise engine environment.

EPNL Comparisons
457 meter (1500 foot) flyover at Mach 0.1, 6.5 scale factor

Configuration	Approach	Takeoff
Hard Wall	81.1	98.5
ACT-E	80.9	98.0

Table 1: EPNL comparisons of baseline hard wall and ACT-E.

5 CONCLUSIONS

A passive advanced casing treatment was tested on an ultra-high bypass ratio scale model in the 9x15 NASA Glenn Wind Tunnel. Although designed to increase stall margin, some of the casing treatment configurations showed a reduction in noise. By varying the flow extraction and injection locations as well as flow amounts, it is possible to reduce the noise by at least 0.5 EPNdB at takeoff and 0.2 dB EPNdB at approach conditions for a single casing treatment configuration relative to a hard wall nacelle configuration. It was also proposed that future casing treatment designs may be able to provide even more noise reduction potential. This is due to the fact that the casing treatments examined in this paper were not designed with any acoustic input whatsoever. Additional research should focus in the two areas of prediction and testing. At this point in time a good aerodynamic prediction code for this type of casing treatment does not exist. The development of this prediction capability would be very useful for future designs. Additional testing could be very helpful in understanding the fluid flow that takes place due to the presence of this advanced casing treatment. Another area of future research could be in the use of rotor tip casing treatment on different cycle engines. While this casing treatment was used on a low tip speed ultra-high bypass ratio engine, it would be interesting to investigate the applicability of this type of casing treatment on a lower bypass ratio, higher tip speed cycle more representative of the actual engines flying today.

6 REFERENCES

[1] David M. Elliott and James H. Dittmar, "Some acoustic results from the NASA/Pratt and Whitney Advanced Ducted Propulsor model," AIAA 2000-0351, (2000).
[2] E. Brian Fite, "Fan performance from duct rake instrumentation on a 1.294 pressure ratio, 725 ft/sec tip speed turbofan simulator using vaned passage casing treatment," NASA TM 214241, (2006).

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
In order to increase stall margin in a high-bypass ratio turbofan engine, an advanced casing treatment was developed that extracted a small amount of flow from the casing behind the fan and injected it back in front of the fan. Several different configurations of this casing treatment were designed by varying the distance of the extraction and injection points, as well as varying the amount of flow. These casing treatments were tested on a 55.9 cm (22 in.) scale model of the Pratt & Whitney Advanced Ducted Propulsor in the NASA Glenn 9 by 15 Low Speed Wind Tunnel. While all of the casing treatment configurations showed the expected increase in stall margin, a few of the designs showed a potential noise benefit for certain engine speeds. This paper will show the casing treatments and the results of the testing as well as propose further research in this area. With better prediction and design techniques, future casing treatment configurations could be developed that may result in an optimized casing treatment that could conceivably reduce the noise further.

15. SUBJECT TERMS
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