Quarterly Progress Report

This report covers the period of March 15, 2014 to June 14, 2015

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Project Title : Noise of High-Performance Aircraft at Afterburner

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Introduction

During this quarter, we have extended our one-dimensional broadband entropy wave generation model (reported in the progress report of the previous quarter) to two dimensions. Currently, we are performing validation tests of the model. The computational domain of the tests is a square. The mean flow carrying the random entropy waves enters the domain from the upper and left boundary in the direction of the diagonal of the square domain. The tests consist of measuring the random temperature fluctuations. The collected data is then used to compute the spectrum as well as the lateral two-point cross-correlation function. The model is considered validated if the measured spectrum and cross-correlation function is in good agreement with that of the input to the model. We expect the result of this effort to be reported in the next progress report.

Through the advocacy of Dr. John Spyropulos and the excellent cooperation of Mr. Allan Aubert, we received a set of F-18E jet noise data for study. The principal objective of our study is to find out if the dominant noise components of the F-18E, especially at high power setting, are the same as those of a high temperature supersonic laboratory jet. Previously, we have performed a similar study of the noise of a F-22A jet. We found that at intermediate power, the dominant noise components are essentially the same as those of a laboratory jet. However, at afterburner condition, the F-22A jet noise is quite different. There are new noise dominant noise components with very different characteristics.

The following is a preliminary report of our F-18E study. It comprises of three parts. They are:

1. A data quality analysis.
2. A comparison of the noise of a F-18E jet at 80N2 power setting and that of a supersonic laboratory jet.
3. Comparisons of the noise at 3 power settings.

1. Data quality study

Two sets of NAVAIR F-18E jet noise data are used in the present study. One set was measured by a line microphone array parallel to the jet flow direction. The array was located at 42 ft from the jet axis as shown in figure 1. The other set was measured by a microphone array in the form of an arc at 50 ft from the jet exit (see figure 1). To avoid contamination by ground reflection, only ground microphone data are considered. NAVAIR data are in the form of 1/3 octave band spectra. To eliminate the higher weighting given to higher frequencies in 1/3 octave band spectra, the data is first reprocessed to narrow band (dB per Hz). In order to facilitate directivity consideration and data comparisons, all data are rescaled to a distance of 50 ft. from the jet exit by the inverse-square law. The data was acquired at four engine power settings. But only data at 3 power settings are found useful. The power settings are 80N2 (low power), Mil (military power) and MaxAB (afterburner).

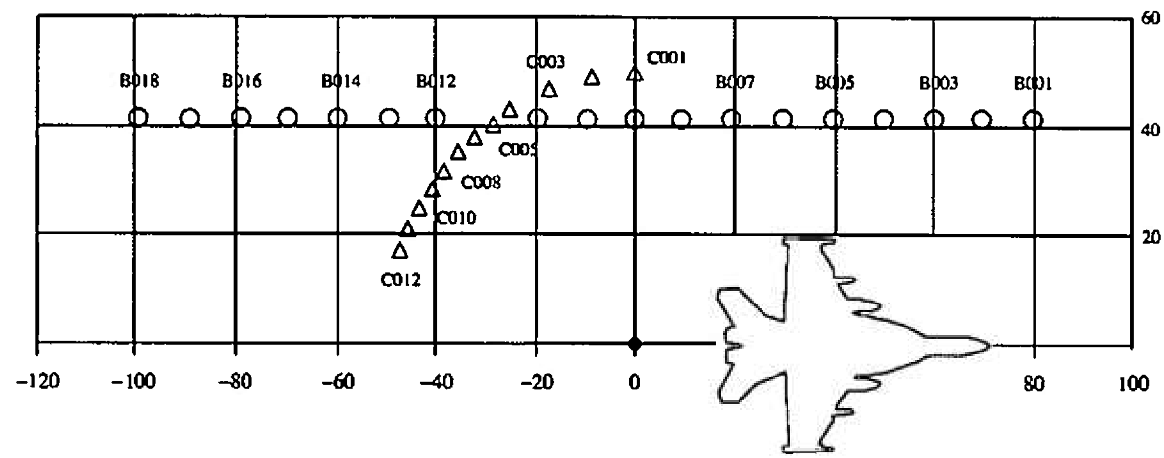

Figure 1. Microphone location map. Circles are microphone locations on the 42 ft line. Triangles are microphone locations on the 50 ft. arc array. Red circles and green triangles indicate microphones with background noise contamination.

The data are generally of good quality. This is evident by simply comparing noise spectra measured at the same angular direction (within 1 degree) by the 42 ft line microphone array and those by the 50 ft arc microphone array. Such comparisons also reveal that there is low frequency background noise contamination (generally less than 100 Hz and in a few cases less than 200 Hz). The source of the background noise is unknown. To show the extent of background noise contamination, it is best to look at low SPL data. For this reason, we concentrate our study on spectral data at 80N2 power setting. Figures 2, 3, 4, 5 and 6 each shows a superposition of a spectrum measured by a 42 ft line microphone and the spectrum measured by a microphone of the 50 ft arc array at the same direction. It is clear from these figures that there are good agreements between the two microphone measurements except in the frequency range where there is strong low frequency background noise at the microphone location. By examining these figures, it is easy to conclude that low frequency background noise is strong mainly for frequencies less than 100 Hz. To provide a measure of the relative SPL between background noise and jet noise, attention is drawn to figure 7 (134^0) and figure 8 (140^0). In these figures, the measured spectra at all three power settings are plotted. In figure 7, the maximum background noise is 123 dB. In figure 8, the maximum level is 127 dB. These are the highest level of background noise observed.

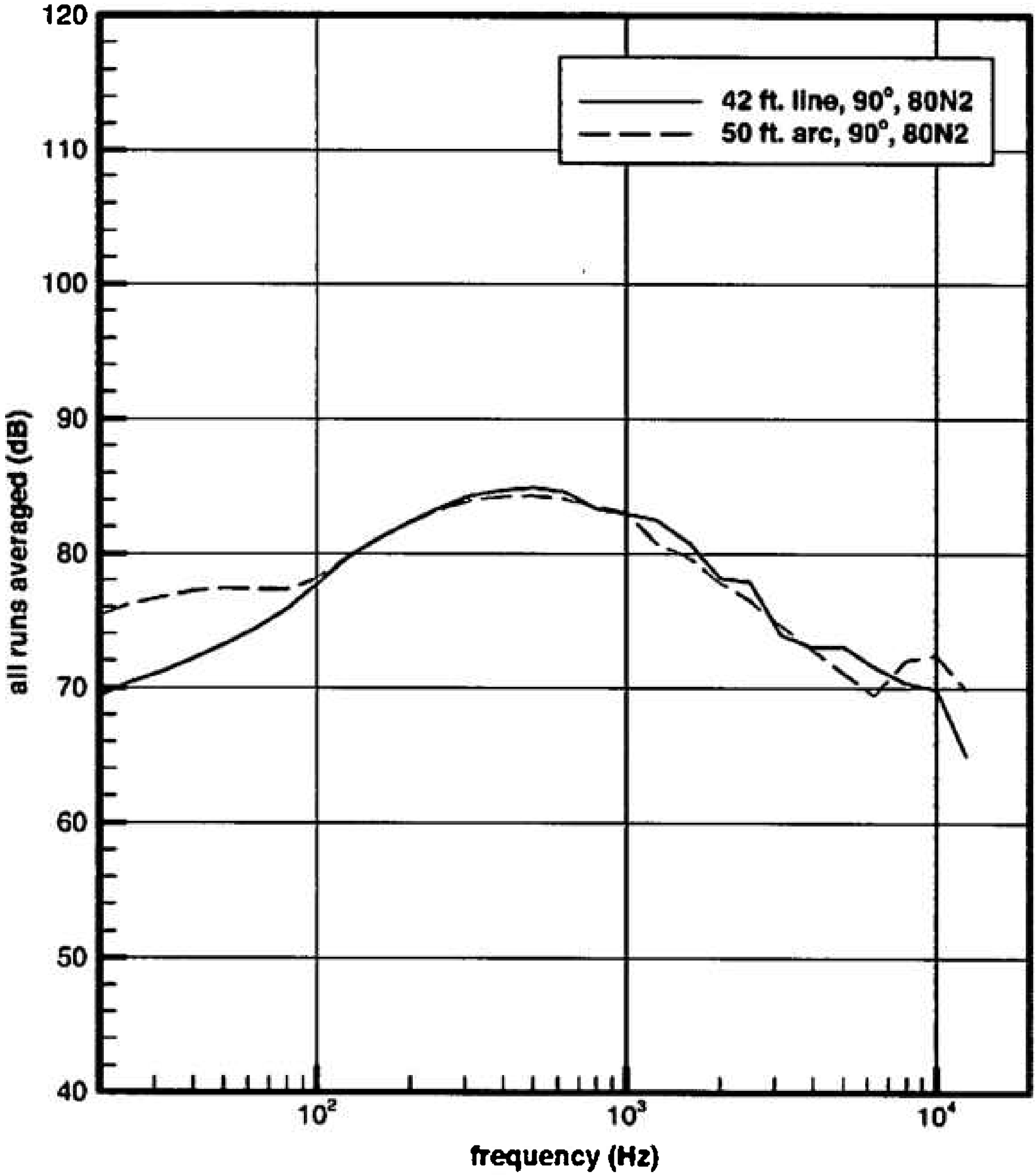

Figure 2. Comparison between noise spectra measured by a microphone on the 42 ft. array and that measured by .a microphone on the 50 ft arc array at 90 degrees at 80N2 power setting.

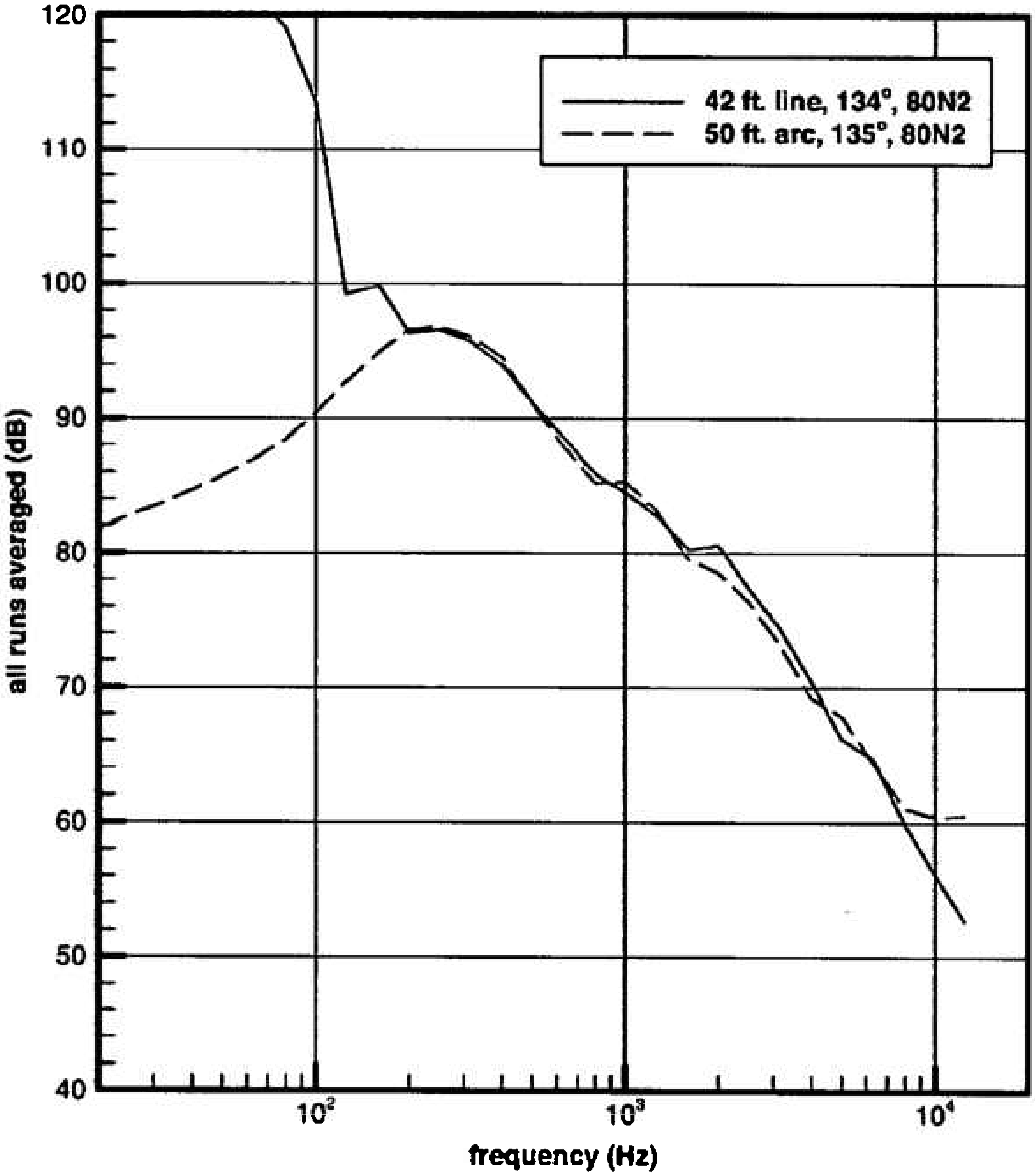

Figure 3. Comparison between noise spectra measured by a microphone on the 42 ft. array and that measured by a microphone on the 50 ft arc array at 134 degrees at 80N2 power setting.

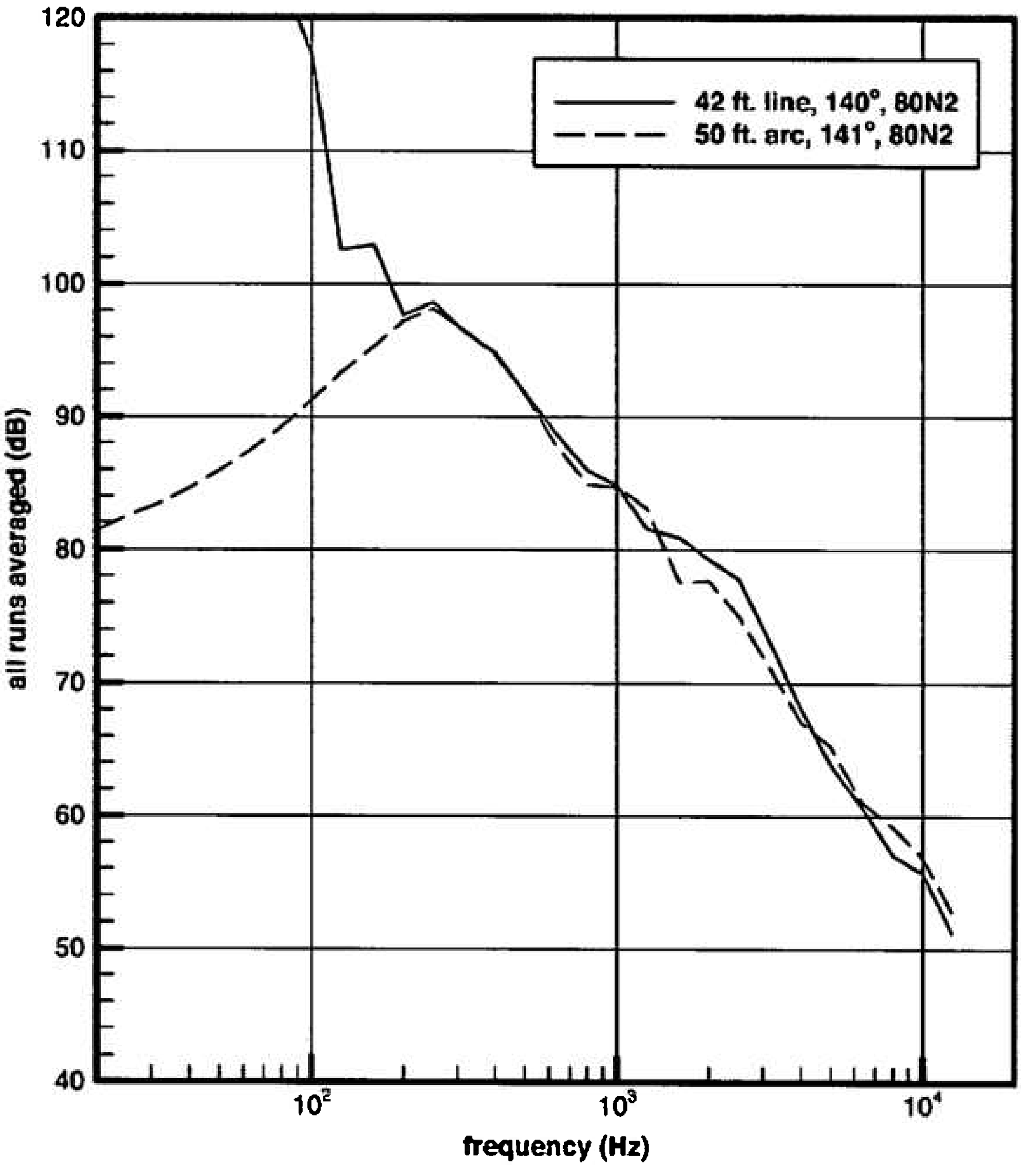

Figure 4. Comparison between noise spectra measured by a microphone on the 42 ft. array and that measured by a microphone on the 50 ft arc array at 140 degrees at 80N2 power setting.

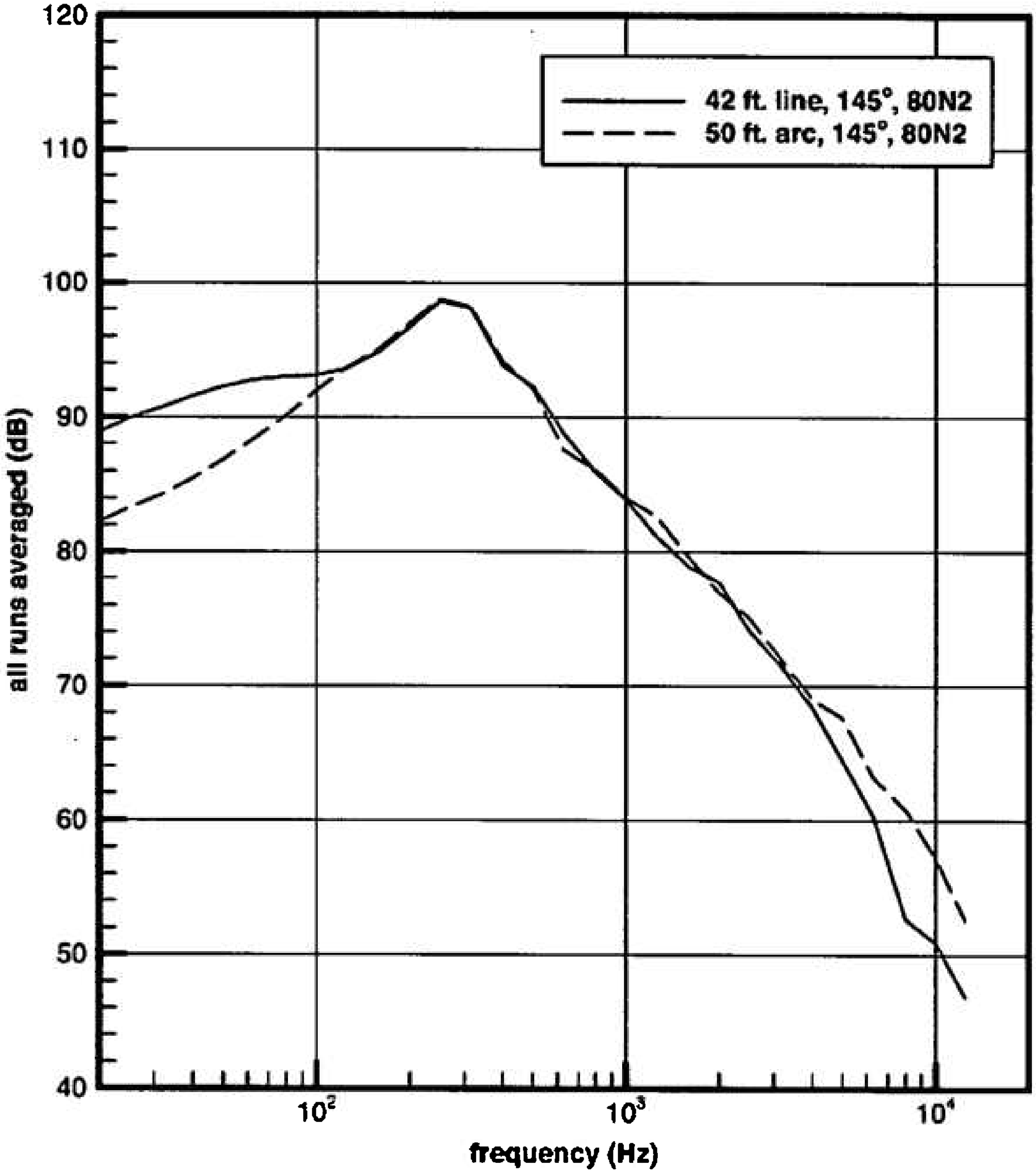

Figure 5. Comparison between noise spectra measured by a microphone on the 42 ft. array and that measured by a microphone on the 50 ft arc array at 145 degrees at 80N2 power setting.

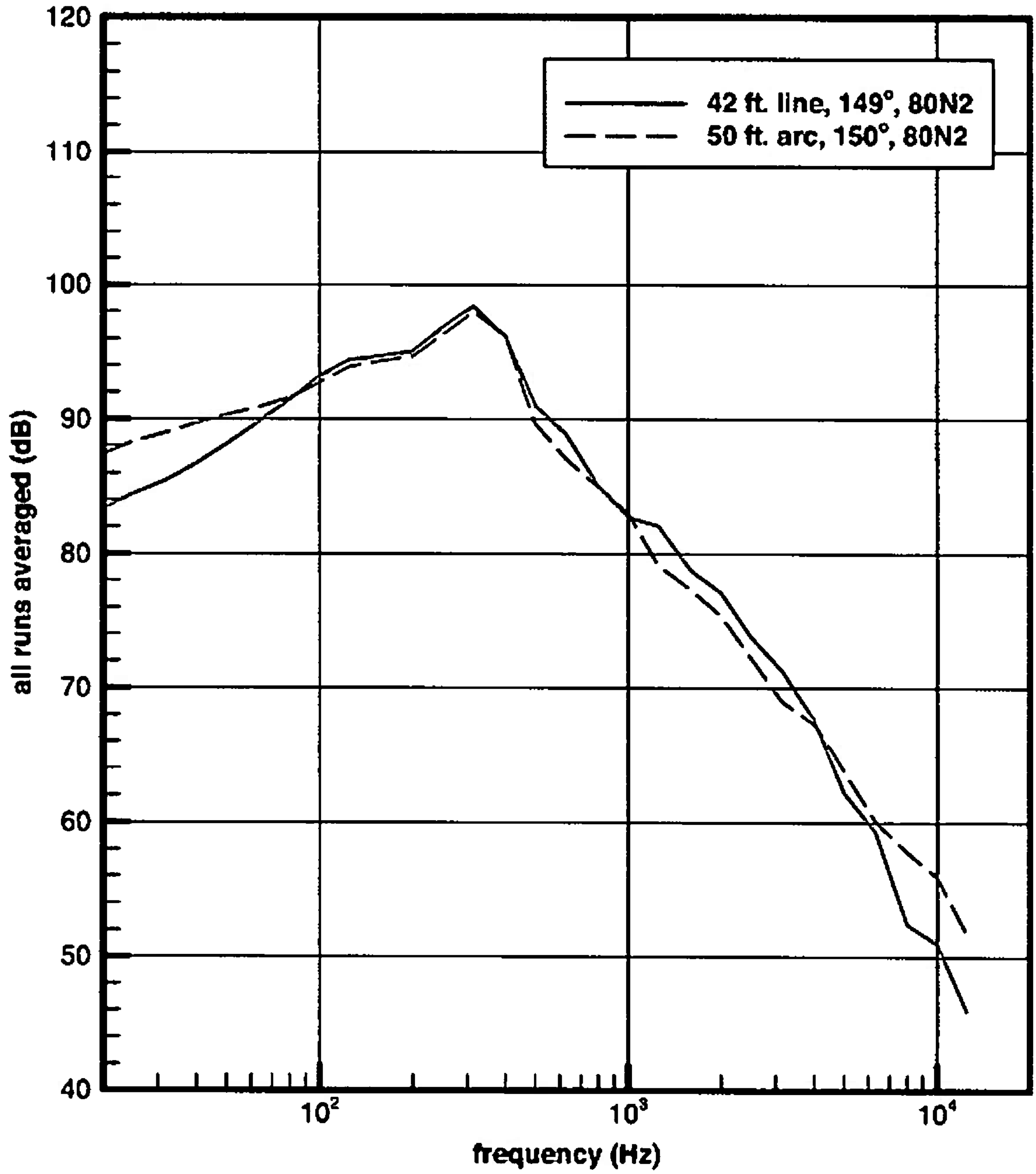

Figure 6. Comparison between noise spectra measured by a microphone on the 42 ft. array and that measured by a microphone on the 50 ft arc array at 150 degrees at 80N2 power setting.

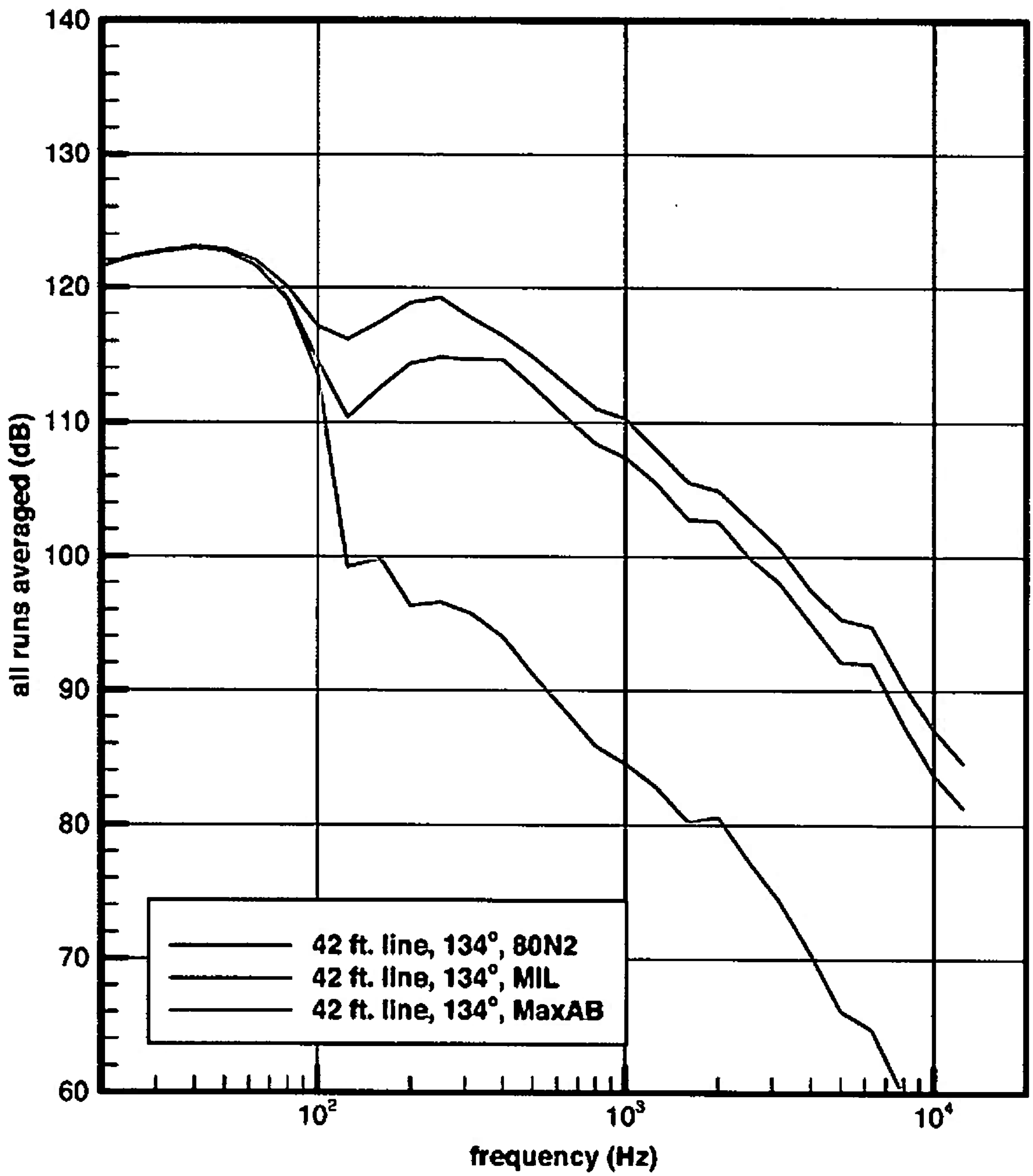

Figure 7. A comparison of the level of back ground noise and jet noise at 134 degrees on the 42 ft line at three power settings.

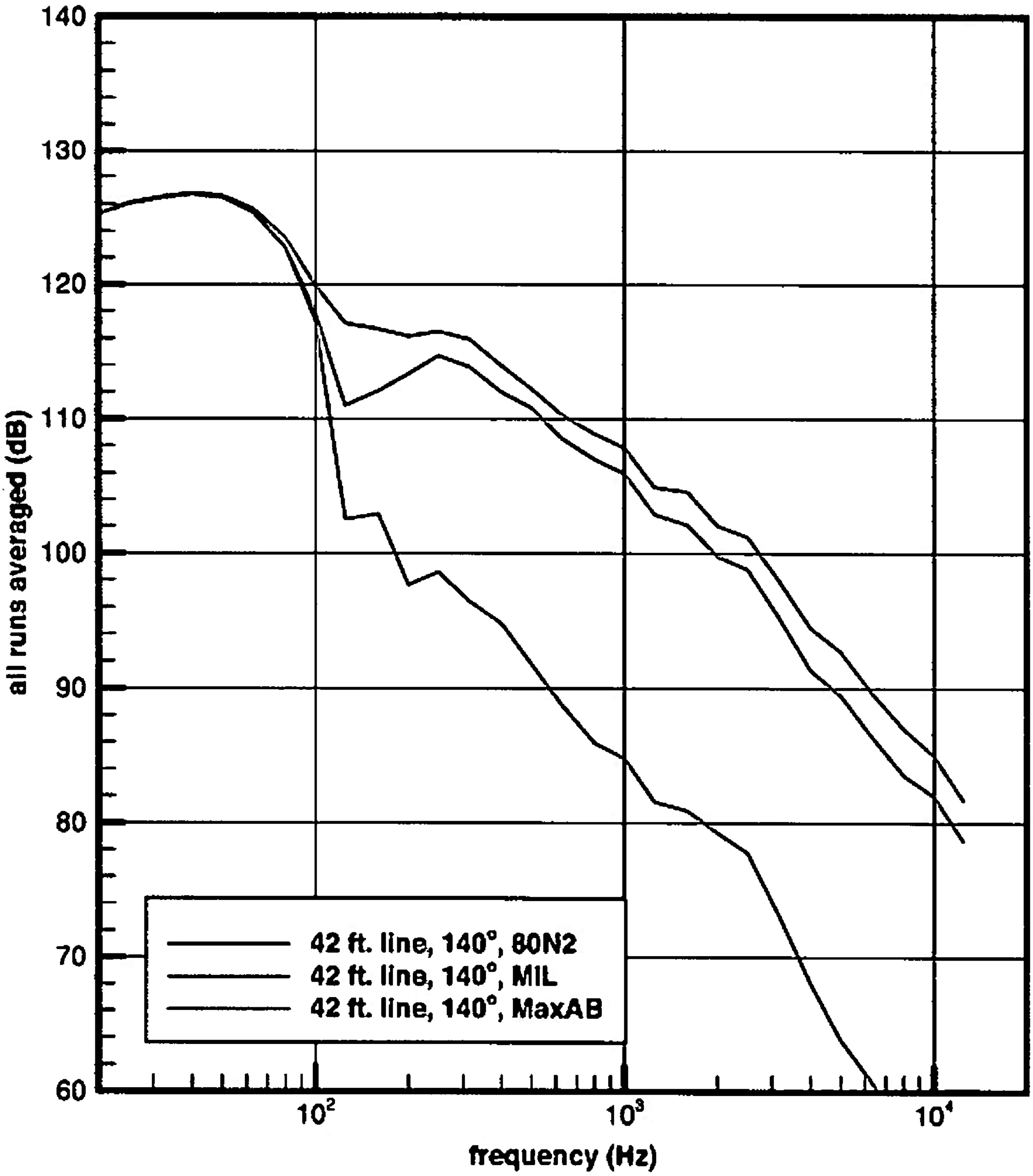

Figure 8. A comparison of the level of back ground noise and jet noise at 140 degrees on the 42 ft line at three power settings.

2. Comparisons between the noise of a F-18E aircraft and that of a laboratory hot supersonic jet.

It is now well established that the noise of a high-speed laboratory jet consists of two dominant components. They are both turbulent mixing noise: one from the fine scale turbulence and the other from the large turbulence structures of the jet flow. It has been found that the two components have very different radiation characteristics. The large turbulence structures noise radiates principally within a cone in the downstream direction whereas the fine scale turbulence noise is radiated in all directions. However, within the Mach wave cone of radiation, the large turbulence structures noise is dominant. As a result, the fine scale turbulence noise cannot be easily observed. The radiation pattern is shown in figure 9. It has also been demonstrated that the spectrum of each of these two noise components fit a nearly universal similarity spectrum regardless of jet temperature, Mach number and direction of radiation. Figure 10 shows the two similarity spectra. The peaky spectrum is for the large turbulence structures noise and the broader spectrum is for the fine scale turbulence noise.

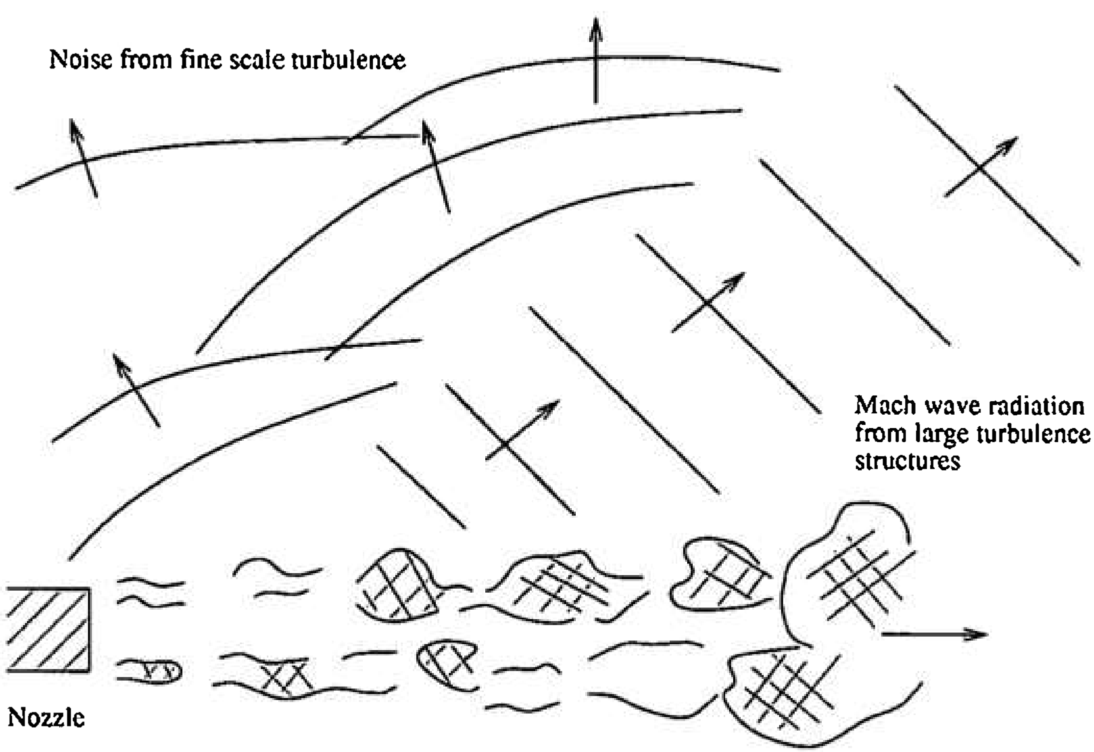

Figure 9. The two noise source model of high-speed jets.

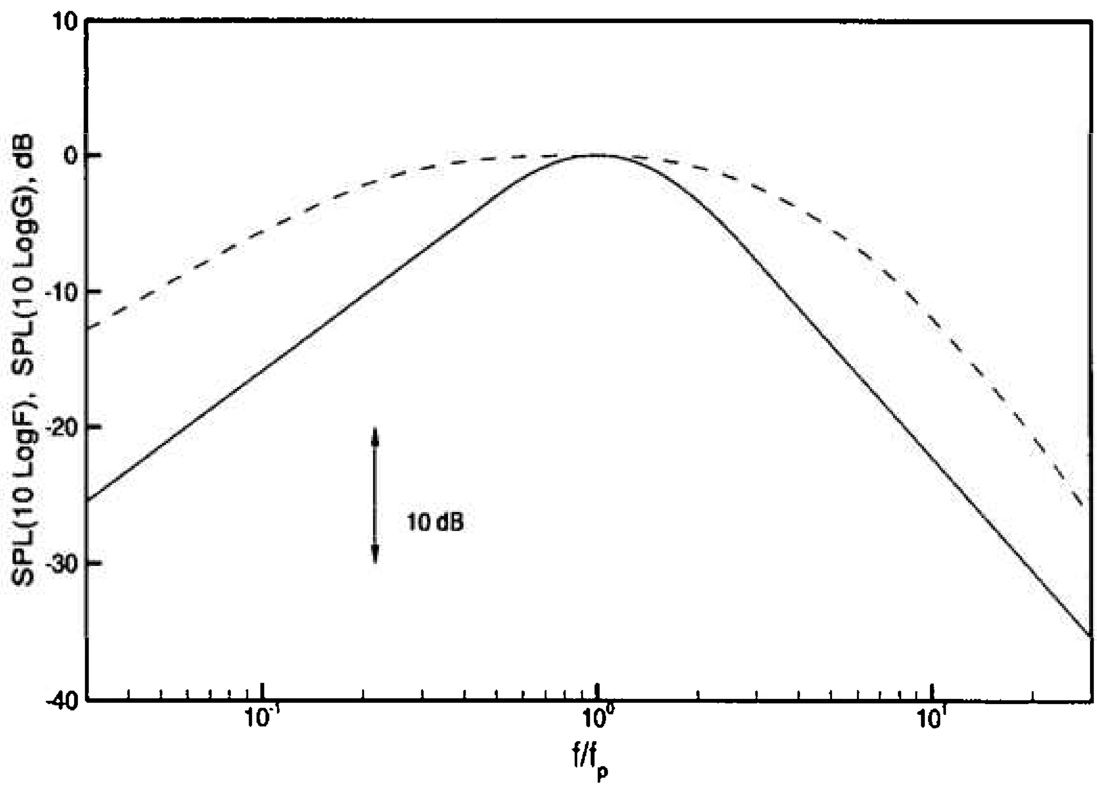

Figure 10. The two similarity spectra of turbulent mixing noise of high-speed jets.

In a previous work analyzing the noise spectra of the noise of a F-22A aircraft (Tam and Parrish, 'The noise of high-performance aircraft at afterburner, Journal of Sound and Vibration, Vol. 352, 103-128, 2015), it was found that when the engine was operating at intermediate power, the jet noise of the engine consisted of two dominant components. The spectrum of each component was a good fit to the similarity spectrum of laboratory jets. This suggests that, at intermediate power, the noise of a F-22A jet is the same as that of a supersonic laboratory jet. Based on this result, it is our expectation that at operating condition 80N2, the noise of a F-18E jet would be very similar to that of a laboratory jet as well. This turns out to be largely true.

Figures 11, 12 and 13 are comparisons between the noise spectra of a F18E jet and the similarity spectrum of fine scale turbulence noise of high-speed jets at 35^0, 54^0 and 77^0. Overall, there are reasonably good agreements. The spectrum at 35^0 exhibits two spikes. We will assess whether they are tones when we analyze the narrow band noise data.

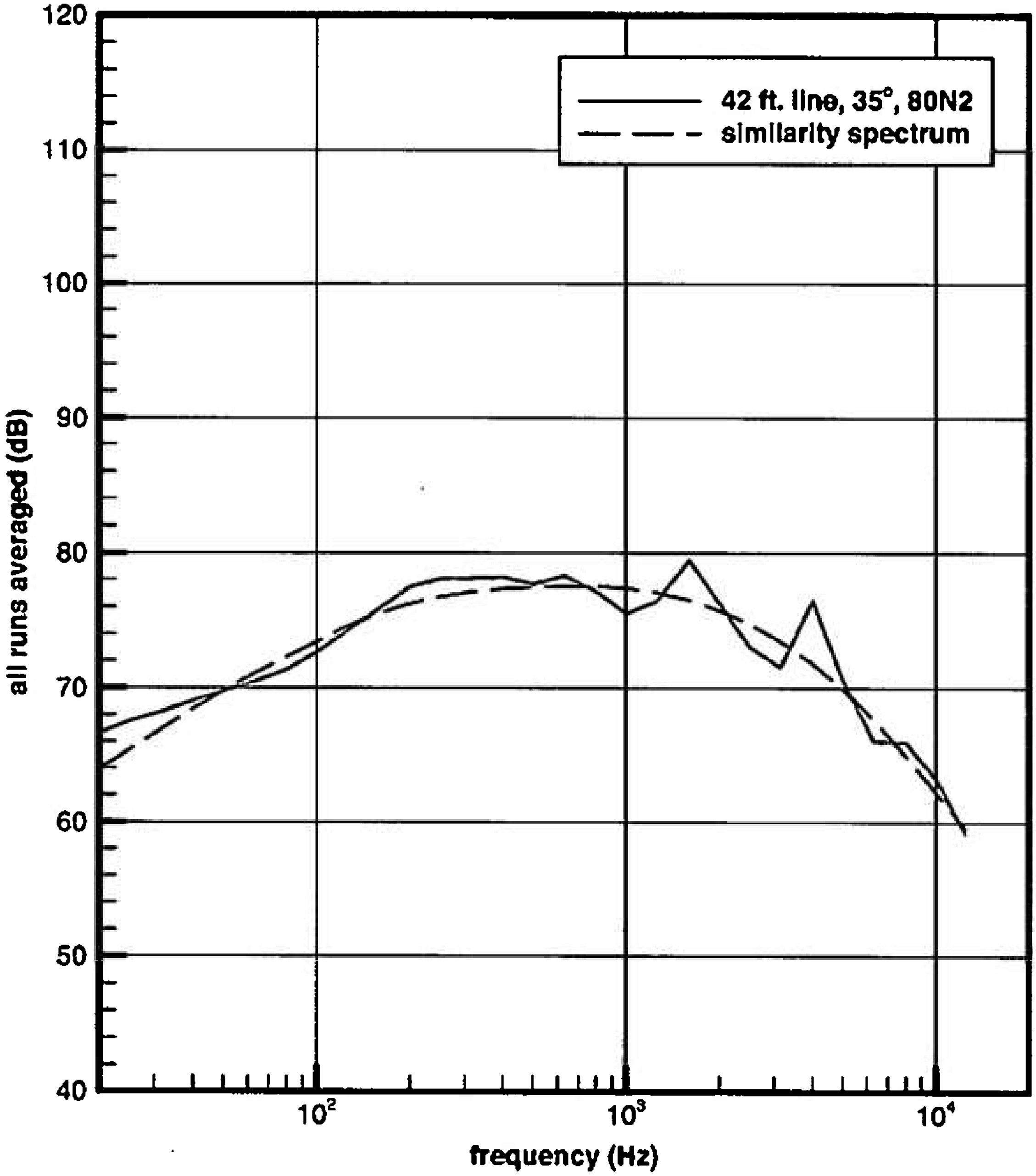

Figure 11. Comparison between the noise spectrum at 35^0 at 80N2 power and the similarity spectrum of fine scale turbulence noise of high-speed jets.

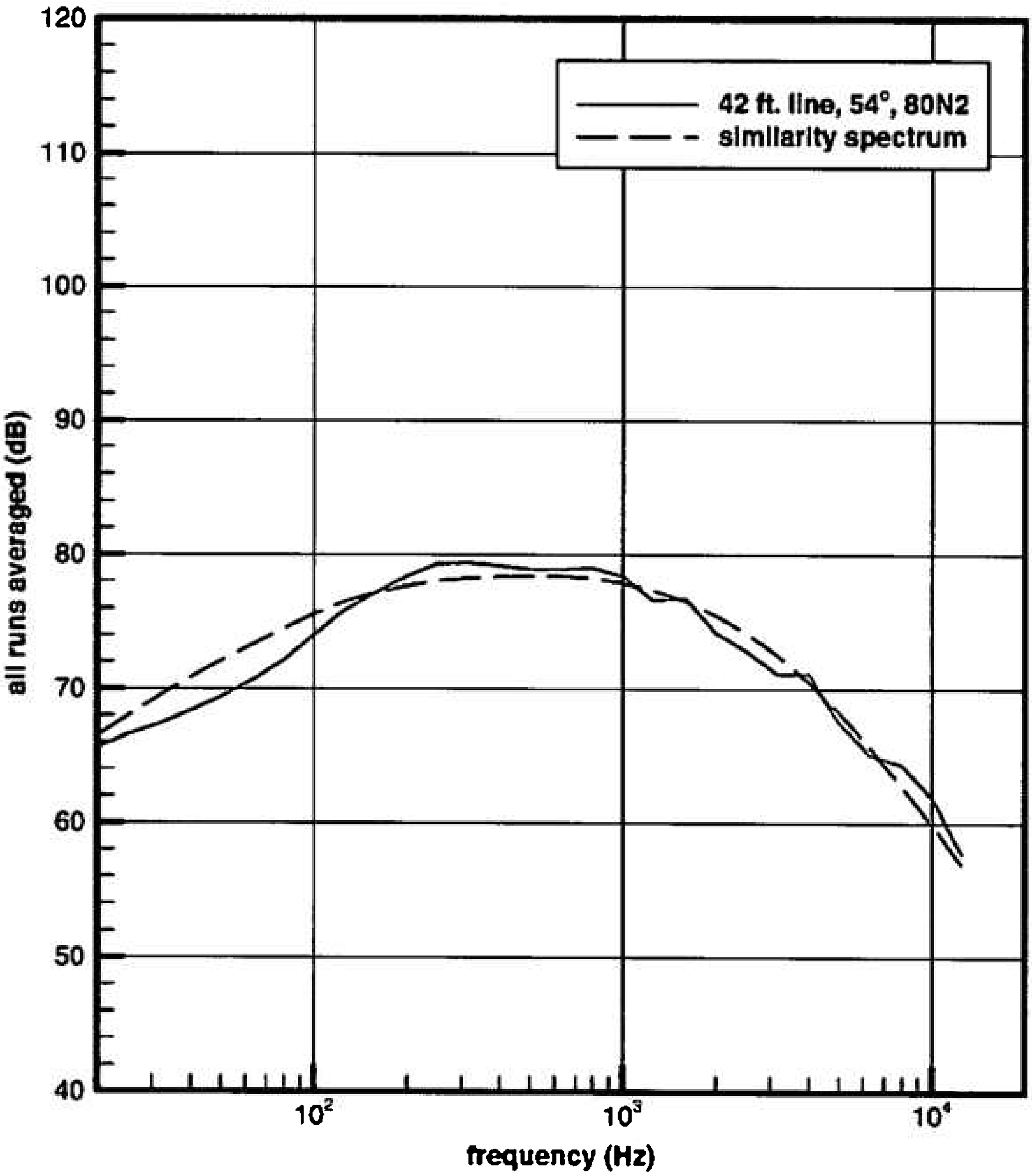

Figure 12. Comparison between the noise spectrum at 54^0 at 80N2 power and the similarity spectrum of fine scale turbulence noise of high-speed jets.

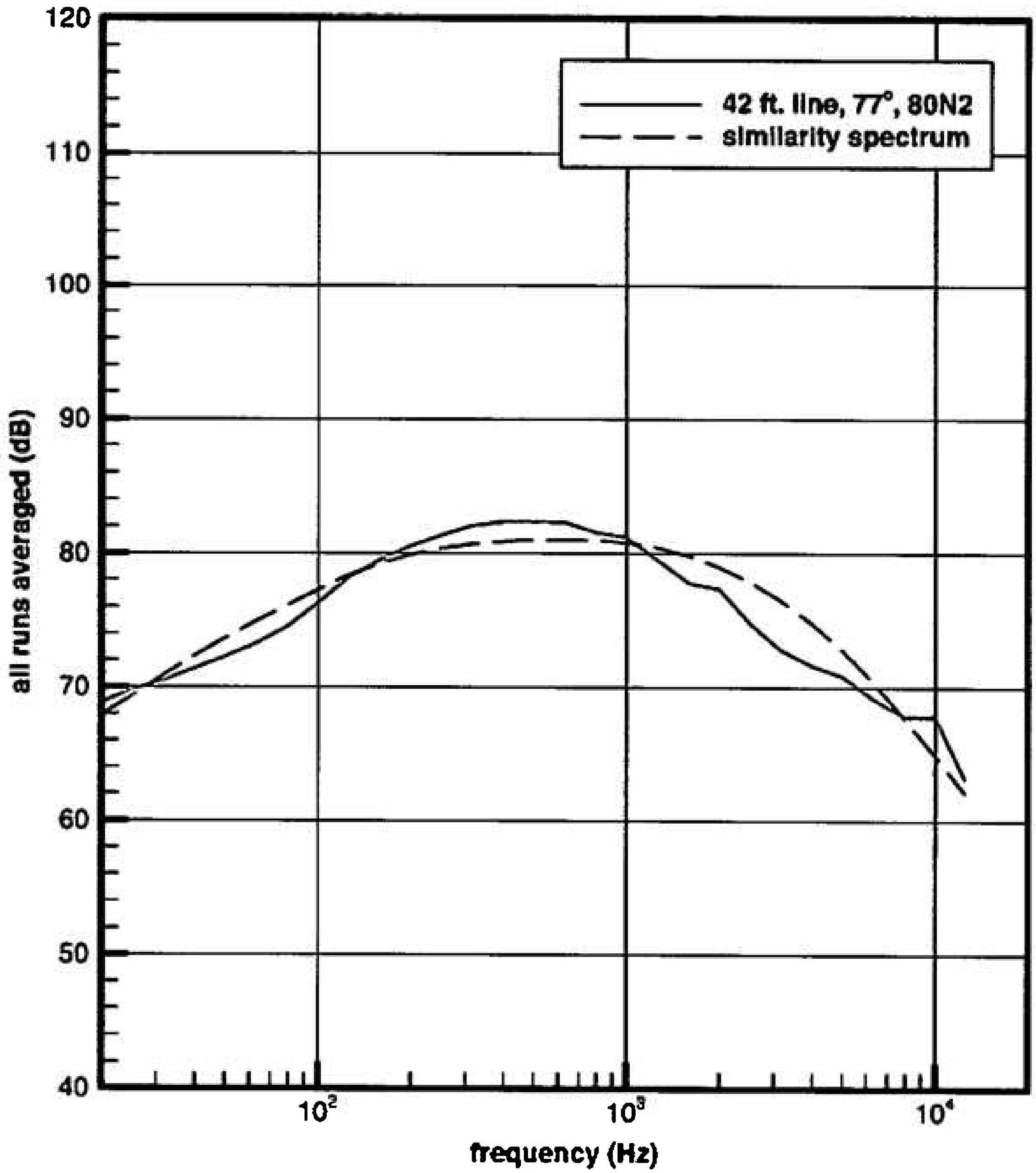

Figure 13. Comparison between the noise spectrum at 77^0 at 80N2 power and the similarity spectrum of fine scale turbulence noise of high-speed jets.

It is known, at $\theta = 130$ degree and larger, the noise spectrum of a laboratory model jet fits the similarity spectrum of the large turbulence structures noise. Figures 14 to 17 are comparisons of the noise spectra of a F-18E aircraft at 130^0, 141^0, 150^0 and 160^0 and that of the large turbulence structures noise. These figures show clearly that there is good agreement at all these angles. At 150^0, the noise spectrum of the F-18E jet shows a somewhat unusual shape. The reason for this is unknown.

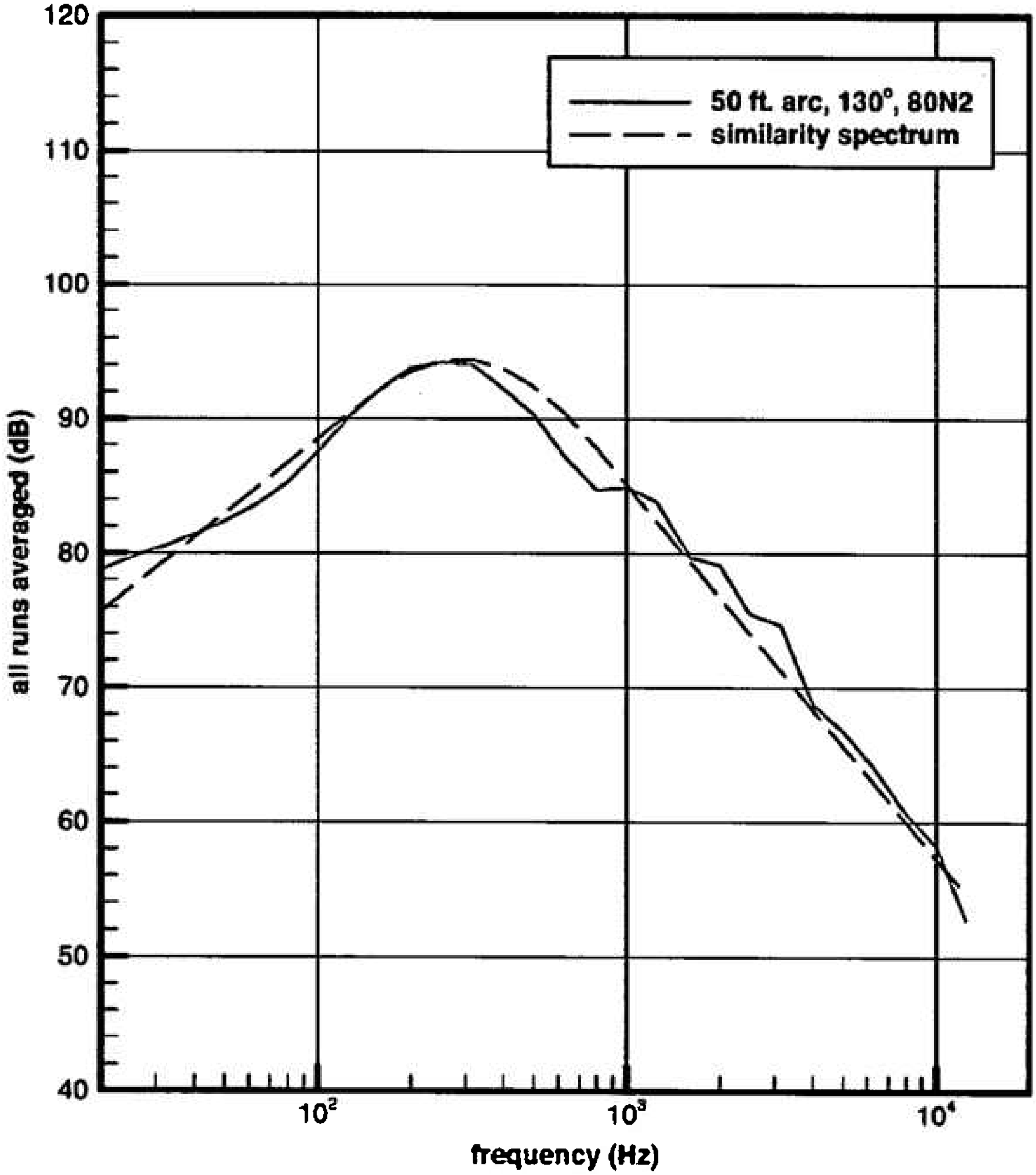

Figure 14. Comparison between the noise spectrum at 130^0 at 80N2 power and the similarity spectrum of the large turbulence structures noise of high-speed jets.

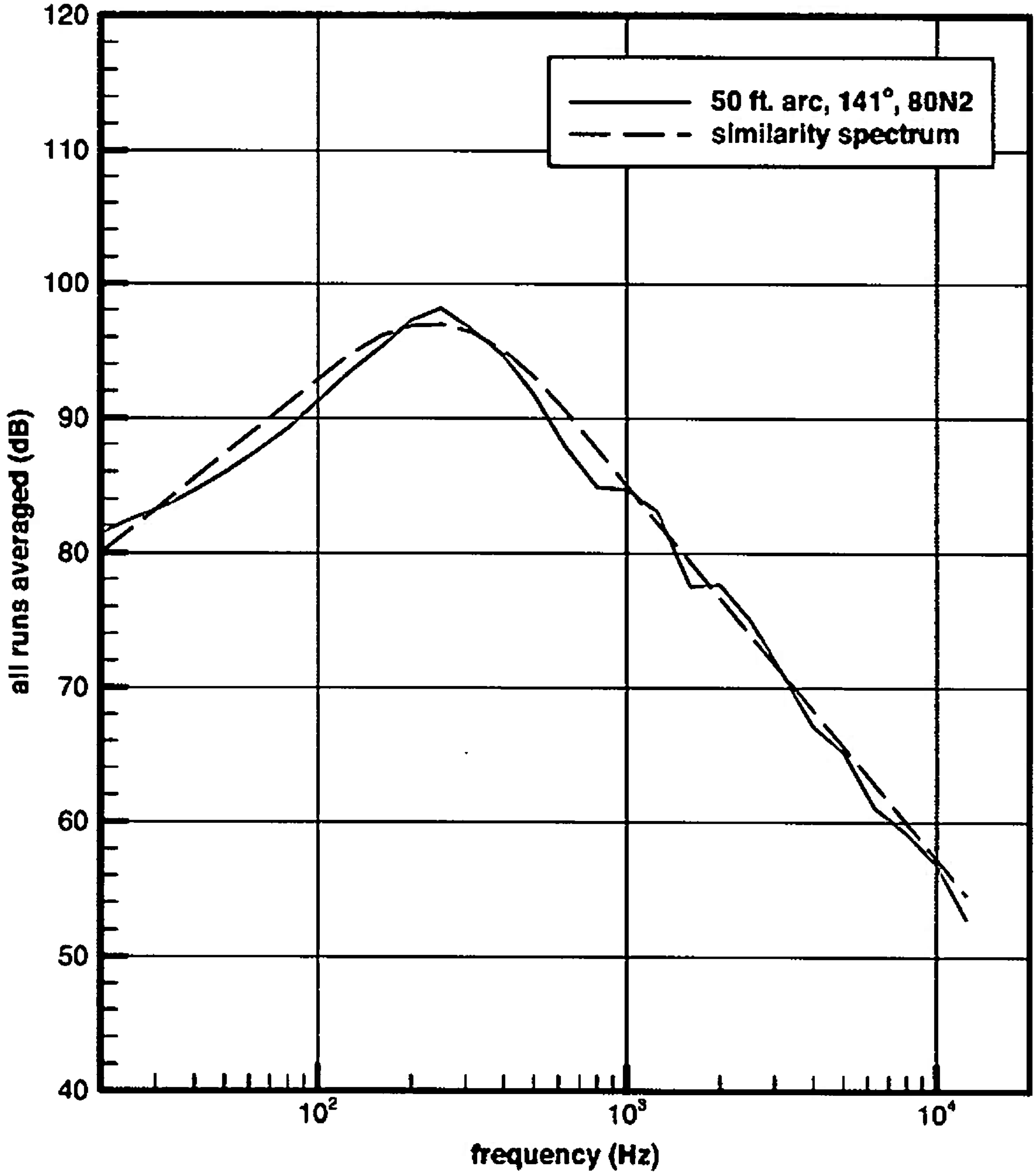

Figure 15. Comparison between the noise spectrum at 141^0 at 80N2 power and the similarity spectrum of the large turbulence structures noise of high-speed jets.

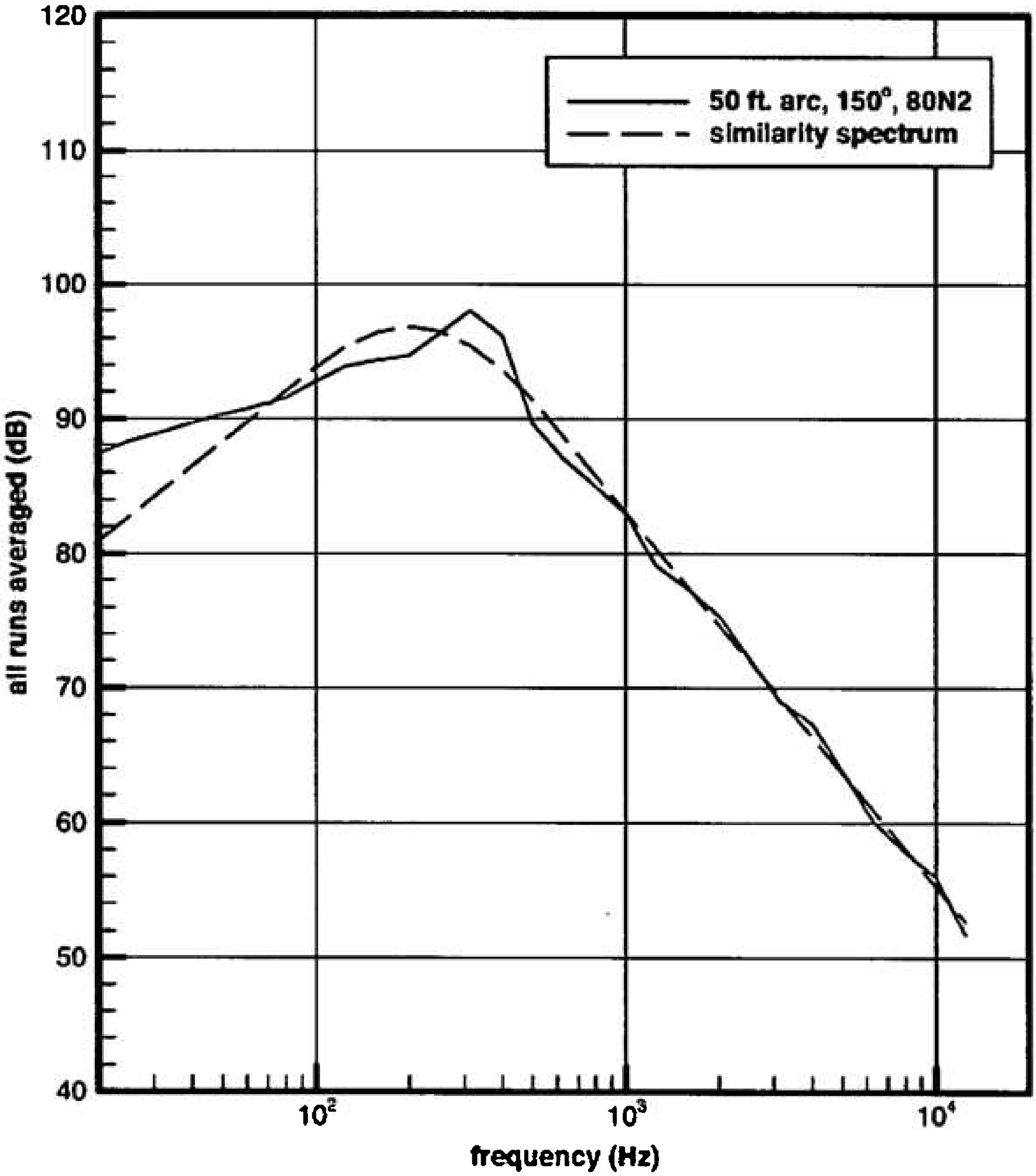

Figure 16. Comparison between the noise spectrum at 150^0 at 80N2 power and the similarity spectrum of the large turbulence structures noise of high-speed jets.

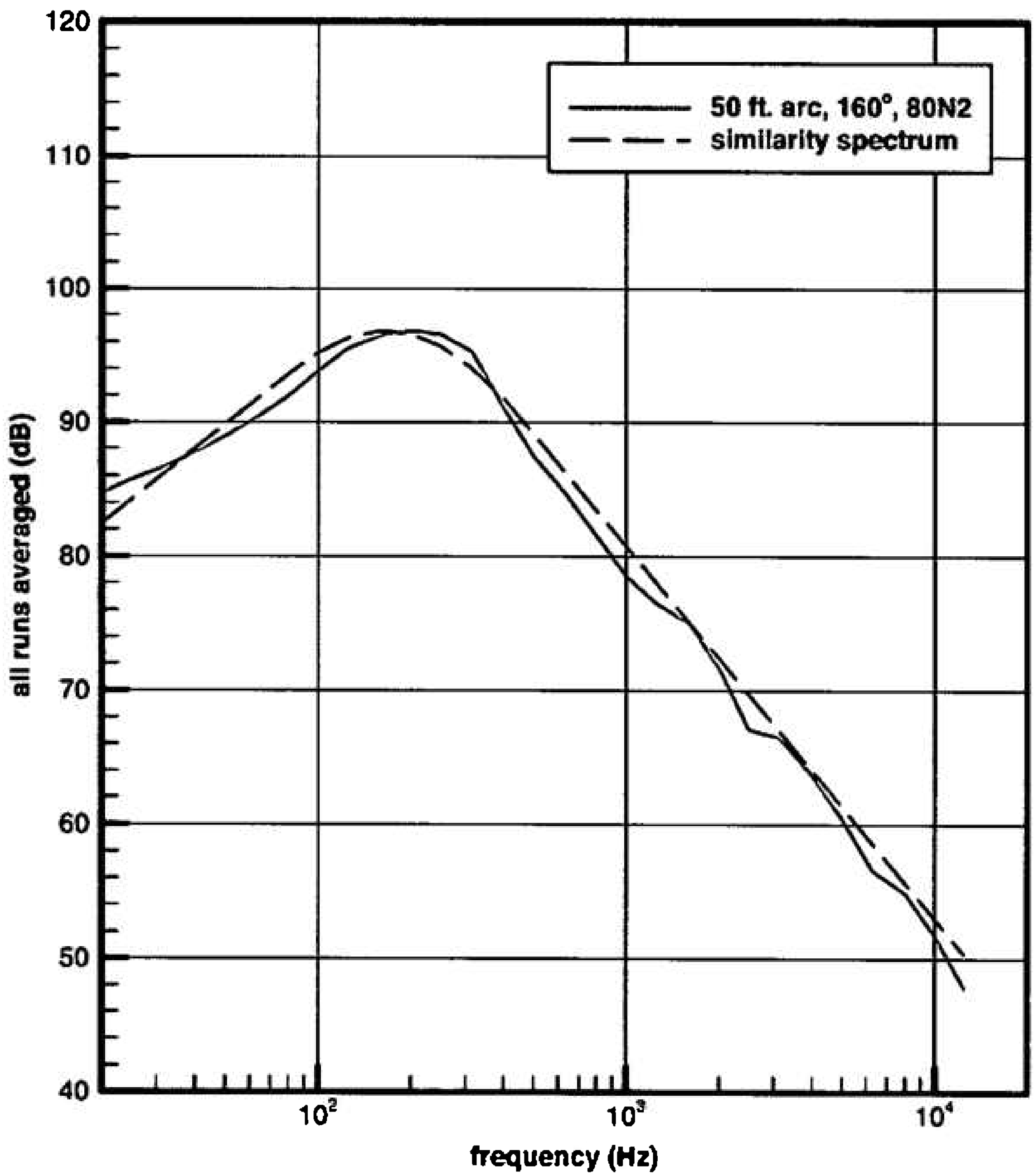

Figure 17. Comparison between the noise spectrum at 160^0 at 80N2 power and the similarity spectrum of the large turbulence structures noise of high-speed jets.

Based on the above comparisons, it is possible to conclude that the noise of a F-18E aircraft at 80N2 power is similar to that of a laboratory model supersonic jet.

3. Influence of power setting on jet noise

80N2 is the lowest power setting for the NAVAIR noise data. The two higher power setting is Mil and MaxAB. At the higher power setting, jet noise increases substantially. The important question is whether there is a change in the dominant noise components of the jet. In this preliminary report, we are limited to demonstrate that there is a qualitative difference between the noise at 80N2 power setting and those at Mil and MaxAB power settings.

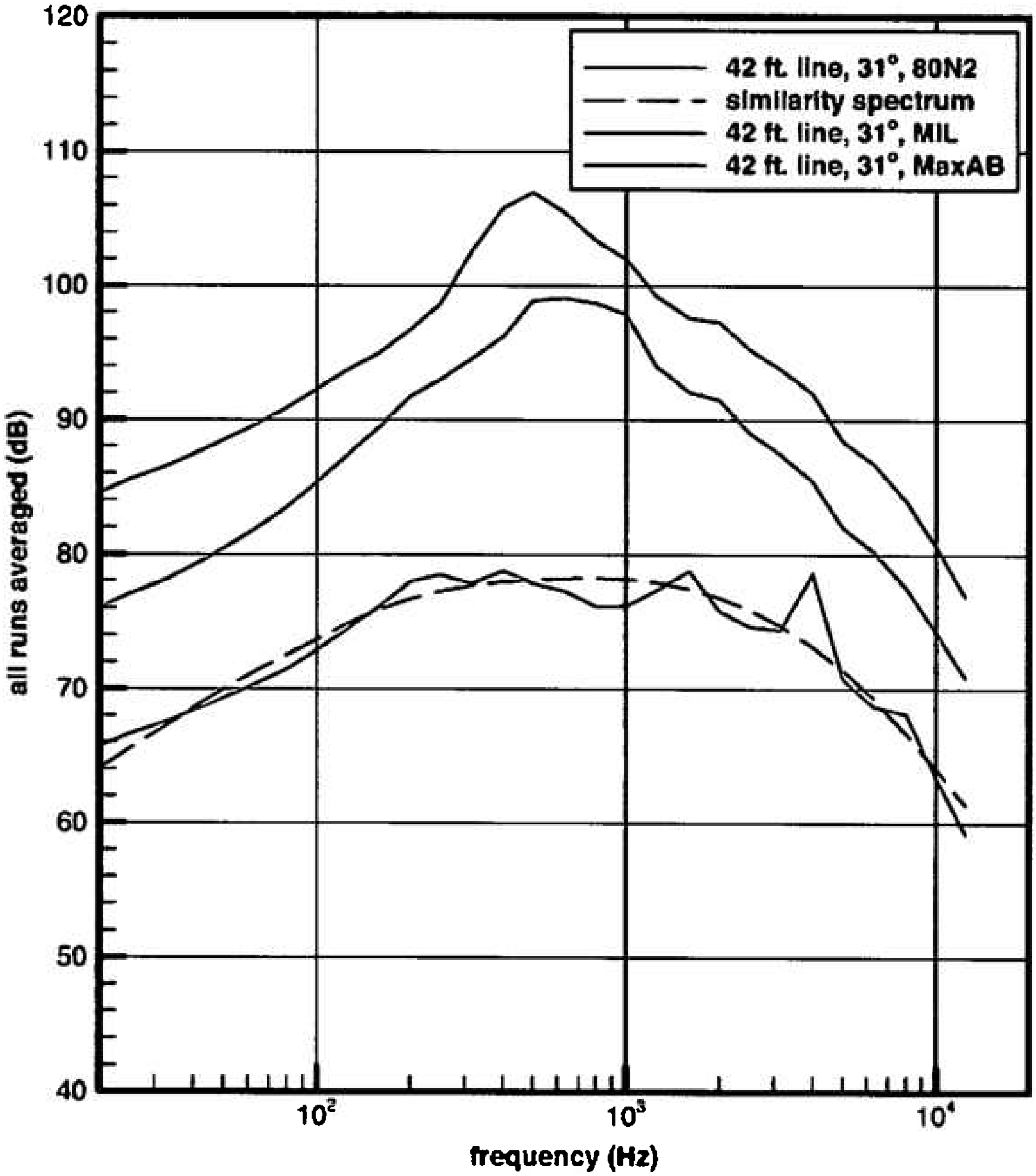

Figure 18. Noise spectrum at 31^0 at 3 power settings. Dashed line is the similarity spectrum of the fine scale turbulence noise of high-speed jets.

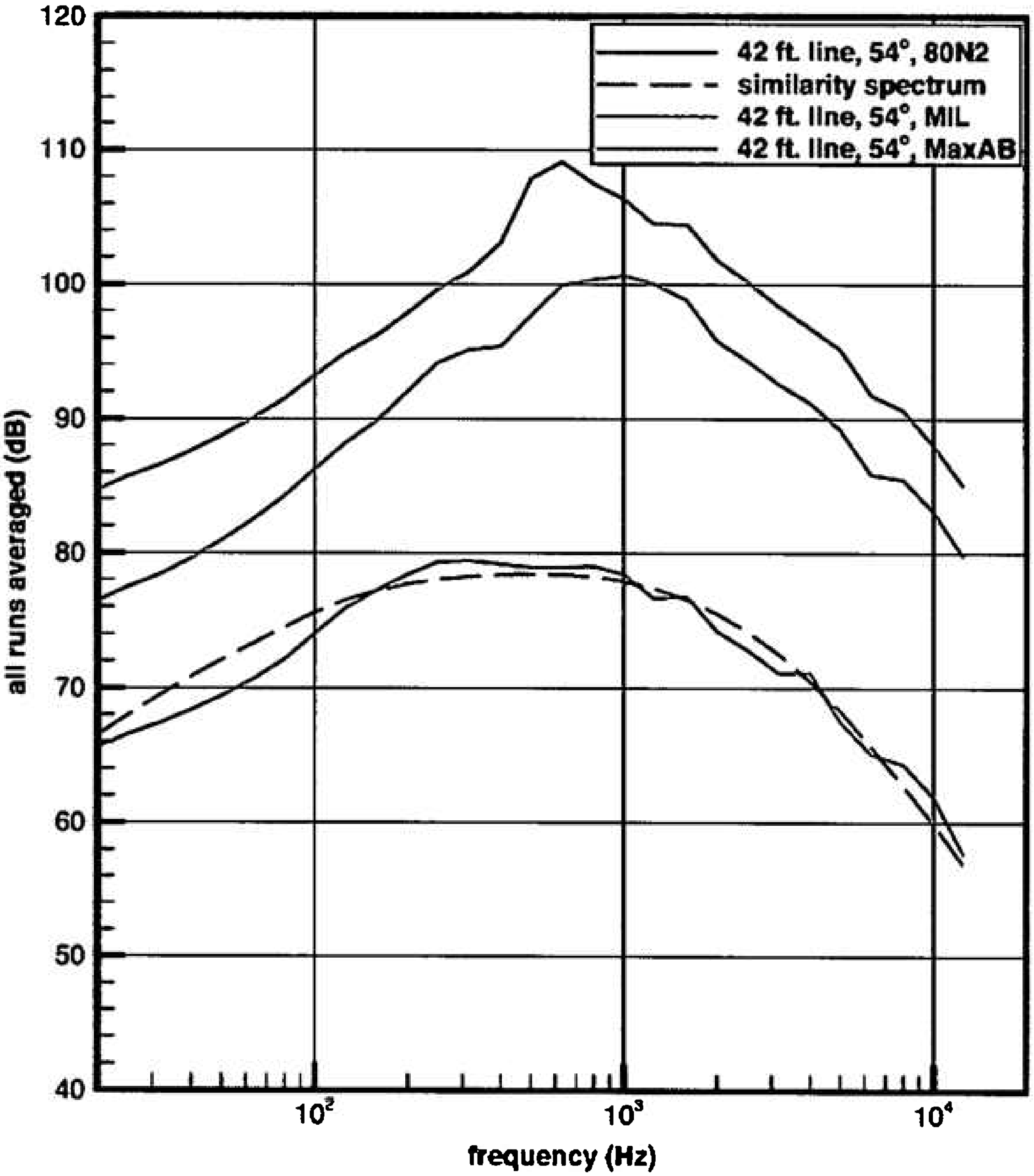

Figure 19. Noise spectrum at 54^0 at 3 power settings. Dashed line is the similarity spectrum of the fine scale turbulence noise of high-speed jets.

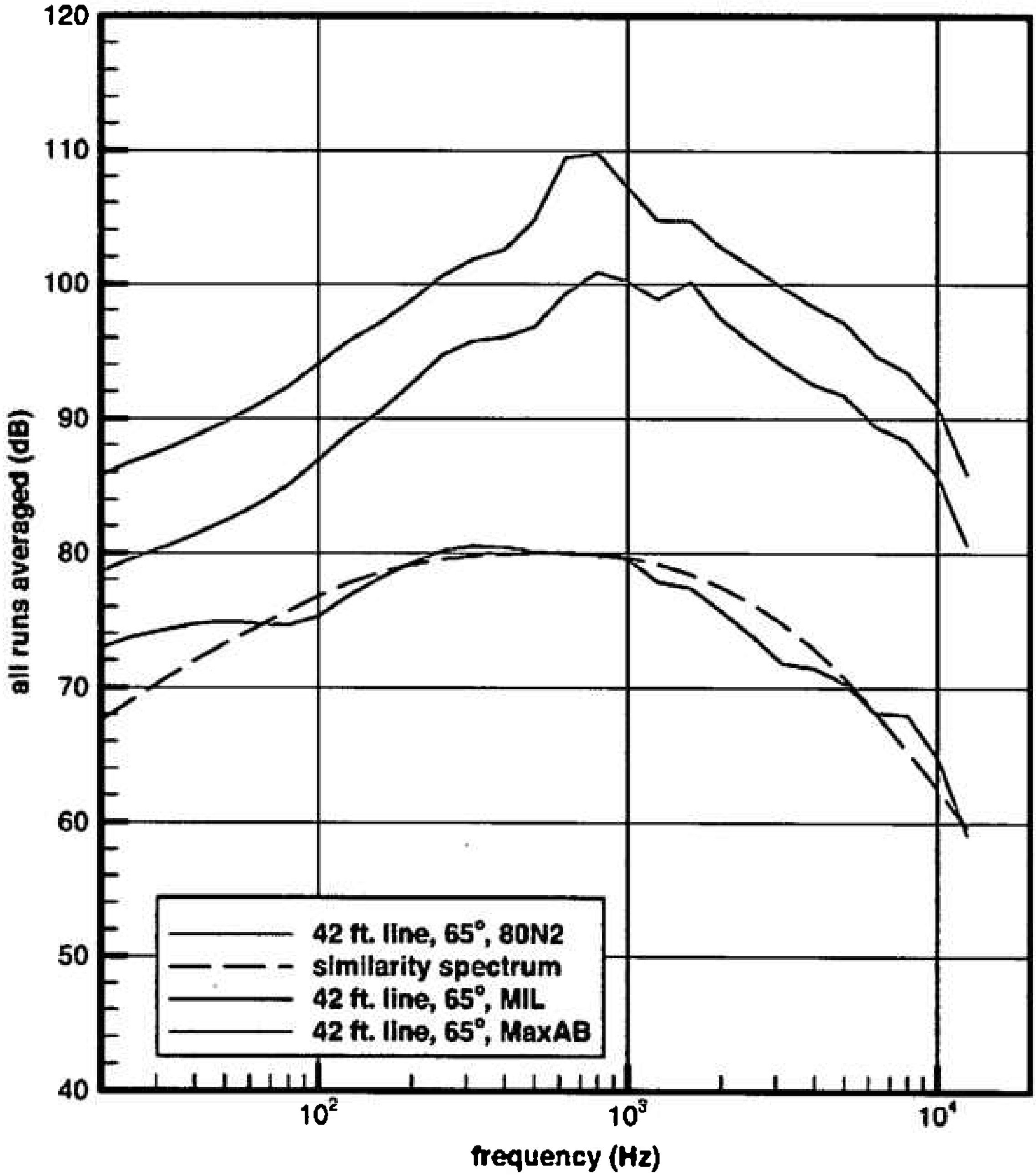

Figure 20. Noise spectrum at 65^0 at 3 power settings. Dashed line is the similarity spectrum of the fine scale turbulence noise of high-speed jets.

Figures 18 to 20 show the noise spectra at 31^0, 54^0 and 65^0 at the three power settings of 80N2, Mil and MaxAB. Clearly, at MaxAB the noise is most intense. This is followed by the noise at Mil. It is worthwhile to point out that the shapes of the spectra at Mil are very similar to those at MaxAB. This is true at all angles. Shown as a dashed line in each of these figures is the similarity spectrum of the fine scale turbulence noise. On comparing the shapes of the spectra at 80N2 and those at higher power settings, it is evident that they are quite different. This suggests that fine scale turbulence noise is no longer the dominant noise component for noise radiated in the upstream and sideline directions at Mil and MaxAB power.

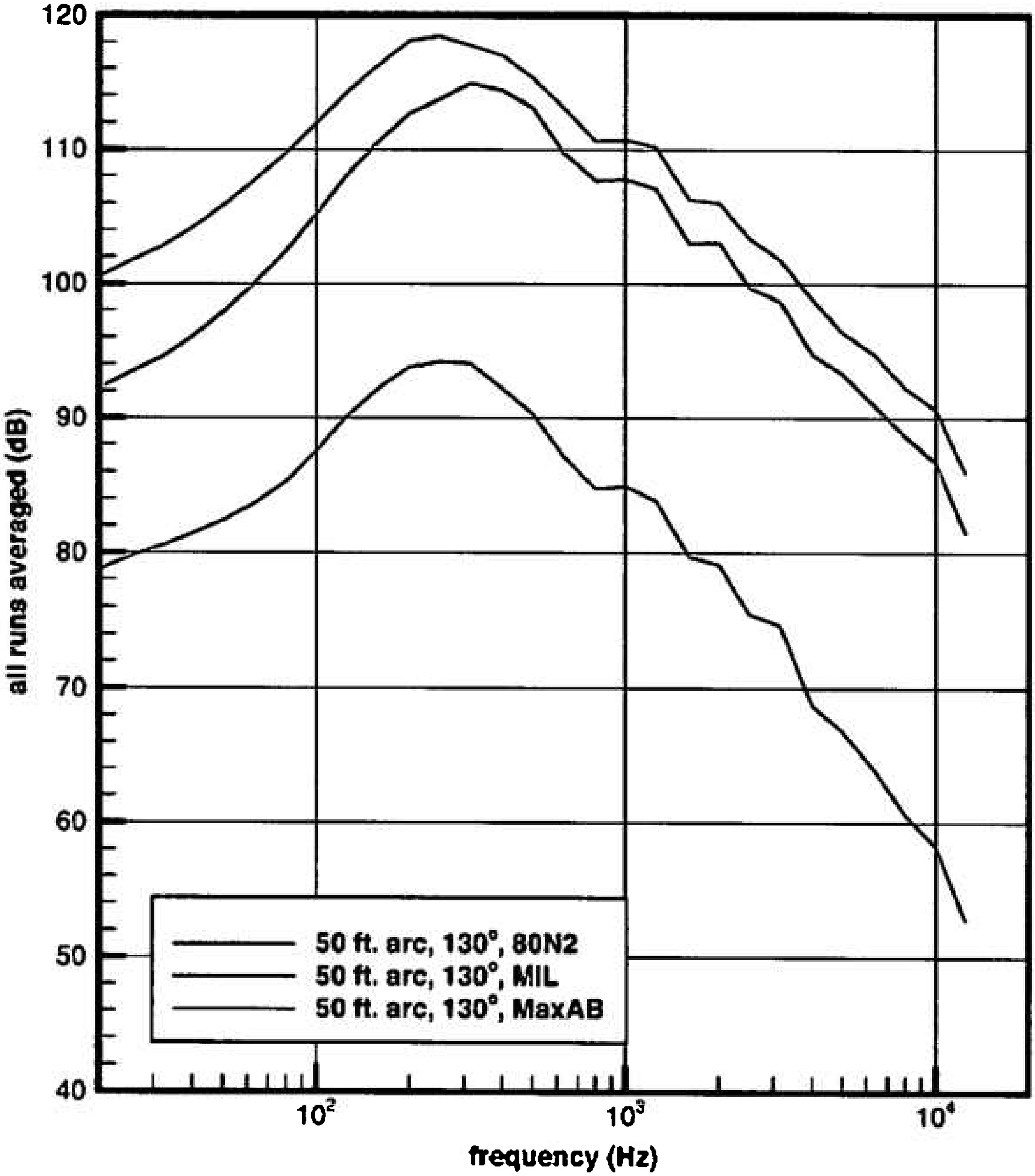

Figure 21. The noise spectra at 130^0 at three power settings.

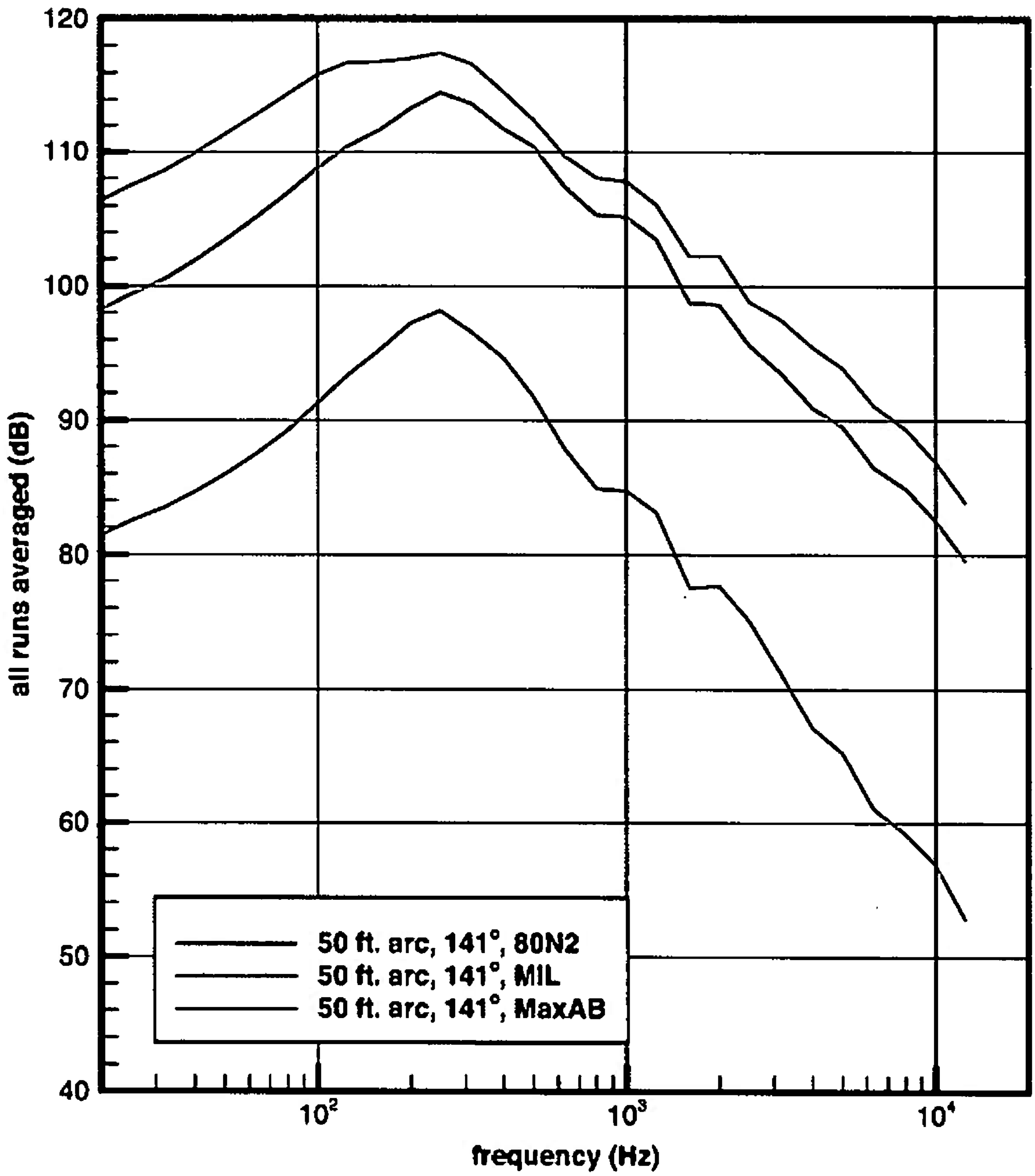

Figure 22. The noise spectra at 141^0 at three power settings.

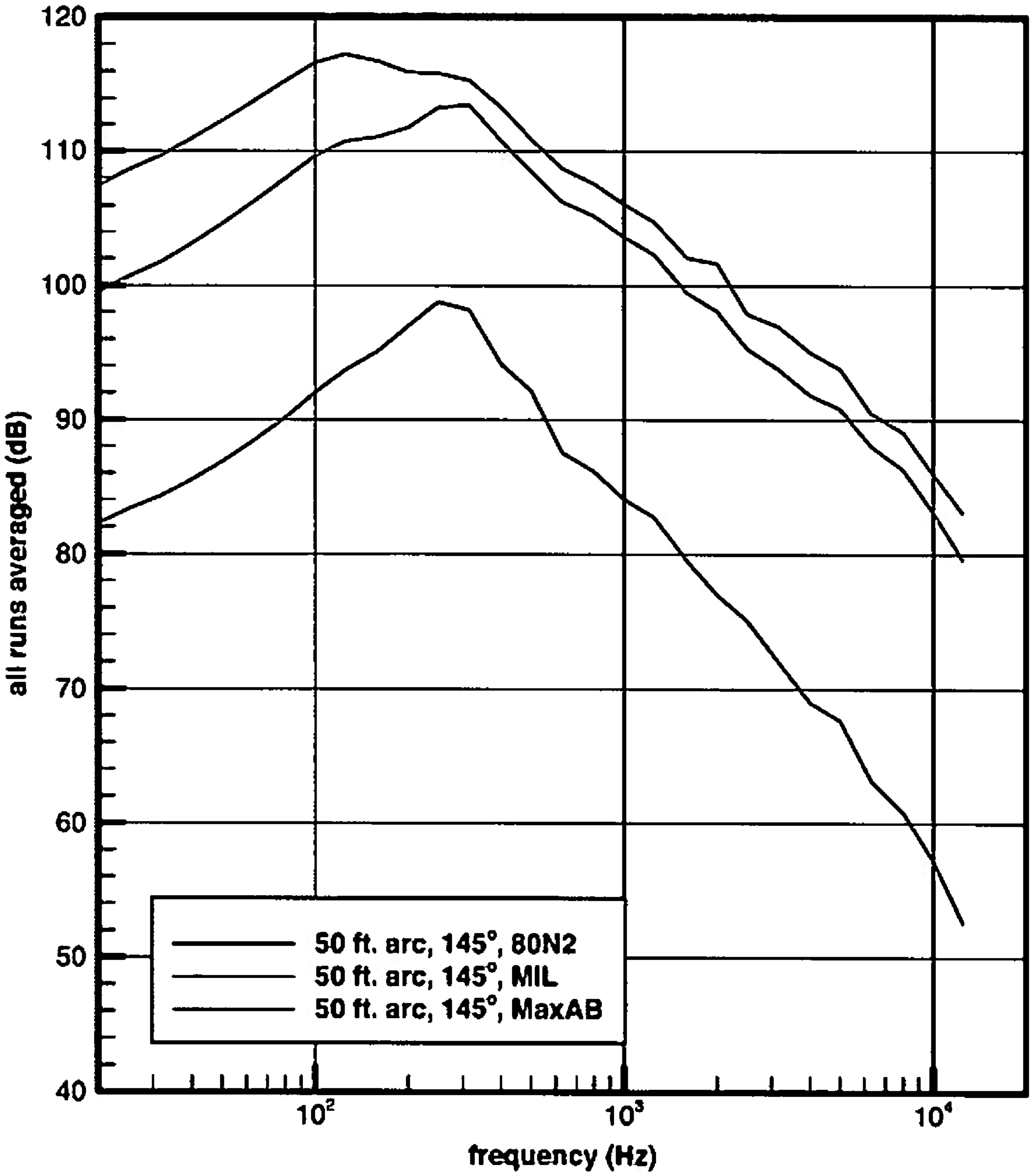

Figure 23. The noise spectra at 145^0 at three power settings.

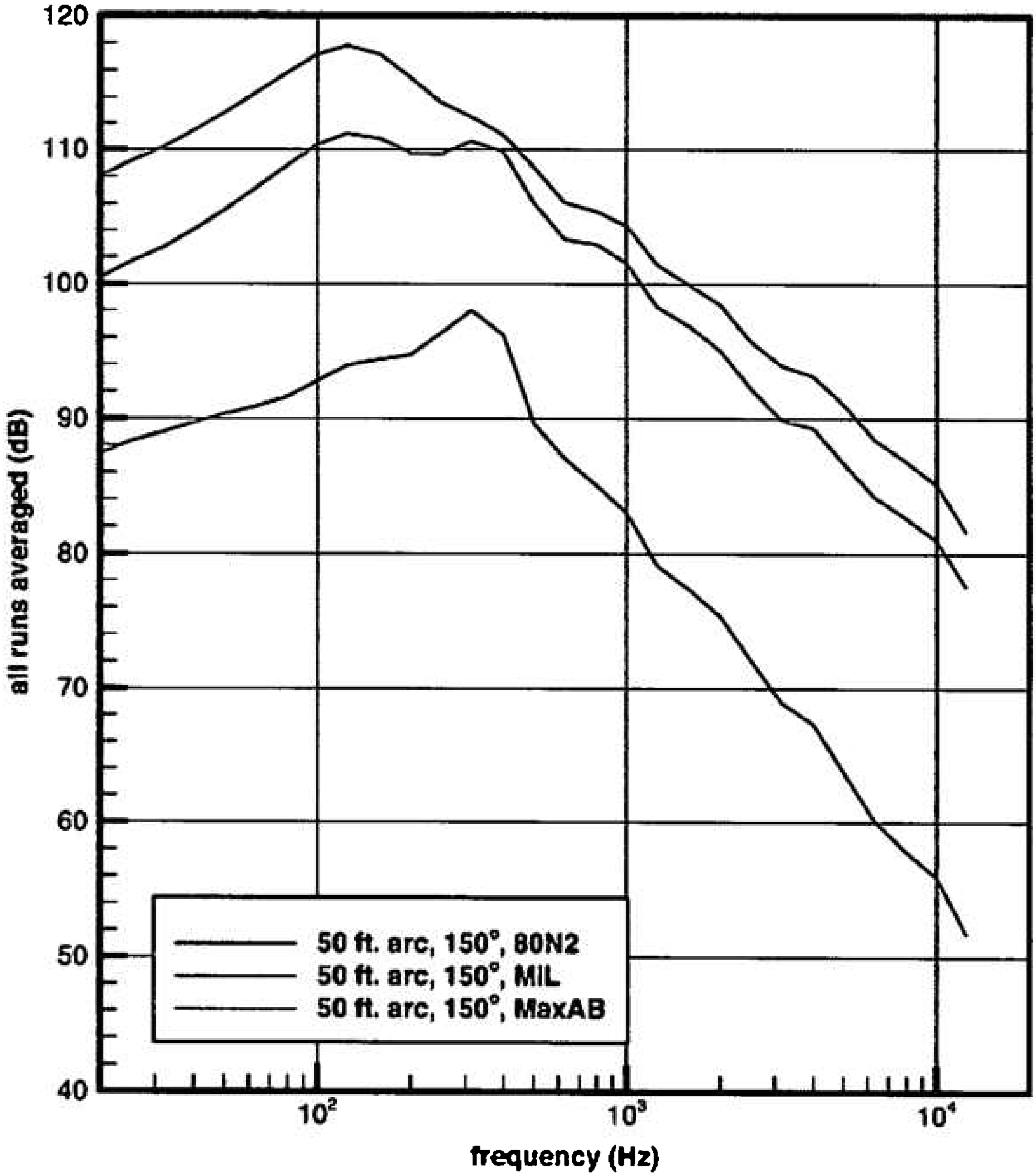

Figure 24. The noise spectra at 150^0 at three power settings.

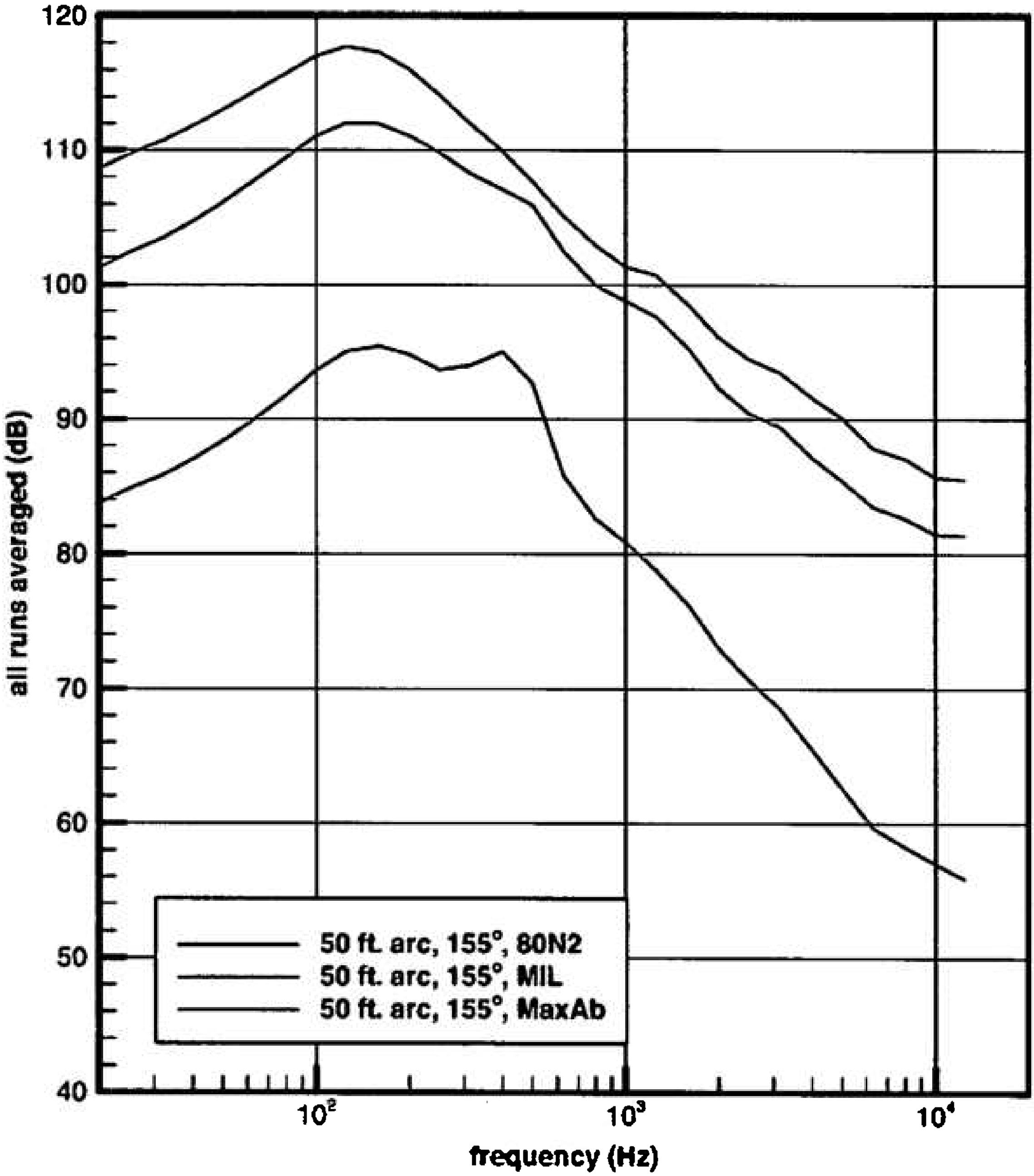

Figure 25. The noise spectra at 155^0 at three power settings.

Figures 21 to 25 compare the spectra at the three power settings at 130^0, 141^0, 145^0, 150^0 and 155^0. On reviewing these figures, it is clear that there is a gradual change in the spectral shape as inlet angle increases. In these downstream directions, the spectral shapes at Mil and MaxAB are no longer always similar. In most directions, they are also different from the shape of the spectrum at 80N2 power. A more detailed analysis of these jet spectra will be carried out during the next quarter. The first goal is to see what we can learn from the changes in the spectral shape.

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14. ABSTRACT
The noise of a F18E aircraft is studied and analyzed. The main objective is to find out whether the noise has the same dominant noise components as those of a laboratory supersonic jet. The noise spectra at 3 power settings were studied. It is found that at low power, the dominant noise componets are very similar to those of a laboratory jet. But at hight power, there are significant differences.

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