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ACOUSTIC EFFECTS ON PROFILE DRAG OF A LAMINAR FLOW AIRFOIL

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SUMMARY

A two-dimensional natural laminar flow airfoil (NLF-0414) was subjected to high-intensity sound (pure tones and white noise) over a frequency range of 2 to 5 kHz, while emersed in a flow of 240 ft/sec (Rn of 3 million) in a quiet flow facility. Using a wake-rake, wake dynamic pressures were determined and the deficit in momentum was used to calculate a two-dimensional drag coefficient. Significant increases in drag were observed when the airfoil was subjected to the high intensity sound at critical sound frequencies. However, the increased drag was not accompanied by movement of the transition location.

INTRODUCTION

It is well known that the transition behavior on laminar flow airfoils is sensitive to freestream disturbance spectra. The disturbances can be in the form of turbulence fluctuations (velocity disturbances) or acoustic fluctuations (pressure disturbances). These freestream disturbances can affect both the location and mode (i.e. dominant instability) of the transition process. In the two-dimensional flows, on an unswept airfoil for example, three of the modes of transition which are of interest include laminar-separation-induced instability, viscous (Tollmien-Schlichting) instability, and roughness-induced instability. In the past, extensive research has been conducted on the effects of acoustic disturbances on laminar separation behavior, and on Tollmien-Schlichting amplification and related transition locations. However, very little information exists concerning the influence of acoustic disturbances on airfoil drag with transition artificially induced by roughness. This report presents the results of an experimental investigation on the effects of acoustic disturbances on the drag of a laminar airfoil with laminar separation and with roughness-induced transition.

SYMBOLS

c	airfoil chord, 24 inches
c_d	section profile-drag coefficient, $\frac{2}{c}\int[(q_w/q_{fs})^{1/2} - (q_w/q_{fs})]dh$
c_l	section-lift coefficient
h	vertical distance in wake profile, inches
q	dynamic pressure, lb/ft^2
Rn	Reynolds number, based on free-stream conditions and airfoil chord
x	airfoil abscissa, inches
z	airfoil ordinate, inches

Subscripts:

fs	free-stream
w	wake

Abbreviations:

dB	decibels
QFF	Quiet Flow Facility in the LaRC Aircraft Noise Reduction Laboratory
NLF	Natural Laminar Flow
OASPL	Overall sound pressure level, dB
SPL	Sound Pressure Level, dB

DESCRIPTION OF AIRFOIL AND EXPERIMENTAL METHOD

Airfoil

A sketch of the section shape for the 14%-thick NLF (natural laminar flow) model airfoil is shown on figure 1. The model was constructed of a rigid polyurethane foam and covered with fiberglass and a polyester resin. It had chord and span dimensions of 24 and 12 inches, respectively, and was sanded in the chordwise direction to assure a smooth aerodynamic finish. It was then painted flat black to aid in flow visualization. A calculated pressure distribution for the test conditions is shown on figure 2. Aerodynamic characteristics of the airfoil over a Mach number range from 0.05 to 0.40 and a Rn range from 3 million to 22 million are found in reference 1.

Test Setup

Figure 3 shows the airfoil mounted in the Quiet Flow Facility (QFF). The anechoic room was 20 feet long by 23 feet high and had $2\frac{3}{4}$-feet-deep acoustical wedges on the walls and ceiling. The model was mounted spanwise between two sideplates, one of which was clear plastic, in a leading edge-down attitude. This model position provided an angle of attack of −0.84° (the angle between the mean flow and the model chord line). This was the angle which produced a cruise lift coefficient of 0.4 as determined in reference 1. Air flow was provided by a 12 inch by 18 inch vertical jet nozzle, which was driven by a centrifugal fan housed in another building to help minimize background noise. Tests were conducted at a chord Reynolds number of 3 million.

Instrumentation

A wake rake was centered 6 inches downstream of the airfoil trailing edge (figure 3). The apparatus consisted of two standard static probes and twenty-seven total pressure probes, 0.125 inches in diameter. Wake-rake pressure measurements were made using variable-capacitance precision transducers, which were connected to an automatic pressure-scanning system that recorded the total wake pressures (averaged over 5 seconds) and related facility pressures. These measured pressures were used to calculate the sectional drag coefficient. Figure 4 shows the calculated drag compared with drag data taken from reference 1.

The noise source was a 120-watt compression driver with an exponential horn designed especially for the driver. The nominal beam coverage of the horn was 40° horizontal by 20° vertical, and had a flat frequency response (±3 dB) from 0.3 to 5.0 kHz. A miniature pressure transducer was embedded in the airfoil surface to monitor the acoustic source.

Test Environment

The airfoil was positioned over the jet nozzle such that the entire airfoil chord was in the potential core of the jet. Based on previous hot-wire surveys, the jet was known to have uniform mean flow and a turbulence level of approximately 0.005.

In this study both the microphone and the noise source were in a fixed position. The noise source was normal to and 15 inches from the airfoil chord, and was visually directed at the first 20% of the airfoil upper surface (suction side). The noise source was a pure tone varying over SPL (sound pressure level) and frequency ranges of 110 to 138 dB and 1.8 to 6 kHz, respectively. White noise was also used as a noise source.

Liquid crystals of the type discussed in reference 2 were used to define the airfoil laminar flow region and any turbulent wedges due to particles on the airfoil surface. The crystals also defined the turbulent regions next to the sideplates, which dictated the spanwise location of the wake-rake.

RESULTS AND DISCUSSION

Presented and discussed in this section are the effects of an acoustic source on the profile-drag of a two dimensional airfoil. All data were taken at a Reynolds number of 3 million and a Mach number of 0.22. The acoustic sources were pure tones and white noise.

Airfoil Aerodynamic Definition

The darkened symbols on figure 4 represent the measured aerodynamic characteristics of the subject airfoil, while the open symbols are data taken from reference 1. At a Rn of 3 million a laminar separation bubble should occur at 74% chord (reference 1). This bubble was observed for the subject airfoil by using liquid crystals. To ensure transition, smooth surface tape (0.1 inches wide and .024 inches thick)) was placed at 68% chord. The difference in the model drag data and the reference data is attributed to trip drag. In general, the data in figure 4 indicate that the model airfoil was performing as designed and the wake rake measurements were sufficiently accurate.

Free Transition

Figure 5 shows the effect of pure tones on the smooth airfoil (laminar bubble present). For the two sound levels shown, the drag increases as frequency increases from 1.8 kHz to approximately 3 kHz. This drag increase may result from the forward movement of the acoustically excited laminar bubble, thus, changing the turbulent reattachment location. For frequencies above 3 kHz the drag change is erratic at an SPL of 130 dB, but increases consistently for the case of 138 dB. This latter drag increase will be discussed in a later section of this paper.

Fixed Transition

Figures 6 through 8 show the airfoil drag behavior when the trip tape was placed at 68% chord (thus, eliminating the laminar bubble) and the acoustic disturbances were varied between SPL values of 110 and 138 dB. Flow visualization (liquid crystals) verified that the boundary layer had fully transitioned from laminar to turbulent flow at approximately 70% chord. The drag rises steadily between 3 and 5 kHz for 138 db (figure 6) in comparison to figure 5, which indicates that the laminar bubble no longer exists. As shown in figures 7 and 8, the drag appears to rise to a maximum at 5 kHz. These two figures show the drag decreasing above 5 kHz for SPL values tested lower than 138 dB. Unfortunately, this could not be observed at 138 dB, as the acoustic source could not be driven to 138 dB above 5 kHz.

The theory of stability of laminar flow assumes that the mean flow in the chordwise direction is influenced by a number of discrete partial fluctuating disturbances. Furthermore, these fluctuations consist of waves propagated in the chordwise direction. Each wave length has an amplification factor that determines if the laminar mean flow is stable or unstable. If the flow is unstable and the disturbance wave is amplified, the transition location will change and increase the length of the turbulent region. However, the Reynolds number must be sufficiently large for the flow to be unstable and the disturbances amplified.

With transition fixed by roughness, no further transition movement was observed (with liquid crystals) in response to an acoustic disturbance. Hence, excitation of the natural instability waves leading to premature transition is not believed to be the primary cause of the drag rise. The increase in drag is the effect of the sound exciting the flow near the airfoil surface (shear layer), thus causing the existing turbulence to become more intense, possess a higher mixing rate (momentum), and increase the skin friction. The sound may have also affected the roughness (trip tape) drag.

The airfoil was made fully turbulent (tripped at 5% chord) and subjected to a pure tone with a sound pressure level of 138 dB over a frequency range shown on figure 9. This resulted in a drag rise similar to that experienced by the laminar airfoil shown on figure 6. This observation supports the conclusion that the drag increase is due to an increase in skin friction or roughness drag. The turbulent airfoil was also subjected to white noise of 138 dB OASPL over a frequency range from 2 to 6 kHz, and the same value of sectional drag coefficient was obtained as when the pure tone of 138 dB SPL and 5 kHz frequency was used. This indicates that the source does not have to be a pure tone, but only have sufficient SPL at the critical frequency in order to affect the drag.

Figure 10 shows a percent change in two-dimensional drag coefficient as a function of sound pressure level at constant frequencies. Once the noise level is sufficiently large, the drag rise is linear in nature. If the frequency is critical (5 kHz), even the lowest SPL investigated has a noticeable affect on the drag (17% increase). This lower SPL was approximately 10 dB above the overall noise level of the flow.

CONCLUSIONS

High-quality repeatable two-dimensional drag data have been measured on a laminar and fully turbulent (NLF-0414) airfoil while being subjected to sound. Significant increases in drag were observed when the sound was of sufficient intensity over a limited range of sound frequencies (more than 40% drag increase for 138 dB). The increase in drag was observed to be linear with SPL in nature and may have been the result of intensifying the existing turbulence near the airfoil surface, thus increasing the skin friction and/or roughness drag of the trip tape.

The results indicate that in the use of a laminar airfoil one must be concerned with increasing the turbulence intensity with sound, as well as affecting the natural instabilities of the flow. Furthermore, the additional drag resulting from acoustic disturbances on fully turbulent surfaces should be considered in all aerodynamic measurements.

Additional drag data need to be acquired using a force balance and a skin friction gage to corroborate the results presented herein. Measurements of fluctuating surface stresses using hot-film sensors should help to better understand the physical phenomena.

REFERENCES

1. McGhee, Robert J.; Viken, Jeffrey K.; Pfenninger, Werner; Beasley, William D.; and Harvey, William D.: Experimental Results For A Flapped Natural-Laminar-Flow Airfoil With High Lift/Drag Ratio. NASA TM-85788, May, 1984.
2. Holmes, Bruce J. and Obara, Clifford J.: Advances in Flow Visualization Using Liquid-Crystal Coatings. SAE Paper No. 871017, April, 1987.

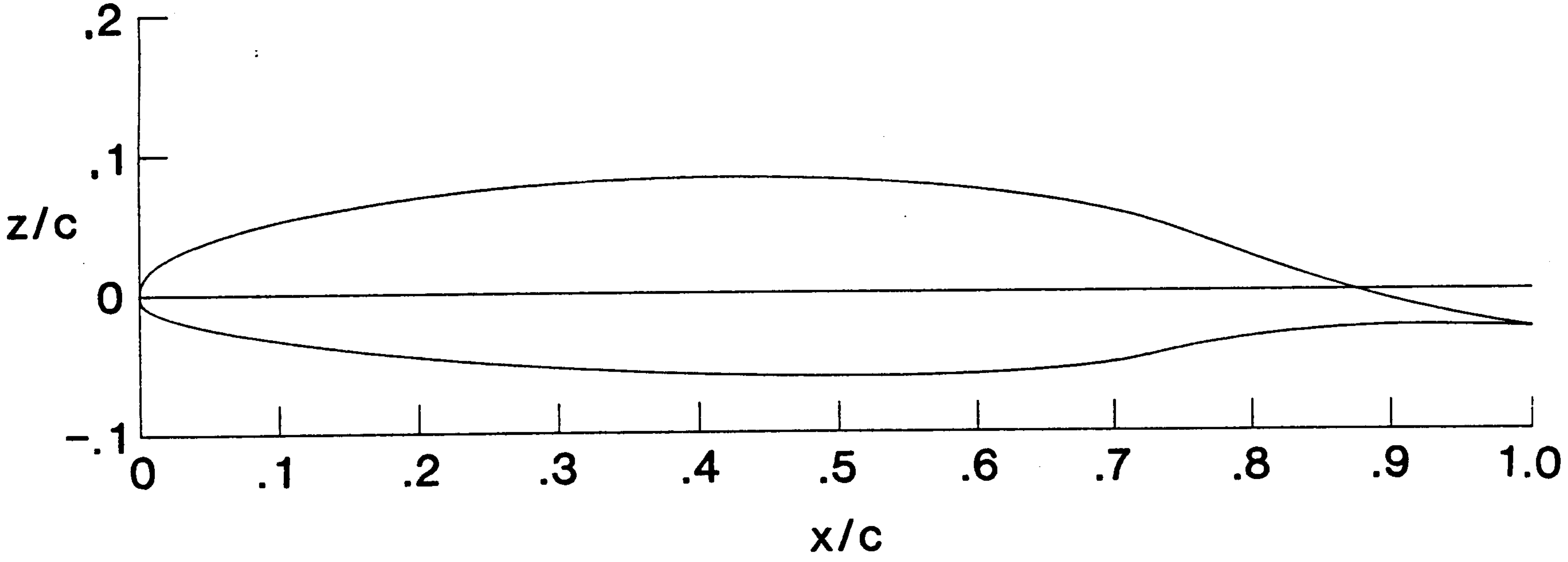

Figure 1.- Sketch of Airfoil Profile.

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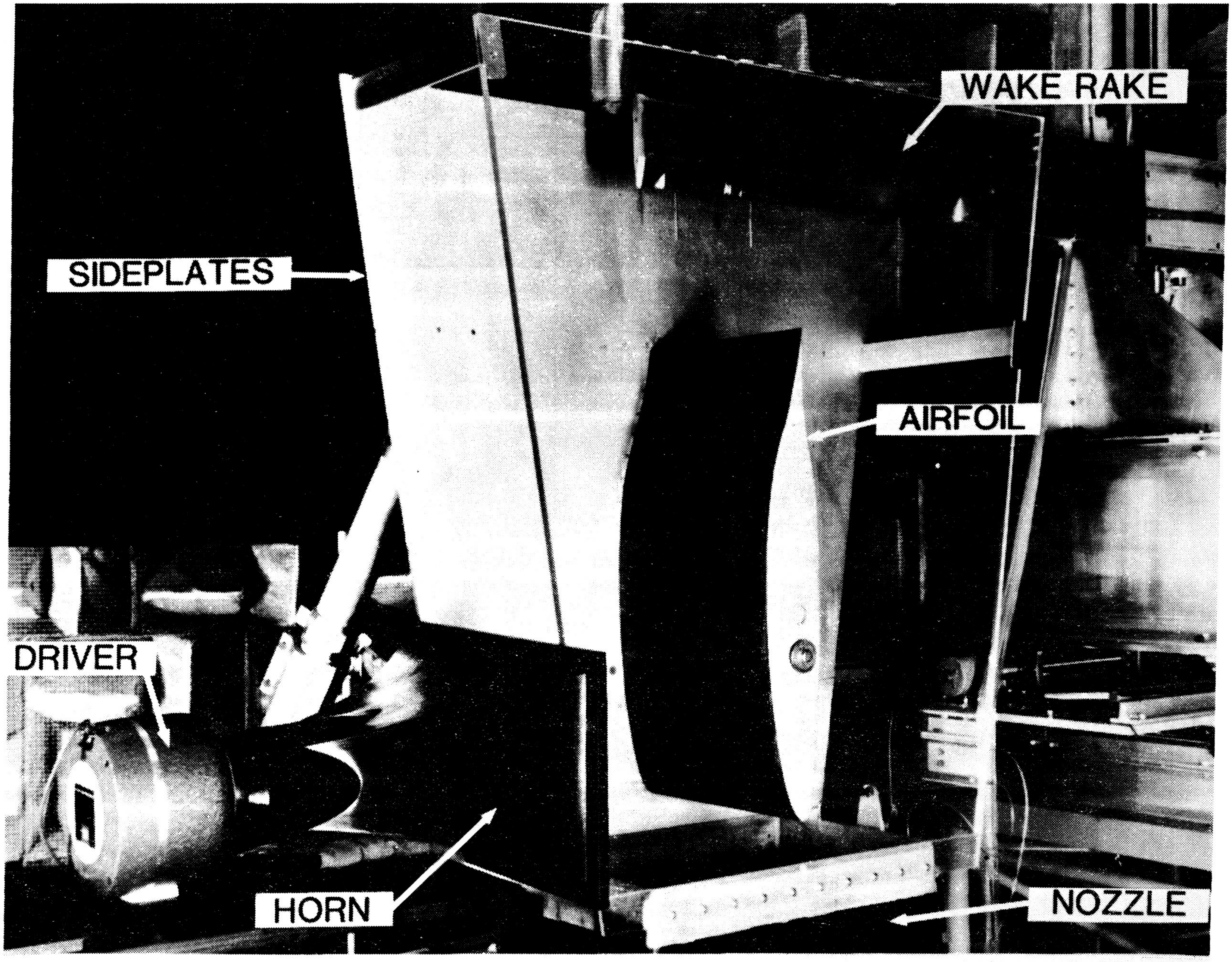

Figure 2.- Photograph of tests Setup.

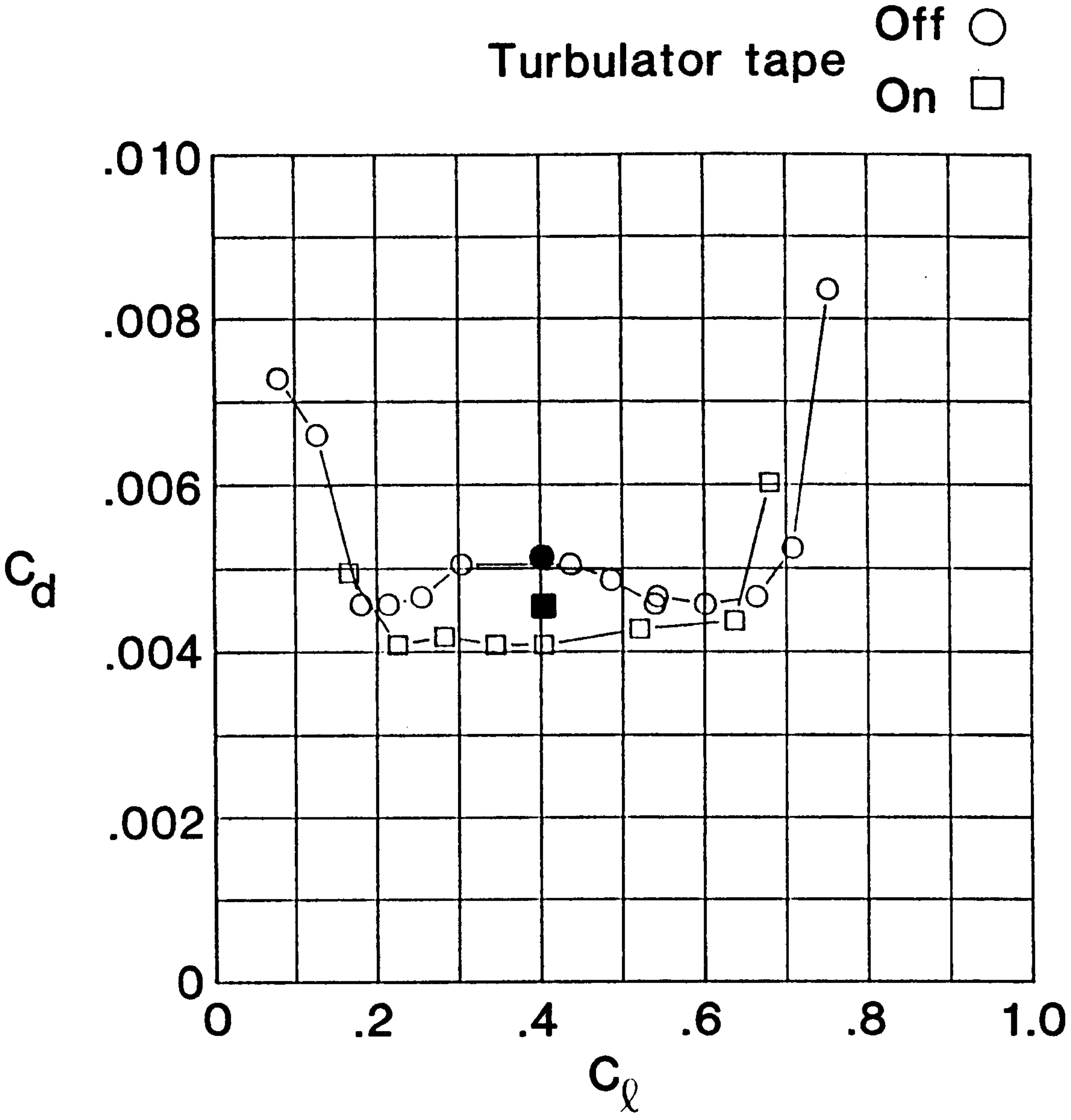

Figure 3.- Drag and Lift Coefficient Variation (Rn. of 3 million.)

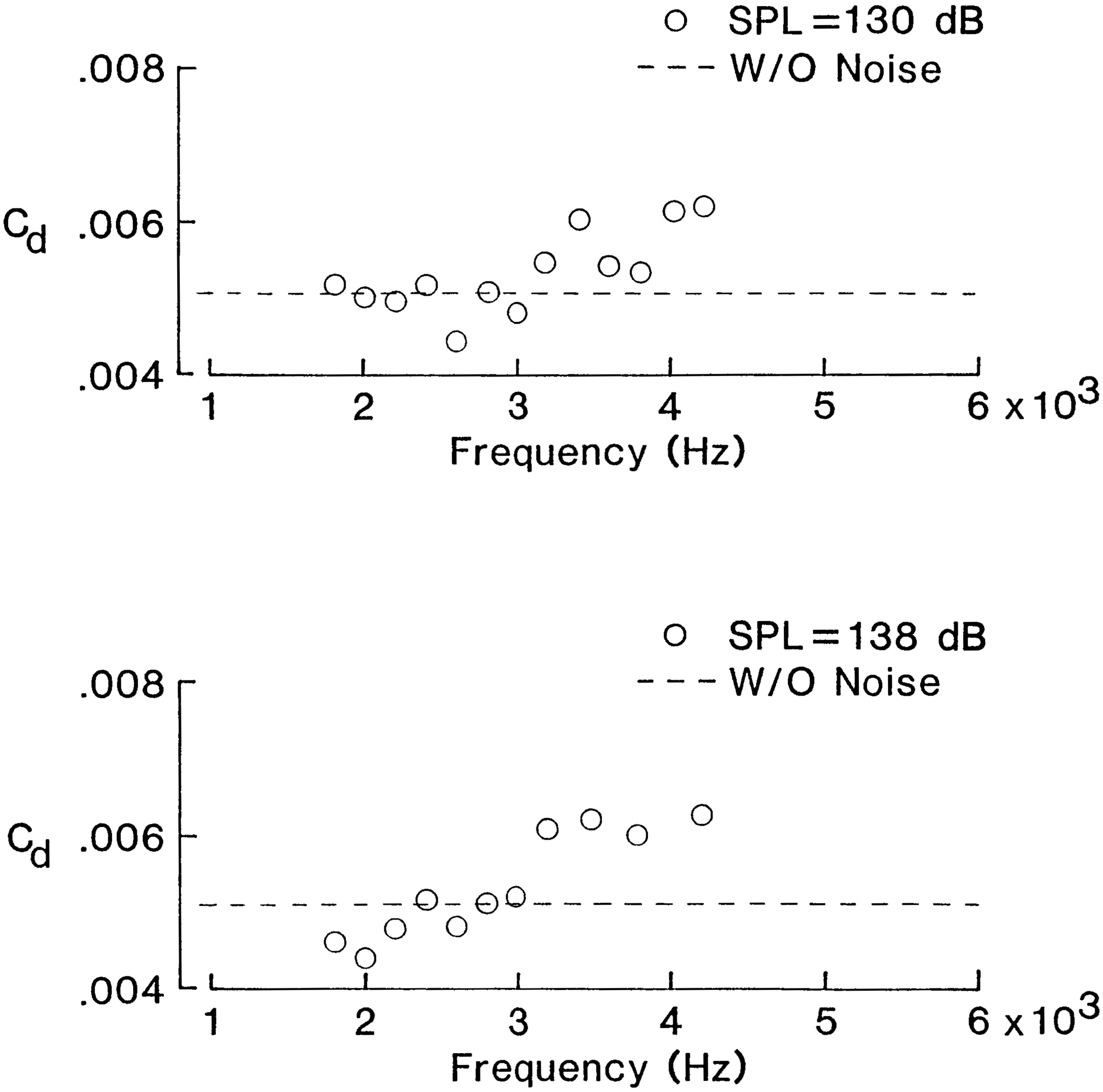

Figure 4.– Noise Effects On Laminar Airfoil With Laminar Bubble (Rn. of 3 million and SPL of 130 and 138 dB).

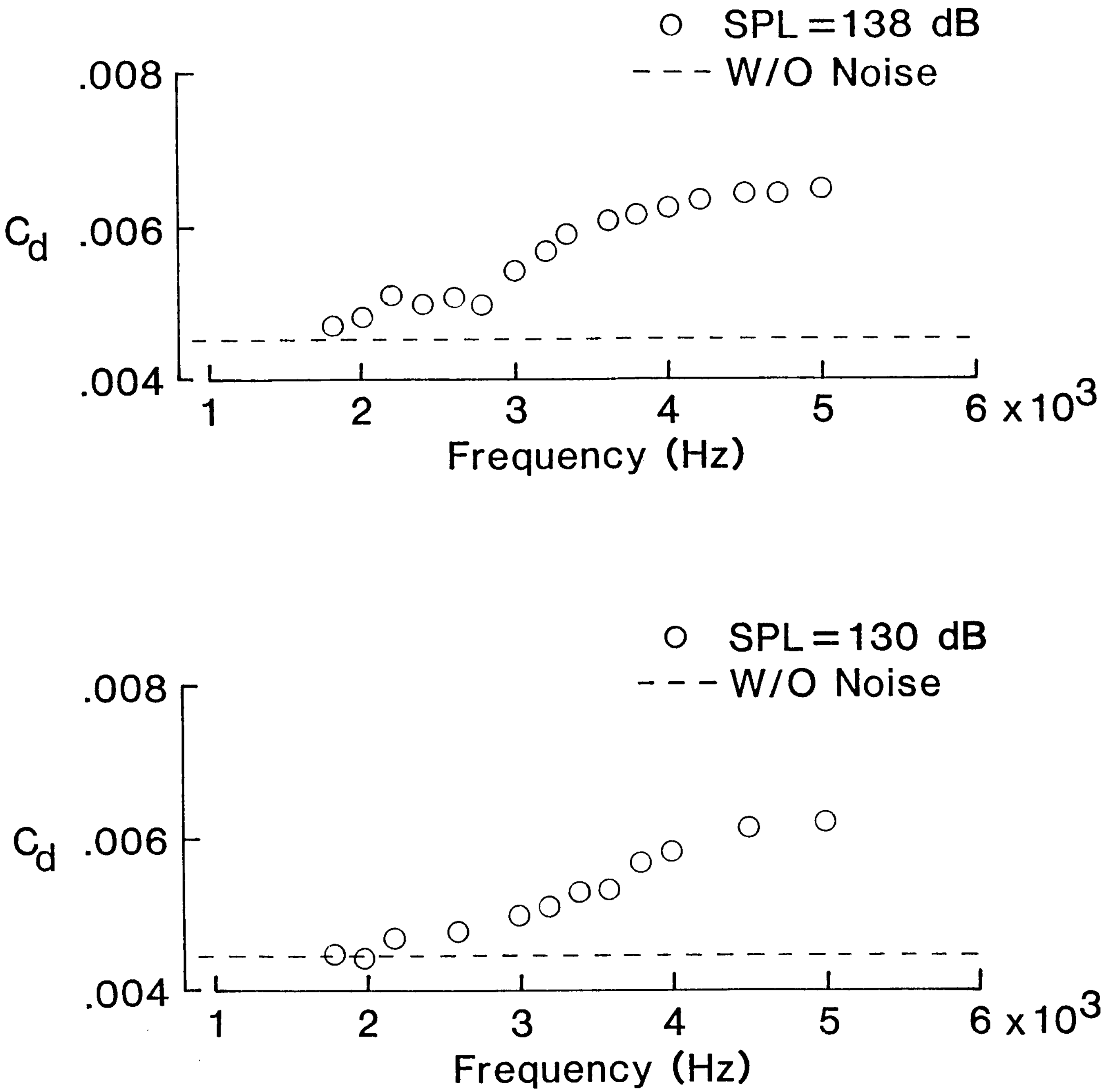

Figure 5.- Noise Effects On Laminar Airfoil With Induced Transition (Rn. of 3 million and SPL of 130 and 138 dB).

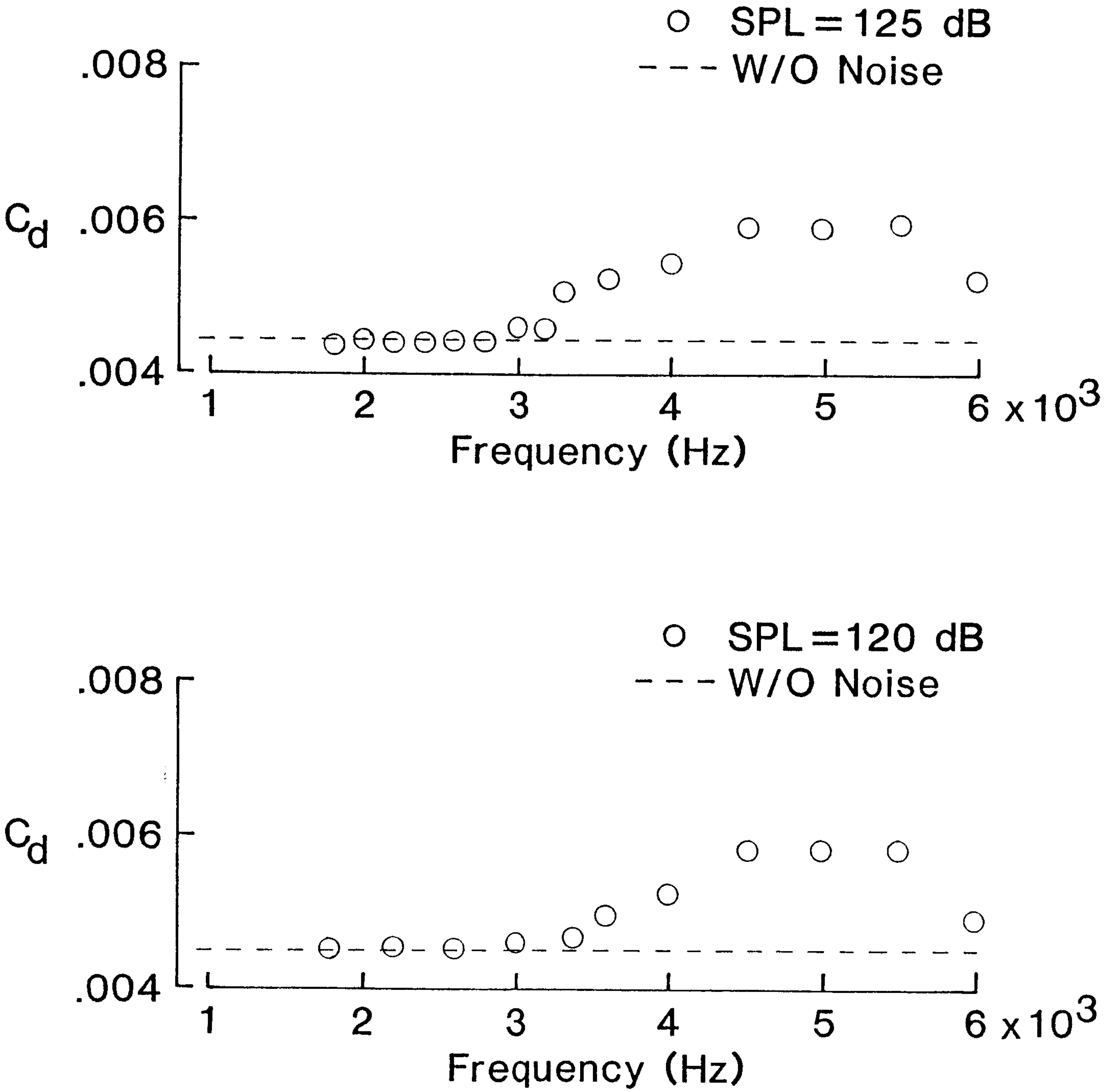

Figure 6.- Noise Effects On Laminar Airfoil With Induced Transition (Rn. of 3 million and SPL of 120 and 125 dB).

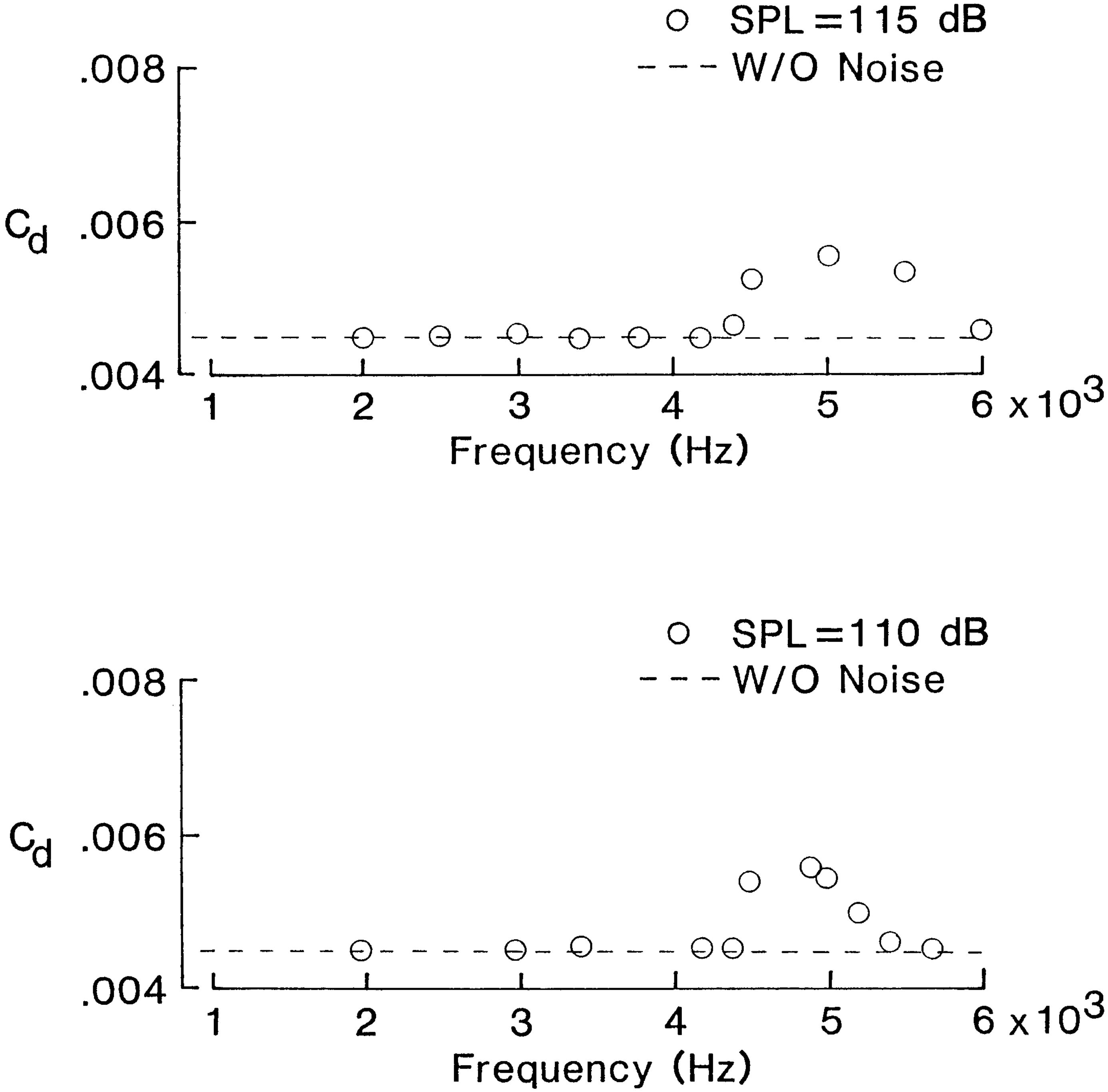

Figure 7.- Noise Effects On Laminar Airfoil With Induced Transition (Rn. of 3 million and SPL of 110 and 115 dB).

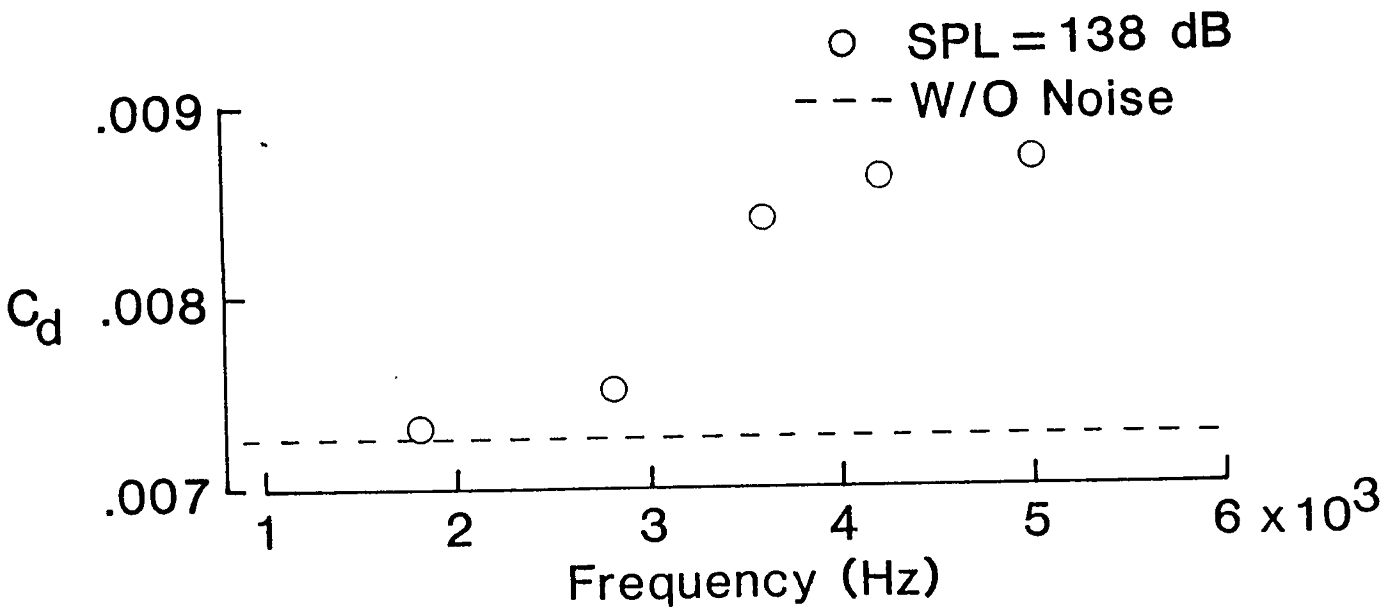

Figure 8.- Noise Effects On Fully Turbulent Airfoil (Rn. of 3 million and SPL of 138 dB).

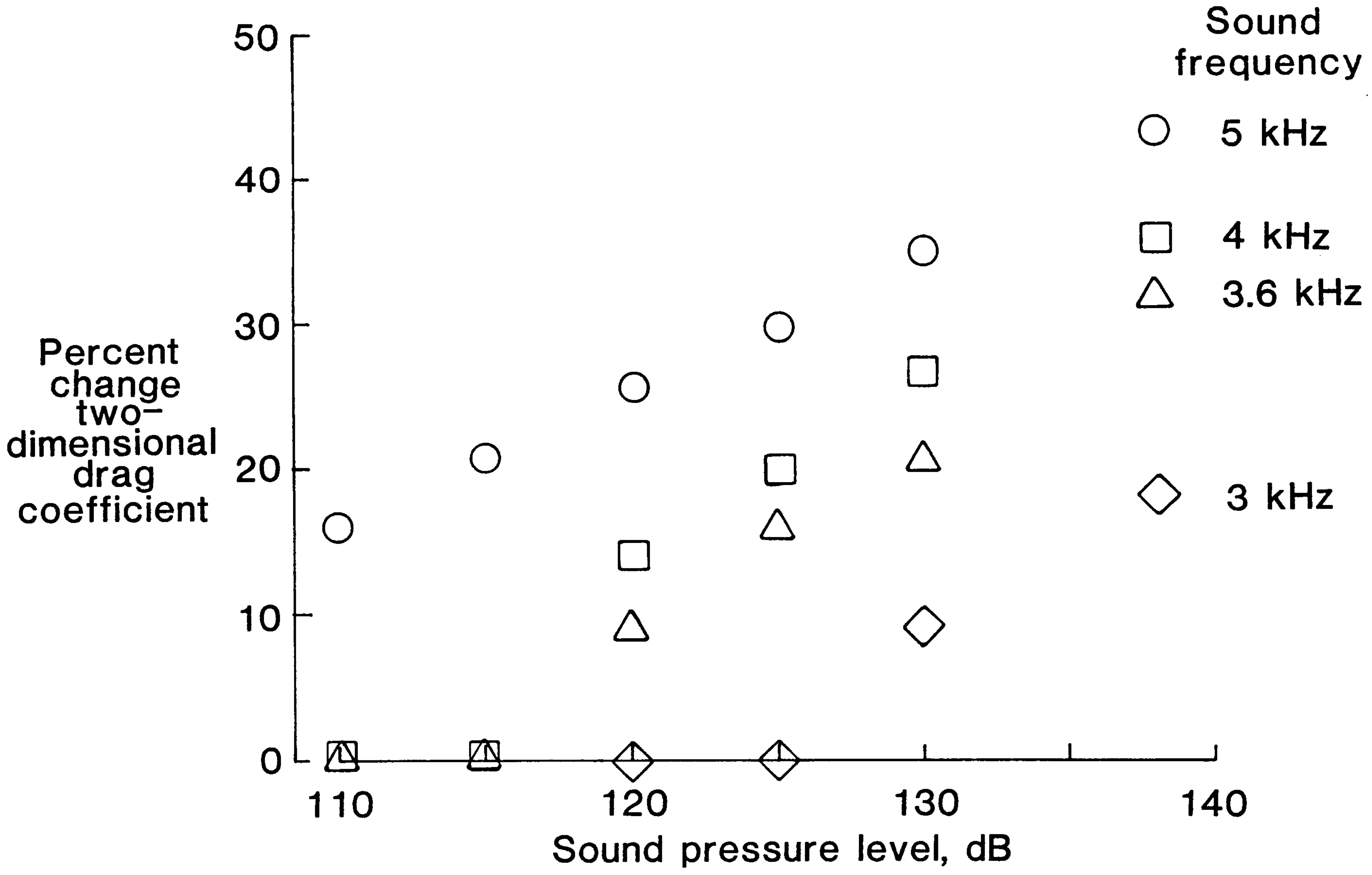

Figure 9.- Percent Change In Two Dimensional Drag Coefficient Variation With Sound Pressure Level At Constant Sound Frequency.

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16. Abstract

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