# Acoustic and Turbulence Influences on Stall Hysteresis

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## Abstract

PAST testing of airfoils at low Reynolds number has revealed stall hysteresis to be a characteristic of airfoil aerodynamic behavior at Reynolds numbers between about 75,000 and 500,000. This important phenomenon, has been seen by some researchers but not by others, and the extent of the loop has varied in results from different investigators. The purpose of this study was to investigate the extent to which wind-tunnel, flow turbulence and acoustic disturances may alter the nature of the flow over an airfoil at low Reynolds number and the character of the stall hysteresis loop. The results indicate that such disturbances may have dramatic effects on stall hysteresis and may be responsible for the lack of stall hysteresis data in many past investigations.

## Contents

Stall hysteresis at low Reynolds number is a result of the influence of laminar bubble breakdown and reformation during stall and stall recovery. Recent research by Marchman et al.,[1] Bastedo and Mueller,[2] Render,[3] and Liebeck and Camacho[4] has shown wide variations in the extent of stall hysteresis for the same Wortmann FX-63-137 airfoil at low Reynolds number. References 3 and 4 found no hysteresis loop in their investigations, whereas Ref. 2 reported loops that extend over a much smaller range of angle of attack than Ref. 1. Although these variations in results may be due to simple failure to look for hysteresis, it is more probable that they are the result of variations in the flow environment during the respective tests.

Tests were conducted in the VPI Stability Wind Tunnel to examine the effects of freestream turbulence and ambient acoustics on low-Reynolds-number stall behavior of the Wortmann FX-63-137. This wind tunnel has a very low ambient freestream turbulence level of 0.02–0.04%. A 5-in.-chord, aspect-ratio 8 model was instrumented with pressure taps to measure pressure distributions and was also tested on a computer-controlled, six-component strain-gage balance system. Forces found by integrating the pressure distributions were coincident with those found from the force balance. The model was tested at two turbulence levels by using a turbulence grid to amplify the ambient turbulence tenfold. Acoustic disturbances were added to the flow via an oscillator generated audio signal and speaker system. Acoustic disturbance levels were ascertained via a model-mounted microphone and fast Fourier transform (FFT) spectrum analyzer. Acoustic chamber tests confirmed that the sound frequency spectrum measured at the wing were, in fact, those produced by the speaker, and no measurable standing wave was produced in the wind-tunnel test section. The ambient turbulence of the wind tunnel is most pronounced in magnitude in the 10–20-Hz range, and this is the part of the spectrum that was amplified by the turbulence grid.

Sample results of increased turbulence are shown in Figs. 1 and 2 for a Reynolds number of 100,000. In Fig. 1 it is seen that an increase in turbulence from 0.02 to 0.2% almost eliminates the hysteresis loop. This is comparable to the difference in results seen in Refs. 1 and 2. Figure 2 shows the pressure distributions seen in the model at an angle of attack of 12 deg at the points labeled A, B, and C on Fig. 1. The additional turbulence is capable of restoring attached flow over the rear half of the wing and even appears to reestablish some sort of laminar bubble but is not capable of restoring full suction around the wing's leading edge. Tests at other Reynolds numbers show similar results but with decreasing influence of increased turbulence on loop size as $Re$ increases.

Test results showed acoustic disturbance influence on the model's aerodynamic behavior to be highly dependent on disturbance frequency. Acoustic disturbances were also shown capable of increasing the angle of attack at which initial stall occurred, a phenomenon not seen with the increase in freestream turbulence and one that is probably highly frequency-dependent. Figure 3 shows the effect of a 100-dB 1970-Hz disturbance at $Re = 100,000$.

Figure 4 shows the influence of several discrete disturbance frequencies on the pressure distribution over the stalled wing at an angle of attack of 15 deg. A 4830-Hz signal was capable of fully restoring an attached upper-surface flow, whereas 5200- and 5500-Hz disturbances, all at the same 110-dB sound level, resulted in only partial restortion of the flow. It is interesting that, for these cases, flow attachment was forced within the prebubble, laminar portion of the boundary layer and not the postbubble, turbulent portion, as seen with added turbulence.

Acoustic disturbance tests showed that a disturbance of the proper frequency and pressure level can often completely restore a fully separated flow to a fully attached state, which remains stable and attached after the disturbance signal is removed. It was shown that sound levels of as low as 95 dB at frequencies around 500 Hz can be used to force flow reattachment. These sound levels and frequencies are well within the range of disturbance likely to be found in many wind tunnels.

The results seem to verify that many of the differences among various low Reynolds test results may be attributable to different levels of wind-tunnel turbulence and background noise. If an adequate knowledge of the full extent of stall hysteresis is to be obtained, all testing must be done in a facility with the lowest possible disturbance environment. The highly frequency-dependent nature of the acoustic disturbance influence indicates the importance of understand-

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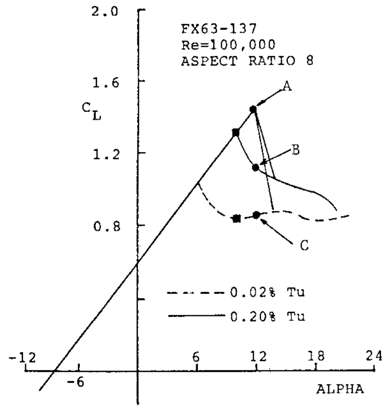


**Fig. 1 Effect of added turbulence on stall hysteresis.**

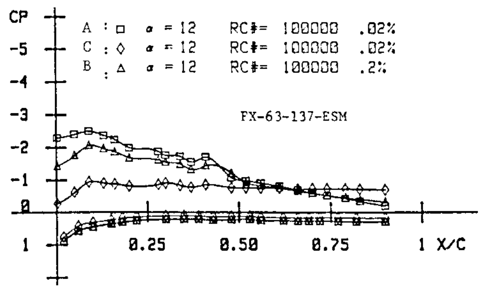


**Fig. 2 Effects of added turbulence on pressure distributions during stall hysteresis.**

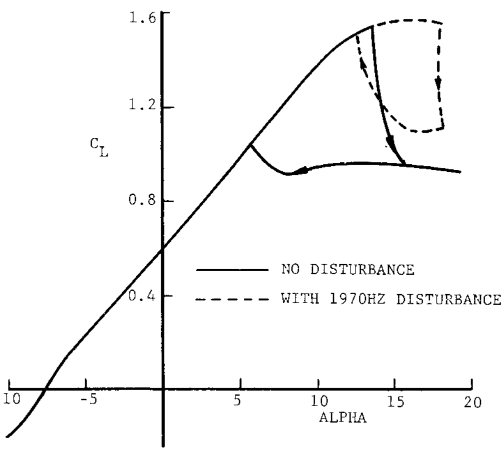


**Fig. 3 Effect of acoustic disturbance on Æ = 8 wing at $Re = 100,000$.**

ing the frequency spectrum of any disturbances. The past practice of stating an overall disturbance magnitude is not fully indicative of the importance of a disturbance in low *Re* flows.

Since the effects of any disturbance are seen to vary with Reynolds number, angle of attack, and other factors, it is important that more research be conducted to find out more about these dependencies. The critical frequencies found to influence the flow over the Wortmann wing may differ substantially from those that would alter the flow over another airfoil section.

Another difference seen among low-Reynolds-number data sets from various wind tunnels, also shown in the full paper, is a difference in zero-lift angle of attack. This difference does not appear to be related to acoustic or turbulence disturbance levels or to the hysteresis loop changes caused by these disturbances. Tests reported by Marchman[5] show that the difference in zero-lift angle of attack noted in comparing the results of Refs. 1 and 2 are most likely due to differences

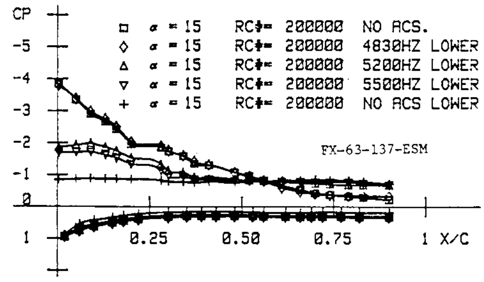


**Fig. 4 Effect of discrete acoustic disturbance frequencies (all at the same sound level) at $Re = 200,000$ for 15 deg.**

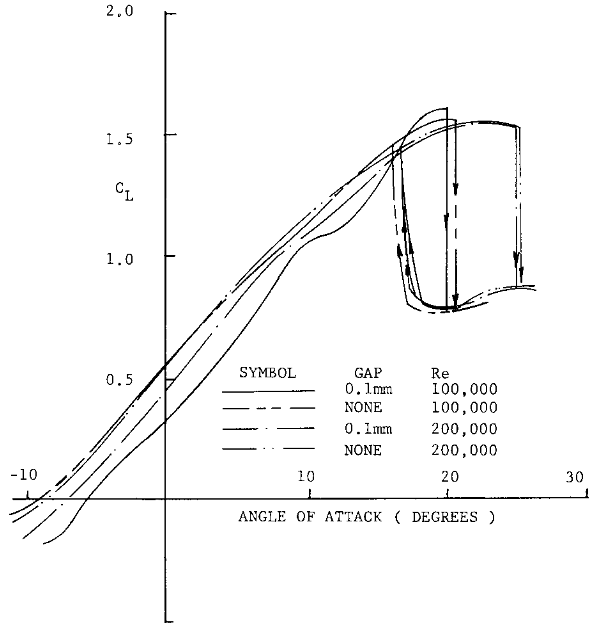


**Fig. 5 Effect of 0.1-mm endplate gap on data.**

in test procedures. The tests reported in Ref. 2 were made using a semispan wing model, which was not attached directly to an endplate. The gap between the endplate and wing, although reportedly only 0.1 mm in size, appears to result in a shift of the zero-lift angle of attack due to flow through the gap. Reference 5 shows that, by sealing the gap, a semispan test will duplicate the results from from tests on a full three-dimensional strut-mounted model in Ref. 1. Further tests have shown that $\alpha_{LO}$ shift due to the model-endplate gap is Reynolds-number-dependent, showing that the negative shift in $\alpha_{LO}$ with increasing Reynolds number reported in Ref. 2 is probably a gap effect caused by the test arrangement and not a natural aerodynamic occurrence at low Reynolds numbers. This effect is shown in Fig. 5 for an Æ = 2 (effective Æ = 4) semispan model tested with a 0.1-mm gap between the wing and endplate.

## References

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