A PRACTICAL INVESTIGATION OF THE EFFECT OF TURBULATOR GEOMETRY ON TRIPPING EFFECTIVENESS FOR A WORTMANN FX-63-137 AIRFOIL

by M. Torres, Malvern Pennsylvania, USA

Abstract

An experiment was conducted to determine the relative tripping effectiveness of different turbulator-tape geometries. Oil-flow photographic data were obtained for a Wortmann FX-63-137 airfoil wing section using a special ground-test rig mounted atop an automobile. Meaningful flow-visualization data was obtained for several turbulator geometries with this practical method. Very little differences were observed between the Z-pattern turbulator geometries for the test conditions achieved.

1. Introduction

While many types of turbulator-tape geometries are considered effective in promoting boundary-layer transition, several geometries are considered to be more effective for a given application. The present investigation was performed to assess the effectiveness of different turbulator geometries in a controlled ground-test experiment using a wing model employing a Wortmann FX-63-137 airfoil.

Numerous experiments have been conducted using oil-flow visualization to qualitatively understand the boundary-layer behavior over aerodynamic surfaces. While wind-tunnel tests can provide precise laboratory conditions, and flight tests can provide actual in-flight conditions, these experimental methods are somewhat costly relative to the typical time and budget available for small-scale parametric testing. A less-accurate, but very meaningful experiment can be conducted using a special ground-test rig mounted atop an automobile. Numerous configurations can be tested in a controlled and very efficient manner, similar to the technique used in high-speed rocket-sled tests. Of course, the minimization of freestream disturbances and model-support interference is a necessity if there is any hope of collecting meaningful data.

2. Experimental Arrangement

A fiberglass, two-dimensional wing model was constructed using a spline fit of published coordinate points for the FX-63-137 airfoil.[1,2] A chord of 8.0 inches (203.2 mm) and span of 16.0 inches (406.4 mm) were selected to provide a reasonable simulation scale. The model was painted white and finished using standard furniture wax and polish to provide an aerodynamically smooth surface.

The wing was mounted to a specially designed ground-test rig, illustrated in Figure 1. This apparatus was constructed to provide a secure mounting of the model while minimizing the flowfield interference due to the automobile. End-plates were attached to the tips of the 2-D wing and the interface was sealed with tape and a coat of wax. A pitot-static tube was mounted to the rig to measure the local flow conditions in the vicinity of the model. The entire rig was attached to the roof of the auto using several bungee cords, and layers of rolled cloth insulated the rig from the automobile. The cloth layers were also used to shim the rig for proper pitch alignment (checked using a standard carpenter's level, relative to a known level surface). All runs were conducted at zero angle of attack.

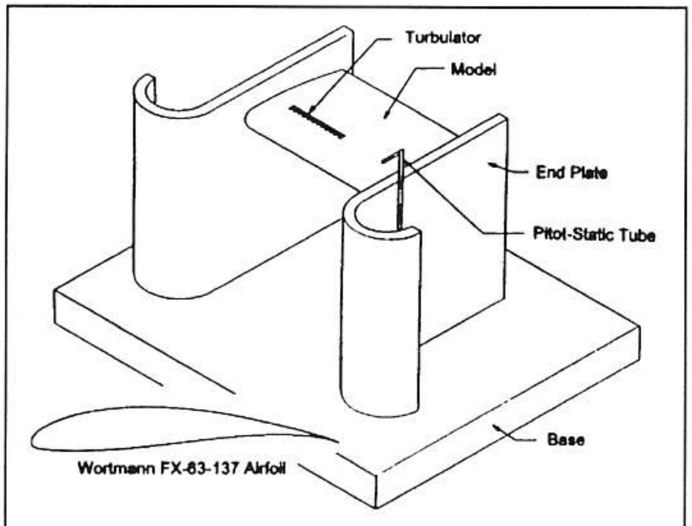


Figure 1. Model and Ground-Test Rig

A ground-test rig mounted atop an automobile can only be useful if it is designed to help minimize flowfield interference and vibration from the automobile, and if tests are conducted in a location such that freestream disturbances are minimized. For this reason, all tests were conducted on a level road, parallel to the 2500-foot runway (762 m) at Morgantown Airport, Pennsylvania. In addition, tests were only conducted when light crossflow conditions existed.

Turbulator-tape patterns were pre-cut with several different leading-edge Z patterns and a straight trailing edge from 0.008-inch thick (0.203 mm) heavy-duty electrical tape. The use of Z- patterned tape is commonly used in both ground and flight applications.[3-7] Turbulator step height was varied by using multiple layers of tape and verifying the composite thickness with a micrometer. The geometric parameters of the turbulator configurations tested are illustrated in Figure 2.

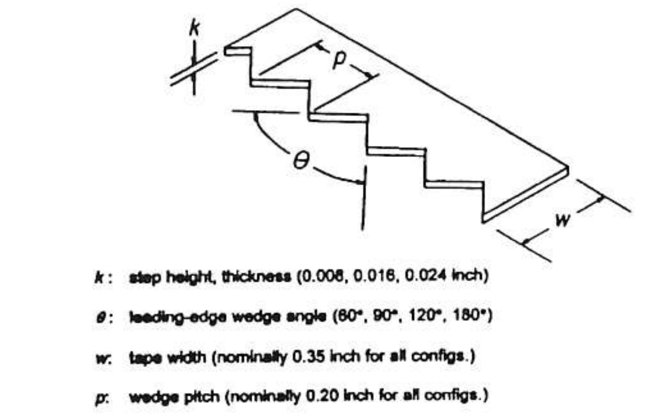


Figure 2. Turbulator Geometric Parameters

All turbulators were positioned such that the forwardmost step location was at $x/c = 0.375$ (determined after observing smooth-wall oil-flow patterns).

Since the primary test parameters were turbulator tape geometry, special effort was made to conduct each test run in a similar fashion to maintain the repeatability of freestream conditions and minimize run-to-run variability. However, two run times were considered. The first time was for a "single-lap" run (2500 ft), and the second corresponded to a "double-lap" run (out-and-back, 5000 ft). The maximum air speed and acceleration/deceleration profile was duplicated as closely as possible using the same driver. The test conditions achieved consistently produced Reynolds numbers ($Re_{c\infty}$ of 0.34×10^6 to 0.36×10^6.

Prior to each run, a thin coat of oil was brushed over the upper wing surface in spanwise strokes. The selected oil was used (dark) SAE 10W-40 motor oil, based on the successful results obtained in many ground and flight-test applications.[7-10] While the ambient temperature during the test was cool (T_∞ = 36°F, 2.2°C), the mixture of additional thinning agents was not necessary during the test. Resulting oil-flow patterns were photographed immediately after each run to record the fresh streaks before any significant "wind-off" effects could perturb the streak pattern.

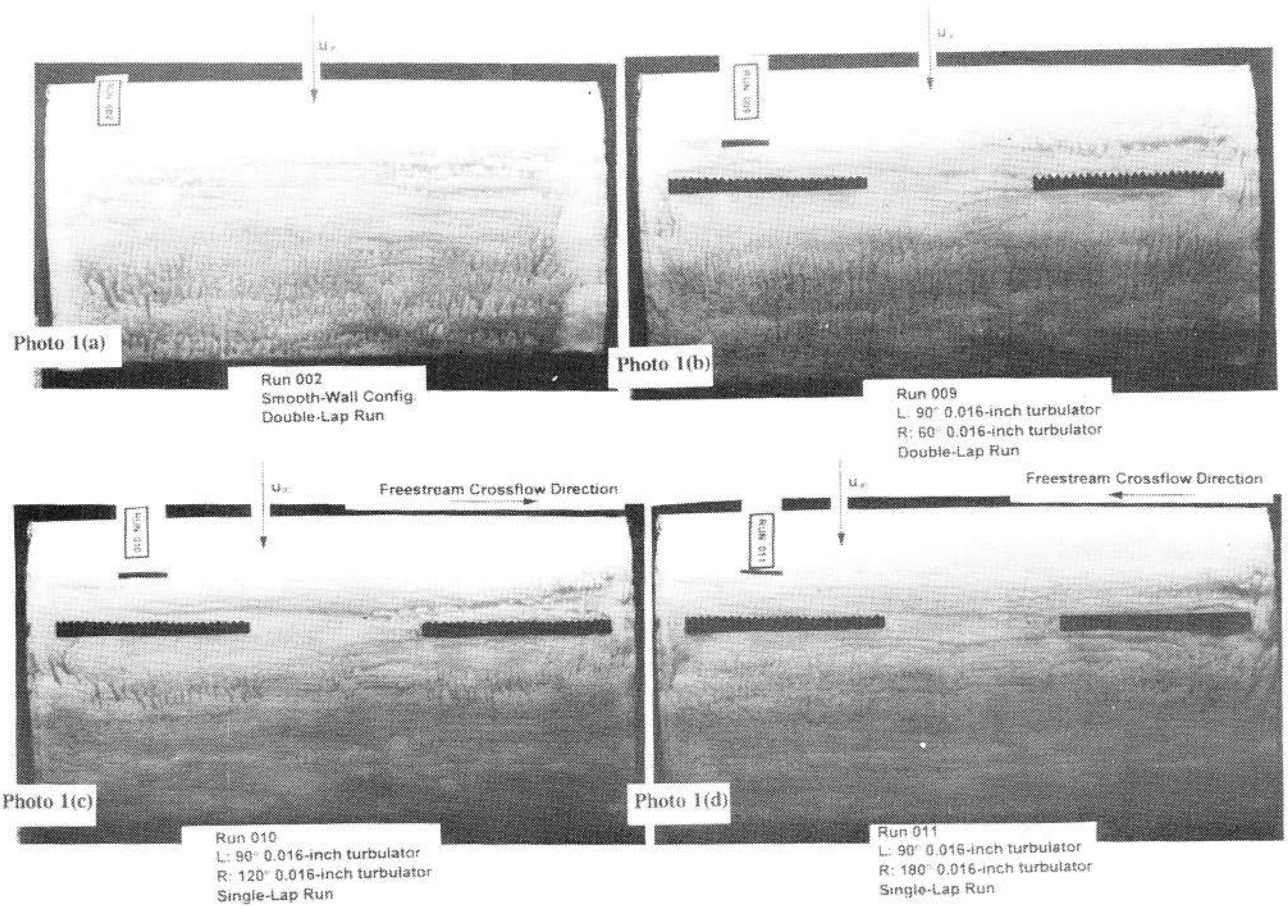
3. Data Assessment

After conducting smooth-wall runs to observe the baseline natural transition and separation characteristics inherent in this airfoil/installation arrangement, runs were performed with (θ =90° turbulators installed on the left half of the model upper surface to determine the effect of turbulator step height *(k)* on the resulting flow pattern, compare these results with the smooth-wall data (right half of the model, and previous runs), and to select a turbulator step height for subsequent turbulator geometry comparisons. After testing 0.024, 0.016 and 0.008-inch step heights at $x/c = 0.375$, the 0.016-inch (0.41 mm) height was selected since it appeared to produce patterns indicating somewhat marginal effectiveness.

Runs were then conducted with a 90°, 0.016-inch turbulator on the left side, and 60°, 120°, 180° (flat) 0.016-inch turbulators on the right side. A summary of the oil-flow patterns recorded are shown in Photos 1(a) through (d). All photographs were illuminated by natural sunlight from the leading edge toward the trailing edge.

The importance of assessing the turbulator results in the context of the smooth-wall results is demonstrated by the possibility of three-dimensional flow effects near the end plates as evidenced in Photo 1(a). In addition, the known crossflow component present in the freestream is noted on each photo to qualitatively assess its influence on the data obtained. These, and similar, effects must be excluded from the assessment of any inferred trends from the observed data.

When comparing Run 002 (smooth-wall) oil-flow data with Run 009 (90°, 0.016-inch turbulator on left; 60°, 0.016-inch turbulator on right), one notices some similarity in the



Photograph 1. Oil-Flow Visualization

oil-streak lengths. Both runs were conducted as double-lap (5000 ft) runs. However, further examination reveals a basic difference in the character of the streaks, aft of the turbulator strips. The smooth-wall data (Run 002) display wide, thick (dark) streaks further aft on the surface ($x/c >$ 0.6), particularly closer to the end plates, less so at the center, while the streaks displayed with turbulators (Run 009) show long, thin (lighter) streaks from approximately $x/c = 0.51$ to 0.78, and very little pooling of oil near the trailing edges in contrast to the pooling shown for the smooth-wall run. This suggests that laminar flow separation may be present near the trailing edge for the smooth-wall run, and that the turbulators were effective in tripping the boundary layer and maintaining attached flow (assuming all other factors are equal). Few differences are shown between the 90° and 60° turbulator streak patterns, the most noticeable being the possible laminar-separation bubble upstream of the 60° turbulator, just aft of the minimum pressure station (dark pooling at x/c approximately 0.31). This was also noted in the smooth-wall streak pattern.

It can also be observed in Photo 1(b) that the streak patterns aft of the turbulators have a somewhat regular spanwise pitch similar to the turbulator pitch, unlike the variable-pitch streaks shown for the smooth-wall run or the center-span portion of the model (no turbulator). While vortex generation by each wedge of the turbulator may contribute to this observed effect, no further study was made, except to note that the flat ($\theta = 180°$) turbulator produced a variable spanwise oil-streak pitch, similar to the smooth-wall data (these data are reviewed below).

A comparison of Run 010 (90°, 0.016-inch turbulator on left; 120°, 0.016-inch turbulator on right), with Run 011 (90°, 0.016-inch turbulator on left; 180° (flat), 0.016-inch turbulator on right), is provided in Photos 1(c) and (d). Both runs were conducted as single-lap (2500 ft) runs. The resulting shorter run times produce less-developed streak patterns, but provide insight into the emerging pattern for each turbulator configuration. This is particularly useful for assessing the 90° turbulator streak-pattern development, since this served as the tare configuration for this investigation.

Crossflow effects are apparent downstream of the 90° turbulator close to the end plate in Photo 1(c), and downstream of the flat turbulator, near the end plate, in Photo 1 (d).

The difference between the streak pattern downstream of the turbulators in Photo 1(c) is noticeably different than the pattern produced in the center of the model span (no turbulator). Little difference is seen between the 90° and 120° turbulator patterns. Slight pooling appears to be starting aft of the 120° turbulator at approximately $0.70 < x/c < 0.75$, while less is seen aft of the 90° turbulator.

Streak patterns aft of the flat turbulator ($\theta = 180°$) show significant differences relative to the 90° turbulator, as shown in Photo 1(d). While the long streaks developing aft of the 90° turbulator extend to $x/c = 0.68$, those aft of the flat turbulator only extend to about $x/c = 0.63$, possibly indicating somewhat less effective boundary-layer tripping (as expected). While this difference appears small, the Z-pattern turbulator configurations produced oil-streak patterns that displayed closer agreement relative to each other.

4. Conclusions and Recommendations

While it was hoped that oil-flow visualization would reveal significant differences in the effectiveness of different turbulator geometries for the FX-63-137 airfoil, no significant differences in trip effectiveness were observed between the 60°, 90°, and 120° turbulator geometries for the conditions tested. However, the 180° (flat) turbulator showed slightly different oil-streak patterns that seem to indicate somewhat less effective boundary-layer tripping (as expected).

While the results obtained with this experimental arrangement are not nearly as accurate as those that can be obtained in a wind tunnel, meaningful observations were made on the character of the boundary layer and relative turbulator effectiveness was assessed for the test conditions achieved.

It is recommended that as more precise data on turbulator-tape geometry effects become available from wind-tunnel tests, and to the extent that any significant effects are demonstrated, these results should be gathered, correlated and made available to the soaring/aerodynamics community.

References

1. Althaus, D., *Niedriggeschwindigkeitsprofile*, Friedr. Vieweg & Sohn Verlagsgesellschaft mbH, Braunschweig/Weisbaden, 1996, p. 393.
2. Selig, M., et al., "Summary of Low-Speed Airfoil Data," University of Illinois at Urbana-Champaign, *www.uiuc.edu/m-selig*, March 1997.
3. Rae, W. H., and Pope, A., *Low-Speed Wind Tunnel Testing*, 2nd ed., John Wiley & Sons, Inc., New York, 1984, pp. 449-457.
4. Althaus, D., ìPerformance Improvement on Tailplanes by Turbulators," *Technical Soaring*, Vol. 15, No. 4, October 1991, pp. 125-128.
5. Boermans, L.M.M., and Bennis, F., "Design and Windtunnel Tests of an Airfoil for the Horizontal Tailplane of a Standard Class Sailplane," *Technical Soaring*, Vol. 16, No. 2, April 1992, pp. 35-40.
6. Baker, R. E., "An Investigation Into Performance Enhancement of a Sports-Class Sailplane by Use of Turbulator Tapes," *Technical Soaring*, Vol. 20, No. 3, July 1996, pp. 78-81.
7. Johnson, R. H., "A Flight Test Evaluation of the Ventus 2b 15-Meter Sailplane, Part 2," *Soaring*, Vol. 60, No. 6, June 1996, pp. 16-22.
8. Johnson, R. H., "A Flight Test Evaluation of the Super Ximango Motorglider," *Soaring*, Vol. 60, No. 12, December 1996, pp. 35-40.
9. Pichou, T., et al., "Effect of Tripping Laminar-to-Turbulent Boundary Layer Transition on Tip Vortex Cavitation," SNAME *Journal of Ship Research*, Vol. 41, No. 1, March 1997, pp. 1-9.
10. Howard, R. M., and O'Leary, J. F., "Flowfield Study of a Close-Coupled Canard Configuration," *AIAA Journal of Aircraft*, Vol. 31, No. 4, July-August 1994, pp. 908-914.