Engineering Notes

Turbulent Damping by Flabby Skins

Donald H. Fisher* and Edward F. Blick†
University of Oklahoma, Norman, Okla.

IN the last five years, considerable interest has been generated in the area of drag reduction by compliant coatings or flabby skins. Much of this interest was stimulated by the work of Kramer[1-3] which indicated a reduction of drag on bodies towed in water by coating the surfaces of the bodies with a compliant coating. The coating was inspired by the flabby skin of the dolphin which, according to Kramer,[3] is responsible for its high speed. The contention being that the dolphin's flabby skin damps the wall-near flow disturbances which retards transition and results in a larger area of laminar flow (with low values of skin friction) over the dolphin. Theoretical analysis by Benjamin,[4] Landahl,[5] and Kaplan[6] indicate that the stability of laminar boundary layer can be altered by the use of compliant boundaries.

The effect of flabby skins in the transition and turbulent region has received a very limited amount of attention. Karplus[7] investigated the scale and degree of turbulence for water flowing over stretched mylar film backed with different damping fluids. He found that in his tests, turbulence sets in sooner for the flexible wall than for a solid wall, but grows to its final value more slowly. The damping fluid behind the film made the surface appear more like a solid surface as the viscosity was increased.

A search of the literature failed to reveal any experimental work that had been done with flabby skins in an air flow. It seems as if the experimental work was limited to hydrodynamics with nothing being done in aerodynamics. With this in mind we were curious to see if the flabby skin concept of drag reduction would work in aerodynamics. So, for an exploratory experiment, we decided to measure the turbulent intensity of flow in the turbulent wake of a small fence along a flat plate covered with a flabby skin.

Rather than measure skin friction coefficients either directly by a balance system or indirectly from velocity profiles, we reasoned that it would be easier and faster to measure turbulence intensities near the plate by use of a hot-wire anemometer. Our reasoning was that, by Von Karman's similarity hypothesis,[8] the turbulence shear stress distribution in a boundary layer is proportional to the turbulence kinetic energy and hence proportional to relative turbulence intensity. Any increase or decrease in the relative turbulence intensities in the boundary layer would then be indicative of corresponding increase or decreases in the Reynolds stresses and wall skin friction.

The size and speed of our wind tunnel limited the amount and thickness of a natural turbulent boundary layer on a flat plate. So, in order to overcome this limitation and in order to magnify the effect of flabby skins on turbulence intensities, a small wood fence $\frac{9}{64}$ in. high was placed perpendicular to a flat aluminum plate covered by a flexible plastic skin (commercial name-clopay frosty) of 0.00225 in. thick.

Received December 20, 1965.

* Graduate Student, School of Aerospace & Mechanical Engineering; now Captain, U. S. Air Force, Wright-Patterson Air Force Base, Ohio.

† Associate Professor, School of Aerospace & Mechanical Engineering. Member AIAA.

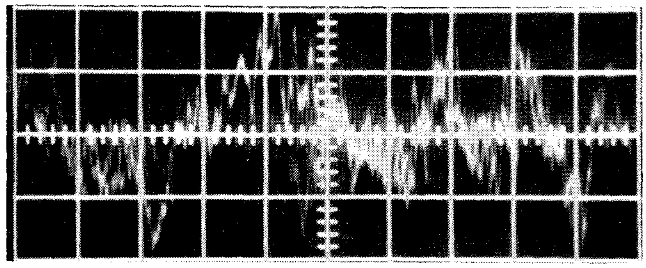

Fig. 1 Oscilloscope picture of turbulence on hard surface plate, 3 in. behind the fence.

Between the aluminum plate and the flexible skin was a $\frac{3}{8}$-in. gap. This gap was filled with either air, water, or automotive lubricating oil (30 weight). The plate length was 37 in. long and 6.75 in. wide and was placed in the tunnel lengthwise. The nominal air speed in the wind tunnel was 29 fps.

A hot-wire anemometer (Flow Corporation Model HWB-3) was then used to measure the axial relative turbulence intensities, u_1'/U_0 at various axial distances downstream of the fence but at a fixed distance of $\frac{9}{64}$ in. above the surface of the flabby skin in the center of the plate. The output of the hot-wire anemometer was fed to either an oscilloscope or a root-mean-square meter.

Figures 1 and 2 are oscilloscope pictures of the turbulence for the hard surface (plastic skin glued to aluminum plate) and flabby skin plate with oil as the damping fluid. The pictures correspond to the turbulence 3 in. behind the fence, and it is evident that the flabby skin with oil damping has less turbulence than the hard surface plate. From Fig. 3 it is apparent that the amount of turbulent damping is a function of the viscosity of damping fluid. The three coatings tested all showed less turbulence than the hard surface, and the turbulent damping increased as the viscosity of the damping fluid increased. Intuitively we feel that this trend must certainly reverse itself if the damping fluid viscosities were to be increased to some larger value. As the viscosity approaches infinity it would seem reasonable to expect the coating to then behave as a hard surface.

It should be noted that the plastic skin was attached to the plate with a small amount of tension transverse to the flow direction. There was essentially no tension parallel to the flow direction. (Karplus[7] placed the tension of this skin parallel to flow direction in his water tunnel studies.) It is interesting that in some of the preliminary tests the tension of the plastic skin was not uniform throughout the length of the plate. The area that had high tension did not seem to reduce the turbulence intensities as well as the low tension areas.

These tests were only exploratory, but they are encouraging in that the flabby skin did reduce the turbulent intensity, and

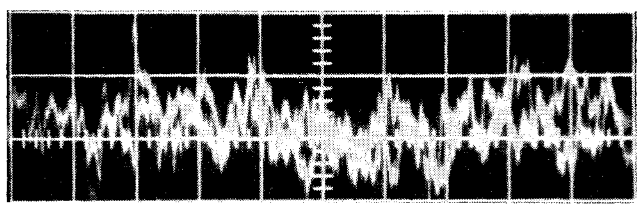

Fig. 2 Oscilloscope picture of turbulence on flexible surface plate, with oil damping fluid, 3 in. behind the fence.

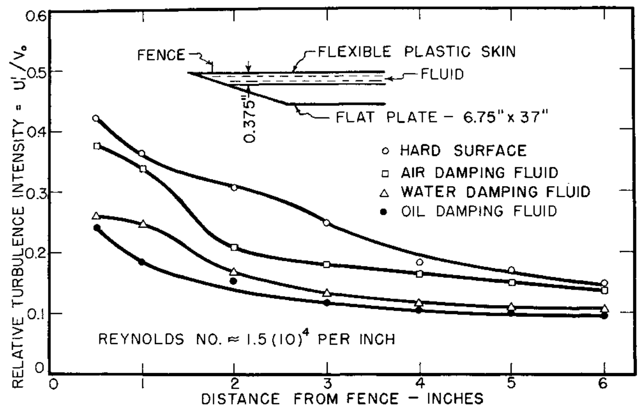

Fig. 3 Variation of relative turbulence intensity.

they lead one to speculate, using Von Karman's similarity hypothesis,[8] that perhaps the skin friction also was reduced. However, it is realized that the tests were not conducted in a natural turbulent boundary layer but rather in a mixture of a fence wake plus a boundary layer.

Therefore, future tests are being planned that will measure the relative turbulence intensities, Reynolds stresses, and skin friction coefficients in natural turbulent boundary layers on flabby skin flat plates. Care will be taken to determine the effect of magnitude and direction of skin tension, skin mass and depth, and viscosity of damping fluid.

References

[1] Kramer, M. O., "Boundary layer stabilization by distributed damping," J. Aerospace Sci. **24**, 459 (1957).

[2] Kramer, M. O., "Boundary layer stabilization by distributed damping," J. Am. Soc. Naval Engrs. **72**, 25–33 (February 1960).

[3] Kramer, M. O., "The dolphins secret," J. Am. Soc. Naval Engrs. **73**, 103–107 (February 1961).

[4] Benjamin, T. B., "Effects of a flexible boundary on hydrodynamic stability," J. Fluid Mech. **9**, 513 (1960).

[5] Landahl, M. T., "On the stability of a laminar, incompressible boundary layer over a flexible surface," J. Fluid Mech. **13**, 609–632 (1962).

[6] Kaplan, R. E., "The stability of laminar incompressible boundary layers in the presence of compliant boundaries," ASRL TR 116-1, Aeroelastic and Structures Research Lab., Massachusetts Institute of Technology (June 1964).

[7] Karplus, H. B., "Turbulent flow transition near solid and flexible boundaries," Rept. IITRI 1205-4, Illinois Institute of Technology Research Institute (March 1963).

[8] Hinze, J. O., *Turbulence* (McGraw-Hill Book Co., Inc., New York, 1959), pp. 491–92.

Small Arms Fire Effects on Aluminum Honeycomb Panels

DONALD R. ALLEN* AND HERBERT W. BALLINGER,†
Beech Aircraft Corporation, Wichita, Kansas

Introduction

ALUMINUM honeycomb paneling is extensively used on aircraft, missiles, and ground support equipment. The widespread usage is, in large measure, based on the ability of the panel to carry great loads with lightweight structures. Present technology produces paneling which, in normal service, has longer life expectancy than the rated life of the aircraft or missile on which it is employed. However, in combat conditions, such paneling is exposed to small arms fire, which can degrade the structural value of the material. It is an object of this study to measure the effects of certain conventional ammunition on several pieces of aluminum honeycomb paneling.

Discussion

A great variety of aluminum honeycomb paneling is manufactured, and an exhaustive study of small arms fire effects would require testing of many different types of such paneling with several types of ammunition. The scope of the present study is restricted to testing a series of 3-in. by 12-in. by 0.54-in. panels with three different kinds of ammunition. The test panels used in this study had aluminum honeycombs 0.5 in. thick with 0.25-in. cells and was made of 0.004N-5052H-39. The honeycomb was sheathed on both sides with 0.020-2024-T3. The skins were bonded to the cores with FM-1000 adhesive cured at 335°–355°F under 20–34 psi for 1 hr. A total of 57 test panels were used in the study. Eighteen of the test panels were exposed to .22 calibre rifle fire. Eighteen other panels were exposed to .30-'06 calibre rifle fire. A final 18-test panels were exposed to .30 calibre carbine fire. Three remaining panels were used as control specimens in the compression-shear test program. Commercial .22 calibre long rifle high speed rim fire ammunition, military .30-'06 calibre ammunition, and military .30 calibre carbine ammunition were employed in the test program. The .22 calibre ammunition and the .30-'06 ammunition were fired from bolt action rifles. The .30 calibre carbine ammunition was fired from a semiautomatic rifle. The .22 calibre long rifle ammunition has an estimated muzzle velocity of 1335 fps, the .30-'06 ammunition 2700 fps, and the .30 carbine 1970 fps. All 54 test firings were conducted with a fixed muzzle-to-specimen distance of 19 in.

Three bullet impact angles of 90°, 60°, and 30° were used in the firing program. Bullet paths through the specimens were in the direction of the 3 in. width. Bullet entry and exit locations were selected to prevent edge-tearing of the specimens. Each test firing condition was repeated in triplicate.

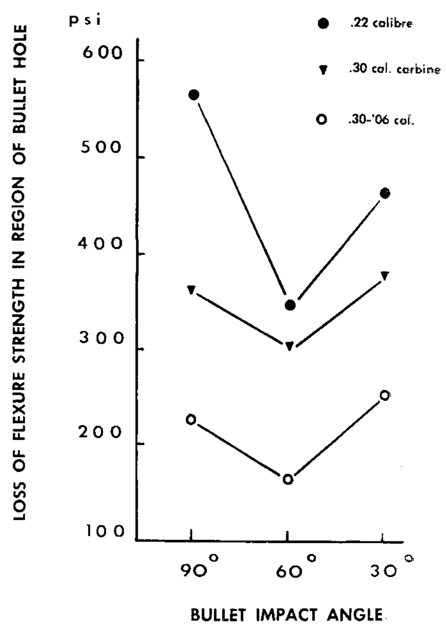

Fig. 1 Loss of flexure strength in regions of bullet holes vs bullet impact angles.

Received November 17, 1965.

* Technical Assistant to Director, Missile Systems Division. Associate Fellow Member AIAA.

† Armament Engineer, Advanced Design, Missile Systems Division.