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Impact Tests of Full-Tempered Glass Windshield Panels

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IMPACT TESTS OF FULL-TEMPERED GLASS WINDSHIELD PANELS*

SUMMARY

This report presents the results of impact and optical deviation tests carried out upon full-tempered glass panels of 1/4-inch, 1/2-inch, 3/4-inch, 1-inch, and 1 1/4-inch thicknesses nominally 12 inches by 36 inches in size

An exponential relationship exists between the penetration velocity and the panel thickness At impact velocities less than that required for failure, no effect upon the full-tempered pane was observed At impact velocities which result in panel failure, the energy-absorption factor of the full-tempered glass was indicated to be relatively low The penetration velocity of these panels is independent of panel temperature

The full-tempered glass panes showed excellent optical characteristics

From weight consideration, the practical application of full-tempered glass panels for aircraft use appears to be limited to low-speed aircraft, windshield installations with a high angle of panel slope, and particularly for side- or corner-window installations of high slope

INTRODUCTION

The purpose of these tests was to determine the penetration velocity and other impact characteristics of full-tempered glass plate The use of this type of panel has been suggested for aircraft windshields because of its excellent optical characteristics, its relative freedom from strength variation due to temperature, and its freedom from cracking at impact velocities less than that required for complete failure.

Initial tests of full-tempered glass panels were made in June 1945, on 1/4-inch- and 1/2-inch-thick panels The results of these tests are included in this report In nearly all tests of double-pane-type windshield installations, a 1/4-inch, full-tempered front pane was used and therefore, has been observed in numerous tests during a period of several years.

TEST PROCEDURE

The panels were mounted in a steel frame and were clamped at the edges with steel strips and rubber and cork gaskets The 3/4-inch, 1-inch, and 1 1/4-inch glass panes tested at a slope of 41° utilized a 1/4-inch, full-tempered front pane simulating a double-pane installation The balance of the panes were tested as single-pane installations. The over-all dimensions of all panes were 13 3/16 inches by 37 9/16 inches.

Freshly killed chicken carcasses of 4 pounds weight, tied in a light cloth bag, were used in the tests The carcass was projected at the desired velocities by means of a compressed-air gun

The panels were tested at two different angles The first series was tested at the same angle as was used in the Douglas DC-3 installation, wherein the slope of the vertical axis is 17° and that of the horizontal axis is 38°. The total angle of slope for this series was 41° The second series was tested at a total angle of slope of 60°, the vertical slope being 0° and the horizontal slope being 60° Impact was obtained at the midpoint of the panels in each case.

Velocity measurements were obtained as the carcass broke two sets of fine steel wires after leaving the muzzle of the gun One set of wires was connected to a direct-reading chronoscope, and the other set was connected to a recording oscillograph The tests were made at room temperature of about 75° F

The optical deviation tests were made by photographing a grid arrangement, first, with no glass panel, and secondly, with the panel between the camera and the grid. The two photographs were taken on one negative with the camera lens axis perpendicular to the glass panel and grid at their respective midpoints. The distance between the grid and glass was arranged so that 1-inch grid spacing corresponded to 10 minutes of arc deviation.

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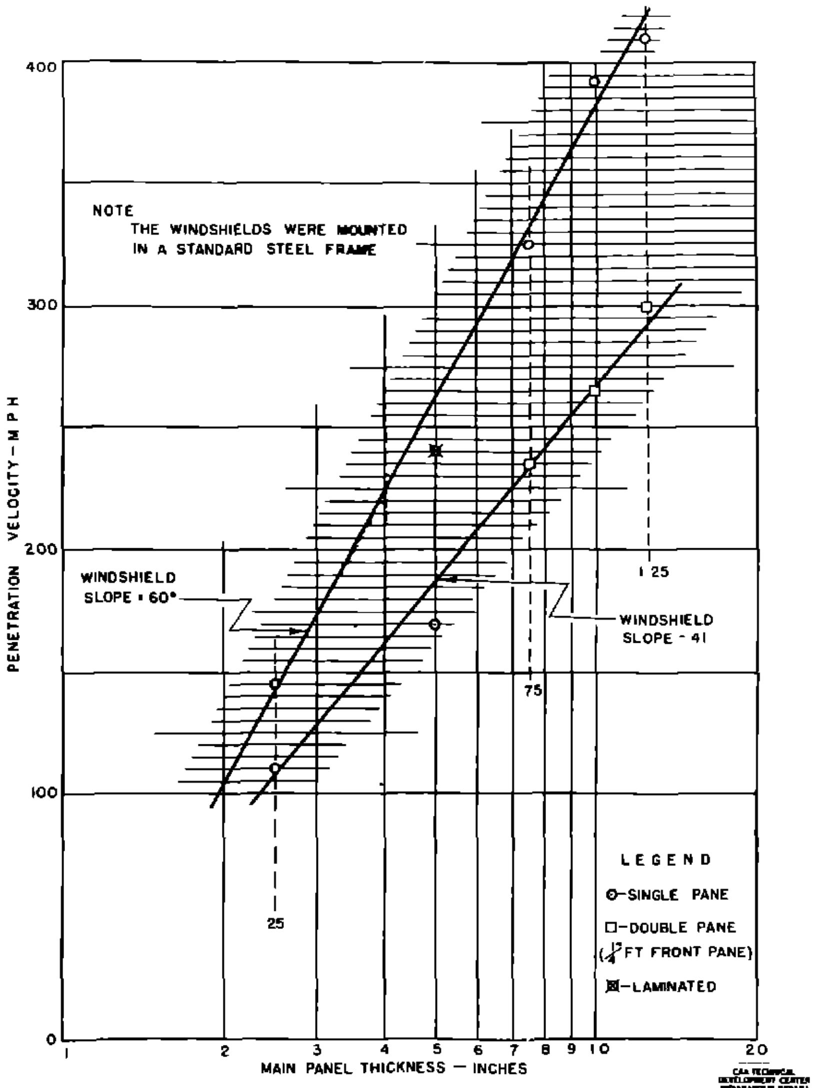

Fig. 1 Penetration Velocity of Full-Tempered Glass Windshield Panels of 1- by 3-Foot Size Tested with 4-Pound Carcass

TEST RESULTS

The results of the impact tests are illustrated graphically in Fig. 1. Each value was determined by three or more tests.

Tests at Angle of Slope of 41°.

The penetration value for the 1/4-inch-thick full-tempered glass pane had been determined previously through its use as the front pane in numerous double-pane installations. The penetration velocity was checked again during the period of the tests of the heavier panels and was found to be 110 mph.

The penetration velocity for the 1/2-inch-thick full-tempered glass pane was given as 190 mph in a previous report.[1] However, subsequent to that report, a 10 per cent correction was made to the frequency standard used for velocity measurement, thereby reducing this value to 171 mph.

[1] "Impact Tests of 1/2-Inch Full-Tempered Glass," CAA Experimental Station, Structures Section Report No. 2, July 1945 (unpublished).

An attempt was made to measure the velocity of the carcass after it had shattered the panel and passed through it Only one such velocity was recorded in the case of a 3/4-inch panel where the carcass velocity before the panel was 258 mph and 158 mph behind the panel In all other cases, either the carcass failed to penetrate the panel or was so deflected that it failed to break the second timing wire spaced 4 feet behind the glass.

In the case of the 1 1/4-inch panels, the first test was of interest in that a carcass velocity of 302 mph caused the glass to shatter completely but not to fall out of the frame The carcass glanced off in a crushed state. Another test at 285 mph resulted in carcass penetration A third test with a carcass velocity of 300 mph resulted in no failure of the 1 1/4-inch pane.

As mentioned previously, in the group of panels tested at an angle of slope of 41°, the panels of 3/4-inch, 1-inch, and 1 1/4-inch thicknesses were tested with a 1/4-inch, full-tempered glass front pane The front pane apparently has little effect upon the impact strength of rear panes of equal or greater thickness Therefore, the results of all tests are plotted together in Fig. 1.

Tests at Angle of Slope of 60°

The penetration value for all panes in this series was obtained by making several tests on a single pane due to shortage of test specimens. The initial velocity for each panel thickness was conservatively estimated from previous tests. The carcass velocity then was increased in 25-mph increments until the panel failed. The value of the penetration velocity was derived by averaging the "failure" and the highest "no failure" figures. After each shot of the 3/4-inch, 1-inch, and 1 1/4-inch panels, the glass was removed and the frame mounting was straightened

The penetration value for a 1/4-inch-thick, full-tempered glass panel was determined to be 145 mph in these tests.

The 1/4-inch panel was a laminated pane consisting of two 1/4-inch, full-tempered panes bonded together with a 0 025-inch vinyl interlayer. The penetration velocity value for the 3/4-inch was 325 mph, for the 1-inch, 392 mph, and for the 1 1/4-inch, 410 mph.

Optical Tests.

Optical deviation photographs of full-tempered glass of 3/4-inch and 1 1/4-inch thickness are shown in Figs 2 and 3

The maximum optical deviation for normal line-of-sight for the three heavier panes appears relatively small compared to that usually obtained with laminated windshield panes with thick vinyl plastic interlayer.

The maximum deviation obtained with any of the panels tested is approximately 2 minutes of arc The maximum rate of change of deviation is approximately 0.25 minute of arc per inch

DISCUSSION

It is noted from Fig. 1 that an exponential relationship exists between the penetration velocity and the panel thickness. This relationship is such that for each doubling of the glass thickness, an increase in the penetration velocity of approximately 80 mph is obtained in the case of panels mounted at an angle of slope of 41° An increase of approximately 120 mph in the penetration velocity is obtained by doubling the thickness of the glass panels mounted at an angle of slope of 60°.

This relationship may be expressed as

$$T = 0\ 136\,(1-0.348\cos\theta)\,e^{\frac{V\cos\theta}{87.3}} \qquad (1)$$

where

T = thickness of the principal pane in inches

V = penetration velocity in miles per hour, and

θ = total angle of panel slope in degrees.

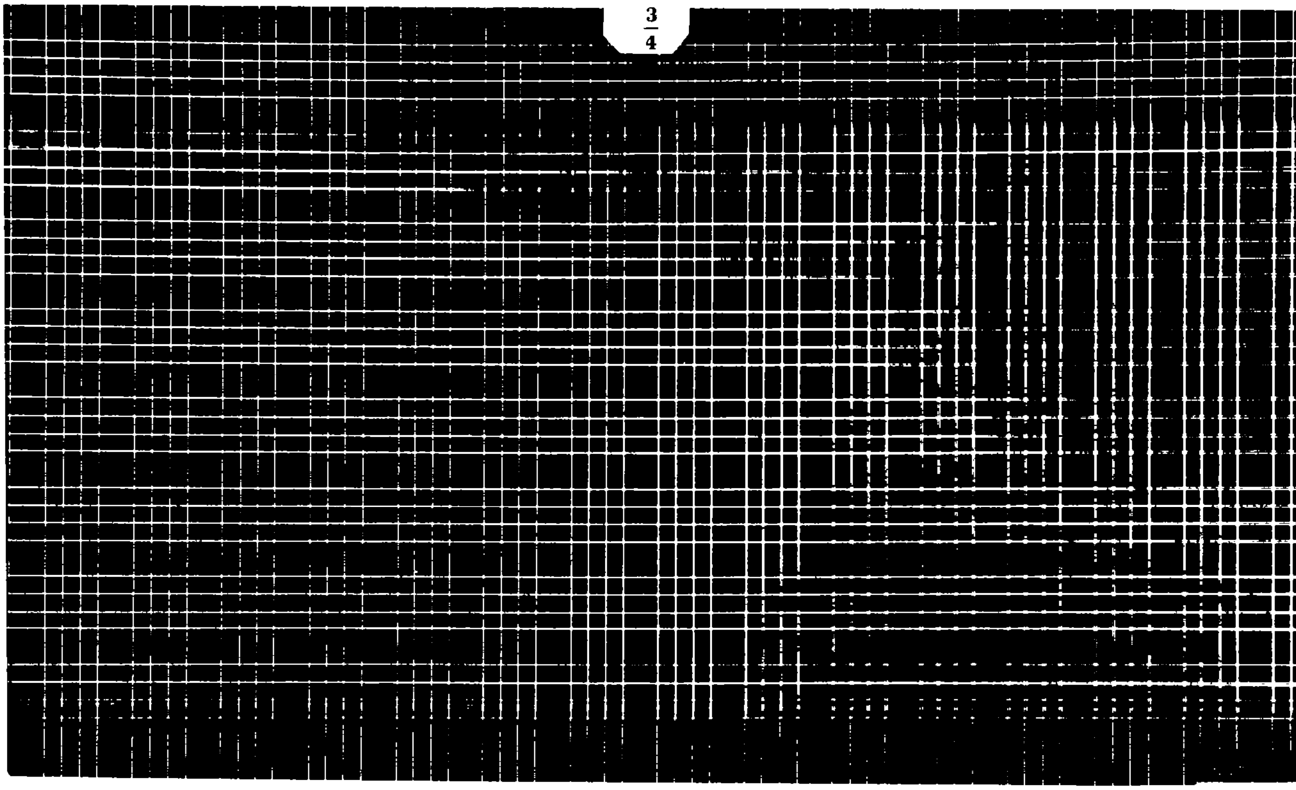

Fig. 2 Optical Deviation Photograph Through Full-Tempered Glass Panel of 3/4-Inch Thickness

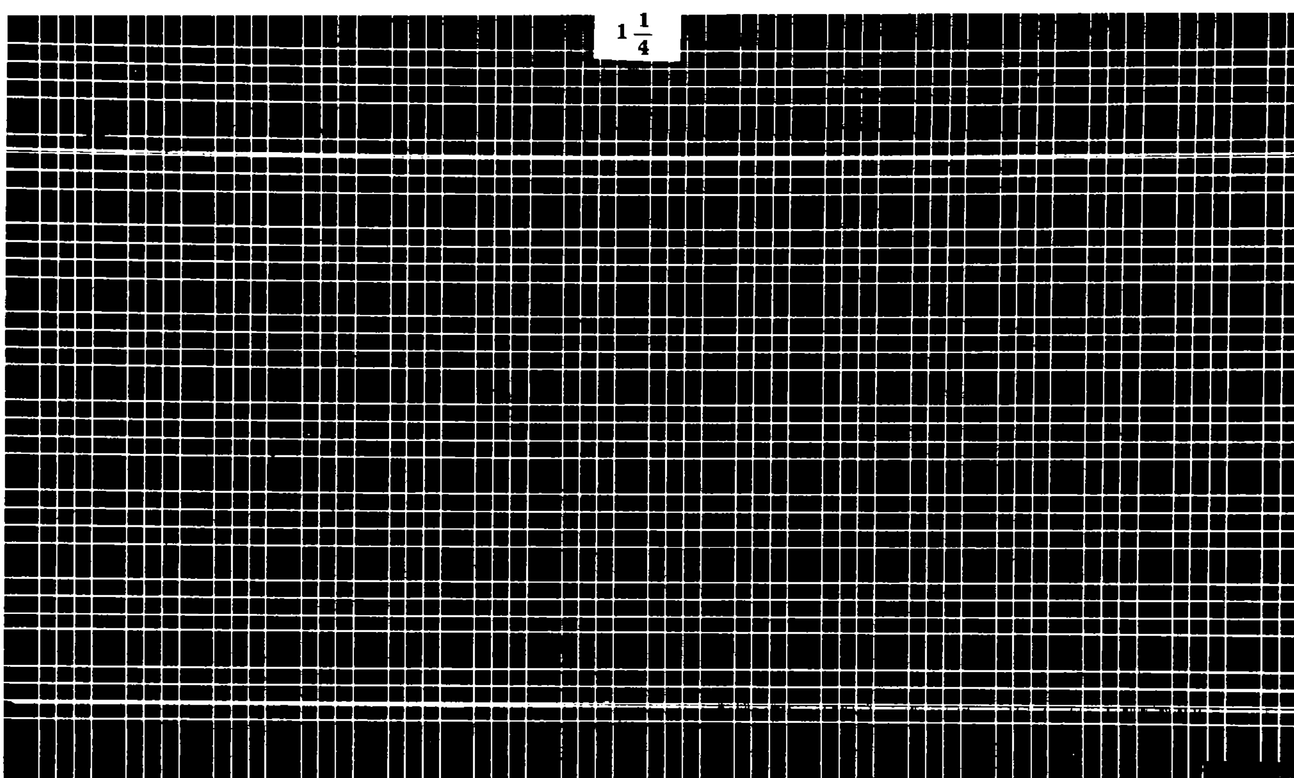

Fig. 3 Optical Deviation Photograph Through Full-Tempered Glass Panel of 1 1/4-Inch Thickness

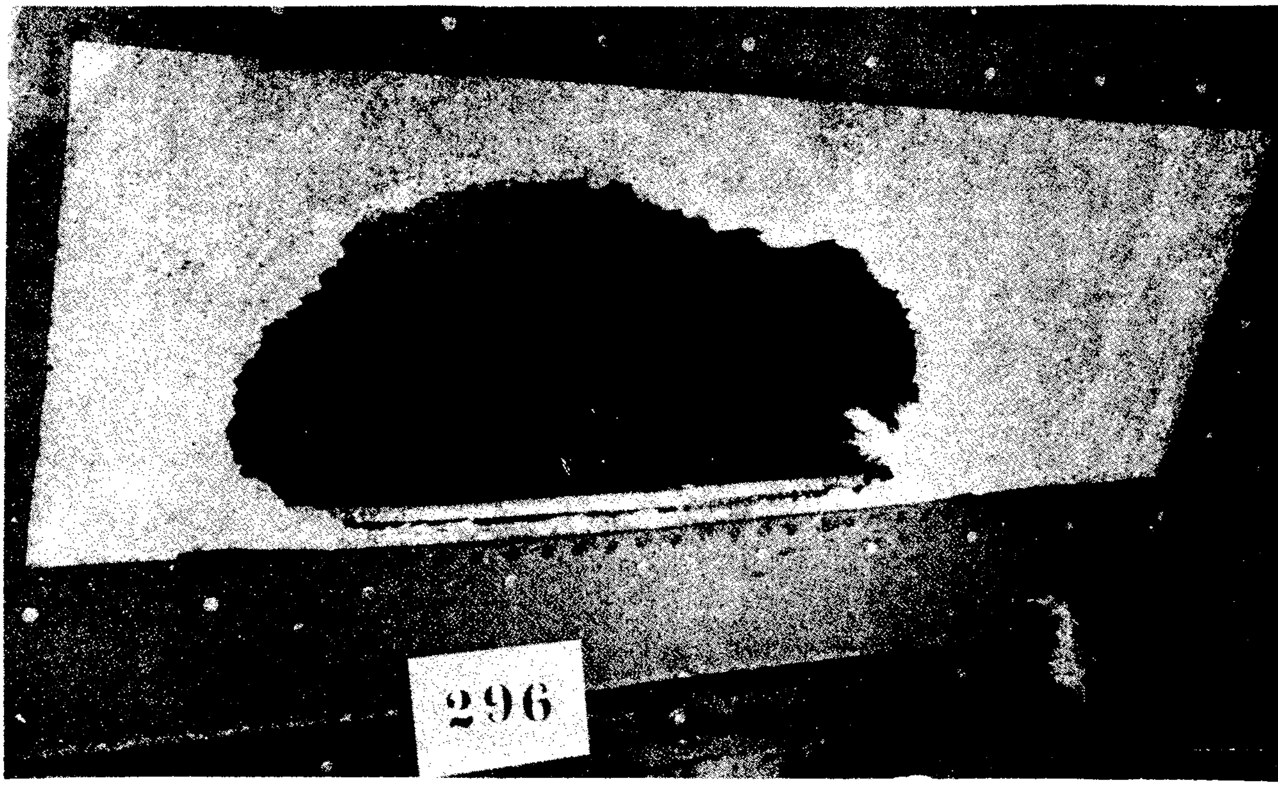

Fig. 4 Fracture of Full-Tempered Glass Panel of 3/4-Inch Thickness From Impact of 4-Pound Carcass at 260 MPH

It is seen that, with such a relationship existing, a glass thickness is soon reached where further increase becomes uneconomical from the standpoint of the weight/strength ratio.

A study of the effect of angle of panel slope upon the penetration velocity indicates that the slopes of the straight lines shown in Fig. 1, which express the relationship between the penetration velocity and the panel thickness, are inversely proportional to the cosine of the windshield slope angle.

The data obtained concerning velocity of the carcass after passing through the panel are limited, but such data and observation of tests where such velocity measurement was not attempted indicate that the full-tempered glass panels absorb only a relatively small portion of the carcass kinetic energy during impact in which the panel fractures. This is a recognized characteristic of full-tempered glass. It may be concluded that this type of panel provides complete protection against bird penetration and glass splintering at energy values less than that required for failure, but very little protection or easing of the impact at greater energy values.

The type of glass fracture which occurs is typical of that obtained in full-tempered glass, as shown in Fig. 4. Complete disintegration of the panel results. The main portion of the glass is broken into approximately cubical blocks, but many fine sharp splinters are produced.

It is apparent from the test results that the use of a 1/4-inch, full-tempered glass front pane has little effect upon the impact strength. This is in agreement with previous test results. It also is indicated that laminated full-tempered glass possesses approximately the same impact strength as a single full-tempered plate of identical total thickness.

General independence of the impact strength of the glass temperature effects, over the temperature range normally existent in aircraft windshields, is well known. Therefore, tests in this connection were considered unnecessary.

CONCLUSIONS

1. The penetration velocity of full-tempered glass panes, when tested with a 4-pound bird carcass, possesses the following approximate relationship to the panel thickness

$$T = 0.136\,(1-0.348\cos\theta)\,e^{\frac{V\cos\theta}{87.3}}$$

where

T = panel thickness in inches
V = penetration velocity in mph
θ = angle of panel slope in degrees.

2. The use of a 1/4-inch, full-tempered glass front pane has little effect upon the impact strength of rear panes of equal or greater thickness
3. At impact velocities less than that required for failure, no effect upon the full-tempered glass pane is observed.
4 At impact velocities which result in panel failure, complete disintegration of the full-tempered glass pane is produced, and only a moderate decrease in the velocity of the bird carcass is obtained in passing through the panel
5. The full-tempered glass panes show low optical deviation values.
6. The impact strength of full-tempered glass panes is essentially independent of panel temperature.
7. From weight considerations, the practical application of full-tempered glass panels for aircraft use appears to be limited to low-speed aircraft, windshield installations with a high angle of panel slope, and particularly for side- or corner-window installations of high slope