IMPACT TESTING OF AIRCRAFT WINDSHIELDS BY MEANS OF A DROPPING PROJECTILE

By
B M Axilrod and M S McKinney
National Bureau of Standards

Pell Kangas and George L Pigman
Aircraft Development Division

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SUMMARY

This investigation was carried out at the National Bureau of Standards in order to study the problem of developing a simplified laboratory procedure for testing the impact strength of aircraft windshields It was required that such a simplified test provide results which would correlate with the results obtained in the Civil Aeronautics Administration tests utilizing a compressed-air catapult for projecting bird carcasses against the windshield panels Further, it was required that the test procedure be suitable for utilization at any location with a minimum of specialized equipment, and readily applicable by aircraft or windshield manufacturers to determine resistance of windshield panels and frame structures to bird collision

Dropping-projectile tests were conducted using selected types of windshield panels which varied widely in their construction and elastic characteristics A shot-filled rubber bag, lead spheres of different size, and a hollow, round-nosed steel dart, loaded to various weights up to 110-lb, were dropped upon these panels with normal incidence of impact The latter type of projectile, of 61-lb weight, was utilized in most of the tests, both with and without a rubber cushion interposed between the dart and the windshield panel Tests were carried out with a maximum height of drop of 65 feet

The limited test results covered by this report indicate that a reasonably satisfactory correlation exists between the dropping-projectile test and the catapult test when using a 4-lb chicken carcass, insofar as panel strength alone is concerned However, the correlation between the dropping-projectile test and the catapult test with a 14-lb carcass, within the ranges of projectile weight and velocity used, was unsatisfactory

Correlation between the catapult tests and the dropping projectile tests, with regard to strength of windshield-cockpit enclosure structure combinations, has not been established An additional extensive program of tests with the catapult and dropping projectiles would be required to establish whether or not this objective might be reached

INTRODUCTION

For the past several years the Office of Technical Development of the Civil Aeronautics Administration has conducted a test program concerned with the development of aircraft windshields of improved resistance to collision with birds in flight In these tests, a compressed-air catapult was used to project bird carcasses at airplane flight velocities against test windshield panels, simulating as closely as possible actual bird collisions.

Data were obtained in these tests concerning the maximum impact velocities at which different types of windshield panels will resist penetration of birds of various weights Further, it was shown by the tests that the windshield arrangement which utilizes a laminated glass-plastic pane with thick polyvinyl butyral plastic interlayer provides maximum impact strength In this report, the windshield arrangement described as Type I incorporates such a glass-plastic rear pane Results obtained in the test program have been reported in previous publications [1,2]

During the course of this program, it was felt necessary to explore the possibility of utilizing a simpler test method than that provided by the compressed-air catapult for the purpose of routine checking or approval of windshield installations The use of the catapult entails the assembly of a considerable amount of test equipment A test method using a dropping projectile could be carried out readily, with minimum equipment, by air-

[1]George L Pigman, "Impact-Resistant Windshield Construction," Aeronautical Engineering Review, Vol 4, No 1, p 9, January 1945

[2]Pell Kangas and George L Pigman, "Development of Aircraft Windshields to Resist Impact with Birds in Flight," Part II, Technical Development Report No. 74, January 1948

craft or windshield manufacturers at any location In addition, data derived from dropping-projectile tests might be used as a basis for acceptance of windshield designs under safety regulations Accordingly, the Civil Aeronautics Administration, in 1943, requested the National Bureau of Standards to investigate the possibility of developing a simple drop test which would provide results correlating satisfactorily with those obtained with the compressed-air catapult

The original bird impact studies were conducted at the laboratories of the Westinghouse Company at East Pittsburgh, Pennsylvania, during 1942 and 1943 These tests were all made using 14-lb turkey carcasses The drop test study at National Bureau of Standards was conducted in this general period during 1943 and 1944 Bird impact tests utilizing 4-lb chicken carcasses were begun in February 1945, when the bird-catapult equipment was moved from East Pittsburgh to the CAA Experimental Station at Indianapolis.

At the time the program was started at the National Bureau of Standards, the probable difficulty of establishing a satisfactory drop test was realized The catapult test utilizes a soft projectile of relatively low mass, traveling at high velocity, whereas a drop test necessarily involves a projectile of relatively large mass and low speed It was not believed certain that, with such a change in impact conditions, a satisfactory relationship between the results of the two types of test could be demonstrated

The present report covers the results of the investigation of drop testing techniques carried out at the National Bureau of Standards. There are also included additional drop test data on methyl methacrylate plastic sheets more recently obtained at the CAA Experimental Station Although the results reported are not conclusive with regard to possibility of establishing a satisfactory drop test, it is considered that publication of the results will be of general interest, and may serve as a basis for further suggestions and work

DESCRIPTION OF WINDSHIELDS

In the drop tests it was desired to utilize a limited number of the various panel types already tested with the catapult Such panels were chosen so as to obtain a wide variety of construction, materials, and impact strength, in order that any simplified test which might be developed would be applicable to all windshield panels which might be considered practical for aircraft use Four types of panel construction were included in the drop test program The panels tested were flat rectangles 13 1/4 by 37 1/2 in in outer dimension, mounted horizontally in a steel frame In the following description of these panels, the dimensions indicated are the thicknesses of their components

Type I - A double-pane windshield with one-fourth inch full-tempered glass front pane, separated by a one-fourth inch air space from a laminated glass-plastic rear pane The rear pane incorporated 7/64-in semi-tempered glass faces and a polyvinyl butyral plastic core extended at the edges with 0 025-in aluminum alloy strip edge reinforcement The rear pane was tested with one-eighth inch and one-fourth inch polyvinyl butyral interlamination, designated as Type Ia and Type Ib, respectively The Type I panel is illustrated in Fig 1

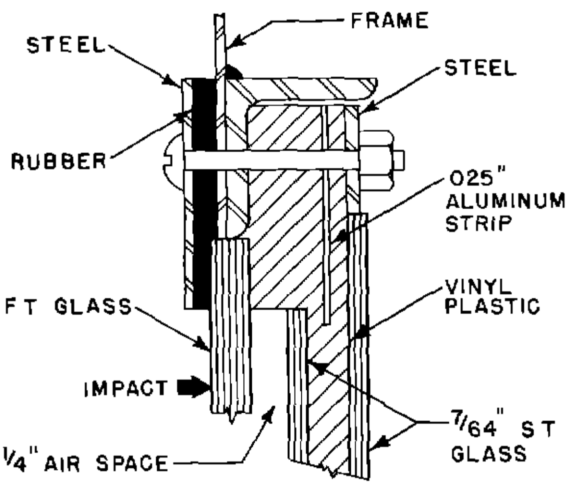


Fig 1 Type I Windshield Arrangement

Type II - A double-pane windshield consisting of a one-fourth inch full-tempered front pane, separated by a one-fourth inch air space from a laminated glass rear pane The rear pane consisted of two one-fourth inch full-tempered glass faces joined with a 0 025-in polyvinyl butyral plastic bonding layer The Type II pane is illustrated in Fig 2

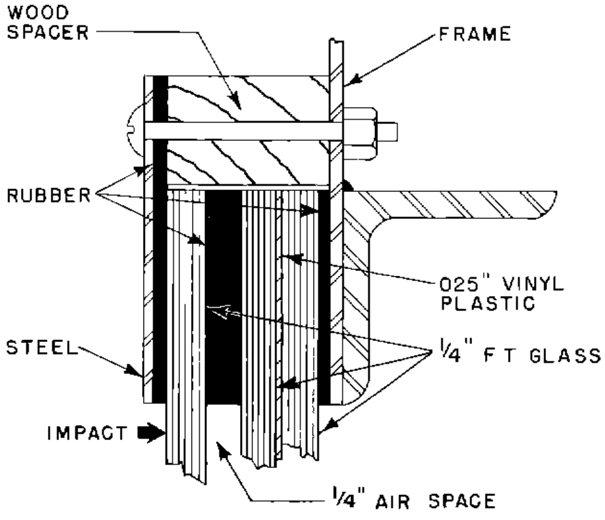


Fig 2 Type II Windshield Arrangement

Type III - A single-pane plastic windshield of one-half inch cellulose acetate, as illustrated in Fig 3

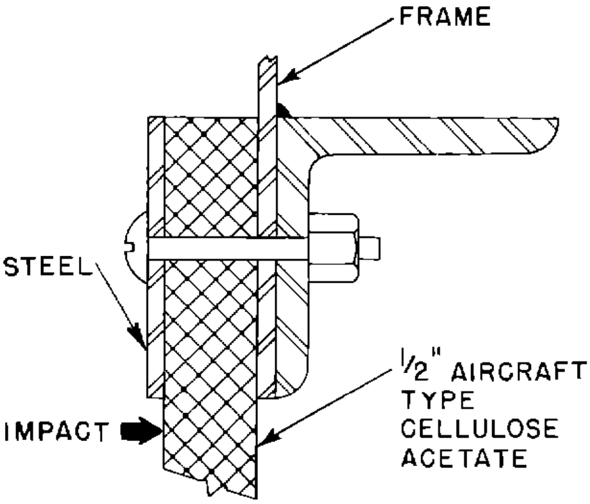


Fig 3 Type III Windshield Arrangement

Type IV - A single-pane laminated windshield with 7/64-in glass faces and 0 015-in polyvinyl butyral bonding layer This type is commonly used in present commercial aircraft, and is illustrated in Fig 4

Type V - A single-pane plastic windshield of one-half inch methyl methacrylate, as illustrated in Fig 5

The polyvinyl butyral plastic, hereinafter designated as vinyl plastic, used in

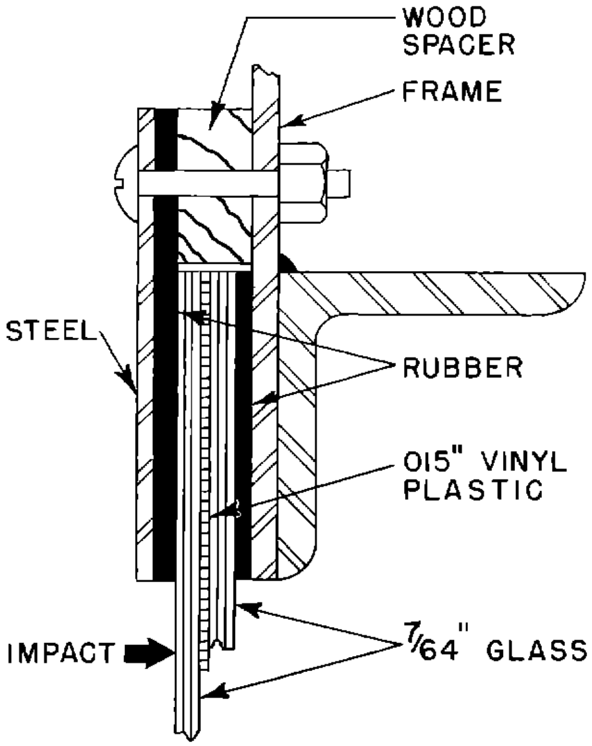


Fig 4 Type IV Windshield Arrangement

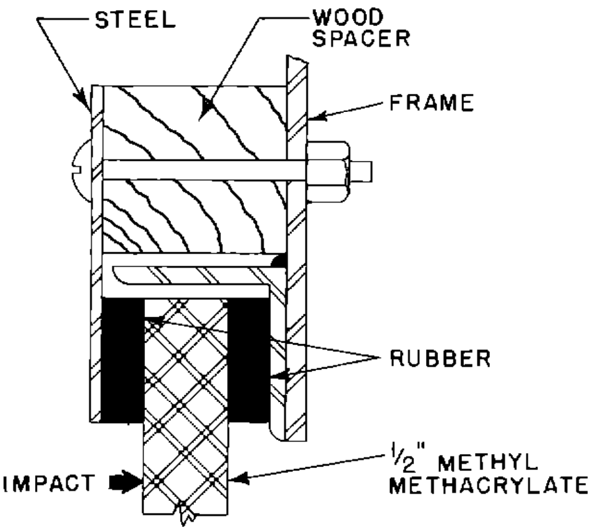


Fig 5 Type V Windshield Arrangement

thicknesses of one-eighth inch and one-fourth inch, utilized a plasticizer content of 20 per cent The 0 015-in and 0 025-in thick vinyl plastic interlayers were made with 30 per cent plasticizer content

Types I and III windshields were held in the frame by bolting. Types II, IV, and V windshields were clamped in place with thick rubber gaskets to uniformly distribute the clamping pressure. The same procedure had been used to support the corresponding panels in the catapult tests.

TEST EQUIPMENT AND PROCEDURE

The steel mounting frame was approximately 24 by 48 in. in size, and identical to that used in the catapult tests. The frame was designed to simulate approximately the elastic and buckling characteristics of an airplane structure, and was bolted to an angle-iron stand grouted to the concrete floor. This is shown in Fig. 6. The tests were carried out with the windshield panels placed horizontally so as to obtain impact at normal incidence. The temperature of the windshield panels was maintained at 25 to 29° C (77 to 84° F) during the tests.

The tests were made in an elevator shaft in which a maximum height of drop of 66 feet was available. The projectile was released by burning or cutting the rope with which it was suspended, as shown in Fig. 7. With this procedure, close control of the point of impact at the center of the windshield panel was obtained.

In the catapult tests the panels were mounted identically to the windshield position in the DC 3 airplane. In this airplane the horizontal axis of the windshield forms an angle of 52° with the longitudinal axis of the airplane, and the vertical axis of the windshield slopes rearward to form an angle of 17° with the vertical, giving a total angle of slope of 41°. The catapult tests were made with a panel temperature of 25 to 27° C (77 to 81° F).

It was assumed that any correlation which might be established between the drop test with normal incidence of impact, and the catapult test with a specific oblique angle of impact, could be extended to other angles of windshield mounting by further determination of the relationship between windshield penetration velocity and windshield slope angle.

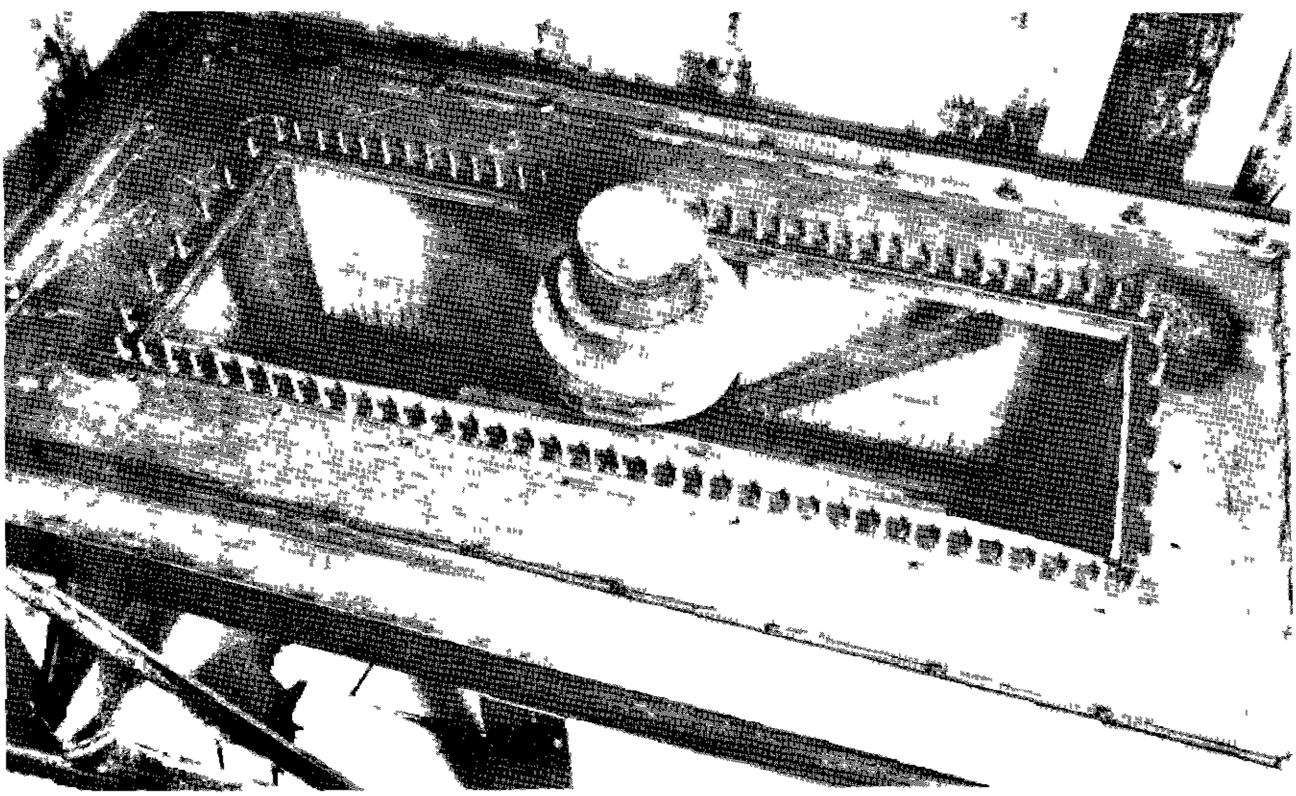


Fig. 6 Windshield Mounting Structure and Butyl Rubber Cushion

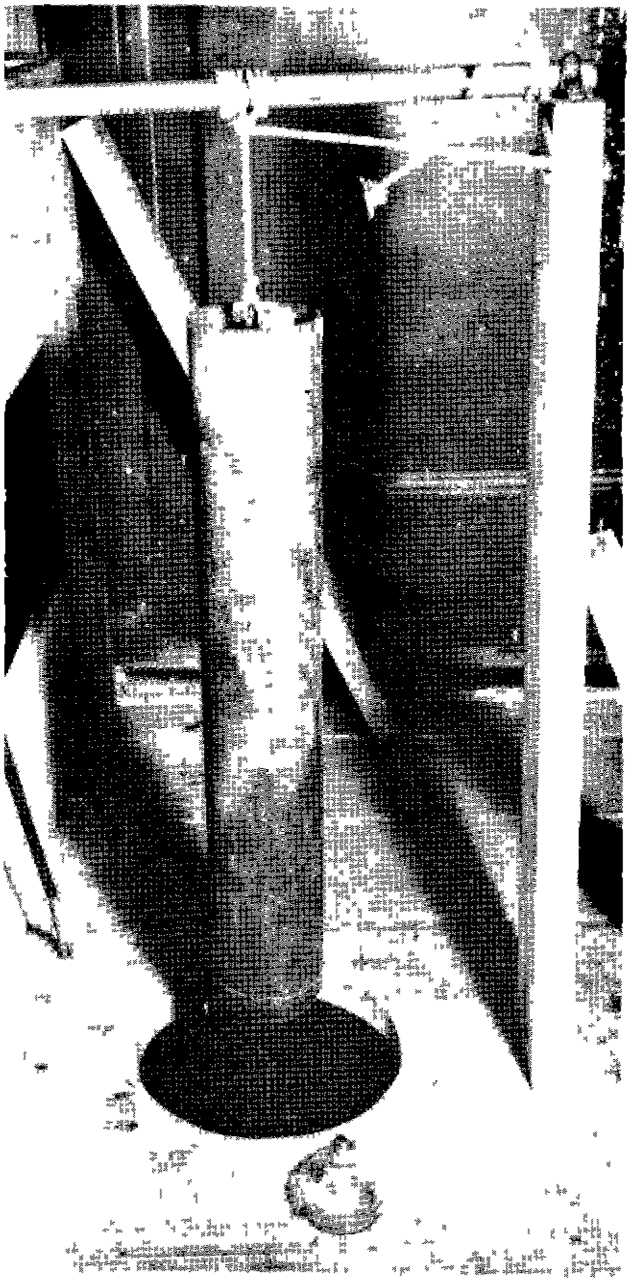


Fig 7 Projectile Before Release

In the catapult tests, each value of penetration velocity was determined as the median value between the highest velocity where no penetration was obtained and the lowest velocity where penetration occurred Similarly, in the drop tests, the height of drop of a projectile of specified weight and type, that barely caused failure of the windshield panel sufficient to permit the projectile to pass through, was chosen as the median value between the maximum height of drop where no penetration occurred and the minimum height of drop where penetration was obtained

SELECTION OF PROJECTILE

The basic problem involved in the test program was the determination of a type of projectile which would provide a qualitatively similar impact to that obtained with the bird carcass in the catapult tests A further consideration was the necessity of adjusting the weight and type of projectile so as to obtain penetration of the strongest panel at the height of 65 feet, which was estimated to be the maximum height which would be practical for a general test of this nature

As stated previously, it was considered possible at the start of the tests that as the nature of the impact varies considerably with large changes of projectile velocity, changes of elastic properties of the projectile, and change in ratio of projectile mass to windshield mass, no type of projectile might be found to satisfy the desired objectives With the drop test necessarily limited to a relatively large projectile mass at low velocity, the only principal fundamental factors which could be adjusted in the selection of the projectile were its elastic characteristics and impact area

Four different projectiles, shown in Fig 8, were used in the tests A shot-filled rubber bag, Type A, weighing 53-lb was tried first Two lead spheres, Types B and C, weighing 60 and 110-lb , respectively, next were used It was found that none of these projectiles would produce penetration of the Type Ib windshield with a height of drop of 65 feet The results obtained with tests of these projectiles are given in Table I, and the appearance of a Type Ib panel after test with the 110-lb lead sphere at a height of drop of 65 5 feet is shown in Fig 9

A hollow, round-nosed, steel dart loaded with lead (Type D shown in Fig 7) was utilized in the succeeding tests This dart was used both in direct impact against the windshield panel, and with interposed rubber cushions of various types to affect the area and general nature of the impact blow The diameter of this dart was 4 3/4-in , and its length was 30-in The weight of the dart was varied from 31 to 110-lb , with most of the tests being conducted with a weight of 61-lb

TABLE I - TESTS WITH VARIOUS PROJECTILES ON TYPE Ib WINDSHIELDS

(Type Ib - Front Pane-1/4-in full-tempered glass
Rear Pane -7/64-in semi-tempered glass
faces laminated with 1/4-in
polyvinyl butyral plastic
interlayer)

N B S Test No	Specimen No	Height of Drop ft	Projectiles Construction	Weight lb	Effect on Windshield
1	Ib-B-1	66	Rubber ball, about 9-in diameter, partly filled with lead shot	53	No penetration, bolts failed on one edge
2	Ib-B-2	66	Same as above	53	No penetration
3	Ib-B-3	66	Lead ball, 6 1/2-in diameter	60	No penetration
4	Ib-B-4	65 5	Lead ball, 8-in diameter	110	No penetration

NOTE Temperature - 25 to 30° C

The specimen designation in all the tables is as follows

The roman numeral is the type of windshield
The capital letters, A, B, and C indicate the manufacturers
The arabic numeral indicates the specimen identity

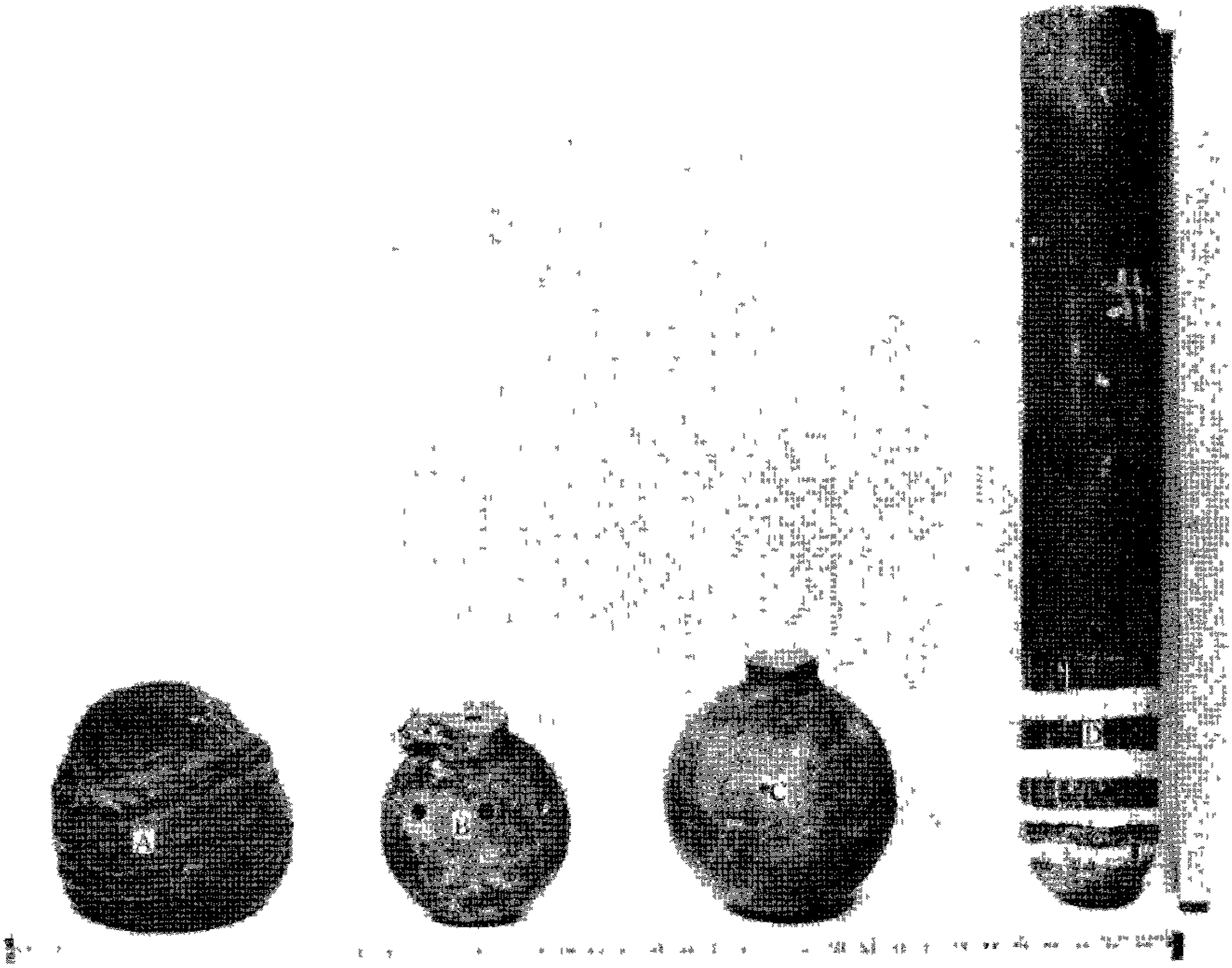


Fig 8 Types of Projectile Utilized in Drop Tests

The cushion found to be most satisfactory was formed of a pile of five butyl rubber discs, each of which was made by the following formula, designated as compound B

	Parts by Weight
GR-I (butyl rubber)	100
Zinc oxide XX Red No 72	5
Stearic acid	3
Tetramethylthiuram disulfide, "Tuads"	1
Sulphur	1 5
Carbon black, "Thermatomic"	5

The discs were molded and vulcanized at 60 psi steam pressure for 90 minutes The cushion was composed of a pile of discs as follows

Diameter (inches)	Thickness (inches)	No of Discs
4 5	1 25	2
6	1 5	1
8	1	2

The discs were placed in order of decreasing diameter with the largest on the bottom

TEST RESULTS

Tests first were made with the Type Ib

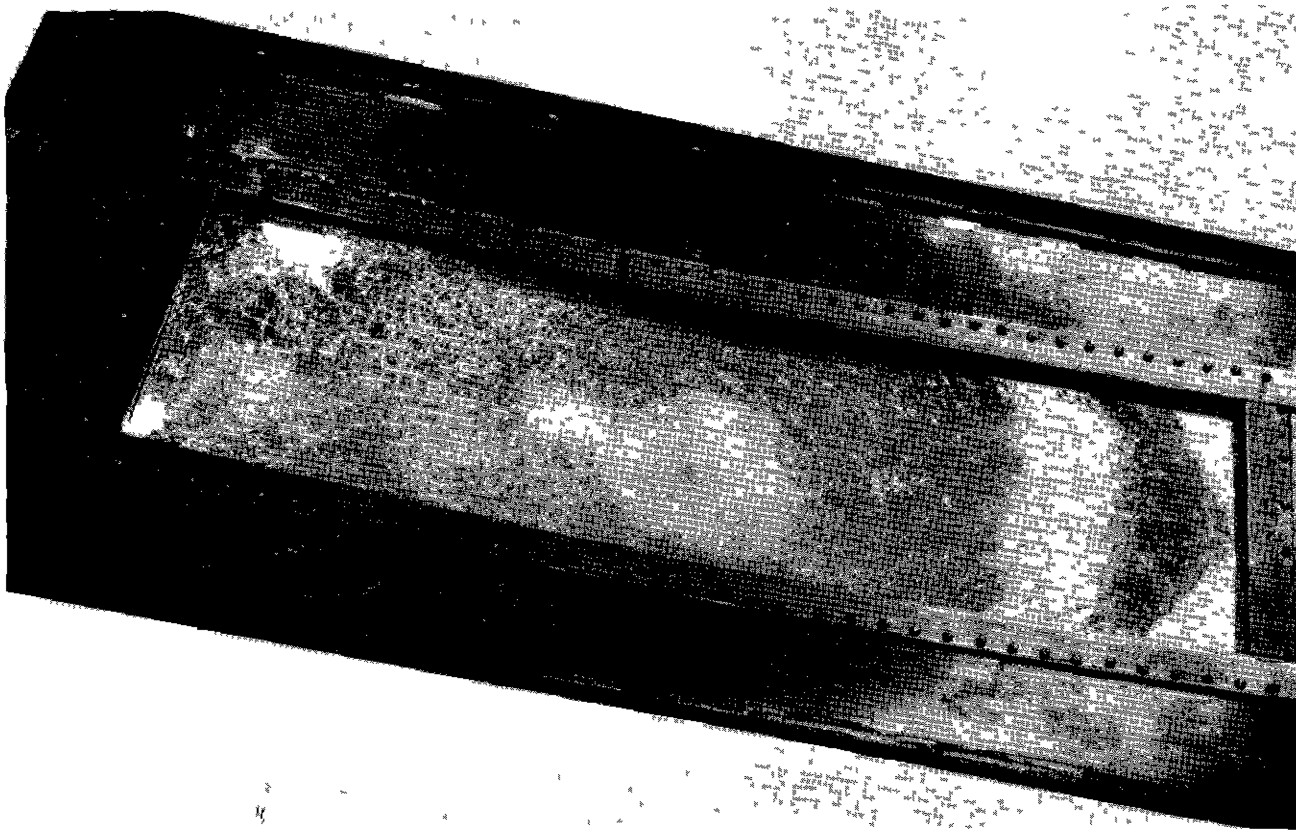


Fig 9 Type Ib Windshield After Test With 110-lb Lead Sphere Dropped 65.5 Feet (Test No 4)

windshield, including one-fourth inch vinyl plastic interlayer, to determine the maximum weight of the steel dart that would not result in penetration with a height of drop of 65 feet This maximum weight was found to be about 60-lb, as indicated by the test data presented in Table II The appearance of a windshield of this type after test is shown in Fig. 10

Type II windshields were then subjected to impact with a 61-lb steel dart to determine the maximum height of drop which would barely cause penetration In testing the Type II windshield, it was noted that the nature of the failure was considerably different from that observed in the catapult tests Instead of the whole windshield being deformed or broken, a hole was punched out, the diameter of which was equal to that of the dart A cushion of butyl rubber, therefore, was placed on the windshield at the point of impact in an attempt to simulate the conditions of the catapult test After several modifications, a cushion 6-in in height, tapered from 4 5 to 8-in in diameter, and of a relatively low degree of stiffness, as described under "Selection of Projectile," was adopted (Fig 6) With this cushion, the maximum height of drop of the 61-lb dart which would barely cause penetration of the Type II windshield was between 24 and 25 5 feet Without the cushion, penetration occurred at two to five feet The data for Type II windshield are given in Table III, and the appearance of typical panels after being tested with and without the cushion is shown in Figs 11 and 12

The data obtained with the Type Ia windshield, including one-eighth inch vinyl plastic interlayer, are given in Table IV, and a typical panel after test with the 61-lb dart and the rubber cushion is shown in Fig 13 The height of drop required for penetration of this windshield was 19 to 24 feet, without the cushion, and greater than 42 feet with the cushion

Cellulose acetate panels, Type III, one-

TABLE II - TESTS WITH STEEL DART ON TYPE Ib WINDSHIELDS

(Type Ib - Front Pane-1/4-in. full-tempered glass
Rear Pane -7/64-in semi-tempered glass
faces laminated with 1/4-in.
polyvinyl butyral plastic
interlayer)

N.B.S. Test No	Specimen No.	Height of Drop ft.	Weight of Dart lb.	Effect on Windshield
8	Ib-A-1	65	60	No penetration
10	Ib-A-2	65	60	No penetration
12	Ib-A-3	65	75	Penetrated
5	Ib-B-5	65	110	Penetrated
6	Ib-B-6	65	60	Penetrated
7	Ib-B-7	65	60	Dart stopped in windshield with 6-in protruding
11	Ib-B-8	65	60	Dart stopped in windshield with 3-in. protruding, many bolts failed on one edge
15	Ib-B-9	31.5	85	No penetration
16	Ib-B-10	31 5	99	No penetration

NOTE Test Temperature - 25 to 27° C except for N B.S. Test No. 6 where the temperature was 19° C.

TABLE III - TESTS WITH STEEL DART ON TYPE II WINDSHIELDS

(Type II - Front Pane-1/4-in full-tempered glass
Rear Pane -1/4-in full-tempered glass faces laminated with 0 025-in polyvinyl butyral plastic interlayer)

N B S Test No	Specimen No	Height of Drop ft	Weight of Dart lb	Type of Cushion	Effect on Windshield
17	II-B-1	31 5	60	None	Penetrated
19	II-B-2	31	60	Cylinder 3 8-in high, 4 5-in diameter, Butyl A	Penetrated
20	II-B-3	31	60	" " ", Butyl B	Penetrated
21	II-B-4	30 8	60	Cylinder 6 2-in high, 4 5-in diameter, Butyl B	Penetrated
22	II-B-5	30 8	60	Frustum of cone 6-in high, 4 5-in diameter at top, 8-in diameter at base, Butyl B	Penetrated
24	II-B-6	15	31	" " " " " "	No penetration
25	II-B-6	31 2	31	" " " " " "	No penetration
26	II-B-7	20	61	" " " " " "	No penetration
27	II-B-8	25 5	61	" " " " " "	Penetrated
28	II-A-1	25 5	61	" " " " " "	Penetrated
29	II-A-2	24	61	" " " " " "	No penetration
30	II-B-9	5	61	None	Penetrated
31	II-A-3	2	61	None	No penetration

NOTE Test Temperature - 26 to 28° C
When cushion was used, the height of drop was measured to the top of the cushion
Butyl compound A had a modulus of elasticity of the order of tread stock, compound B was considerably softer

TABLE IV - TESTS WITH STEEL DART ON TYPE Ia WINDSHIELDS

(Type Ia - Front Pane-1/4-in. full-tempered glass
Rear Pane -7/64-in semi-tempered glass
faces laminated with 1/8-in.
polyvinyl butyral plastic
interlayer)

N B S Test No	Specimen No	Height of Drop ft	Weight of Dart lb	Cushion	Effect on Windshield
42	Ia-B-1	31	61	None	Penetrated
44	Ia-B-2	37 8	61	Yes	No penetration
46	Ia-B-3	15	61	None	No penetration
48	Ia-B-4	24	61	None	Dart stopped for about a minute in windshield after penetrating about 10-in , then slid on through
50	Ia-B-5	22	61	None	Dart stopped after penetrating about 6-in
52	Ia-B-6	19	61	None	No penetration in rear panel, hole about 1/2 by 1 1/2-in occurred in impact area
53	Ia-B-7	41 8	61	Yes	No penetration but rear panel failed for distance of about 1-ft along edge near center

NOTE Test Temperature - 25 to 27° C
When cushion was used, the height of drop was measured to the top of the cushion
The cushion was 6-in high, tapered, and of Butyl B rubber, same as used in tests 22-29, Table III

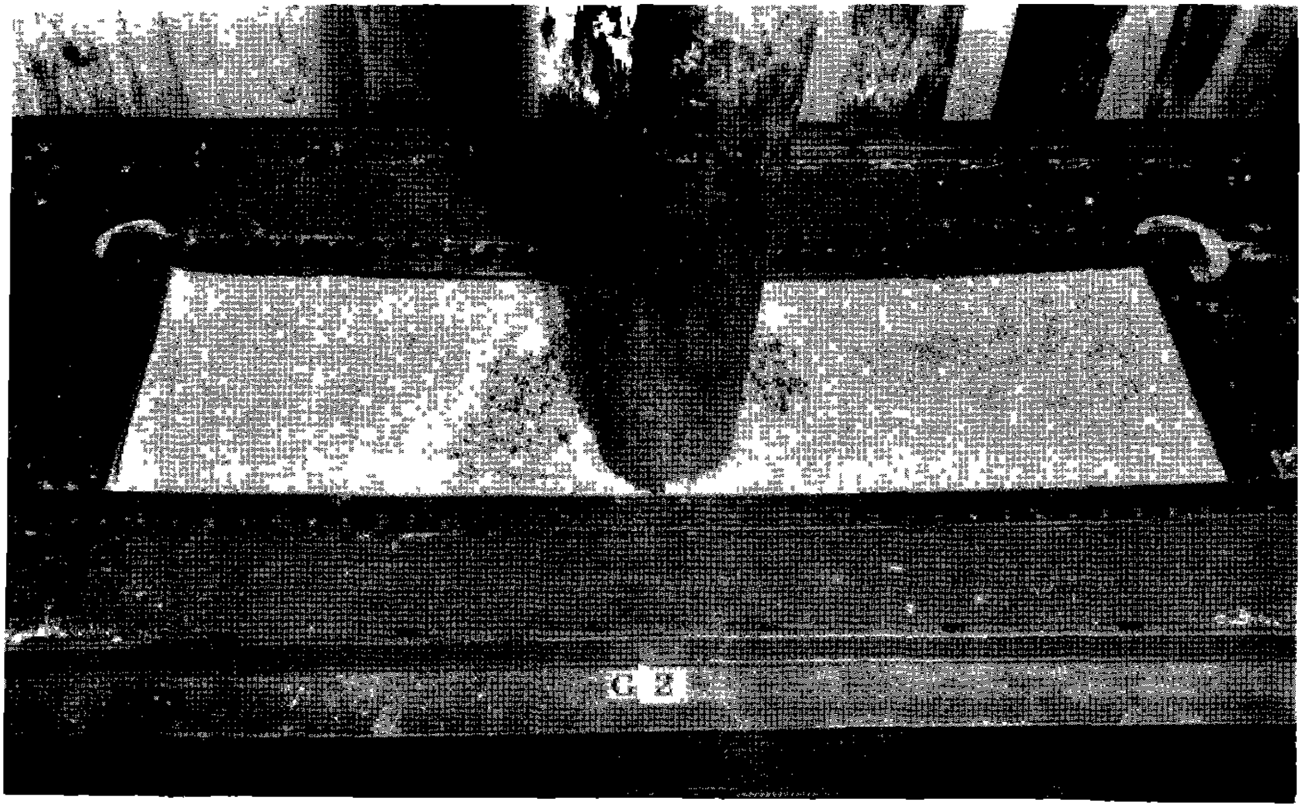


Fig 10 Type Ib Windshield After Test With 60-lb Steel Dart Dropped 65 Feet (Test No 11)

half inch thick, were found to be of variable strength. The test data for the Type III windshield are presented in Table V, and the appearance of a typical panel after test without the cushion is shown in Fig 14 Without the cushion, both penetration and non-penetration were obtained in the range 15 to 20 feet following a single impact with the 61-lb dart The only tests made with the cushion were carried out with panels that had been tested once before without failure or apparent damage. From two such tests it was indicated that the height of drop required for penetration was greater than 31 feet, and probably greater than 37 feet Tests at greater heights of drop were not conducted with the Type III windshield with cushion because of the severe bouncing of the dart obtained when failure of the panel did not occur.

The results of the tests on the Type IV windshield are given in Table VI, and a typical failure is shown in Fig 15. The height of drop penetration by the 61-lb steel dart for the Type IV windshield was about one foot without the cushion and 3 5 to 4 5 feet with the cushion

Methyl methacrylate panels, Type V, one-half inch thick, were found to be uniform in strength The results are given in Table VII. The minimum height of drop required for penetration without the cushion was approximately four feet With the cushion, the value was between 20 and 26 feet An example of borderline failure caused by dropping the 61-lb dart from three foot height is shown in Fig 16 An example of a penetration failure when the cushion was used is shown in Fig 17

DISCUSSION OF RESULTS

The values of penetration velocity of the five types of windshield panes derived from impact with a 4-lb bird carcass are plotted in Fig 18a against the values of height of drop for penetration of the same type panes derived from drop tests with the 61-lb steel dart, with and without the rubber cushion Similarly, in Fig 18b are plotted the values of penetration velocity of four types of windshield

TABLE V - TESTS WITH STEEL DART ON TYPE III WINDSHIELDS

(Type III - 1/2-in. cellulose acetate)

N.B.S Test No	Specimen No.	Height of Drop ft	Weight of Dart lb	Cushion	Effect on Windshield
9	III-C-1	65	60	None	Penetrated
13	III-C-2	31.5	75	None	Bolts failed along one edge, panel tore on other edge and bent back to allow dart to go through
14	III-C-3	31.5	85	None	Penetrated
18	III-C-4	31.2	60	None	Penetrated
23	III-C-5	31.2	31	None	Penetrated
35	III-C-6	6	61	None	No penetration
36	III-C-6	10	61	None	Penetrated
37	III-C-7	10	61	None	No penetration
38	III-C-7	31	61	Yes	No penetration
39	III-C-7	15	61	None	No penetration
40	III-C-7	15	61	None	Penetrated
41	III-C-8[1]	15	61	None	No penetration
43	III-C-8[1]	37.3	61	Yes	No penetration
45	III-C-9[1]	19.8	61	None	No penetration
47	III-C-10[1]	31	61	None	Penetrated
49	III-C-11[1]	20	61	None	Penetrated
51	III-C-12[1]	15	61	None	No penetration, panel failed at bolts near center of one edge and split so part of panel bent along opposite edge as a hinge, deflection of 2-in. at broken edge

[1] Conditioned at 25° C and 50 per cent relative humidity for at least two days until one to three hours prior to test

NOTE Temperature - 25 to 29° C
When cushion was used, the height of drop was measured to the top of the cushion
The cushion was 6-in high, tapered, and of Butyl B rubber, same as in tests 22-29, Table III

TABLE VI - TESTS WITH STEEL DART ON TYPE IV WINDSHIELDS

(Type IV - Single pane, 0 109-in semi-tempered glass faces laminated with 0.015-in vinyl plastic interlayer)

N B S Test No	Specimen No	Height of Drop ft	Weight of Dart lb.	Cushion	Effect on Windshield
32	IV-A-1	4 5	61	Yes	Dart stopped momentarily then pushed through
33	IV-A-2	3.5	61	Yes	No penetration, windshield split one edge to center
34	IV-A-3	1	61	None	Dart stopped but split panel

NOTE Temperature - 25 to 27° C
When cushion was used, the height of drop was measured to the top of the cushion
The cushion was 6-in., tapered, and of Butyl B rubber, same as used in tests 22-29, Table III.

TABLE VII - TESTS WITH STEEL DART ON TYPE V WINDSHIELDS

(Type V - 1/2-in. methyl methacrylate)

CAA Test No	Specimen No.	Height of Drop ft	Weight of Dart lb.	Cushion	Effect on Windshield
417	V-C-1	10	61	None	Penetrated
418	V-C-2	5	61	None	Penetrated
419	V-C-3	3	61	None	Cracked pane
420	V-C-4	10	61	Yes	No effect
421	V-C-5	20	61	Yes	No effect
422	V-C-6	26	61	Yes	Penetrated
423	V-C-7	26	61	Yes	Penetrated

NOTE Tests conducted at CAA Experimental Station, Indianapolis, Indiana.

Test Temperature - 75 to 80° F.
When Butyl B rubber cushion was used, the height of drop was measured to the top of the cushion.
The cushion was 6-in high, tapered, and of Butyl B rubber, same as used in NBS tests 22-29 and 32-33.

TABLE VIII - COMPARISON OF RESULTS OF DROPPING-PROJECTILE IMPACT TESTS AND CATAPULT TESTS

Windshield Type	Minimum Height of Drop for Penetration Tests with 61-lb. Steel Projectile: Without Cushion, ft	With Rubber Cushion[1], ft	Catapult Tests, Maximum Velocity For No Penetration: 14-lb Carcass, mph	4-lb. Carcass, mph
Type I, flexible-edge glass laminate				
a. 1/8-in vinyl plastic	19 to 24	42 to >42	130	280
b 1/4-in. vinyl plastic	65	-	160	440
Type II, tempered glass laminate	2 to 5	24 to 25 5	140	170
Type III, cellulose acetate	15 to 20	>31(probably >37)[2]	90	140
Type IV, single-pane glass laminate	about 1	3.5 to 4 5	<75	75
Type V, methyl methacrylate	4	23	-	160

[1]Butyl B rubber cushion 6-in. in height, tapered from 4.5 to 8-in. in diameter.

[2]Data obtained for panels subjected to one or more previous tests.

Fig 11 Type II Windshield After Test With 60-lb Steel Dart Dropped 31 5 Feet (Test No 17)

panes obtained with the 14-lb bird carcass catapult tests and the drop tests The penetration velocity values which are utilized in Fig 18a and 18b were reported previously in connection with the catapult test program.[3]

Except for the values concerning cellulose acetate, Type III, the correlation shown in Fig 18a between the drop tests and catapult tests using the 4-lb bird carcass appears to be good Cellulose acetate, although erratic in strength, demonstrates greater impact strength when tested by the 61-lb dropping projectile than the methyl methacrylate sheet plastic However, in the high-speed catapult tests with 4-lb bird carcass, the reverse is true The test values for Type V, methyl methacrylate, fit very well into the curve formed by Types Ia, Ib, II, and IV in Fig 18a

It has been observed that the cellulose acetate panes, when tested by both the dropping projectile and the compressed-air catapult, react in a different manner qualitatively to these two test methods than do all of the other materials utilized Types Ia and Ib panels, incorporating relatively thick vinyl plastic interlayers, behave as relatively flexible and tough materials in both tests However, Type III, cellulose acetate, when tested by the air catapult with high-speed impact, shows the type of failure associated with brittleness, but, when tested by the dropping projectile with low-speed impact, behaves more as a tough and elastic material with high energy absorption characteristics

This qualitative difference between cellulose acetate and all the other materials tested may explain the relatively high impact strength of cellulose acetate with the low-speed drop tests and its relatively low impact strength with the high-speed impact test method This difference is illustrated in the position of the cellulose acetate test value in the curve shown in Fig 18a

Another characteristic of the cellulose acetate panes which was revealed in the drop tests is their erratic impact strength under low-speed impact conditions Both failure and non-failure of the cellulose acetate panels occur randomly over the range of height of drop from 10 to 20 feet Factors which may affect this erratic behavior are the sensitivity of cellulose acetate to temperature at the time of test and to humidity conditions during storage prior to test In the drop tests on cellulose acetate, the humidity conditions were controlled as shown in Table V

It is apparent, in Fig 18b, that no correlation exists between the two types of test when the drop test results are plotted against the catapult test results obtained with the 14-lb bird However, good correlation cannot be expected between the drop test results and both the 4-lb bird and 14-lb bird catapult test results, when it is known that the

[3]See footnote 1

Fig 12 Type II Windshield After Test With 60-lb Steel Dart Dropped 30.8 Feet upon Rubber Cushion (Test No 22)

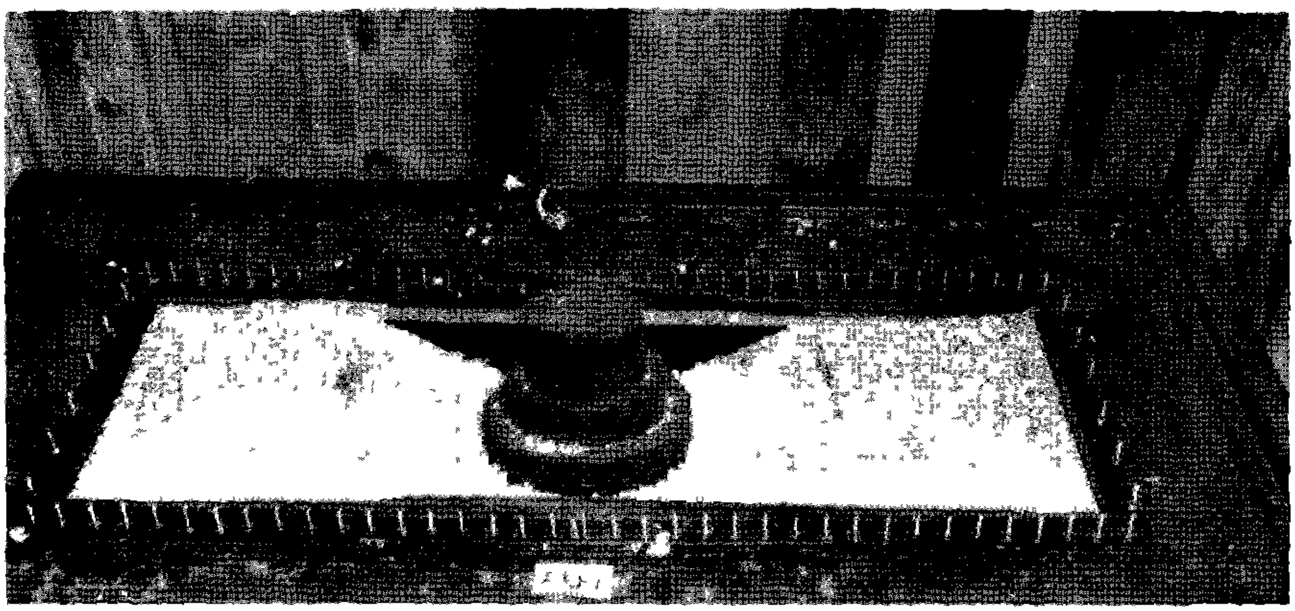


Fig. 13 Type Ia Windshield After Test With 6.-lb Steel Dart Dropped 41 8 Feet upon Rubber Cushion (Test No 53)

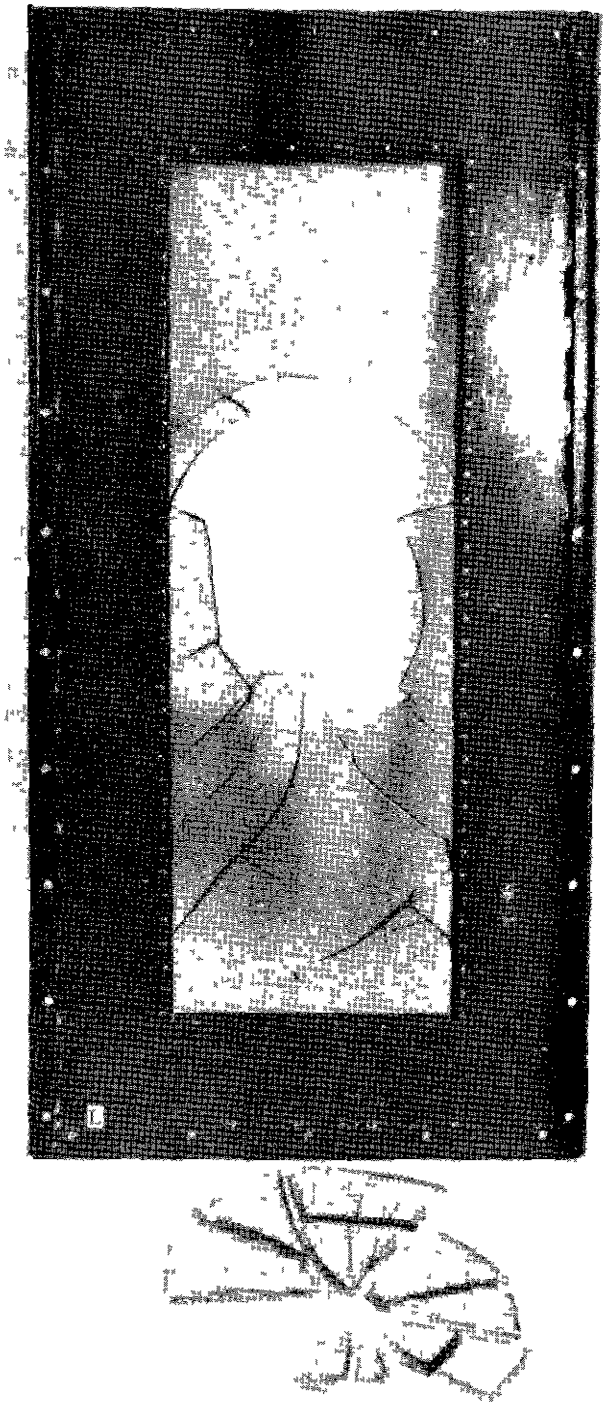


Fig 14 Type III One-Half Inch Cellulose Acetate Windshield After Test With 60-lb Steel Dart Dropped 65 Feet (Test No 9)

catapult test results obtained separately with the two bird weights do not correlate well between themselves It has been shown in the catapult tests that variation of the mass of the bird from 4 to 14 lb causes a qualitative change in the nature of the impact, which results in two different impact strength relationships between the different types of windshield panels

The relatively rigid and brittle Type II windshield, with a rear pane utilizing one-fourth inch full-tempered front faces laminated with 0 025-in vinyl plastic interlayer, is farthest out of order with respect to the other types forming the curve in Fig 18b In the catapult tests with the 14-lb bird, the impact resistance of Type II is slightly greater than Type Ia utilizing one-eighth inch vinyl plastic interlayer, and considerably greater than Type III cellulose acetate pane In the catapult tests with the 4-lb bird, Type II penetration velocity is less than that for Type Ia and nearly as low as Type III

As Type II impact strength in the drop tests using the 61-lb steel dart is less than either Type Ia or Type III, the correlation shown in Fig 18a, comparing drop test values with those obtained with catapult tests using the 4-lb bird, is better than that shown in Fig 18b, wherein the catapult test values are derived from the use of the 14-lb bird

As the drop tests all were conducted with the windshield panels mounted in a standard steel frame and supporting structure, the relationships shown in Figs 18a and 18b cannot be applied directly to windshield panels mounted in actual cockpit structures However, it may be assumed that a similar qualitative relationship could be established for this condition insofar as the panel strength is concerned

TEST LIMITATIONS

The correlation shown in this report between the dropping-projectile test and the catapult test with a 4-lb bird carcass applies to the impact strength of the windshield panel alone No attempt has been made to extend the correlation beyond this point

In order to obtain a completely satisfactory drop test procedure with results which would correlate in every way with the catapult test results, the following additional correlation and data would be required

(1) It would be necessary to demonstrate that the dropping projectile would produce failures of the mounting frame and supporting

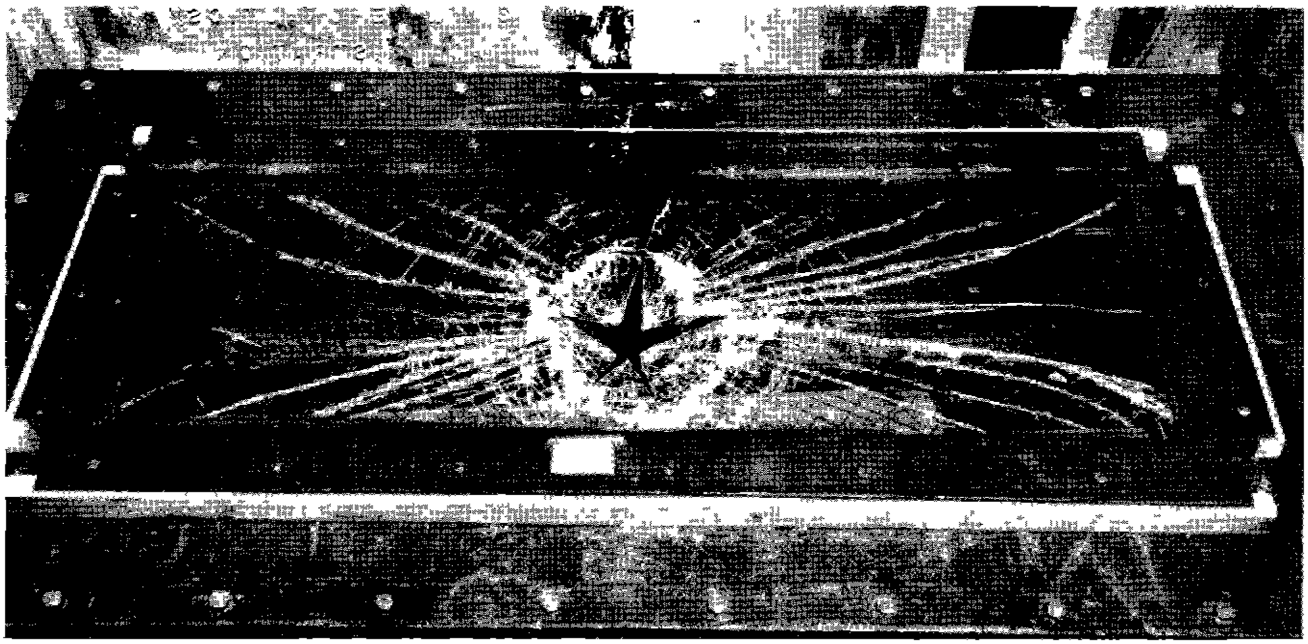


Fig 15 Type IV Windshield After Test With 61-lb Steel Dart Dropped One Foot (Test No 34)

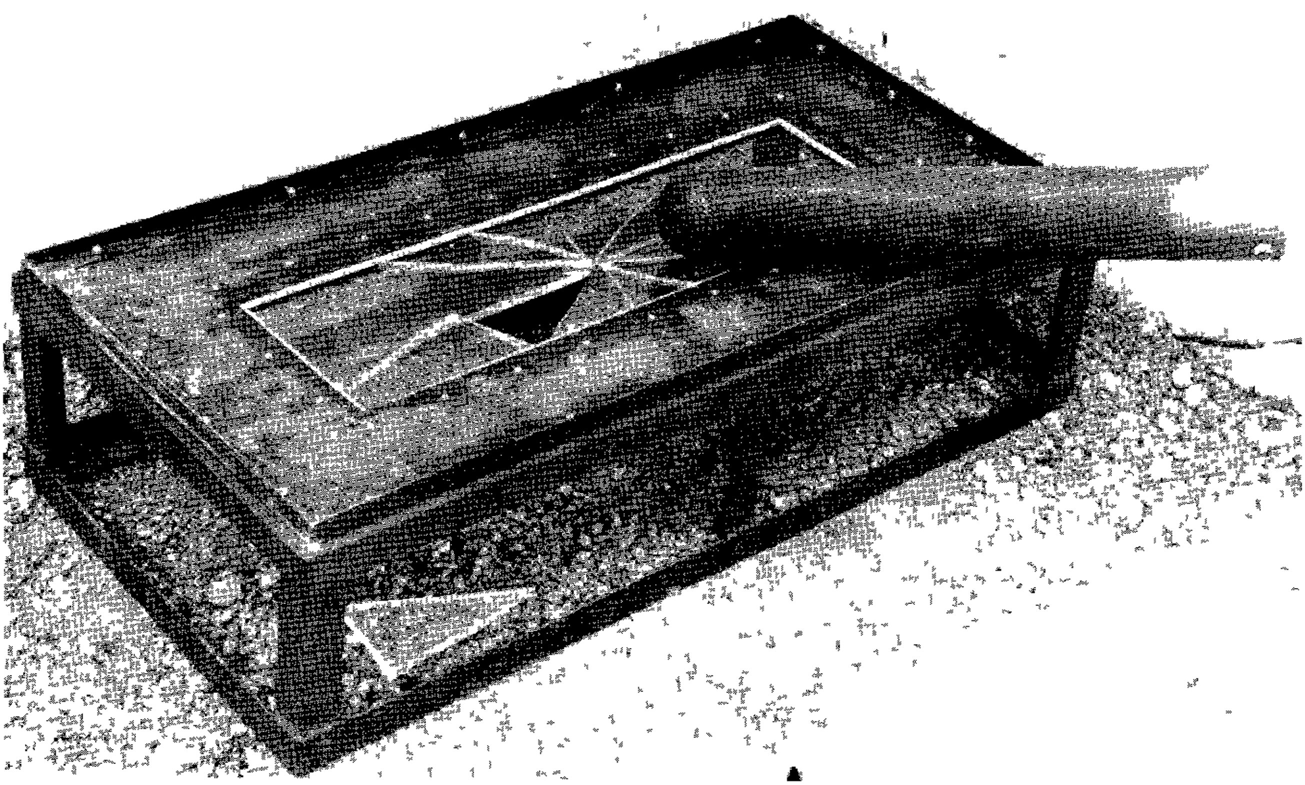


Fig 16 Type V, Methyl Methacrylate, Windshield After Test With 61-lb Steel Dart Dropped Three Feet

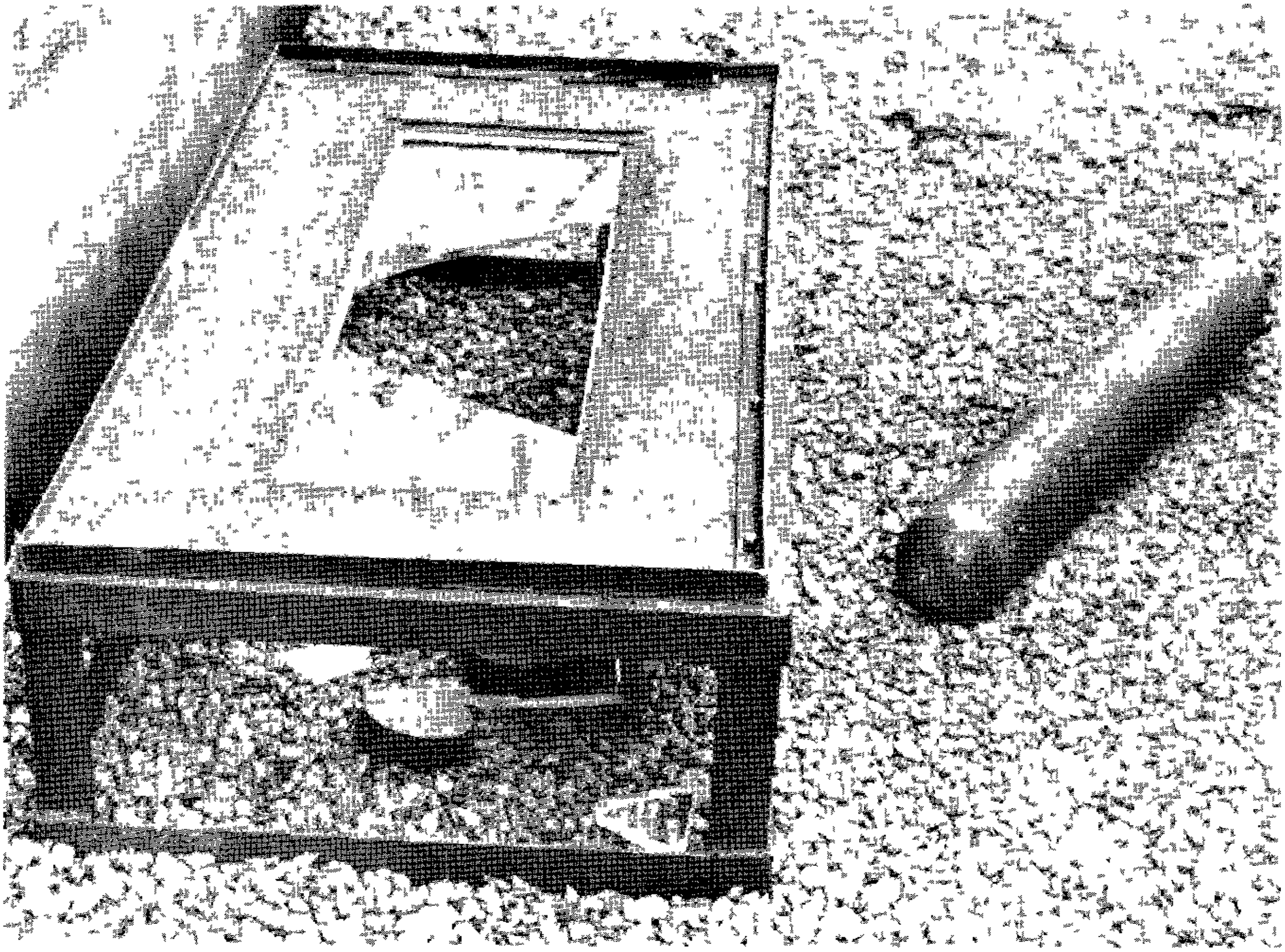


Fig 17 Type V, Methyl Methacrylate, Windshield After Test With 61-lb Steel Dart Dropped 26 Feet upon Rubber Cushion

structure similar to those obtained with the catapult tests of windshield-cockpit enclosure structure combinations, and at heights of drop which would correlate with the velocities required to produce similar failures with the catapult No certainty exists that such added correlation could be found

(2) Accumulation of extensive additional catapult test data would be required to show the variation in windshield panel impact strength over a wide range of panel temperatures and panel mounting angles These data would be needed because of the uncertainty of finding a direct correlation between the two types of test over a wide range of these variable conditions, and the desirability of reducing the drop test to the simple condition of a fixed standard temperature and a 90° angle of impact

The additional correlation required in connection with failure of panel mounting frames and their supporting structures could be established only by an extensive test program involving both catapult tests and dropping projectile tests upon windshield panels mounted in a variety of different frame and cockpit structures No plan for conduct of such a test program now is being contemplated

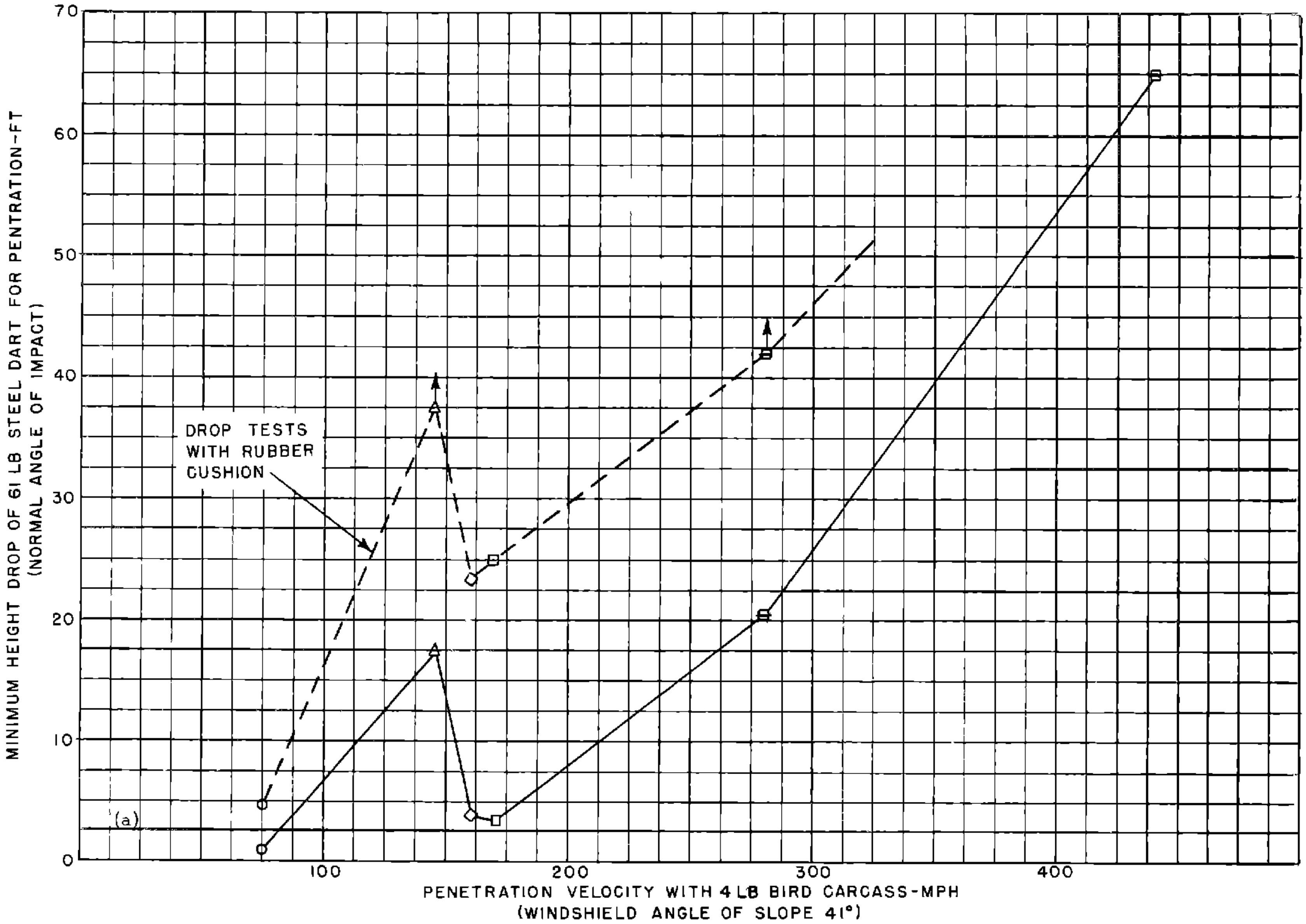
The additional catapult data required, showing variation of impact strength of windshield panels with change in temperature and mounting angle, have been secured in recent conduct of the general windshield test program, and will be presented in future reports

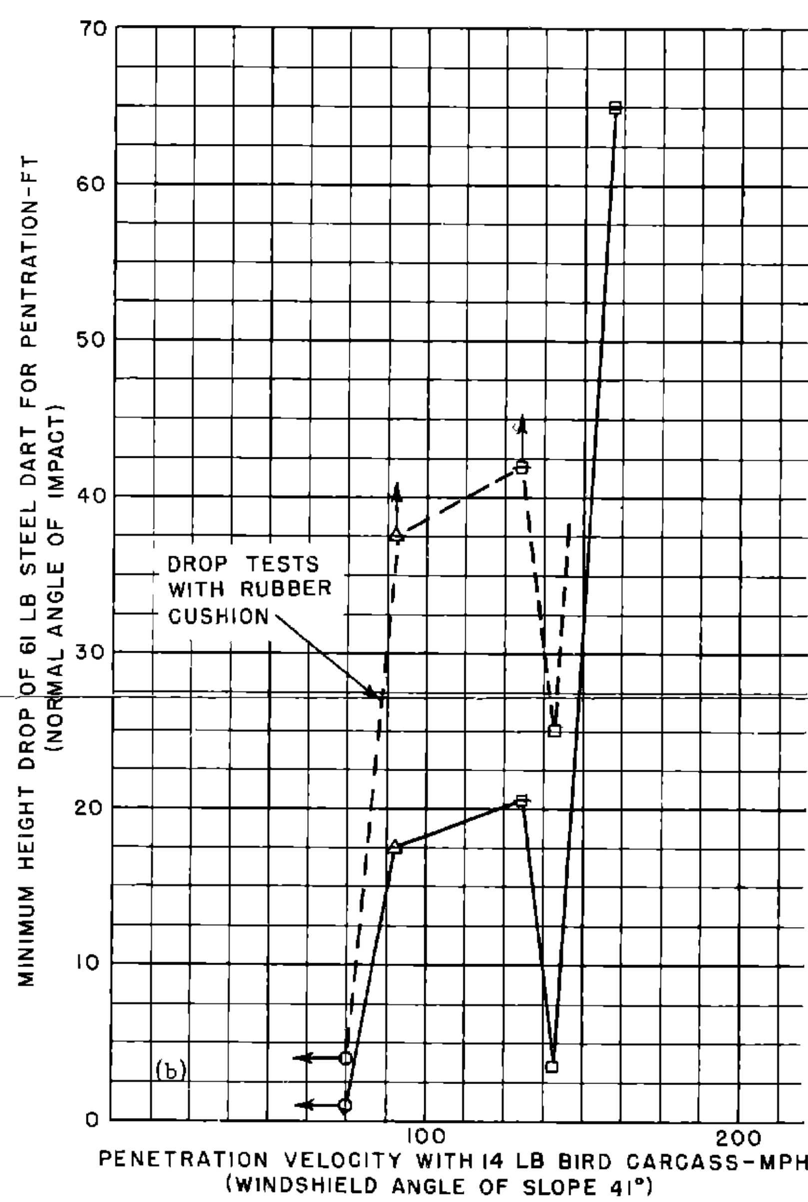
CONCLUSIONS

1 Drop tests involving a 61-lb round-nosed steel dart, dropped with normal incidence upon six different types or thicknesses of windshields mounted in steel frames, show that a reasonably good correlation exists between results of such a test and of catapult tests conducted with 4-lb bird carcasses projected at airplane flight velocities against similar windshield panels in similar mounting arrangements This is true for all types of panes tested except the cellulose acetate pane An unsatisfactory correlation exists between these two types of test when comparison is made with the catapult test values obtained by use of the 14-lb bird carcass This may be expected since the 4-lb and 14-lb bird catapult data do not correlate well together

2 The use of a 6-in high rubber cushion to increase the duration and area of the impact causes no important qualitative change in the drop test results

3 The correlation found between the two types of test applies to the impact strength of the windshield panels alone Further extensive catapult and drop tests would be required to determine whether the correlation could be extended to cover failures of the windshield frame and supporting structure, as commonly observed in the catapult test program





LEGEND FOR FIGURE 18a & FIGURE 18b

SYMBOL		DESCRIPTION
⊟	TYPE Ia, FRONT PANE	0 25" F T GLASS
	REAR PANE	0 109" S T GLASS LAMINATED WITH 0 125" VINYL PLASTIC
⊟	TYPE Ib, FRONT PANE	0 25" F T GLASS
	REAR PANE	0 109" S T GLASS FACES LAMINATED TO 0 25" VINYL PLASTIC
□	TYPE II, FRONT PANE	0 25" F T GLASS
	REAR PANE	0 25" F T GLASS FACES LAMINATED TO 0 025" VINYL PLASTIC
△	TYPE III, SINGLE PANE	0 5" CELLULOSE ACETATE
○	TYPE IV, SINGLE PANE	0 109" S T GLASS FACES LAMINATED TO 0 015" VINYL PLASTIC
◇	TYPE V, SINGLE PANE	0 5" METHYL METHACRYLATE
↑	HEIGHT INDICATED OR GREATER	
←	VELOCITY INDICATED OR LESS	

Fig 18 Comparison of Results of Dropping Projectile Impact Tests and Catapult Tests