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ENHANCEMENT OF F/RF-4 TRANSPARENCY SYSTEM BIRD IMPACT RESISTANCE*

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ABSTRACT

Birdstrikes to the crew enclosures of USAF F/RF-4 aircraft have resulted in major aircraft damages and severe pilot injuries. Analysis of operational bird impact statistical data indicates that the trend of damaging bird impacts of the F-4 is continuing to rise. Impacts to the F-4 transparency system also continue to rise resulting in a continued flight safety risk to the aircraft and the aircrew. The Air Force Wright Aeronautical Laboratories, Improved Windshield Protection Office has initiated a program to develop a transparency system for the F-4 aircraft which has four-pound, 500-knot bird impact capability. The first step in this program was to experimentally determine the existing transparency system capability by bird impact testing full-scale flight hardware. Eight impact locations on the windshield and forward canopy were tested to failure with four-pound birds. Tests on experimental, laminated windshield side panels were also conducted to investigate the capability of the windshield frame. The baseline birdstrike test results are presented through the use of post-test photographs, test films, and an impact capability diagram. Program progress subsequent to the baseline testing will be reviewed.

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This is an update of the report, "Bird Impact Evaluation of the F/RF-4 Transparency System," prepared by Capt R. Simmons, AF Wright Aeronautical Laboratories, and G. Stenger, University of Dayton Research Institute. The report was presented at, and is included in the proceedings of, the FAA-sponsored conference and training workshop on Wildlife Hazards to Aircraft, 22-27 May 1984. Report #DOT/FAA/AAS/84-1.

BIRD IMPACT EVALUATION OF THE F/RF-4 TRANSPARENCY SYSTEM

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ABSTRACT

Birdstrikes to the crew enclosures of USAF F/RF-4 aircraft have resulted in major aircraft damages coupled with severe fatal pilot injuries. Analysis of operational bird impact statistical data indicates that the trend of damaging bird impacts of the F-4 is continuing to rise. Impacts to the F-4 transparency system also continue to rise resulting in a continued flight safety risk to the aircraft and the aircrew. The Air Force Wright Aeronautical Laboratories, Improved Windshield Protection Office has initiated a program to develop a transparency system for the F-4 aircraft which has four pound, 500 knot bird impact capability. The first step in this program was to experimentally determine the existing transparency system capability by bird impact testing full scale flight hardware. Eight impact locations on the windshield and forward canopy were tested to failure with four pound birds. Tests on experimental, laminated windshield side panels were also conducted to investigate the capability of the windshield frame. The baseline birdstrike test results are presented through the use of post test photographs and an impact capability diagram.

INTRODUCTION

Due to the advancement in radar detection techniques as well as the development and increased use of terrain following instrumentation, an increased amount of high-speed flight time is performed at altitudes below 10, 000 feet. Many air force high-speed aircraft transparency systems were not designed to meet the increased bird impact risk associated with this phase of the flight operation. The F/RF-4, Figure 1, is but one example of an aircraft which was not designed with a transparency system capable of surviving the bird impact event. Analysis of birdstrike statistical data obtained from the Air Force Inspection and Safety Center at Norton AFB, California shows that during the period January 1971 to March 1981, 30 of the 68 reported birdstrikes against the transparency resulted in penetration into the crew compartment. Associated with these penetrations were 12 injuries (some permanently disabling) to aircrew personnel, loss of one aircraft, and one pilot fatality. Recent birdstrike data continues to show an increase in the number of impacts and, without significant changes in the mission requirements that have resulted in this increasing birdstrike rate, an even larger number of damaging birdstrikes may be expected for the F/RF-4 aircraft in the future.

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BACKGROUND/OBJECTIVE

As a result of the loss of a USAF F-4E aircraft and a pilot fatality due to a windshield birdstrike in November 1980, the Improved Windshield Protection Program Office was directed to develop an improved bird impact resistant transparency system for the F/RF-4 aircraft. The initial phase of this program included an experimental test series which was conducted to determine the baseline bird impact capability of the current F/RF-4 transparency system.

The primary objective of this bird impact test program, conducted during the periods August-October 1982 and February 1983 was to determine the minimum bird penetration velocity as a function of birdstrike location for the windshield and forward canopy. Secondary objectives of the test program were to: (1) collect sufficient data (photographic, strain, and accelerometer) to support the subsequent transparency system redesign effort; and (2) to investigate the capability of the windshield support structure to absorb (and transfer into the fuselage) the energies associated with the bird impact event.

EXPERIMENTAL PROCEDURE

The bird impact testing of the F/RF-4 transparency system was accomplished at Range S-3 of the von Karman Gas Dynamics Facility of the Air Force System Command's Arnold Engineering Development Center. Figure 2 shows the test area arrangement. Capabilities of th S-3 Range are continued in Reference 1. The basic procedure employed in testing in the S-3 Range consists of launching bird carcasses at specified velocities (using an air-driven launcher) into predetermined impact locations on a test article. For the F-4 baseline tests, six impact locations on the windshield and forward canopy were investigated with the fuselage aligned at 0° pitch and 0° yaw relative to the launch path. Side impact tests were conducted at one location on the windshield side panel and one on the forward canopy with the fuselage yawed at 15° relative to the launch path.

Test Fixture/Test Articles

To more closely simulate the actual bird impact response of the transparency and to get realistic load transfer, an F-4 forward fuselage section was used as the test fixture (see Figure 3). All transparencies and related hardware were actual aircraft structures removed from aircraft in storage at the Military Aircraft Storage and Disposition Center at Davis-Monthan AFB, Arizona. Test articles consisted of the forward windshield assembly (two plexiglass side panels, laminated glass center panel, and supporting structure) and the forward canopy assembly. The cross-section of each transparency component is shown in Figure 4.

The windshield frame capability was determine by utilizing laminated side panels which were designed, developed, built, and donated by Goodyear Aerospace Corporation, Litchfield Park, Arizona. The laminated panel cross-section may be seen in Figure 5. When a transparency failed in a test, it was removed from the frame, the frame was inspected, and if no structural damage had occurred, another transparency was mounted in place.

Projectiles and Sabots

Projectiles launched during this test program were nominally four-pound chicken carcasses. The birds were asphyxiated, quick-frozen, and stored at 0°F until needed. Prior to testing, the carcass was thawed in still air at room temperature (75°F) for approximately 24 hours or until the body cavity temperature was 70 ±10°F. Adjustments to the bird carcass weights were required to achieve the desired weight within ±0.1 pound. These adjustments were accomplished by clipping carcass appendages or injecting water into the body cavity. In no case did the adjustment exceed 10 percent of the bird weight.

The packaged bird was mated to the launch tube using a one-piece sabot of balsa wood construction. The sabot materials density was nominally 10 lb/ft providing a sabot weight of 1.7 lb and a total launch weight of 5.7 lb. Separation of the bird and sabot after launch was accomplished with the use of the tapered and threaded cylindrical sabot stripping section attached directly to the vent section of the launch tube (Figure 2). As the launch package entered the stripper section, the sabot velocity was gradually decreased by the shearing of thin layers of sabot material, permitting the bird to exit in free-flight.

Instrumentation

Instrumentation for this series of tests was primarily designed to collect data for use with analytical transparency analysis tools. Four to five high-speed movie cameras were used to record the impact event. The cameras were situated in such a manner as to gain an overall perspective of the impact point (Figure 6). In addition to the high-speed cameras, still photographic coverage was used to record pre- and post-test conditions.

A total of 20 strain gages were monitored during each impact. These gages were located in such a manner as to record the load characteristics of the transparency support structure during impact.

Two accelerometers were used to monitor the motion of the frame during bird impact. X-ray shadowgraphs were used to monitor the bird position and orientation prior to the impact (Figure 2). They were also used to verify the impact velocity.

Test area temperature was measured by two thermcouples positioned near the test transparencies.

Impact Location/Impact Velocities

The eight impact locations used may be seen in Figure 7. These locations were chosen through the use of an angle of incidence study and represent areas where the maximum energy could be transferred from the traveling bird to the stationary structure. At least two impact locations on each transparency system component were investigated so that a capability map could be developed for the entire system. Impacts at locations "A" through "G" were made with the fuselage section aligned at 0° pitch and 0° yaw relative to the launcher flight path. Impact locations "H" and "I" were chosen to investigate the transparency capability in the sill area. Impacts at these two locations were made with the fuselage yawed at a 15° (clockwise) angle so that sufficient bird contact could be made with the test article.

The initial impact velocity was slightly below the expected failure velocity. Failure velocities were analytically determined at each impact location by employing the prediction methods found in Reference 2. Succeeding impact velocities were increased until transparency failure at that location occurred. The failure velocity range could then be bracketed between the highest velocity at which failure had not occurred and the velocity at which failure had occurred.

TEST RESULTS

The baseline birdstrike capability for the F/RF-4 transparency system was defined with a total of 25 bird impacts at eight locations on the transparency system. The results of these tests have been summarized in a capability diagram as shown in Figure 8. This diagram presents the four-pound bird impact capability of the existing windshield system with the fuselage oriented at 0° pitch and 0° yaw. This diagram is based on the actual test data with the areas being defined after considering the recorded post-test observations, the high-speed movies, the strain data, the impact angle of incidence, and the proximity to the edge attachment. The values represent an approximate threshold of failure velocity (in knots) for various areas on the windshield and canopy.

Windshield Side Panel

The most critical impact location was on the forward area of the 0.38-inch thick stretched acrylic windshield side panel, impact point "A." The impact angle of incidence was 27 degrees at the target point. Impact point "A" was initially impacted with a four-pound bird at 190 knots which resulted in no damage. A subsequent shot at 200 knots resulted in about half of the four-pound bird penetrating the transparency (see Figure 9). The transparency frame was not damaged.

The aft area of the windshield side panel was tested at location"B" and was found to have a failure threshold of 210 knots. The small increase was due to the reduced angle of incidence: 21 degress.

Windshield Center Panel

The 1.2-inch-thick laminated glass windshield center panel demonstrated the highest capability of any part of the current transparency system. A four-pound, 300 knot shot on the forward end of the glass center panel (location"D") resulted in a substantial amount of glass spalling off the inside surface; however, no bird penetrated. A shot at 375 knots at location "D" resulted in the failure of the glass center panel. This test was classified a failure because much of the lower half of the transparency spalled into the cockpit, and the pilot would have been facing a considerable wind blast even though no bird actually penetrated (see Figure 10).

A four-pound, 375 knot shot was made on the aft end of the windshield center panel at location"C" and resulted in a small amount of the bird penetrating the windshield and canopy frames. Some glass was spalled into the cockpit; however, neither the glass nor the bird would have posed a serious threat to the pilot, and this test was classified a pass.

A 450 knot shot at location "C" resulted in a substantial amount of spalled glass. In addition, the center panel was pushed down, buckling the windshield arch supports, and the bird impacted the forward frame of the forward canopy. This failed the canopy frame and transparency, resulting in several large pieces of spalled acrylic as shown in Figure 11. This test was classified a failure because of the potential injury to the pilot.

One shot was made at 300 knots on the sheet metal panel forward of the windshield center panel. Some bird penetrated the structure and the capability was estimated to be 250 knots.

Forward Canopy

The 0.30-inch thick stretched acrylic canopy was impacted seven times at three locations ("F," "G," and "I"). The demonstrated capabilities were 240 knots at location"F," 220 knots at location"G," and 230 knots at location"I." A 300 knot area was added in the capability diagram to reflect the decreased angle of incidence. No damage to the frame or support structure was found in any of the tests. The transparency, when failed, spalled several large pieces of acrylic (estimated at over 8 sq. in.), in addition to many small pieces. This spalled acrylic could cause serious injury to the pilot. Also, the pilot would be subject to considerable wind blast and buffeting through the large holes left in the transparency (Figure 12).

Windshield Frame

The capability of the F-4 production frame was determined by utilizing laminated panels formed in the F-4 side panel shape. The panels were mounted in the framework using aircraft grade bolts. Five impacts were made on the windshield structure with the laminated panels installed, one at location "A" and four at location "B." The impact at location A and the first impact at location "B" were performed at 450 knots with catastrophic failure of the frame occurring in both instances. The impact point "B" failure resulted in parts of the windshield arch entering the forward cockpit, posing a significant hazard to the pilot (Figure 13). For this reason, it was determined to perform additional tests at location "B." The three subsequent tests at location "B" resulted in a frame failure at a velocity of 375 knots. Failure at this velocity could have been predicted from a plot of the strain data taken at gage location GL4 (closest gage to the failure point) and the impact velocity (Figure 14). Note how rapidly the stress rises with velocity in this particular loading situation; the magnitude of the loads in the structure appear to be extremely sensitive to velocity in the 350-to-375 knot range. Frame baseline capability was accepted as 375 knots.

CONCLUSIONS

The F/RF-4 transparency birdstrike tests have established the existing capability of the transparency system and have generated a useful data base for designing and evaluating various bird impact resistant designs. In-field service has demonstrated the need for improved birdstrike protection and these tests confirm this need.

The data generated from these tests show that the acrylic side panels and forward canopy must be replaced with bird resistant designs which will provide the degree of protection required. Also, the tests indicated that a new or reinforced windshield frame is required.

A program currently under way will evaluate several alternative bird impact resistant transparency system designs. The result will be an affordable transparency system which will protect the F/RF-4 crew during high speed, low level flight.

REFERENCES

1. The Facilities Handbook (Eleventh Edition), Arnold Engineering Development Center, Arnold Air Force Station, Tennessee, April 1981.

2. Lawrence, D. H., Jr., Guidelines for the Design of Aircraft Windshield/Canopy Systems, AFWAL-TR-80-3003, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, OH, February 1980.

3. Storslee, J. H., Bird Impact Testing of Windshield and Canopy Assemblies for the F-4 Aircraft, AEDC-TSR-82-V39, Arnold Engineering Development Center, Arnold AFS, TN December 1982.

4. Storslee, J.H., AFWAL F-4 Canopy Birdstrike Test Project, C784VJ, Arnold AFS, TN, October 1982

Figure 1. F/RF-4 Aircraft.

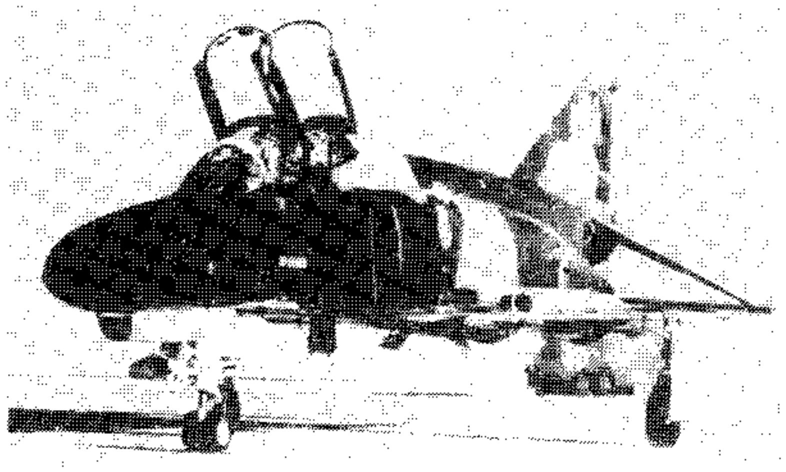

Figure 2. AEDC Test Area Arrangement.

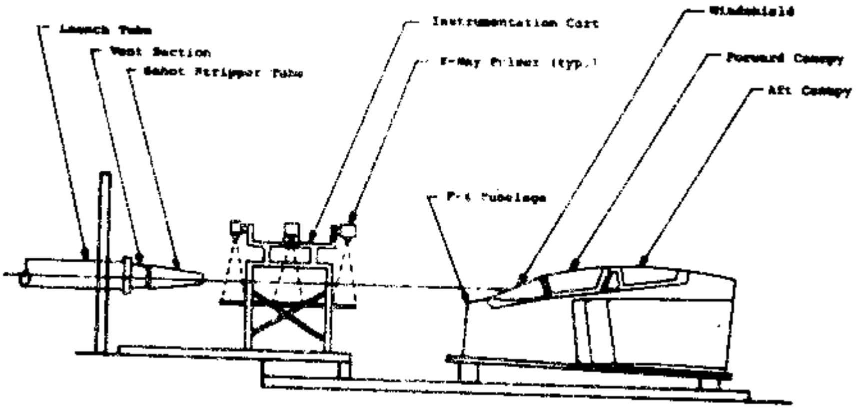

Figure 3. F-4 Forward Fuselage Installed in S-3 Range.

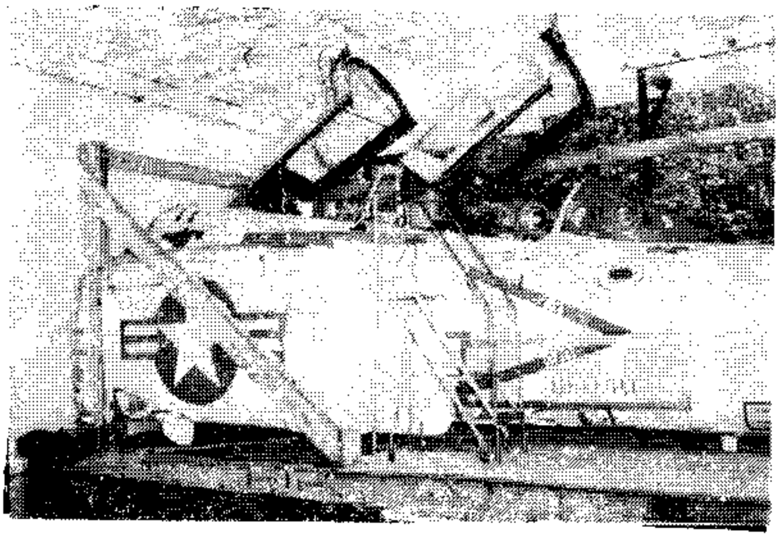

Figure 4. Cross-Sections of Production Transparency System.

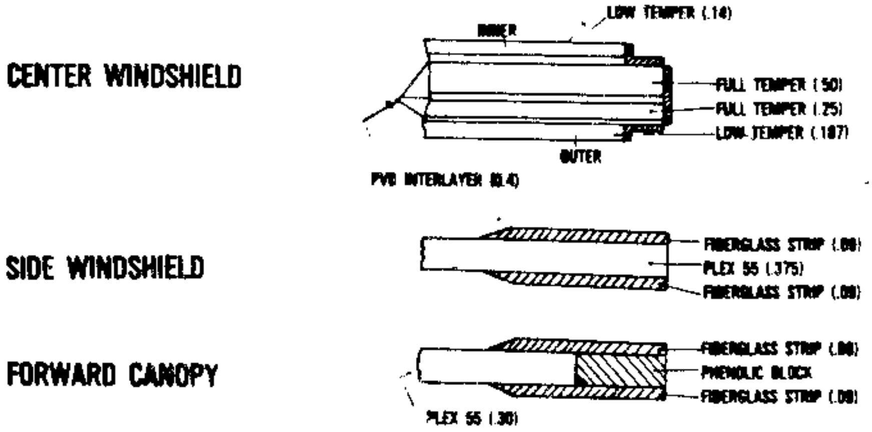

Figure 5. Laminated Side Panel Cross-Section.

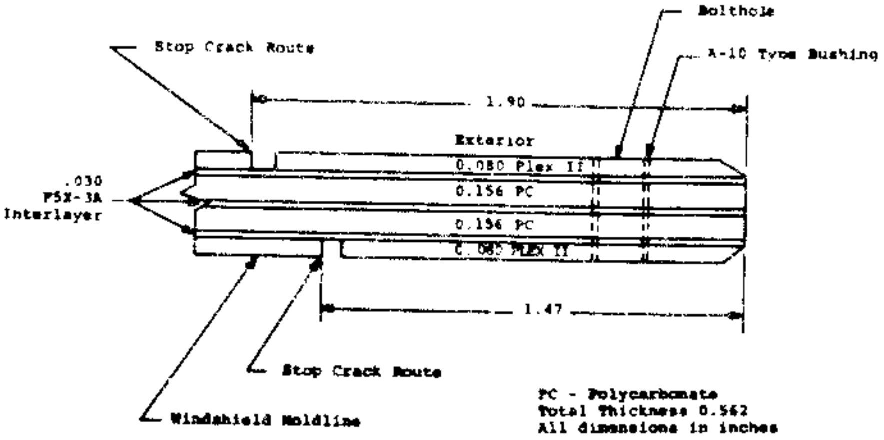

Figure 6. Location of Motion Picture Cameras.

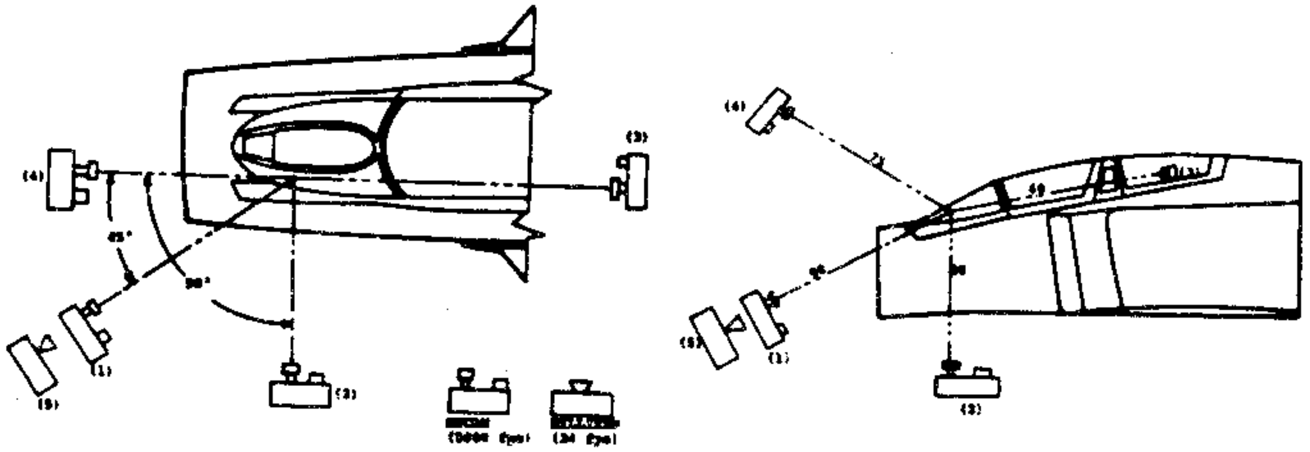

Figure 7. Impact Locations.

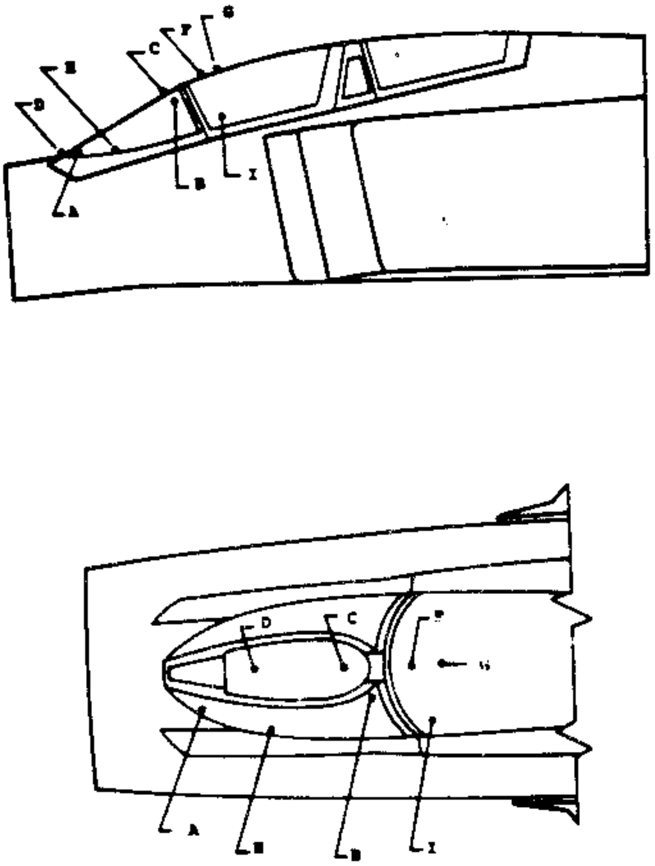

Figure 8. Bird Impact Capability Diagram.

(FOUR POUND BIRD; VELOCITY IN KNOTS)

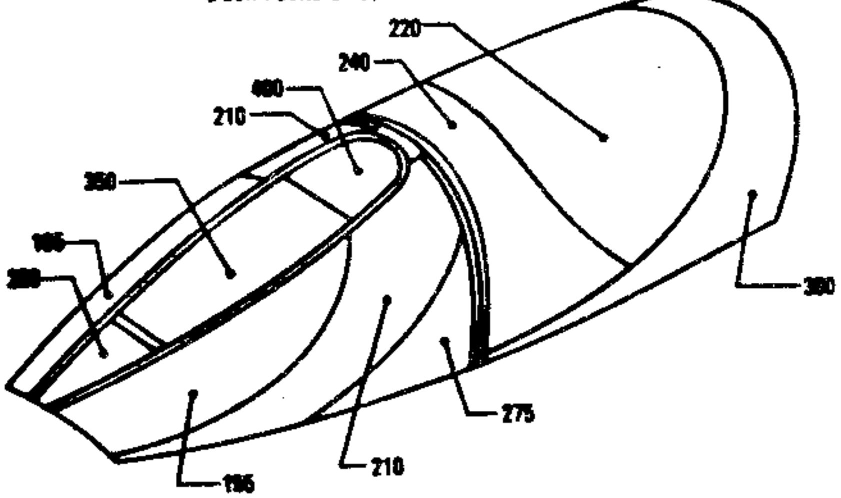

Figure 9. Post Test Damage, 200 Knot Side Panel Impact.

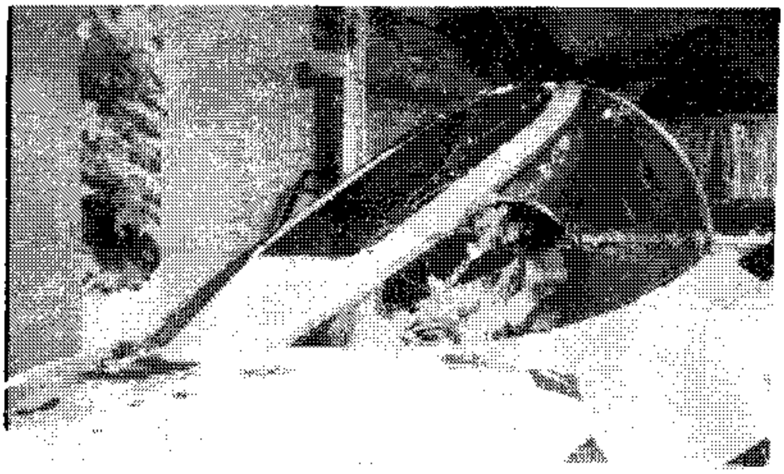

Figure 10. 375-Knot Impact Low on Center Panel.

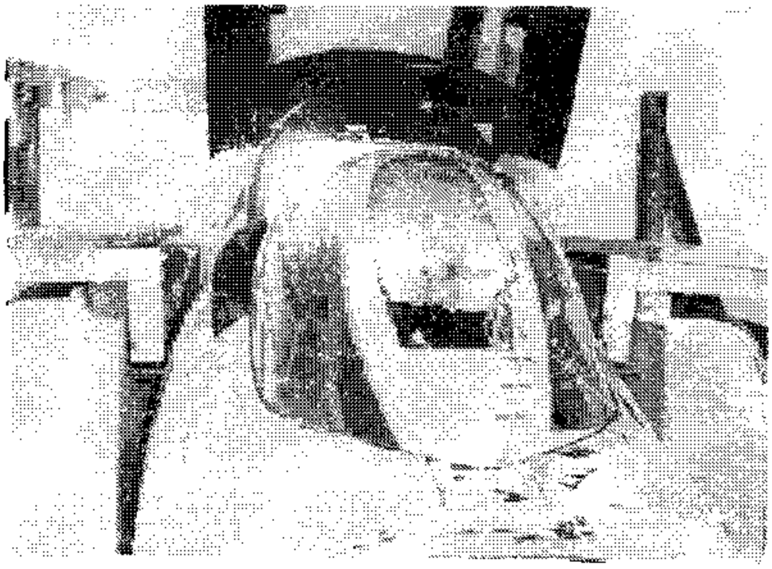

Figure 11. Post Test Damage, 450-Knot Impact Upper Center Panel.

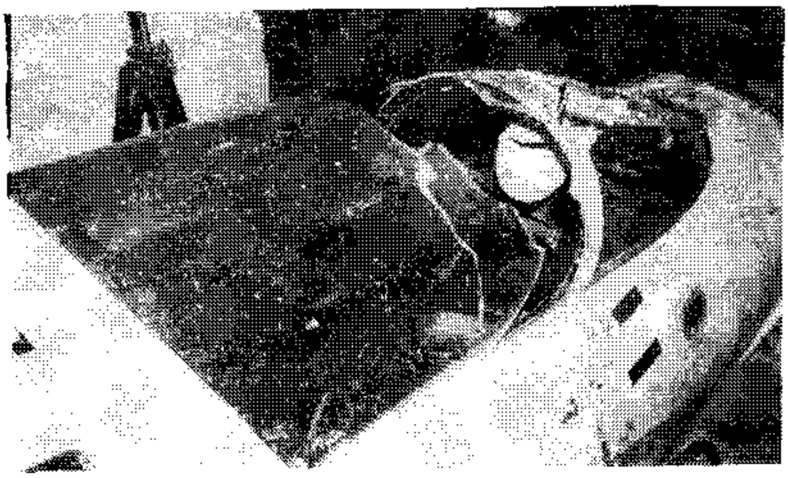

Figure 12. 270-Knot Impact, Centerline of Forward Canopy.

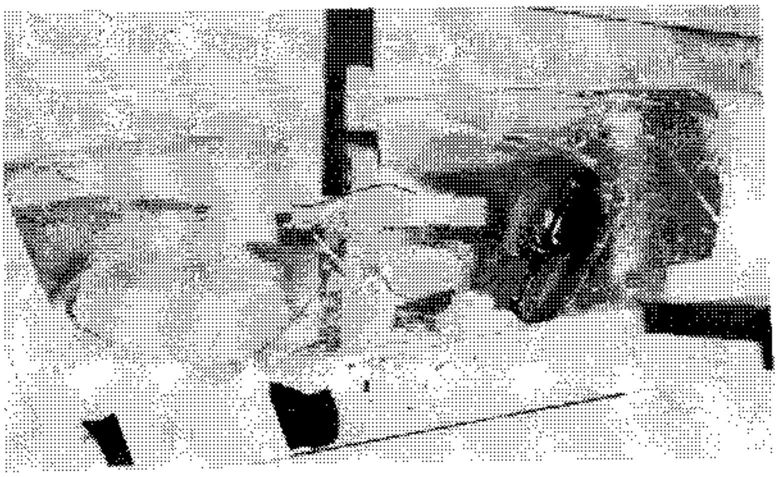

Figure 13. Failed Windshield Arch Fragments.

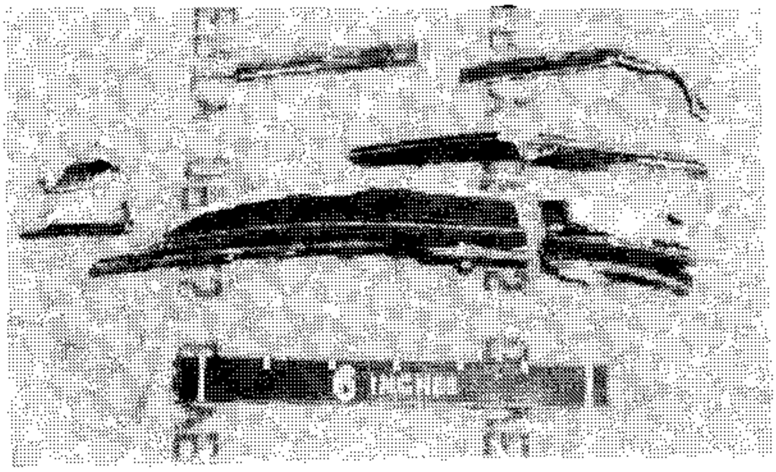

Figure 14. Maximum Stress vs. Velocity Gage GL4 Impact on Location B.