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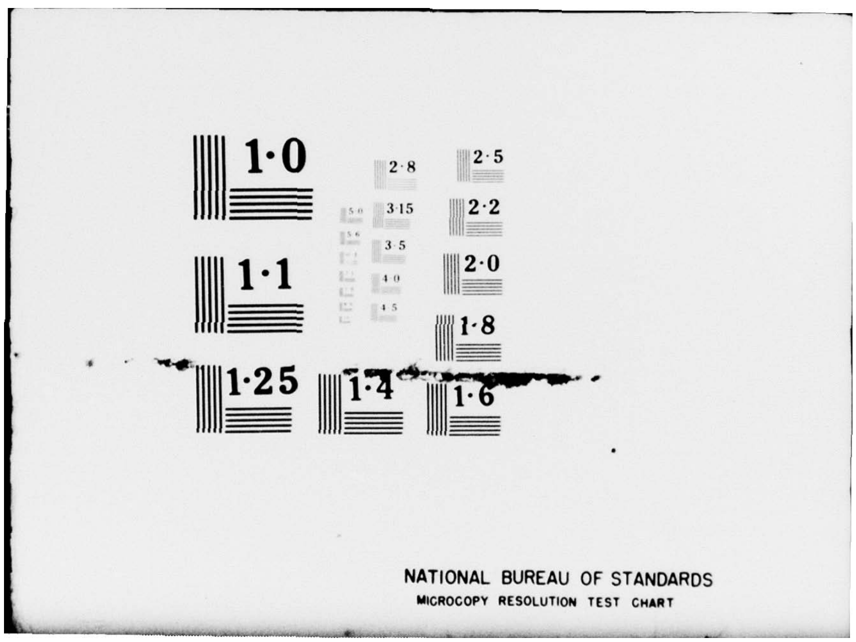
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OPTICAL EVALUATION OF F/FB-111 FIELD-SERVICE-TEST WINDSHIELDS

September 1977

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USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

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This technical report has been reviewed and is approved for publication.

WAYNE F. PROVINES, Major, USAF, BSC
Project Scientist

BENJAMIN KISLIN, Colonel, USAF, BSC
Supervisor

ROBERT G. MCIVER
Brigadier General, USAF, MC
Commander

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(10) Wayne F. Provines, Major, USAF, BSC
Benjamin Kislin, Colonel, USAF, BSC
Thomas J. Tredici, Colonel, USAF, MC

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Ten shipsets (pairs) of F/FB-111 bird-impact-resistant windshields plus four shipsets of spares were optically evaluated in the USAF School of Aerospace Medicine (USAFSAM) windshield laboratory before installation into aircraft. This was in support of a field-test program directed by the Air Force Flight Dynamics Laboratory. To elicit distortion characteristics, the USAFSAM effort included the determination of light-transmissivity properties and haze values, prism-deviation mapping, and grid-board photography. Seven of these windshields were optically evaluated also after the test, for pre- versus post-field-service direct comparison.

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OPTICAL EVALUATION OF F/FB-111 FIELD-SERVICE TEST-WINDSHIELDS

INTRODUCTION

This report describes the principal effort by the USAF School of Aerospace Medicine (USAFSAM) in support of the F/FB-111 bird-impact-resistant windshield field-service-test program (Air Force Flight Dynamics Laboratory Project 1426-75-01 and Tactical Air Command Project 75C-126W).

The F/FB-111 windshield design is rather atypical for flight aircraft in that it consists of two side-by-side windshields forming a cone section installed at 68 degrees from vertical and viewed through an oblique angle by the aircrew (Fig. 1).

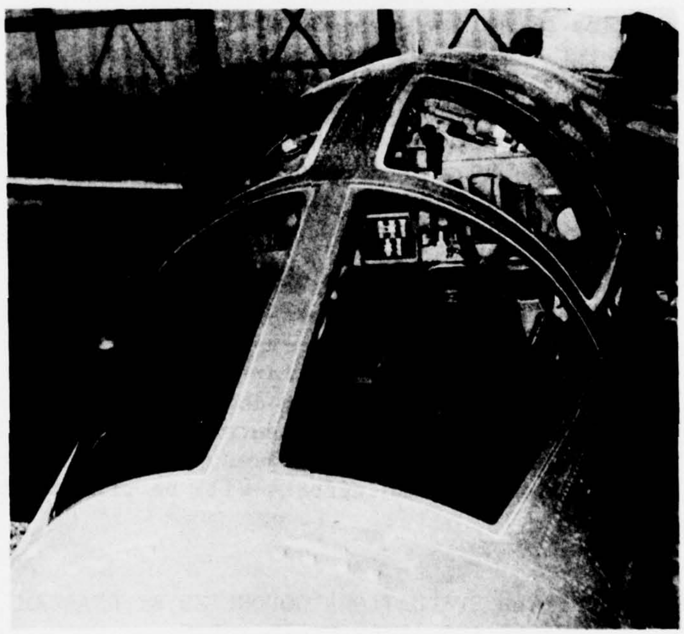

Figure 1. F-111F, 70-2390, front view.

Early in the aircraft's operational history, windshield-optics problems arose which included: nighttime multiple imaging, roll or band distortion, and subtle but significant visual symptoms and headache complaints from the aircrew. After an extensive investigative program by General Dynamics, the distortion and visual-symptoms problems were, with exceptions, resolved by imposing (implementing and fulfilling) complicated specifications pertaining to magnification (lensing) and prismatic changes (displacement grading). The multiple images remained but were generally aircrew acceptable due primarily to adaptation.

A more serious windshield concern arose in the form of destructive birdstrikes. Because of its high-speed, low-level mission requirements, the F/FB-111 has a high probability in encountering birdstrikes of enormous impact force. When a number of strikes occurred on the 0.85-cm (0.33-in) thick, 3-ply, chemically tempered glass windshields, catastrophic windshield failure occurred with bird penetration; and aircraft loss resulted in some instances. Concerned about this loss potential, the U.S. Air Force requested the development of a windshield that would survive a high-speed birdstrike at mission profile and velocity (TAC "Required for Operational Capability" (ROC) #26-71). Pittsburgh Plate Glass (PPG) Industries, under contract award, developed a windshield, approximately 2.54 cm (1 in) thick, of a 10-ply design composed of acrylic, polycarbonate, and proprietary innerlayers. The structural properties of this windshield will defeat penetration in a high-speed bird impact. The Air Force Flight Dynamics Laboratory (AFFDL) development program manager was directed to field-test ten shipsets of the PPG windshields for approximately 1 year before recommending full-fleet retrofit. The purpose of the field test was to evaluate the environmental effects upon the unproved plastic materials and to monitor aircrew acceptance of potential optical-error characteristics imparted in the manufacturing process.

USAFSAM's contribution in response to the TAC ROC was multifaceted. A standard optical evaluation of all test windshields before aircraft installation was performed to establish an optical-properties data bank for post-field-test comparison and for correlation with pilot-response data. Efforts were also made to obtain data not addressed by the manufacturer; certain common measurements technics were refined; and additional evaluation technics and procedures were devised. More detail on these additional USAFSAM efforts will be presented in forthcoming reports.

STANDARD OPTICAL EVALUATIONS CONDUCTED BY USAFSAM BEFORE AND AFTER FIELD TESTS

The initial USAFSAM windshield-optics evaluation included the following determinations:

1. Light transmissivity

   a. Normal incidence

   b. Designed pilot-eye-position incidence

2. Haze (light scatter) value

3. Prism-deviation mapping

4. Grid-board photography

Instrumentation and Procedures Required to Generate Optical Data

The light-transmission quality of the F/FB-111 windshield was determined in the normal and installed-angle positions. A Pritchard luminance meter and a Spectra standard light source (100-ft L, or 29.19 cd/m^2) were the equipment employed. The Pritchard was aligned in the designed pilot-eye position for the installed-angle measurements.

To determine its haze value, the windshield was positioned adjacent to the beam port of a Gardner haze meter and the meter value was recorded. Due to the haze meter design, readings were restricted to the periphery of the windshields; i.e., 12.5 cm (5 in) in from the edge-attachment borders.

To generate the prism-deviation map, the windshield was vertically suspended from a hoist, fore-arch area up. A template placed over the windshield divided it into approximately 10- X 10-cm (4- X 4-in) squares (Fig. 2). A HeNe laser beam was posed normally through each square, and the beam divergence was read from a target vectored and calibrated in minutes of arc. These deviation maps are used to determine if the windshield meets boresight specifications. With technic refinement, these data have afforded accurate information in predicting multiple-image locations through the windshield.

Distortion effects were obtained by evaluating a grid board photographed through the windshield (Fig. 3). Lensing and displacement grading values were determined by the procedure described in General Dynamics Report FZM-12-10952A, "Optical Evaluation of the F-111 Windshield," 20 May 1970. This procedure was successful, for the most part, in resolving aircrew visual complaints in the glass windshields.

Table 1 provides the optical specifications required and the measurements made for the field-test windshields. An instrument calibration error invalidated some haze measurements. Table 2 identifies each windshield and the aircraft in which it was installed. Multiple serial numbers associated with an individual aircraft indicate changes in windshields during the program.

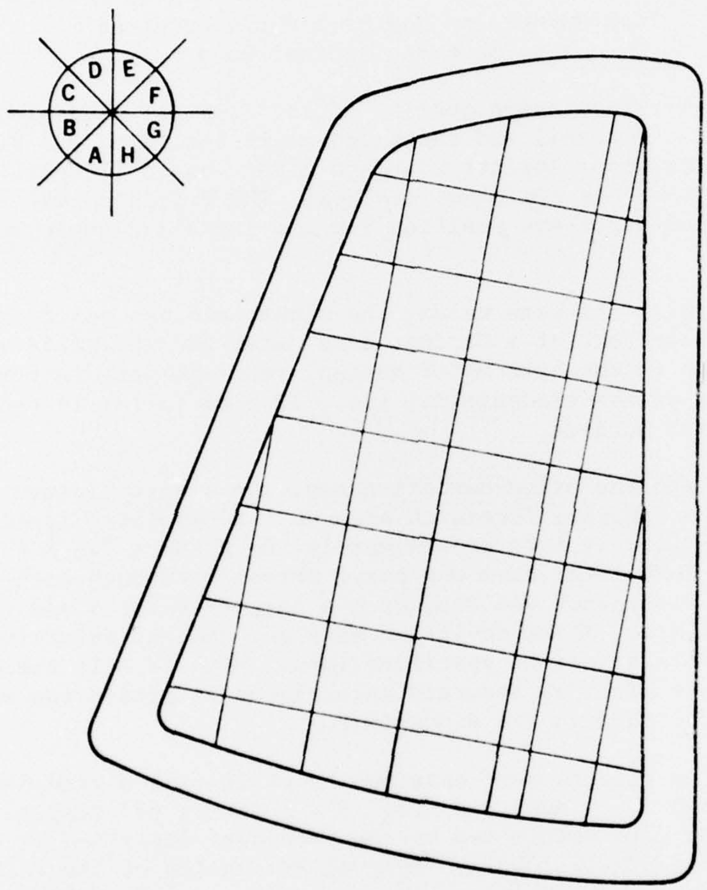

Figure 2. Prism-deviation overlay pattern.

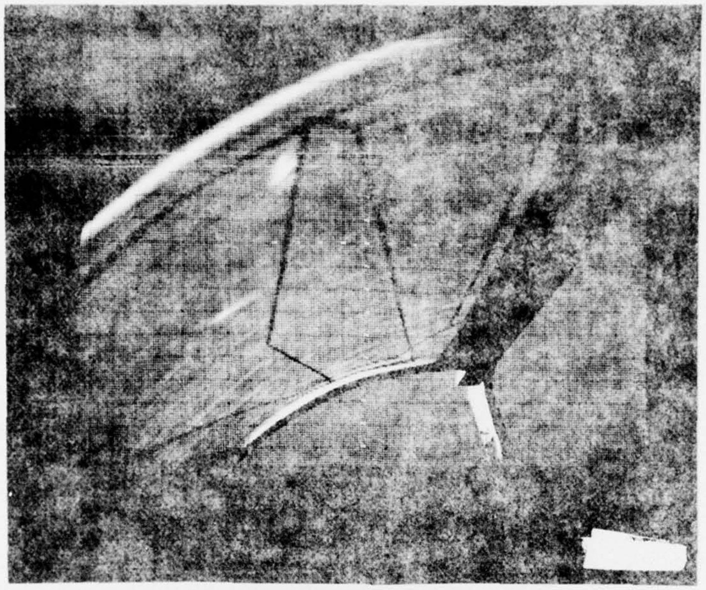

Figure 3. Grid-board distortion photograph--prefield test.

All but two of the original 20 field-test windshields met optical specifications (late in the study three replacement windshields exceeded displacement-grading specifications). The two originals exhibited slightly higher-than-acceptable deviation values near the fore-arch area, and one displayed a "bull's eye" at the upper left area near the optical free zone, as seen in Figure 3. These properties were not considered a compromise to flight safety, and the subspecification windshields were included in the field test. Questionnaires were distributed to the using squadrons, and responses on these two windshields were not particularly different from the flyer reactions on the rest of the windshields. Roll or band distortion, apparent in all windshields, was most pronounced near the edges and toward the lower one-third of the windshield, i.e., toward the fore arch. Windshields of later production runs showed less severe distortion bands.

Aircrew response to these new windshields varied. This report does not address the response analysis and correlation; however, the aircrew comments centered on distortion, hazing, multiple imaging, and a rainbowing effect near the windshield edges. Of the ten original windshield shipsets (five gold-coated, five noncoated), only one set (aircraft F70-2390) was rejected by aircrews after multiple flights as unacceptable with respect to flight safety. Complaints on this windshield set included depth-perception difficulty in landing, extensive hazing, excessive distortion, and wide multiple-image separation. Since this windshield set had met the operative optical specifications, it was assumed that some degrading property had escaped detection. This set was removed from the aircraft and sent to USAFSAM for study. Except for a wide multiple-image separation and a dynamic depth-perception alteration (which is

TABLE 2. CHART OF BIRD-RESISTANT-TRANSPARENCY INSTALLATION

Aircraft	LH Windshield S/N	RH Windshield S/N	LH Canopy S/N	RH Canopy S/N
F70-2389 Mountain Home	502915	502911	502907	502904
F70-2390 Mountain Home	504969 509107 605290	504006 509125 605286	503948	503947
E68-062 Upper Heyford	503931 605270	503955 605217	503962	503966
E68-064 Upper Heyford	503932	503930	503926	502923
A67-098 Nellis	502912	503929	503935	503934
A67-058 Nellis	504995 606304	505014 605292	504971	504973
FB-243 Plattsburgh	504972	504005	504975	504974
FB-244 Plattsburgh	502914	503965	504989	504996
C-125 Australia	503933	505023	504999	505012
C-126 Australia	504990	504976	504997	505020

not statistically significant), the origin of the aircrew visual complaints is unresolved on an optical basis. Two additional windshield sets which met optical specifications were installed on this aircraft; again, severe aircrew complaints resulted in their subsequent removal. Factors other than degraded optics are suspected in the windshield rejections on this aircraft.

Postservice evaluations of seven windshields are included in the data section (see Table 1). As had been forecasted, haze values of these sets increased due to exterior surface erosion caused by the flight environment and improper cleaning procedures. Surface scratching is presumed to be the primary causative factor, since hand polishing of windshields 503929 and 504995 reduced the haze. Comparisons of prism-deviation maps of three windshields (504990, 504995, 503931) before and after field use are within instrument-error tolerance, indicating no change in optics due to aging or environmental factors. Figures 4 and 5 are pre- and postservice maps of one typical windshield (504995). Distortion photographs before and after field use of the three windshields also show no changes.

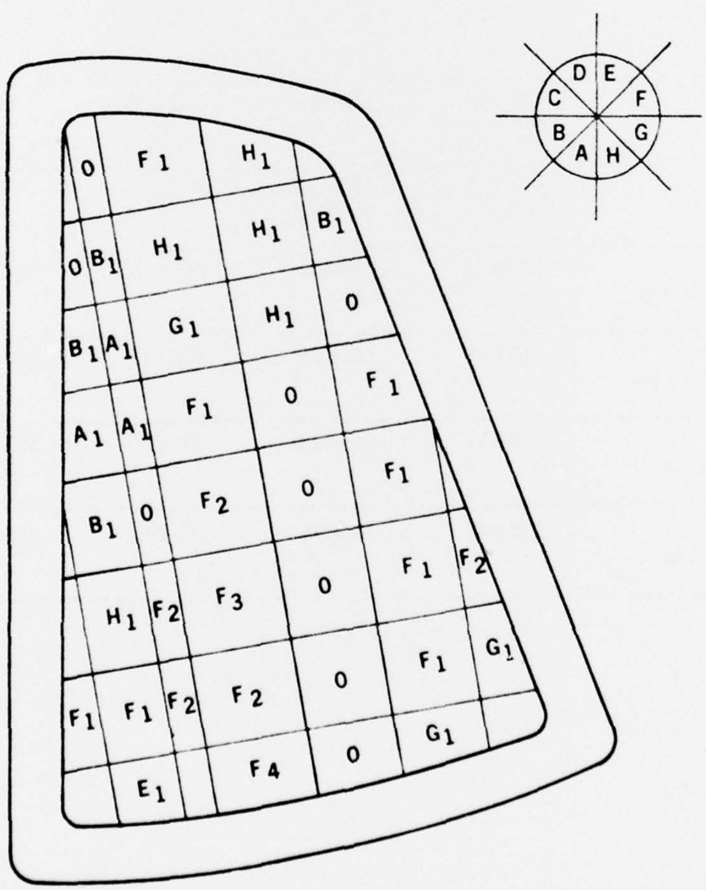

Figure 4. Pre-service-test deviation map.

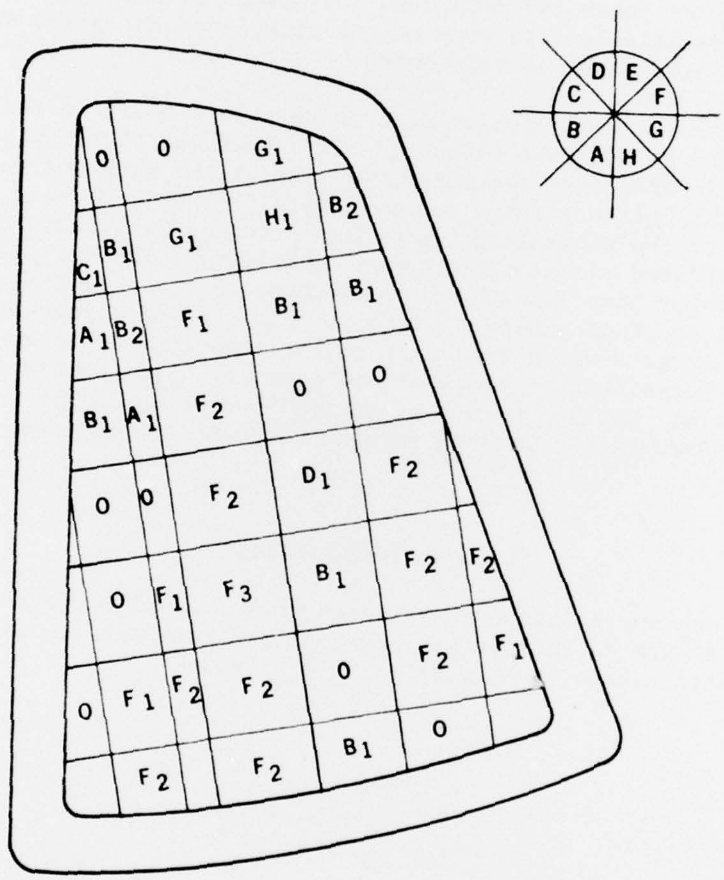

Figure 5. Post-service-test deviation map.

Two unforeseen visual problems arose during the field-service test. Aircrews reported colored fringes or "rainbowing" in the windshields, especially near the edges when flying into a clear daytime sky. These patterns were not particularly annoying with the early shipsets, but complaints became more serious when replacement windshields were installed. The rainbow patterns are attributed to the birefringent properties of the polycarbonate layers that become manifest when looking through them into the partially polarized sky. Later production runs of the replacement windshields diffused and displaced the fringe patterns toward the edge of the windshields and to some extent alleviated the pilot dissatisfaction associated with the rainbowing.

The other visual problem of considerable concern is that of a veiling glare caused by sunlight reflected off a degraded glare-shield surface and then mirrored into the aircrew's eyes by the back surface of the windshield. This glare effect, combined with the inherent haze of the plastic materials of the windshield, can cause a target/background contrast reduction and reduced visual performance capability. This is particularly manifest under hazy atmospheric conditions and/or when the sun is located at certain overhead angles. Difficulty in reading letters and numerals on ground targets was a direct cause for removing a shipset from aircraft C-126. A nonreflective cloth placed over the glare shield greatly reduces this problem. Whether or not a materials solution can be found to this degraded-glare-shield problem remains unknown at this time.

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GLOSSARY

SOME OPTICAL TERMS AS APPLIED TO AIRCRAFT WINDSHIELDS

TRANSMISSIVITY: The percentage of incident light passing through an optical medium. All transparencies reflect and absorb some light, resulting in a viewed image that is less bright than the actual object.

DISTORTION: Light refracted or bent in various ways as it passes through an optical medium results in a viewed image not being a true representation of the object--i.e., straight lines appear crooked, wavy, etc. Many types of distortion occur. Three of these have been particularly noteworthy on both the F-111 glass- and plastic-windscreen problems.

1. Lensing--A magnification or minification effect which may vary in extent from one portion of a transparency to another. Lensing causes objects to be increased or decreased in size and may have a degrading effect on visual focusing; it also has the potential for disrupting the binocular visual system.

2. Displacement Grading--A gradual apparent slope of a line away from its true horizontal or vertical orientation when viewed across the transparency. The magnitude of displacement grading varies from one portion of the F-111 windshield to another but usually is most pronounced approximately one-third the distance down the aft-arch area. The visual effect is that of creating a slight rotation of the horizon and, if pronounced, is suspected as causing a degrading binocular visual effect.

3. Roll or Band Distortion--A wavy or rippling effect usually noted at the fore one-third area of the F-111 windshield. Viewed objects appear to undulate as seen through the affected area.

MULTIPLE IMAGES: Internal interface reflection (light reflecting back and forth within the transparent media surfaces) effects one or more additional visual images, of lesser intensity, of a single object--usually an external light source located in a dark background. The multiple-images' locations with respect to the primary (real) image depend upon the geometry, slope, and prism deviation of the transparency. The images may appear, disappear, and swirl, depending upon the interrelation of the above factors.

HAZE: A scattering effect of light passing through an optical medium. This scatter is caused by imperfections (such as scratches) on the surface and/or effects within the medium itself. The visual effect is that of an object appearing cloudy, obscured, or less distinct from its background (reduction in contrast).

RAINBOWING: When light passes through a birefringent medium, colors may appear due to diffraction. The resultant colors and patterns depend on stresses within the medium. This effect is accentuated if the incident light is polarized to some amount. Sky light is a good example.