AD-A273 700

WL-TR-93-3088

BIRDSTRIKE RESISTANT CREW ENCLOSURE PROGRAM

PROGRAM TECHNICAL SUMMARY

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AUGUST 1993

FINAL REPORT FOR 08/01/84 - 03/01/92

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FLIGHT DYNAMICS DIRECTORATE
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
AUGUST 1993

3. REPORT TYPE AND DATES COVERED
FINAL 08/01/84--03/01/92

4. TITLE AND SUBTITLE
BIRDSTRIKE RESISTANT CREW ENCLOSURE PROGRAM;
PROGRAM TECHNICAL SUMMARY

5. FUNDING NUMBERS
F33615-84-C-3404
PE 64212
PR 1926
TA 01
WU 10

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Dayton Research Institute
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8. PERFORMING ORGANIZATION REPORT NUMBER
UDR-TR-92-87

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Flight Dynamics Directorate
Wright Laboratory
Air Force Materiel Command
Wright-Patterson Air Force Base, Ohio 45433-7562

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
WL-TR-93-3088

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
This final report defines the program objectives, presents an abstract for each technical report generated, and lists the major papers and presentations resulting from the technical effort. Major program accomplishments, both generic and specific, are also enumerated.

14. SUBJECT TERMS
Birdstrike, Crew Enclosure, Aircraft Transparency, Residual Stress, Polycarbonate, MAGNA, T-38, F/RF-4, F-16, F-111, A-7, B-1B, F-18, F-15, Coating, Frameless Transparency.

15. NUMBER OF PAGES
33

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18

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

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TABLE OF CONTENTS

FOREWORD

The efforts documented in this report were performed by the Aerospace Mechanics Division of the University of Dayton Research Institute (UDRI), Dayton, Ohio, under Contract F33615-84-C-3404, "Birdstrike Resistant Crew Enclosure Program," for the Flight Dynamics Directorate, Wright-Patterson Air Force Base, Ohio. Air Force administrative direction was provided by Capt. Donato J. Altobelli, AFWAL/FIEA, from July 1984 through June 1987; Capt. Paul Kolodziejski, WRDC/FIVR, from June 1987 through December 1990; and Mr. Russell E. Urzi, WL/FIVR, from December 1990 through March 1992, the Program Managers.

The work described herein was conducted during the period 16 July 1984 to 2 March 1992. Project supervision and technical assistance was provided through the Aerospace Mechanics Division of UDRI with Mr. Dale H. Whitford, Supervisor, and Blaine S. West, Head, Structures Group and Project Engineer. Principal Investigators were Blaine S. West, Kenneth I. Clayton, Gregory J. Stenger, Richard A. Nash, B. Basava Raju, Andrew J. Piekutowski, Michael P. Bouchard, Donald A. Skinn, William R. Braisted, Thomas J. Whitney, and Geoffrey J. Frank.

The active support, insight, and technical direction of Ralph J. Speelman on this program are gratefully acknowledged; similarly, the guidance of Capt. Steve Hargis, Capt. Steve Kolbow, Capt. Duncan Dversdall, Mr. Bob Pinnell, Mr. Malcolm Kelley, Lt. Joe Davisson, Lt. Tong C. (TJ) Choe, and Mr. James Terry.

SECTION 1
INTRODUCTION

This report is composed of three major sections. Section 1 presents the background and overall program objectives. A compilation of abstracts from the reports prepared and issued to document the program effort, along with a listing of directly related papers presented throughout the contract period, is presented in Section 2. Significant program accomplishments are summarized in Section 3; recommendations are presented in Section 4.

The U. S. Air Force recognizes the importance of protecting the aircraft crew from flight safety hazards and at the same time reducing the cost of lost and damaged aircraft. In 1972, an Improved Windshield Protection ADPO was established within the Flight Dynamics Directorate at Wright-Patterson Air Force Base. Under the direction of this office, a number of advanced development programs have been and continue to be conducted to examine bird avoidance concepts and new material systems; develop the technology/methodology required to design, test, and analyze aircraft transparencies; and apply advanced technologies to the development of improved low-cost bird-resistant transparent crew enclosures.

The primary objective of this program was to apply state-of-the-art technology in support of ongoing transparency efforts to improve hazard tolerance, optical quality, durability, and to lower the cost of ownership of current and future bird resistant transparency systems. Secondary objectives of the proposed program were test method development and standardization; development of windshield system trade-off criteria for current and future transparency systems; and support of full scale tests.

SECTION 2

COMPILATION OF ABSTRACTS (BIBLIOGRAPHY)

Presented below, in chronological order, is a compilation of abstracts taken from the referenced reports which were prepared and issued to document the work accomplished under Contract No. F33615-84-C-3404. Included also is a list of directly related papers which were presented throughout the contract period.

2.1 REPORT ABSTRACTS

Bowman, D.R., Test Information for Bird Impact Testing of In-Service Aged F-111 Windshield Transparencies, UDR-TM-85-35, November 1985.

ABSTRACT: This document is a plan for full-scale birdstrike testing of in-service aged F-111 ADBIRT windshield transparencies. A description of the test article, test matrix, test setup, test facility and conditions, and data acquisition and instrumentation were included.

West, B.S., K.I. Clayton, and F.J. Giessler, Mission Integrated Transparency System (MITS) 1995 Baseline Requirements Study, UDR-TR-86-85, July 1986.

ABSTRACT: This report presents a consensus of the transparency requirements for 1995 High Performance military aircraft. It was obtained by personal visits to government and industry designers, manufacturers, and users of transparency systems. The material is organized into five general technology areas: natural hazards, man-machine interface, combat hazards, supportability, and fuselage integration. Each area has been divided into several subtopics. Natural hazards cover temperature, weathering, birdstrike, abrasion, lightning, static charge, and other environmental conditions. Man-machine interface includes optics, HUD integration, ingress/egress, and vision. Combat hazards cover signature, lasers, chemical/biological, nuclear, and ballistic. Supportability includes service life, removal criteria, change-out time, interchangeability, repair, and ground handling. Fuselage integration is concerned with structural integrity, aerodynamic effects, weight, electrical continuity, and maintenance. Each area is ranked according to priority of baseline requirements integration for each of two selected flight profiles.

Technological deficiencies have been identified as well as those technologies which are expected to emerge and mature prior to the 1995 time frame.

Skinn, D.A., Sensitization of Bird Avoidance Model (BAM) to Raptors and Breeding Ducks, UDR-TR-87-01, January 1987.

ABSTRACT: The Birdstrike Avoidance Model (BAM) statistically distributes bird populations in the airspaces across the contiguous United States. The population distributions reflect data collected over the years by various wildlife research organizations. BAM simulates low-level flight routes and estimates the number of bird/aircraft strikes. The BAM is a flight planning tool which identifies the safer of contending flight routes. BAM has been operational since 1981; however, only the influence of migratory waterfowl is modelled. This report summarizes the effort to incorporate the influence of raptor behavior into the BAM and to improve the performance of the BAM. Computer programming concepts and BAM data structures are also discussed.

Skinn, D.A., Birdstrike Avoidance Model (BAM) Programmer's Guide, UDR-TR-87-36, March 1987.

ABSTRACT: The BAM statistically distributes bird populations in the airspaces across the contiguous United States. The population distributions reflect data collected over the years by various wildlife research organizations. BAM simulates low-level flight routes and estimates the number of bird/aircraft strikes. The BAM is a flight planning tool which identifies the safer of contending flight routes. BAM has been operational since 1981; however, only the influence of migratory waterfowl is modelled. BAM has just recently been enhanced to be sensitive to the effects of migratory raptorial bird species. This report discusses calculation methods, programming techniques, and maintenance of data structures. Complete documentation of the enhanced BAM includes narrative descriptions, flow charts, data dictionaries, and cross reference listings of program modules.

Skinn, D.A., Birdstrike Avoidance Model (BAM) User's Guide, UDR-TR-87-37, March 1987.

ABSTRACT: The BAM statistically distributes bird populations in the airspaces across the contiguous United States. The population distributions reflect data collected over the years by various wildlife research organizations. BAM simulates low-level flight routes and estimates the number of bird/aircraft strikes. The BAM is a flight planning tool which identifies the safer of contending flight routes. BAM has been operational since 1981; however, only the influence of migratory waterfowl is modelled. BAM has just recently been enhanced to be sensitive to the effects of migratory raptorial bird species. This report is the BAM User's Guide and presents the requirements and instructions for executing the BAM on a CDC computer running under the NOS operating system. BAM solutions for three scenarios are included. Frontal areas of several aircraft in the Air Force inventory are provided.

Raju, B.B., Evaluation of Residual Stresses in Aircraft Transparencies by Surface Wave Ultrasonic Method, UDR-TR-87-62, April 1987

ABSTRACT: This report documents a program which was conducted to:

- Design, fabricate, and set up a photoelastic test apparatus capable of measuring residual stresses in aircraft transparencies
- Evaluate the accuracy of the scattered-light photoelastic technique by conducting scattered-light photoelastic experiments on four-point bending polycarbonate specimens having known analytical solutions and other experimental solutions.
- Establish a scattered-light photoelastic experimental procedure for monolithic polycarbonate F-16 transparencies by measuring residual stresses at a typical station on the transparency
- Evaluate the scattered-light photoelastic properties of acrylic plastic material.
- Determine the feasibility of using acoustic wave ultrasonic techniques to determine residual stresses in transparencies.

Bouchard, M.P., An Experimental Analysis to Evaluate Pullout of the F-4 Wraparound Windshield During Birdstrike, UDR-TR-86-102, AFWAL-TM-87-167, July 1987.

ABSTRACT: A simple lab test is described which simulates pullout of the F-4 one-piece windshield from its channel-shaped aft arch when impacted by a 4-pund bird along the centerline 8 inches forward of the aft arch. The test method described is a quasi-static three-point beam test performed in an MTS servohydraulic load frame. Verification of the test method by accurately simulating the maximum centerline deflection and windshield pullout during a full-scale birdstrike test at 392 knots is presented. The test method is used to predict whether or not the windshield will pull out from a redesigned arch having a deeper channel when impacted at 500 knots. The test results indicate that the deeper channel arch should prevent pullout during a 500 knot birdstrike.

Bouchard, M.P., Failure Analysis of Birdstrike-Tested Recoated Monolithic F-16A Forward Canopies, UDR-TR-86-07, AFWAL-TR-87-3050, August 1987.

ABSTRACT: Birdstrike tests of recoated monolithic F-16A polycarbonate canopies to evaluate the effects of recoating on impact resistance resulted in catastrophic structural failure of three of the five tested canopies at or below the desired pass velocity. The effort documented herein was an investigation and analysis of these five canopies after birdstrike testing. The report details the tests that were conducted including visual inspection, film studies, photomicrographs, crack propagation tracing, MTS and falling weight three-point beam tests, salt-blast abrasion tests, and gel permeation chromatography tests. The conclusions included (1) two of the failures occurred because of contact between the HUD container glass and canopy while the other resulted from a surface flaw on the canopy; (2) there was no discernable chemical degradation of the polycarbonate due to the recoating process, and (3) the interior coating degraded with increasing service life, resulting in lower abrasion resistance but increased bird impact resistance.

Skinn, D. A., The Role of the Birdstrike Avoidance Model (BAM) in the Environmental Impact Study, UDR-TM-87-46, December 1987.

ABSTRACT: This report defines the effort required to analyze the birdstrike risks for currently defined SAC low-level training routes. It also summarizes the enhancements to the BAM required to incorporate the BAM into the GEIS.

Bouchard, M.P., Evaluation of the Effects of Artificial and Natural Environmental Exposures on Laminated F-16 Transparency Materials, UDR-TR-87-86, AFWAL-TR-88-3016, June 1988.

ABSTRACT: This investigation was carried out to determine the effects of natural an accelerated weathering on baseline laminated F-16 transparency material. Accelerated weathering consisted of ultraviolet radiation/elevated temperature, elevated temperature with alternating ultraviolet/condensation, and intense sunshine with water spray. Outdoor natural weathering was accomplished in a variety of climates. Haze and transmittance tests, modified crazing tests, and flatwise tension tests were conducted to determine the effects of the exposures and to correlate natural and accelerated weathering effects.

Poormon, Kevin L. and Blaine S. West, Crazing of Acrylic as a Function of Surface Smoothness, UDR-TM-88-23, July 1988.

ABSTRACT: This report documents an investigation into the effects of surface finish on material crazing. Samples were fabricated from Polycast MIL-P-8184. Tests indicated that the smoother the surface, the less susceptible the material is to craze.

Braisted, W.R., Transparency Fasteners Study Based on MAGNA Finite Element Analysis Results, UDR-TR-88-146, December 1988.

ABSTRACT: As part of an effort to evaluate possible alternative windshield systems for the B-1B aircraft, finite element analyses were performed to evaluate the structural performance of the current production and alternate candidate configurations when subjected to either internal pressurization or birdstrike loads. The performance of the fasteners that attach the windshield to the support structure were deemed important in conducting the system evaluations. This report describes the process by which finite element analysis results of the B-1B windshield were used to determine loads in the fasteners joining the transparency to the supporting framework. The following descriptions are specific to the B-1B project, but the general procedure could be applied to most transparency analyses. Any future use of these algorithms would require slight modifications to account for the differences in fastener, transparency, and frame geometry. To provide a quantitative sense for the data manipulations which follow, a simple example problem will be analyzed and traced through each stage in the analysis.

Bowman, D.R., G.J. Stenger, and B.S. West, Definition and Reduction of the F-18 Windshield Bird Hazard, UDR-TR-87-27, AFWAL-TR-88-3110, February 1989.

ABSTRACT: Since 1983 there have been nine reported bird impacts on the F-18 windshield, resulting in one penetration and one injured pilot. The number of penetrations can be expected to increase as the F-18 fleet size increases. This program was initiated to develop a windshield system with an increased bird impact capability for the F-18 aircraft. The results of this seven-part study were integrated into a design recommendation.

Bouchard, M.P., An Experimental Evaluation of the Air Cannon Test Technique for use in Impact Resistance Screening of Polycarbonate, UDR-TR-87-15, AFWAL-TR-88-3109, February 1989.

ABSTRACT: An evaluation of the air cannon test technique for impact resistance screening of polycarbonate was conducted. Tests were performed on plate specimens of various spans and thicknesses impacted by projectiles of various diameters, masses, and velocities. Strain rate, failure energy, failure mode, and percent thickness reduction were recorded. Falling weight tests were also conducted and results compared with the air cannon results. The air cannon results showed the same trends in the failure energy-versus-geometric parameter and in failure mode as the falling weight results. The air cannon test technique yielded strain rates characteristic of birdstrike for both thin (1/8 inch) and thick (1/2 inch) plates while the falling weight test achieved such strain rates only for thin (1/8 inch) plates. The air cannon technique is, therefore, the test of choice when strain rate is critical. When strain rate is not critical, the falling weight test is the method of choice because of its low testing and maintenance costs. Further air cannon

testing should be conducted to refine some of the findings, especially in regard to the nonlinear dependence of failure energy on projectile velocity (mass).

Bouchard, M.P., F-16 500 knot Canopy Development Design Recommendations, UDR-TM-89-16, August 1989.
ABSTRACT: The objective of this effort was to provide design recommendations to increase the bird impact resistance of F-16 A/B/C/D canopies from the current specification of 350 knots to 500 knots. The effort included a review of all available literature documenting birdstrike testing of F-16 canopies and determination of current bird impact capabilities. Other design factors were then considered, including canopy weight, HUD effects, and optics. All information and considerations were then distilled into a set of design guidelines, which were subsequently used to evaluate vendor-proposed 500 knot laminated canopy configurations.

Bowman, D.R., G.J. Stenger, and B.S. West, Full-Scale Birdstrike Testing of In-Service Aged F-111 ADBIRT Windshield Transparencies, UDR-TR-88-39, WRDC-TR-89-3075, August 1989.
ABSTRACT: A test program consisting of 22 full-scale birdstrike tests of F-111 ADBIRT windshield transparencies was conducted. Test hardware was developed to simulate flight structure, and 4-pound artificial birds were used to impact the transparencies at the most critical location, the upper inboard corner. Testing was completed on windshield panels ranging from unaged baseline windshields to windshields which had been in service for more than 5 years. The structural integrity of F-111 ADBIRT windshield transparencies was found to be significantly reduced by in-service aging. Capability envelopes were developed for each vendor's windshield, relating bird impact resistance capability to installed age. In addition, to increase understanding of support structure behavior during birdstrike, the aft arch was instrumented with strain gages, and a finite element analysis of the aft arch was performed. Also, a birdstrike risk assessment analysis was made to evaluate the risk of flying the F-111 with degraded windshield panels.

Berens, A.P., B.S. West, and D.R. Bowman, A Probabilistic Model for Evaluating Birdstrike Threat to Aircraft Crew Enclosures, UDR-TR-89-92, November 1989.

ABSTRACT: A probabilistic model was developed, which can be used to analyze birdstrike risk to aircraft transparencies. The model uses bird weight and population data, aircraft transparency strength data, aircraft flight profile data, and flight time data to calculate birdstrike probability. The basic equations required were derived and programmed for computer use, and a basic parametric study was conducted to evaluate the sensitivity of the birdstrike risk to variations in the parameters of the model.

Raju, B.B., and B.S. West, Nondestructive Measurement of Residual Stresses in Aircraft Transparencies, UDR-TR-88-65, WRDC-TR-89-3099, November 1989.

ABSTRACT: This report documents a program which was conducted to:

- Design, fabricate, and set up a photoelastic test apparatus capable of measuring residual stresses in aircraft transparencies.
- Evaluate the accuracy of the scattered-light photoelastic technique by conducting scattered-light photoelastic experiments on four-point bending polycarbonate specimens having known analytical solutions and other experimental solutions.
- Establish a scattered-light photoelastic experimental procedure for monolithic polycarbonate F-16 transparencies by measuring residual stresses at a typical station on the transparency.
- Evaluate the scattered-light photoelastic properties of acrylic plastic material.
- Determine the feasibility of using acoustic wave ultrasonic techniques to determine residual stresses in transparencies.

Bowman, D.R., Birdstrike Probability Program User's Manual, UDR-TR-88-70, WRDC-TR-89-3112, January 1990.

ABSTRACT: A user's manual was written for the birdstrike probability computer program which was developed by the University of Dayton Research Institute in the late 1970's. This program is used to evaluate the relative performance of aircraft transparency systems in terms of birdstrike resistance. The probability of a birdstrike causing damage (penetration) on a system can be evaluated and the total number of birdstrikes and penetrations for a given number of flight hours can be calculated. This user's manual explains the development of program input data and includes example calculations, historic input data for various military aircraft systems, and the birdstrike probability program computer listing.

Bouchard, M.P., and W.R. Braisted, B-1B Improved Windshield Development Volume II: MAGNA Analysis: Baseline and Parametric, UDR-TR-88-129, WRDC-TR-89-3123, February 1990.

ABSTRACT: This report documents analyses which supported a study aimed at eliminating B-1B windshield problems which surfaced when the aircraft became operational. Optics and durability were immediately degraded by delamination. The many edge attachments made windshield changeout difficult and time-consuming, thereby affecting supportability. The objective of these analyses was to evaluate the impact of design configuration changes proposed to alleviate the in-service problems on the structural performance of the current production configuration, which served as a baseline, and the alternate design configurations. The fasteners were evaluated based on the MAGNA output using additional computer programs. Computations were made first assuming all fasteners were present, then assuming every other fastener was removed. The models and analyses are discussed and summary results for each design configuration presented. Conclusions are drawn regarding the viability of the proposed alternate design configurations in view of their impact on the structural performance of the windshield system.

Bowman, D.R., and B.S. West, An Investigation into the Structural Degradation of In-Service Aged F-111 ADBIRT Windshield Transparencies, UDR-TR-90-34, June 1990.

ABSTRACT: The birdstrike resistance capability of F-111 ADBIRT windshield transparencies was found to be significantly reduced by in-service aging. A test program was conducted to determine the cause of degradation. The program consisted of laboratory coupon tests of in-service aged and baseline F-111 ADBIRT windshield coupons; research of polycarbonate degradation and craze testing; fractography; and finite element analysis of the windshield edge attachment. Coupon testing indicated no polycarbonate degradation. Analysis of the edge attachment revealed numerous fatigue cracks at the edges and in the vicinity of the bolt holes. These fatigue cracks were the direct cause of the reduction in birdstrike resistance of in-service aged windshields. Finite element analysis showed significant tensile stresses at the edges for various pressure/thermal load cases. These stresses were high enough to propagate existing cracks, and in several cases the stresses were high enough to initiate cracks. Craze testing of the sealants, cleaners, and other chemicals used to install or clean aircraft windshields indicated that many of the substances which are used in conjunction with aircraft transparencies cause crazing of polycarbonate. This crazing, in conjunction with the cyclic in-service pressure/thermal loads, is the most likely initiator of the fatigue cracks in F-111 ADBIRT windshields.

Stenger, G.J, and G.J. Frank, Crack Formation in F-15 Aircraft Canopies, UDR-TR-90-110, October 1990.

ABSTRACT: Cracks have been reported in F-15 transparencies. The cracks extend from the free edge of the transparency into the acrylic parallel to the transparency surface. Similar cracks were reported on F-4 transparencies in the early 1970's. Investigations at that time indicated that the crack growth had two phases: crack initiation and crack growth. Crack initiation was attributed to absorption and desorption of moisture. Crack growth was caused by thermal stresses due to the difference in coefficients of thermal expansion between the stretched acrylic transparency and the fiberglass edge attachment. Tests have been performed on samples from F-15 canopies to validate the crack growth mechanism. Research on the F-4 cracks showed that crack growth does not occur if nylon-acrylic composite, which has a coefficient of thermal expansion similar to that of stretched acrylic, is used as an edge reinforcement material.

Clayton, K.I., and M.P. Bouchard, B-1B Improved Windshield Development, Volume I - Requirements Review and Alternate System Definition, UDR-TR-88-129, WRDC-TR-91-3087, April 1991.

ABSTRACT: Considering the currently available technology base, design requirements applicable to a near-term B-1B improved windshield configuration were established.

Considering the emerging technology base and projected combat environment, 1995 mission-oriented requirements applicable to B-1B derivative transparency systems were established. An evaluation of supplier-submitted near-term configuration modifications to improve existing B-1B windshield performance pointed to the optical quality of the thermally-tempered glass face ply as the major problem with current windshields, resulting in a recommendation being made to use chemically-tempered glass face plies. Samples of near-term producible transparent materials, hardened against projected combat threats, were procured and tested to evaluate material degradation. The additional requirement to protect the aircrew from defined laser/nuclear threats was also investigated by test. Considering supplier input, trade study analyses, and the test evaluation of available hardened material samples, a redesigned windshield, hardened in accordance with 1995 mission oriented requirements and preassembled in a mounting frame, was recommended for next generation B-1B retrofit aircraft.

Bouchard, M.P., An Experimental Evaluation of the Impact Resistance of Recoated F-16A Monolithic Polycarbonate Flat Sheet, UDR-TR-89-41, WRDC-TR-90-3078, May 1991.
ABSTRACT: F-16A coated monolithic polycarbonate forward canopies experiencing coating degradation are being reworked by the vendor by stripping the degraded coating and applying a new protective coating, thereby restoring the canopy for additional useful service life. The basic objective of the current investigation was to determine whether or not the impact resistance of monolithic polycarbonate flat sheet material for the F-16A forward canopy is degraded by the stripping and recoating process. The effects of laboratory storage and QUV weathering, laboratory storage, and/or stripping/recoating (which was performed by the vendor). The coupons were then impact tested using either the falling weight beam test technique (ASTM F736-81) or a high rate (40,000 in/min center deflection rate) open loop servohydraulic (MTS) beam test technique. The primary conclusion of the investigation was that the strip and recoat process did not degrade the impact resistance of the polycarbonate relative to the impact resistance of new coated polycarbonate. In other words, the strip and recoat process restored the impact resistance of the reworked polycarbonate to its original newly-fabricated, newly-coated state, regardless of prior conditioning (QUV weathering or laboratory storage).

Bowman, D.R., Analysis of F-16 Birdstrike Risk, UDR-TR-91-94, July 1991.

ABSTRACT: An analysis of birdstrike risk was made for the current F-16 coated monolithic polycarbonate canopy, the current F-16 laminated acrylic/polycarbonate canopy, and a proposed F-16 500-knot birdstrike resistant canopy. To calculate birdstrike risk, the volume of space swept out by the aircraft transparency during flight in the bird environment is determined. This volume is multiplied by a bird density (number of birds per unit volume) to determine the number of birdstrikes. The number of birdstrikes are then multiplied by a probability of penetration to determine the number of penetrating birdstrikes. This probability of penetration is based on the transparency birdstrike resistance capability, the probabilistic birdweight distribution, and the aircraft probabilistic velocity distribution. The number of projected birdstrikes, damaging birdstrikes, and penetrating birdstrikes were calculated per million flight hours and for 5- and 10-year periods.

Stenger, Gregory J., Geoffrey J. Frank, Daniel R. Bowman, and William R. Braisted, Hybrid Composite Material Evaluation for Transparency Frame Applications, UDR-TR-91-12, WL-TR-91-3075, January 1992.

ABSTRACT: The objective of this program was to screen various composite configurations to determine which laminate designs best met the stiffness, strength, and toughness design requirements necessary to withstand a birdstrike event. Hybrid composite materials offer an attractive alternative to traditional metals because of their potential light weight, tailored strength and stiffness, formability, and nonmagnetic and noncorrosive properties. The beam test program, summarized in this report, was conducted to evaluate hybrid composite materials which consisted of various combinations of graphite, glass, and Kevlar fibers and stainless steel sheets in an epoxy matrix. The five best hybrid materials from this beam test program were further evaluated for their applicability in a windshield frame design. Data generated in the beam test program were used as input into a finite element model used for design analysis.

Bowman, D.R., Investigation of a Relationship Between Uniaxial and Biaxial Chemical Stress, UDR-TR-90-127, WL-TR-91-3076, January 1992.

ABSTRACT: Chemical crazing is directly responsible for many aircraft transparency removal. Laboratory chemical stress craze testing can be used to evaluate the effects of different chemicals on aircraft transparencies. Most craze testing to date has been uniaxial, while the stress state in an installed aircraft transparency is biaxial. The unixial craze test is easier to conduct and requires less and more simple fixturing than the biaxial craze test. It is desirable to be able to use uniaxial data to predict the effects of a biaxial stress field on crazing. An experimental program was conducted to develop a relationship between uniaxial and biaxial chemical stress crazing of aircraft grade cast acrylic with isopropyl alcohol. ASTM Standard Test Methods F484 and F1164 were used as guidelines for the uniaxial craze testing and biaxial craze testing, respectively. Time to craze as a function of stress level was determined and used to develop relationships between uniaxial and biaxial crazing in the form of craze initiation criterion, using theoretical and empirical equations.

Bowman, D.R., Coupon and Birdstrike Testing of F-111 ADBIRT Windshields which have been Subjected to Simulated Pressure/Thermal Service Life, UDR-TR-91-73, WL-TR-91-3088, January 1992.

ABSTRACT: This program consisted of birdstrike testing, crack analysis, and coupon testing of F-111 ADBIRT windshield transparencies which have been subjected to pressure/thermal testing in the WPAFB Building 68 Transparency Durability Facility. Three pairs of F-111 ADBIRT windshield transparencies (left and right hand) were used in this program, one pair each from Sierracin/Sylmar Corp., Swedlow, Inc., and PPG Industries, Inc. The edges and bolt holes of all of the transparencies were examined for edge cracking. The three right-hand windshields were birdstrike tested, and the three left-hand windshields were used for coupon testing. Dynamic mechanical analysis (DMA), gel permeation chromatography (GPC), tensile, and edge attachment testing were conducted. Simulated service life in the durability facility did not produce as much structural degradation in terms of birdstrike resistance as in-service aging. A significant number of cracks were found in the windshields in the vicinity of the edge attachments, similar to cracking from in-service aged windshields. Coupon testing revealed no bulk polycarbonate degradation.

Clayton, K.I., Sealant Material Evaluation, UDR-TR-92-23, March 1992.

ABSTRACT: PR 1829 and PR 1826 polythioether sealants, manufactured by Products Research and Chemical Corp., were evaluated by viscosity of base compound, flow, application time, tack free time, standard curing rate, specific gravity, crazing, peel strength, and repairability. Crazing tests of both PR 1829 sealant and PR 186 adhesion promoter were conducted on four substrates: MIL-P-83310, MIL-P-5425, MIL-P-8184, and MIL-P-25690. A search was made to identify candidate dry seal materials capable of extending the useful temperature range to approximately -100°F to +450°F. "SKYFLEX" dry sealants, GUA 1001 and GUA 1002, supplied by W.L. Gore and Associates, are expanded teflons which offer the attributes of "Tacky Tape" but greatly expand the temperature resistance to 600°F. They consist of a high tensile strength material which exhibits excellent strength retention after exposure to fluids and excellent sealability when used in a faying surface application.

Braisted, W.R., G.J. Stenger, and P.G. Szalek, Frameless Transparency System Birdstrike Resistance Evaluation, UDR-TR-92-44, March 1992.

ABSTRACT: Recent advances in manufacturing technologies permit the production of large plastic components by injection molding. The techniques required to manufacture aircraft transparencies by injection molding are currently being developed as a portion of the Frameless Transparency Program (FTP). A test program was conducted to evaluate the bird impact resistance of several candidate materials to be used in the FTP. Eleven polycarbonate panels were birdstrike tested, and triangulation techniques were used to obtain deflection time history data during the birdstrike. An explicit finite element analysis code was employed to analytically predict the impact response. Results and conclusions from the test program, triangulation, and analysis are presented.

Whitney, T.J., and G.J. Stenger, Determination of Stresses on Laminated Aircraft Transparencies by the Strain Gage-Hole Drilling and Sectioning Method, UDR-TR-90-106, WL-TR-92-3025, April 1992.

ABSTRACT: Reducing the incidence of transparency changeouts due to craze of the outer acrylic ply requires knowledge of stress levels in in-service aircraft transparencies.

Laboratory and field craze data may then be correlated to predict craze onset. Experiments conducted during the first phase of this study verified that the strain gage-hole drilling method, with calibration modification, can measure biaxial stress states in laminated transparencies with an error of less than 10 percent for stresses over 500 psi. A device to apply this method to full-scale transparencies was then designed and fabricated. In the second phase, stresses due to three mechanisms (residual stress, installation, and cabin pressurizing) in full-scale transparencies were measured. For comparison purposes and to identify the contribution of particular mechanisms to the stress state, the sectioning method was also used. The measurements made on full-scale transparencies removed from service due to craze indicate residual stresses are too low to cause crazing in a "uniform" environment (one free from wide temperature variation and extended contact with crazing agents). Stresses due to transparency installation and cabin pressurizing were also low relative to the maximum principal stress criteria used in this study. Recommendations include examination of other craze criteria, examination of other stress inducing mechanisms such as moisture desorption from the surface, and examination of cyclic loading and chemical exposure on craze.

Frank, G.J., and G.J Stenger, Evaluation of Alternatives for increasing A-7D Rearward Visibility, UDR-TR-90-121, WL-TR-92-3009, April 1992.

ABSTRACT: Experience has shown that the present A-7D canopy provides poor rearward visibility for defensive maneuvering against adversary behind the A-7. Alternatives were identified and evaluated for increasing rearward visibility, including: increasing the length of the canopy transparency; adding external mirrors; modifying the existing internal mirrors; using a refractive lens; and altering the canopy profile. This evaluation showed that increasing the transparency length would provide the greatest increase in rearward visibility with the least distortion. The feasibility of extending the transparency was analyzed using a finite element model which showed that the transparency could be extended without increasing the maximum stress levels. Advanced composites were used to design an alternate canopy frame to allow the transparency to be extended by 5 inches. This frame was designed to be as stiff and strong as the current aft frame. The design required no modification to the surrounding fuselage and did not change the overall canopy weight.

Whitney, T.J., Effect of Creep and Stress Relaxation on Crazing of Cast Acrylic, UDR-TM-91-12, 1992.

ABSTRACT: Craze initiation criteria found in the literature often do not differentiate between the critical stresses and critical strains required for craze formation. While initial stress and initial strain at the beginning of a test are related through material properties, viscoelastic effects cause strains to increase in a constant load test, and stresses to relax in a constant strain test. Changes in stress or strain in a craze test could corrupt time-to-craze data if the viscoelastic effects of a material on crazing are not understood. In this program, chemical craze tests on tensile-creep and tensile-stress relaxation specimens of cast acrylic were conducted to determine if chemical crazing is a stress or strain induced phenomenon. Craze tests showed specimens under constant load to have constant initial craze times, regardless of the magnitude of the load, and despite increasing strain due to creep. Craze tests on constant displacement specimens showed initial craze times to increase, regardless of the magnitude of the displacement, as the stress decreased over time due to stress relaxation. Results, therefore, indicate that stress in the material is the driving factor for craze initiation.

Frank, G.J., and G.J. Stenger, Frameless Transparency System Latch Insert Evaluation, UDR-TR-92-21, May 1992.

ABSTRACT: Recent advances in manufacturing technologies permit the production of large plastic components by injection molding. The techniques required to manufacture aircraft transparencies by injection molding are currently being developed as part of the FTP. Part of this program is the development of latch inserts for attaching the transparency to the aircraft. Tests were conducted to evaluate the integrity of various latch insert configurations under thermal and mechanical loads which represented expected flight mission conditions. Tests were also conducted to evaluate the room temperature failure load of the latch inserts. Configurations evaluated included latch inserts made from aluminum, glass-filled polycarbonate, and glass-filled polyetherimide

overmolded with different formulations of polycarbonate and nylon. Results and conclusions from the test program are presented.

Whitney, Thomas J. and Gregory J. Stenger, Erosion Evaluation of Transparency Protective Surface Treatments, UDR-TR-92-80, July 1992.

ABSTRACT: Dust erosion of transparency systems has led to a need for improved abrasion resistance. The most recent approach has been to coat the surface of these systems with tough, durable polymers. However, many of these coatings are subject to delamination and pitting upon impact, especially after exposure to UV and moisture. The objective of this study was to evaluate commercially available coatings for improvement in erosion resistance to sand, salt, and water. Both artificially weathered and non-weathered (baseline) materials were tested. Tests were conducted at PDA Engineering's Dust Erosion facility, the USAF Whirling Arm rain erosion facility, and at the University of Dayton salt erosion facility. Haze and transmittance values and visual observations (including micrographs) were used to evaluate damage. Results showed wide variation in damage response among the materials tested. however, ranking of materials for erosion resistance was, with few exceptions, consistent among test methods.

Frank, G.J., and G.J. Stenger, Frameless Transparency System Material Property Evaluation, UDR-TR-92-51, July 1992.

ABSTRACT: Recent advances in manufacturing technologies permit the production of large plastic components by injection molding. The techniques required to manufacture aircraft transparencies by injection molding are currently being developed as part of the FTP. Tests were conducted to characterize the thermal expansion coefficients and room temperature mechanical properties of injection molded materials being considered for use in the FTP. Mechanical tests included tensile, shear, bulk modulus, and falling dart impact. Coupons used for measuring the properties were cut from injection molded panels made from several formulations of polycarbonate or nylon and from injection molded latch inserts, which are intended to attach the transparency to the aircraft, made from glass-filled polycarbonate and glass-filled polyetherimide. Results and conclusions from the test program are presented.

Bowman, Daniel R., Gregory J. Stenger, and Blaine S. West, Definition and Reduction of the F-15 Windshield Birdstrike Hazard, UDR-TR-92-28, August 1992.

ABSTRACT: An analysis was conducted of the F-15 transparency system existing birdstrike resistance capability. Alternate systems which would increase birdstrike resistance capability were defined. A birdstrike risk assessment was conducted for the existing system and for alternate systems with improved birdstrike protection.

Bouchard, M. P., T. W. Held, and W. R. Braisted, Development of an Advanced F-16 A/C Forward Canopy, UDR-TR-92-88, in progress.

ABSTRACT: The development of an F-16 A/C forward canopy which meets USAF 1995-2000 mission requirements is described. USAF future mission requirements specify protection against impact by a 4-pound bird up to 540 knots, "444" performance and supportability (maintain mission performance requirements for a minimum of 4 years, after which the transparency can be changed out in 4 hour by 4 technicians), optical compatibility with emerging HUD (Heads-Up Display) and night vision goggle technology, conformance with all other current requirements, and competitive procurability. The program initiated with a review of available birdstrike test data. This review demonstrated that the birdstrike requirement can be met with current technology and resulted in design guidelines for improved bird impact resistance while meeting the additional future requirements. Subscale coupons were then fabricated and tested to screen potential laminates for impact resistance and to obtain mechanical properties for use in finite element analysis (FEA). The mechanical properties of transparency polymeric materials are sensitive to strain rates, so that it was important to quantify these effects for accurate results in subsequent FEA. Nonlinear dynamic FEA for final analytic bird impact evaluation was then performed. This task used the recently-developed X3D explicit FEA code developed by University of Dayton Research Institute which provides strain rate-dependent material properties, direct modelling of the bird, element and ply failure criteria, and rapid turnaround on workstation and mainframe computers. Final designs were then selected in view of their ability to meet all design requirements. The report documents the methods and results of each step of the canopy development and summarizes the final design recommendations.

Bouchard, M.P, Mechanical Properties of Aircraft Transparency Materials at Various Strain Rates, UDR-TR-92-89, in progress.

ABSTRACT: When subject to dynamic loading, the response of the polymeric materials typically used to fabricate aircraft transparencies can be highly strain rate dependent. Accurate FEA prediction of transparency response to bird impact requires accurate strain rate-dependent material properties as input data (along with appropriate viscoelastic material models in the FEA code to properly account for the rate dependencies). Little rate-dependent testing of the materials of interest has been performed and very little data is available in the open literature. Such testing is not straightforward because of wave propagation phenomena and high elongations of some of the materials. High rate material characterization of the individual transparency ply materials for advanced F-16 prototype canopies are described. Test specimens and methods, and resulting mechanical properties of polycarbonate, cast acrylic, and urethane are given for tension, shear, and bulk loading modes at nominal strain rates ranging from quasi-static up to 100 in/in/sec at room temperature.

Stenger, G. J., A-7 Improved Windshield Program, UDR-TR-90-35, in progress.

ABSTRACT: The A-7 transparency system was designed to withstand normal flight loads, not the forces associated with high speed bird impact. The National Guard Bureau (NGB/XOO) stated that the A-7 flies low level missions operating routinely at 480 knots with dashes in excess of 500 knots. From April 1976 to December 1984 there were nine penetrating birdstrikes on the A-7 windshield and one on the canopy, even though (according to the NGB/XOO) some A-7 units have prohibited all tactical low level navigation attack tactics training for 4.5 to 5 months of the year. A three-phase program approach was used to develop an improved transparency system for the A-7D/K aircraft. The objectives of Phase I, System Assessment Studies, was to define the current system capability, generate and evaluate alternate transparency system designs, and select a system for development. In Phase II, Improved System development, the selected system was developed and demonstrated. Phase III supported the fleet implementation. This report summarizes the first two phases of this program which resulted in the installation of a single piece windshield, having 4-pound 480-knot birdstrike capability, for flight evaluation.

2.2 PRESENTATIONS

Simmons, R. and Greg Stenger, "Bird Impact Evaluation of the F/RF-4 Transparency System," presented at the Wildlife Hazards to Aircraft Conference and Training Workshop, Charleston SC, May 22-25, 1984.

West, Blaine S., "Development of Bird Impact Resistant Crew Enclosures for Aircraft," paper presented at the Structural Impact and Crashworthiness Conference, London, England, July 16-20, 1984.

Stenger, G. J., Briefing to NAVAIR, Washington, D. C., on "Findings and Recommendations of the F-18 Alternate Transparency Development Program," 1 August 1985.

West, B. S., "Impact Testing with Artificial Birds," paper presented at the ASTM F7.08 Seminar, Washington, 17 October 1985.

Bowman, Daniel R., "The Effect of Combined Stress and Simulated Weathering on the Durability of Aircraft Transparencies," presented at the 12th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 26, 1986.

Clayton, K. I., "Classified Briefing on MITS for Government Review and Concurrence," Wright-Patterson AFB OH, April 22, 1986.

Clayton, K. I., "Formal Classified Briefing on MITS to Government and Industry," Wright-Patterson AFB OH, April 30, 1986.

Stenger, G. F., "Briefing to LTV Aerospace & Defense Co. and Participating Transparency Vendors on the Recommended A-7 Single Piece Windshield Design," 14 August 1986.

West, B. S., G. J. Stenger, M. P. Bouchard, D. R. Bowman, B. B. raju, and K. I. Clayton, "Bird Resistant Crew Enclosure Program, Oral Review," presented to AFWAL/FI at Wright-Patterson AFB OH, 9 September 1986.

Stenger, G. J. and D. R. Bowman, "Development of a Design Recommendation for a 500 knot Birdstrike Aft Arch for the Single Piece F-4 Windshield," presented at the 13th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 24, 1987.

Stenger, G. J., D. R. Bowman, and B. S. West, "The Effect of In-Service Aging on Bird Impact Resistance of F-111 ADBIRT Windshield Transparencies," presented at the ASTM F7.08 Meeting, Arlington TX, October 14-15, 1987.

Bowman, D. R., G. J. Stenger, and B. S. West, "The Effect of In-Service Aging on Bird Impact Resistance of F-111 ADBIRT Windshield Transparencies," presented at the 14th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1988.

Stenger, G. J., D. R. Bowman, and B. S. West, "Development of Simulated Flight Structure for Birdstrike Testing," presented at the 14th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1988.

Poormon, Kevin L. and Gregory J. Stenger, "Correlation of F-18 Windshield Birdstrike Test Results with a Structural Analysis," presented at the 14th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1988.

Bowman, Daniel R., "The Cause and Effect of Structural Degradation of In-Service Aged F-111 ADBIRT Windshield Transparencies," presented at the 15th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1989.

Scherzinger, William M. and Daniel Bowman, "A Finite Element Model of the F-111 ADBIRT Windshield Edge Attachment," presented at the 15th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1989.

West, Blaine S. and Kevin L. Poormon, "Crazing of Acrylics as a Function of Surface Smoothness," presented at the 15th Annual AIAA Mini-Symposium on Aerospace Science and Technology, March 31, 1989.

Bowman, D. R. and B. S. West, "The Cause and Effect of Structural Degradation of In-Service Aged F-111 ADBIRT Windshield Transparencies," presented at the 15th Conference on Aerospace Transparent Materials and Enclosures, Monterey CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Stenger, G. J. and W. R. Pinnell, "Evaluation of Composite Materials for Bird Impact Resistant Transparency Systems," presented at the Conference on Aerospace Transparencies and Enclosures, Monterey CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Dversdall, Lt. D., Capt. S. J. Hargis, and G. J. Stenger, "A-7 Improved Transparency Development Program," presented at the Conference on Aerospace Transparencies and Enclosures, Monterey CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Stenger, G. J. and J. L. Terry, "Definition and Reduction of the F-18 Windshield Birdstrike Hazard," presented at the Conference on Aerospace Transparencies and Enclosures, Monterey CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Stenger, G. J., M. P. Bouchard, and D. R. Bowman, "Bird Impact Resistant Windshield Aft Arch Design Methodology," presented at the 15th Conference on Aerospace Transparent Materials and Enclosures, Monterey, CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Clayton, K. I., "Screening Tests for Hardened Transparency Materials," presented at the 15th Conference on Aerospace Transparent Materials and Enclosures, Monterey CA, January 16-20, 1989 and published in WRDC-TR-89-4044, April 1989.

Bowman, Daniel R., "F-111 ADBIRT Windshield Degradation Study Results Update," presented at the Fall ASTM F7.08 Meeting, Indian Wells CA, September 12-17, 1989.

Scherzinger, William M. and Daniel R. Bowman, "Analysis of the Flatwise Tension Test for Laminated Aircraft Transparencies," presented at the 16th Annual AIAA Mini-Symposium on Aerospace Science and Technology, Dayton, Ohio, March 1990.

Kolodziejski, Lt. Paul and Daniel R. Bowman, "Development of a Correlation Between Uniaxial and Biaxial Crazing of Acrylic," presented at the 16th Annual AIAA Mini-Symposium on Aerospace Science and Technology, Dayton, Ohio, March 1990.

Stenger, Gregory J. and William R. Pinnell, "Evaluation of Composite Materials for Bird Impact Resistant Transparency Systems," presented at the 1990 Spring Conference on Experimental Mechanics, Albuquerque NM, June 4-6, 1990.

Kolodziejski, P. J. and Daniel R. Bowman, "Development of a Correlation Between Uniaxial and Biaxial Crazing of Acrylic," presented at the ASTM Sub-Committee F7.08 Meeting, Grenelefe FL, October 1990.

Bowman, D. R. and G. J. Stenger, "Evaluation of the Thick Hybrid Composite Beams for Bird Impact Resistant Aircraft Transparency Support Structure," presented at the 17th Annual AIAA Mini-Symposium on Aerospace Science and Technology, Dayton, Ohio, March 1991.

2.3 ASTM STANDARDS

F 1164, "Test Method for Evaluation of Transparent Plastics Exposed to Accelerated Weathering Combined with Biaxial Stress."

F 1293, "Standard Test Method for Evaluation of Coated Transparent Plastics Subjected to Cyclic Flexural/Thermal Fatigue."

F 1362, "Standard Test Method for Shear Strength and Shear Modulus of Aerospace Glazing Interlayer Materials."

In progress, "Proposed Standard Practice for Impact Resistance of Monolithic Polycarbonate Sheet by Means of a Gun-Propelled Projectile."

SECTION 3
PROGRAM ACCOMPLISHMENTS

Contributions to the technical knowledge associated with the design of birdstrike crew enclosures fall into two categories: general and specific. Some of the generic contributions resulting from this contractual effort are:

- Identification of technology deficiencies.
- Transfer of new technology to industry.
- Technology demonstration through application.
- Standardization and development of test methods through participation in ASTM F7.08.

Itemized below are some specific accomplishments resulting from the program effort which was conducted under Contract No. F33615-84-C-3404 during the period 16 July 1984 to 2 March 1992. Details of these accomplishments are documented in the WL reports referred to in Section 2.

- Evaluated impact resistance of F-111 windshield transparencies removed from service using 22 full scale birdstrike tests, as well as numerous laboratory coupon tests. In addition, evaluated windshields which were subjected to pressure thermal-simulated service life in the WPAFB Building 68 Transparency Durability Facility.
- Determined cause of in-service degradation of bird impact resistance of laminated F-111 windshields.
- Identified next generation mission-oriented requirements and technology deficiencies as part of the MITS Baseline Study.
- Incorporated raptors and breeding ducks into the Bird Avoidance Model.
- Evaluated nondestructive methods of evaluating residual methods of measuring residual stress.
- Conducted failure analysis of birdstrike tested recoated monolithic F-16A forward canopies which determined failure initiation at the point where the HUD contacts the windshield, and that there was no discernable chemical degradation of the bulk polycarbonate.
- Evaluated the bird impact resistance of the F-18 windshield, and made a

recommendation for increasing its bird impact capability.

- Evaluated alternate F-16 canopy designs which would meet the 500 knot birdstrike capability requirement and made design recommendations.
- Wrote a user's guide for the probabilistic model for evaluating the birdstrike threat to aircraft crew enclosures.
- Evaluated the B-1B windshield delamination problem using the MAGNA finite element program.
- Evaluated the F-15 transparency edge cracking problem and confirm it to be related to the difference in the coefficient of expansion between the stretched acrylic and the edge attachment.
- Evaluated alternate windshield configurations for the B-1B which would eliminate current operational problems and address the 1995 mission requirements.
- Reviewed and recommended available dry sealant materials which would be compatible with current aircraft transparency material.
- Conducted tests to evaluate the material properties, including impact resistance, of candidate injection molded material in support of the Frameless Transparency Program.
- Validated the strain gage-hole drilling method for measuring residual stresses in a surface acrylic ply of a laminated transparency.
- Evaluated alternatives for increasing the rearward visibility of the A-7D aircraft.
- Evaluated candidate alternate latch insert designs in support of the Frameless Transparency Program.
- Standardized three ASTM test methods.
- Evaluated the effect of surface finish on the craze resistance of stretched acrylic.

SECTION 4

RECOMMENDATIONS

Recommendations for addressing existing transparency system technology deficiencies and future aircraft requirements are enumerated below.

- Develop fast changeout transparency concepts (meets part of 444 goal).
- Develop criteria in support of removal for cause.
- Develop a method for acquisition and analysis of field removal data.
- Continue to validate/demonstrate new technology through application to existing and new aircraft systems.
- Continue to expand the existing data base and establish a more detailed data base on in-service problems, failure modes, and cause for removal.
- Continue transparency test criteria development/verification.
- Improve mechanical property characterization of transparency materials at both high- and low-strain rates.
- Develop high temperature transparency materials for advanced tactical fighter systems.
- Investigate methods to evaluate rain erosion resistance of coated transparency materials with the goal of producing test standards suitable for ASTM submission.
- Transfer Design Guide to a computerized development tool or data base.
- Develop methods to improve frangibility of canopies in ejection-critical areas.
- Perform basic studies on the use of transparent fibers for canopy reinforcement and ductile fibers for support structure reinforement.
- Develop an Aircraft Transparency System Design Short Course.
- Evaluate the physical effects of combat hazard protection.
- Develop transparency criteria/methodology for defeating the hostile environment.
- Support development of an Analytical Design Package (ADP) which will integrate the software used in analysis of aircraft transparencies.
- Develop realistic and validated bird FEA model.
- Develop integrated bird impact resistant canopy/HUD system concepts.
- Develop test method for high speed rain erosion (+800 knots).

- Continue to validate/demonstrate new technology through application to existing and new aircraft systems.
- Update AFWAL-TR-80-3003, "Guidelines for the Design of Aircraft Windshield/Canopy Systems," as required.
- Further develop/demonstrate in-flight/flightline environmental simulator.
- Continue development/evaluation of new materials and material systems for transparency and support structure.
- Improve existing analytical models for polymeric materials to improve correlation to test results.
- Develop a method to evaluate the durability of photochromic material.
- Evaluate the effect of modifying mass, stiffness, and geometry properties of typical windshield systems on deflection under bird impact.
- Develop photoelastic methods for evaluating surface residual stresses in transparencies.
- Develop improved methods of triangulation data capture for bird impact testing (i.e., rid dropout, glare problems).