

UNCLASSIFIED

AD NUMBER

**ADB013203**

LIMITATION CHANGES

TO:

**Approved for public release; distribution is unlimited.**

FROM:

**Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; 01 SEP 1976. Other requests shall be referred to Air Force Flight Dynamic Laboratory, Wright-Patterson AFB, OH 45433.**

AUTHORITY

**AFFDL ltr, 17 Mar 1978**

THIS PAGE IS UNCLASSIFIED

THIS REPORT HAS BEEN DELIMITED  
AND CLEARED FOR PUBLIC RELEASE  
UNDER DOD DIRECTIVE 5200.20 AND  
NO RESTRICTIONS ARE IMPOSED UPON  
ITS USE AND DISCLOSURE.

**DISTRIBUTION STATEMENT A**

APPROVED FOR PUBLIC RELEASE;  
DISTRIBUTION UNLIMITED.



2

AD No. \_\_\_\_\_  
DDC FILE COPY  
ADB013203

IMPROVED WINDSHIELD AND CANOPY PROTECTION  
DEVELOPMENT PROGRAM

H. EDWARD LITTELL, JR.  
PPG INDUSTRIES, INC.  
PITTSBURGH, PA. 15238

TECHNICAL REPORT  
AFFDL-TR-74-75

DDC  
RECEIVED  
JUN 26 1976  
C

JUNE 1974

Distribution limited to U.S. Gov't. agencies only  
Test and Evaluation; 1 SEP 1976. Other requests  
for this document must be referred to

AIR FORCE FLIGHT DYNAMICS LABORATORY  
AIR FORCE SYSTEMS COMMAND  
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

Attch. FEW

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

*Donald C. Chapin*  
 Donald C. Chapin, Captain, USAF  
 Project Engineer

|                                |                                     |
|--------------------------------|-------------------------------------|
| White Section                  | <input type="checkbox"/>            |
| Gold Section                   | <input checked="" type="checkbox"/> |
| Blue Section                   | <input type="checkbox"/>            |
| <i>Letter on file</i>          |                                     |
| BY                             |                                     |
| DISTRIBUTION/AVAILABILITY CODE |                                     |
| Dist.                          | AVAIL. AND/OR SPECIAL               |
| <i>B</i>                       |                                     |

FOR THE COMMANDER

*Robert E. Wittman*  
 Robert E. Wittman  
 Program Manager, Improved Windshield ADPO  
 Vehicle Equipment Division

Copies of this report should not be returned unless return is required by security considerations, contractual obligations, or notice on a specific document.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE                                                                                                        |                       | READ INSTRUCTIONS<br>BEFORE COMPLETING FORM                                                          |  |
|----------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------------------------------------------------------------------------------------------|--|
| 1. REPORT NUMBER<br>(18) AFEDL TR-74-75                                                                                          | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER                                                                        |  |
| (6) Improved Windshield and Canopy Protection Development Program                                                                |                       | (9) 4. TYPE OF REPORT & PERIOD COVERED<br>Final Technical Report,<br>7 March 1973 through 1 May 1974 |  |
|                                                                                                                                  |                       | (14) 5. PERFORMING ORG. REPORT NUMBER<br>NP-1132                                                     |  |
| 7. AUTHOR(s)<br>(10) H. Edward Littell, Jr.                                                                                      |                       | (15) 6. CONTRACT OR GRANT NUMBER(s)<br>F33615-73-C-3099                                              |  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>PPG Industries, Inc.<br>Glass Research Center<br>Pittsburgh, Pa. 15238            |                       | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>Project No. 1926                      |  |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>Air Force Flight Dynamics Laboratory<br>Improved Windshield Protection Program Office |                       | (11) 12. REPORT DATE<br>June 1974                                                                    |  |
| 14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)<br>(16) AF-1926                                      |                       | (12) 244p.                                                                                           |  |
|                                                                                                                                  |                       | 15. SECURITY CLASS. (of this report)<br>Unclassified                                                 |  |
|                                                                                                                                  |                       | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE                                                           |  |
| 16. DISTRIBUTION STATEMENT (of this Report)                                                                                      |                       |                                                                                                      |  |

distribution limited to U.S. Gov't. agencies only  
 Post and Evaluation: 1 SEP 1976. Other requests  
 for this document must be referred to AFEDL/FEW

(ent from Report)

## 18. SUPPLEMENTARY NOTES

## 19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Windshields                      Mounting Frame  
 Edge Attachment                          and Reinforcement  
 Interlayer  
 Temperature/Pressure Testing

## 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report discusses a program to develop high performance aircraft windshields and canopies capable of sustaining impacts by 4 lb birds at speeds of 500 knots and above. The designs were to interface with existing aircraft and deviate as little as possible from the physical characteristics or reliability of production designs.

(Continued)

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

405120

y/p

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

→ A multi-task program evaluated not only bird impact resistance but structural and thermal qualities of materials and designs which influenced overall performance. In the first task, basic material and design properties were established and constructions proposed for full-scale thermal and bird impact testing. Thermal tests on complete windshields compared glass-plastic vs. all-plastic configurations, while bird impacts established the effect of impact location, panel design and support structure. Conclusions from the test portion were the basis of constructions selected for prototype production. Eighteen windshields and six canopies, including optical parbs, were produced and delivered for Air Force evaluation.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## FOREWORD

This Final Technical Report covers transparency development activity under Contract F33615-73-C-3099, "Improved Windshield Protection Development Program". The work was conducted by PPG INDUSTRIES, Inc., Glass Research Center, Pittsburgh, PA, and Works No. 23, Creighton, PA.

The research reported herein covered the period from March 1973 through April 1974. It was performed for the United States Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The Air Force Project Engineer was Captain Donald C. Chapin, USAF, AFFDL/FEW. PPG INDUSTRIES has assigned NP1132 as a secondary number to this report.

The draft of this report was submitted 21 May 1974.

Acknowledgment is given to Mr. Robert G. Spindler for compiling the section on Material Evaluation and to Mr. Leonard M. Cook for writing the sections on Thermal/Pressure Capability.

## TABLE OF CONTENTS

| SECTION                                            | PAGE |
|----------------------------------------------------|------|
| I. GENERAL INTRODUCTION .....                      | 1    |
| II. TASK I                                         |      |
| 1. Introduction .....                              | 2    |
| 2. Material Evaluation .....                       | 3    |
| 3. Edge Attachment .....                           | 25   |
| 4. Thermal/Pressure Capability .....               | 35   |
| 5. Impact Resistance .....                         | 52   |
| III. TASK II                                       |      |
| 1. Introduction .....                              | 79   |
| 2. Thermal/Pressure Capability .....               | 80   |
| 3. Task II Bird Impact Tests .....                 | 92   |
| 4. Recommended Windshield and Canopy Designs ..... | 117  |
| IV. TASK III                                       |      |
| 1. Introduction .....                              | 122  |
| 2. Prototype Fabrication and Delivery .....        | 123  |
| 3. Performance Summary .....                       | 132  |
| APPENDIX 1 .....                                   | 136  |
| APPENDIX 2 .....                                   | 193  |
| APPENDIX 3 .....                                   | 234  |



# LIST OF ILLUSTRATIONS

| FIGURE |                                                                                                | PAGE |
|--------|------------------------------------------------------------------------------------------------|------|
| 1      | Durometer (Shore D) Vs. Temperature of 3GH Vinyl, 112 and ETA                                  | 7    |
| 2      | Tensile Strength of Interlayer Materials                                                       | 9    |
| 3      | Elongation of Interlayer Materials                                                             | 10   |
| 4      | Tear Strength of Interlayer Materials                                                          | 11   |
| 5      | Stress-Strain Curves of 112 and 3GH Vinyl at Various Temperatures                              | 13   |
| 6      | Stress-Strain Curves of 112 Interlayer at Various Temperatures                                 | 14   |
| 7      | Compressive Shear Test Samples                                                                 | 15   |
| 8      | Compressive Shear Strength of 3GH Vinyl, ETA and 112 Interlayers to Chemically Tempered Glass  | 16   |
| 9      | Compressive Shear Strength of 112 and ETA to Polycarbonate                                     | 18   |
| 10     | Compressive Shear Strength of 3GH Vinyl, ETA and 112 Interlayers to As-Cast Acrylic            | 19   |
| 11     | Peel Adhesion of 112 and ETA to Polycarbonate                                                  | 20   |
| 12     | Peel Adhesion of 112 and ETA Interlayers to As-Cast Acrylic                                    | 21   |
| 13     | F-111 Edge Reinforcement Test Specimen No. 1                                                   | 26   |
| 14     | Edge Reinforcement Specimen and Test Set-Up                                                    | 27   |
| 15     | Tensile Shear Bond Specimen                                                                    | 31   |
| 16     | Maximum Burst Pressure/Temperature Test Profile                                                | 36   |
| 17     | Thermal/Pressure Test Fixture                                                                  | 37   |
| 18     | Design Configurations Tested in Thermal/Pressure Facility                                      | 39   |
| 19     | Temperature Gradient in Acrylic-Faced Design Specimen No. 1                                    | 41   |
| 20(a)  | Thermal Sample No. 5 - Before Test                                                             | 44   |
| 20(b)  | Thermal Sample No. 5 - After Test                                                              | 45   |
| 21     | Bubbles and Delamination in Glass-Faced Panel No. 9 After Completion of T/P Test (Through D-3) | 48   |
| 22     | Bubbles in Acrylic Polycarbonate-Faced Panel No. 11 After Completion of Test D-2               | 49   |
| 23     | Resistance to 150 gm Missile Penetration                                                       | 53   |
| 24     | Task I Bird Impact Sample and Mounting Frame                                                   | 55   |
| 25     | Preliminary Task I Flat Panel Bird Impact Target Area                                          | 56   |
| 26     | Task I Canopy Bird Impact Panel and Mounting                                                   | 57   |

# LIST OF ILLUSTRATIONS (Cont'd)

| FIGURE |                                                                                                        | PAGE    |
|--------|--------------------------------------------------------------------------------------------------------|---------|
| 27     | Summary of Task I Preliminary Bird Impacts (Group 2)                                                   | 60      |
| 28     | Summary of Task I Preliminary Bird Impacts (Group 3)                                                   | 61      |
| 29     | Summary of Task I Preliminary Bird Impacts (Group 4)                                                   | 62      |
| 30     | Task I Bird Impact Test Panels with Edge Attachments                                                   | 65 & 66 |
| 31     | Preliminary Task II Windshields - Primary Design                                                       | 72      |
| 32     | Preliminary Task II Windshields - Alternate Design                                                     | 73      |
| 33     | Final Canopy Flat Panels                                                                               | 75      |
| 34     | Recommended Preliminary Task II Canopies                                                               | 78      |
| 35     | Schematic of Thermal System Used in Full-Scale Thermal/Pressure Test                                   | 81      |
| 36     | Strain Gage and Thermocouple Locations on Windshield Nos. 28 and 29 Subjected to Thermal/Pressure Test | 84      |
| 37     | Full-Size Thermal/Pressure Test Set-Up                                                                 | 85      |
| 38(a)  | Bubbles and Delamination in Glass-Faced Windshield No. 29 Caused by Thermal/Pressure Test              | 89      |
| 38(b)  | Bubbles and Acrylic Damage in All-Plastic Windshield No. 28 Caused by Thermal/Pressure Test            | 90      |
| 39     | Task II Bird Impact Test Windshield in Rigid Frame                                                     | 93      |
| 40     | Windshield Bird Impacts in Frame                                                                       | 94      |
| 41     | PPG Test Frame Used During In-House Tests at NRC                                                       | 97      |
| 42     | F-111 Crew Module Used for Task II Bird Impacts                                                        | 98      |
| 43     | Modified Windshields for Module Testing                                                                | 101     |
| 44     | Aft Beam Windshield Sections; Nominal 500 KT Impacts in F-111 Module                                   | 104     |
| 45     | Windshield-Arch Combinations                                                                           | 106     |
| 46     | Two PC Ply Windshield                                                                                  | 107     |
| 47     | Final Task II Canopies                                                                                 | 113     |
| 48     | Task II Canopy Bird Impacts                                                                            | 116     |
| 49     | Recommended Windshield                                                                                 | 118     |
| 50     | Recommended Canopy Construction                                                                        | 120     |
| 51     | Task III L/H Windshield (401611 RF) Gridboard Photo                                                    | 127     |
| 52     | Task III R/H Windshield (401612 RF) Gridboard Photo                                                    | 128     |
| 53     | Impact Results for WT-45 and -46                                                                       | 235     |



# LIST OF TABLES

| TABLE |                                                                                                                                       | PAGE      |
|-------|---------------------------------------------------------------------------------------------------------------------------------------|-----------|
| I     | Preliminary Edge Attachment Tensile Tests                                                                                             | 28        |
| II    | Additional Preliminary Edge Attachment Tensile Tests                                                                                  | 30        |
| III   | Tensile Strength of Edge Reinforcements                                                                                               | 33        |
| IV    | Tensile Strength of Double PC Ply Edgemembers                                                                                         | 34        |
| V     | 15" Circular Sample Test Scheme                                                                                                       | 38        |
| VI    | Initial Temperature/Pressure Test Results on 15" Circular Panels                                                                      | 42        |
| VII   | Results of Final Temperature/Pressure Tests on 15" Circular Panels                                                                    | 47        |
| VIII  | Relative Temperature/Pressure Performance of Outboard Constructions Laminated to the Proposed Two Structural Ply Polycarbonate Design | 51        |
| IX    | Interlayer Embrittlement Range                                                                                                        | 54        |
| X     | Constructions for Task I Preliminary Bird Impact Tests                                                                                | 59        |
| XI    | LCOS Restraint Panel Constructions                                                                                                    | 64        |
| XII   | Constructions for Task I Preliminary Canopy Bird Impacts                                                                              | 74        |
| XIII  | Test Plan                                                                                                                             | 82        |
| XIV   | Results of Thermal/Pressure Tests                                                                                                     | 86        |
| XV    | Summary of Initial Corner Impacts in Module                                                                                           | 103       |
| XVI   | Final Windshield Tests - Task II                                                                                                      | 108       |
| XVII  | Aft-Beam Corner Bird Impact Tests on F-111 Windshields                                                                                | 110 & 111 |
| XVIII | Ultimate Tensile Loading of Task III Edge Designs                                                                                     | 123       |
| XIX   | Task III Structural Windshields                                                                                                       | 125       |
| XX    | Task III Optical Windshields                                                                                                          | 126       |
| XXI   | Task III Optical and Structural Canopies                                                                                              | 130       |
| XXII  | Performance Summary - Windshield                                                                                                      | 134       |
| XXIII | Performance Summary - Canopy                                                                                                          | 135       |

## SECTION I

### GENERAL INTRODUCTION

This program is one phase of a multi-faceted project oriented toward developing the technology for improving the bird impact resistance of aircraft transparencies. The objective of this particular effort was to demonstrate the technology in the form of F-111 windshields and canopies capable of resisting, without penetration or catastrophic failure, the impact of a 4 lb bird up to a speed of Mach 1.2 but not less than 500 knots indicated aircraft speed. In addition to the impact resistance, these designs were to interface with the existing aircraft and deviate as little as possible from the weight, structural reliability or optical characteristics of current production designs.

The specific windshield and canopy designs to meet the contract requirements evolved in a sequential four-task effort.

#### 1. TASK I

This basic material and design evaluation included a data search, laboratory materials capability study, preliminary design testing and edgemember design development.

#### 2. TASK II

In Task II, full-size windshields and canopies were fabricated and tested in order to establish specific designs to meet the contract requirements.

#### 3. TASK III

Eighteen prototype windshields and six prototype canopies of approved construction were produced and delivered for Air Force evaluation.

#### 4. TASK IV

The final activity has included preparation and submission of this report plus drawings and a fabrication specification required to document the final configuration.

Because each of the tasks was a discrete portion of the contract, this report will be divided into three primary sections presenting the information relative to each task. Since Task IV items will be submitted as separate documents, Task IV will not be included in this Final Technical Report.

## SECTION II

### TASK I

#### 1. INTRODUCTION

The purpose of Task I was to obtain sufficient supporting data for use in recommending specific full-size test panel configurations. This was achieved primarily by testing in the areas critical to performance of the transparencies; namely, material properties, impact resistance, edge attachment design and thermal/pressure effects.

A portion of the materials capability study was carried out as part of PPG's in-house programs prior to award of this contract. Where applicable for drawing conclusions, this data has been included with new information generated under Task I.

Each of the four areas of study will be discussed as a separate section. The general conclusions and recommendations which were made for Task II have been included in the section on Impact Resistance.

## 2. MATERIAL EVALUATION

To fulfill the stringent performance requirements of this contract, an interlayer material was required having good elevated temperature stability, low temperature ductility, and adequate physical properties through the temperature range of -65°F to 300°F.

Interlayers evaluated under this contract were chosen for their commercial availability and compatibility in composites containing glass, acrylics, and polycarbonates.

The interlayers tested under this contract were as follows:

1. 3GH Aircraft Vinyl - Polyvinyl butyral interlayer plasticized with 21 parts of triethylene glycol di-2-ethyl butyrate.
2. Monsanto Ethylene Terpolymer - Classified as a thermoplastic adhesive for bonding glass to polycarbonate, and for this report is classified as Ethylene Terpolymer or ETA. Material Used was adhesive 138200, Batch Number 148567.
3. PPG 112 Interlayer - This interlayer was developed by PPG INDUSTRIES, Inc., and is a thermoplastic urethane sheet material developed for use in glass, acrylic and polycarbonate laminates.

The plasticizers in 3GH Aircraft Vinyl attack polycarbonate, and therefore, this interlayer cannot be used directly against polycarbonate. Although methods are available to provide a barrier against plasticizer attack, such techniques were not evaluated for this contract due to the poor elevated temperature and low temperature ductility characteristics of this interlayer. However, because 3GH Aircraft Vinyl has considerable flight history, it was used as a "yardstick" during comparative physical evaluations of the 112 and Ethylene Terpolymer interlayers.

An experimental interlayer which was also evaluated was TCP Vinyl. This was a polyvinyl butyral interlayer plasticized with tricresyl phosphate which does not attack PC.

Interlayer material properties obtained under this contract include the following:

1. Light Transmittance and Haze of 112, Ethylene Terpolymer and 3GH Vinyl.
2. Thermal Conductivity of 112.
3. Thermal Expansion of 112.

4. Specific Heat of 112.
5. Compressive Shear Strength of 112, Monsanto Ethylene Terpolymer, and 3GH Aircraft Vinyl.

In an effort to fully evaluate and draw specific conclusions on inter-layer performance, additional material properties not obtained under this contract are included in this report.

These properties were obtained under a separate PPG-financed Research Program and are listed below:

1. Hardness
2. Thermal Stability
3. Tensile Strength
4. Elongation
5. Tear Strength
6. Stress-Strain Data
7. Peel Adhesion Data

a. Properties

(1) Transmittance and Haze

Transmittance and haze data obtained on the above three inter-layers are summarized as follows:

| <u>Material</u>        | <u>% Transmittance<br/>Loss per .100"<br/>Interlayer Thickness<br/>(Illuminant "C")</u> | <u>% Haze<br/>Gain per .100"<br/>Interlayer Thickness</u> |
|------------------------|-----------------------------------------------------------------------------------------|-----------------------------------------------------------|
| 3GH Aircraft Vinyl     | 1.5                                                                                     | 0.5                                                       |
| Ethylene Terpolymer    | 6.0 - 6.5                                                                               | 6.0 - 7.0                                                 |
| 112 (Task II Samples)  | 3.28                                                                                    | 0.58                                                      |
| 112 (Task III Samples) | 2.1 - 2.4                                                                               | 0.7 - 0.8                                                 |

This data was obtained by fabricating glass-interlayer-glass laminates, varying the thickness of the interlayer between .030" and .250", keeping the glass thickness at .110". The data depicts the superior transmittance and haze properties of Vinyl compared with 112 and Ethylene Terpolymer. The Ethylene Terpolymer had a very high transmittance loss and haze gain compared with 3GH Vinyl and 112; and this would restrict this interlayer's use to minimal thicknesses in composite designs.

(2) Density

Density Data on these interlayers are as follows:

| <u>Material</u>                  | <u>Density (lbs/ft<sup>3</sup>)</u> |
|----------------------------------|-------------------------------------|
| 3GH Vinyl <sup>1</sup>           | 68.1                                |
| Ethylene Terpolymer <sup>2</sup> | 62.3                                |
| 112                              | 72.2                                |

(3) Thermal Conductivity

Thermal conductivity tests were conducted on 112 interlayer at 75°F via a Dynatech Model TCHM-F4 Thermal Conductivity Instrument. The results of these tests indicate an average conductivity of 2.00 BTU - in/ft<sup>2</sup>/hr/°F. As a comparison, Mil Handbook-17 indicates that 3GH Vinyl has a conductivity of 1.48 BTU - in/ft<sup>2</sup>/hr/°F at 75°F.

(4) Thermal Expansion

Thermal expansion tests were conducted on 112 interlayer at test temperatures ranging from -65°C to 110°C. The tests were conducted on a DuPont 900 Thermal Analyzer with the following results:

| <u>Test Temperature<br/>(°C)</u> | <u>Thermal Expansion<br/>(in/in/°C)</u> |
|----------------------------------|-----------------------------------------|
| -65                              | 9.8 x 10 <sup>-5</sup>                  |
| 0                                | 2.0 x 10 <sup>-4</sup>                  |
| +85                              | 3.9 x 10 <sup>-4</sup>                  |
| +110                             | 4.2 x 10 <sup>-4</sup>                  |

Similar Data on 3GH Vinyl and Ethylene Terpolymer were not available.

(5) Specific Heat

The specific heat of 112 interlayer was determined at test temperatures ranging from -45°C to 117°C and is indicated as follows:

<sup>1</sup>Richard S. Hassard, Plastics for Aerospace Vehicles, Part II, Transparent Glazing Materials, p. 5-1, Mil Handbook-17A, Part II (Proposed Revision), Jan. 1973.

<sup>2</sup>Data obtained from Monsanto Research Corporation.

| Test Temperature<br>(°C) | Specific Heat<br>(Cal/gm - °C) |
|--------------------------|--------------------------------|
| -54                      | .244                           |
| -32                      | .323                           |
| 0                        | .364                           |
| +30                      | .344                           |
| +80                      | .342                           |
| +117                     | .443                           |

(6) Index of Refraction

The index of refraction of these interlayers is as follows:

| Material                         | Index of Refraction |
|----------------------------------|---------------------|
| 3GH Vinyl <sup>3</sup>           | 1.483               |
| Ethylene Terpolymer <sup>4</sup> | 1.480               |
| 112                              | 1.497               |

(7) Hardness

Durometer measurements were taken on 112, 3GH Vinyl and Ethylene Terpolymer from 0°F to 140°F. As shown in Figure 1, the hardness (Durometer Shore D) of 112 is less than 3GH Vinyl and greater than Ethylene Terpolymer at all temperatures. It is important to note that above room temperature, the hardness of Ethylene Terpolymer was very poor and at 140°F, its hardness is almost zero.

This data indicates that the current Ethylene Terpolymer formulation was very soft at temperatures of 140°F and above and would not be a good interlayer in composites requiring high interlayer temperatures.

(8) Thermal Stability

Thermal stability tests were conducted on 112 laminates at temperatures of 250°F and 300°F. These 12" x 12" laminates consisted of .125" thermally tempered glass - .090" 112 - .125" thermally tempered glass. Three samples of each composite were continuously exposed to the above temperatures until the first indication of bubbles was seen. At 250°F, no bubbles were apparent after 100 hours exposure. At 300°F, bubbles were initiated between 48 and 52 hours exposure. As a comparison, Mil-Handbook-17 indicates that 3GH Vinyl will

<sup>3</sup>Richard S. Hassard, Plastics for Aerospace Vehicles, Part II, Transparent Glazing Materials, p. 5-1, Mil-Handbook-17A, Part II (Proposed Revision), Jan. 1973.

<sup>4</sup>Data obtained from Monsanto Research Corporation.



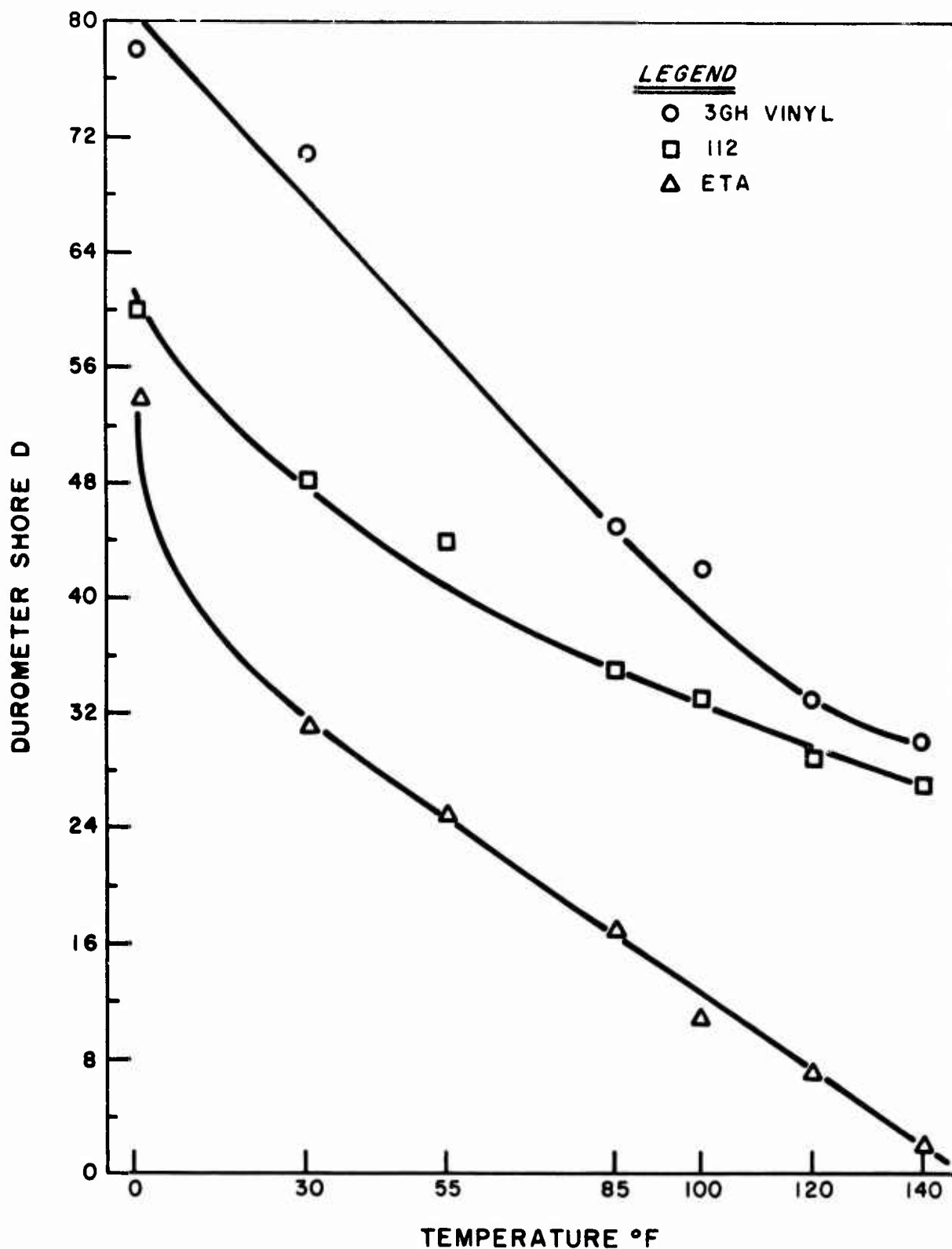


FIGURE I. DUROMETER (SHORE D) VERSUS TEMPERATURE OF 3GH VINYL, I12 & ETA.

produce bubbles between 3 and 4 hours exposure at 250°F. This data establishes the better elevated temperature stability of 112 over 3GH Vinyl.

(9) Tensile Strength

A comparison of tensile strengths of 112, Ethylene Terpolymer and 3GH Vinyl is shown in Figure 2 and depicts the better tensile strength of 112 over the temperature range of -65°F to 200°F. The tensile strength of 3GH Vinyl and Ethylene Terpolymer drops off considerably at temperatures above 120°F, while the 112 interlayer has a tensile strength above 500 psi at 200°F. This excellent strength characteristic at elevated temperatures is beneficial for structural integrity when a composite utilizing this interlayer is exposed to high temperature regimes.

(10) Elongation

The maximum elongation at failure of interlayer materials is an indication of its ability to deform without producing failure. As shown in Figure 3, the 112 has greater elongation at failure when compared to 3GH Vinyl and Ethylene Terpolymer at test temperatures from -65°F to 200°F. Failures of the 112 interlayer could not be attained at temperatures above 120°F because the maximum elongation of the testing apparatus is limited to 550% with an environmental chamber. This data indicates that better impact performance at low temperatures (via interlayer deformation) can be attained with 112 than with the Ethylene Terpolymer or 3GH Vinyl.

(11) Tear Strength

As shown in Figure 4, tear strength tests on 112, 3GH Vinyl and Ethylene Terpolymer show the better performance of 112 interlayer over Ethylene Terpolymer from -65°F to 180°F. At temperatures below 40°F, the tear strength of 3GH Vinyl is greater than 112; however, above 40°F, the tear strength of 112 is considerably better than 3GH Vinyl. Tear strength depicts the ability of an interlayer to resist cohesive failure and as shown by the data, the 3GH Vinyl and Ethylene Terpolymer have very poor tear strength above 40°F, while 112 interlayer has good tear strength up to 180°F.

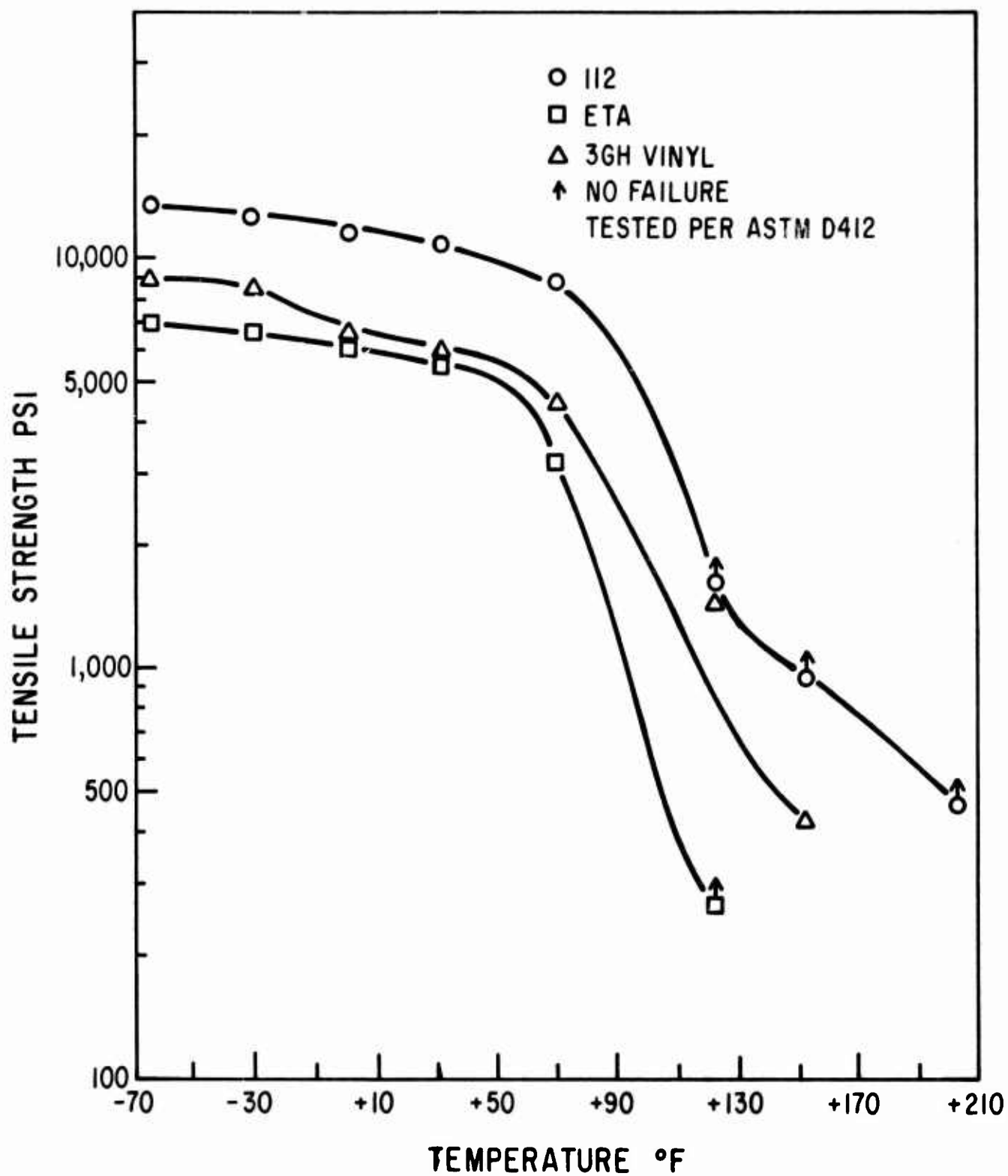


FIGURE 2. TENSILE STRENGTH OF INTERLAYER MATERIAL

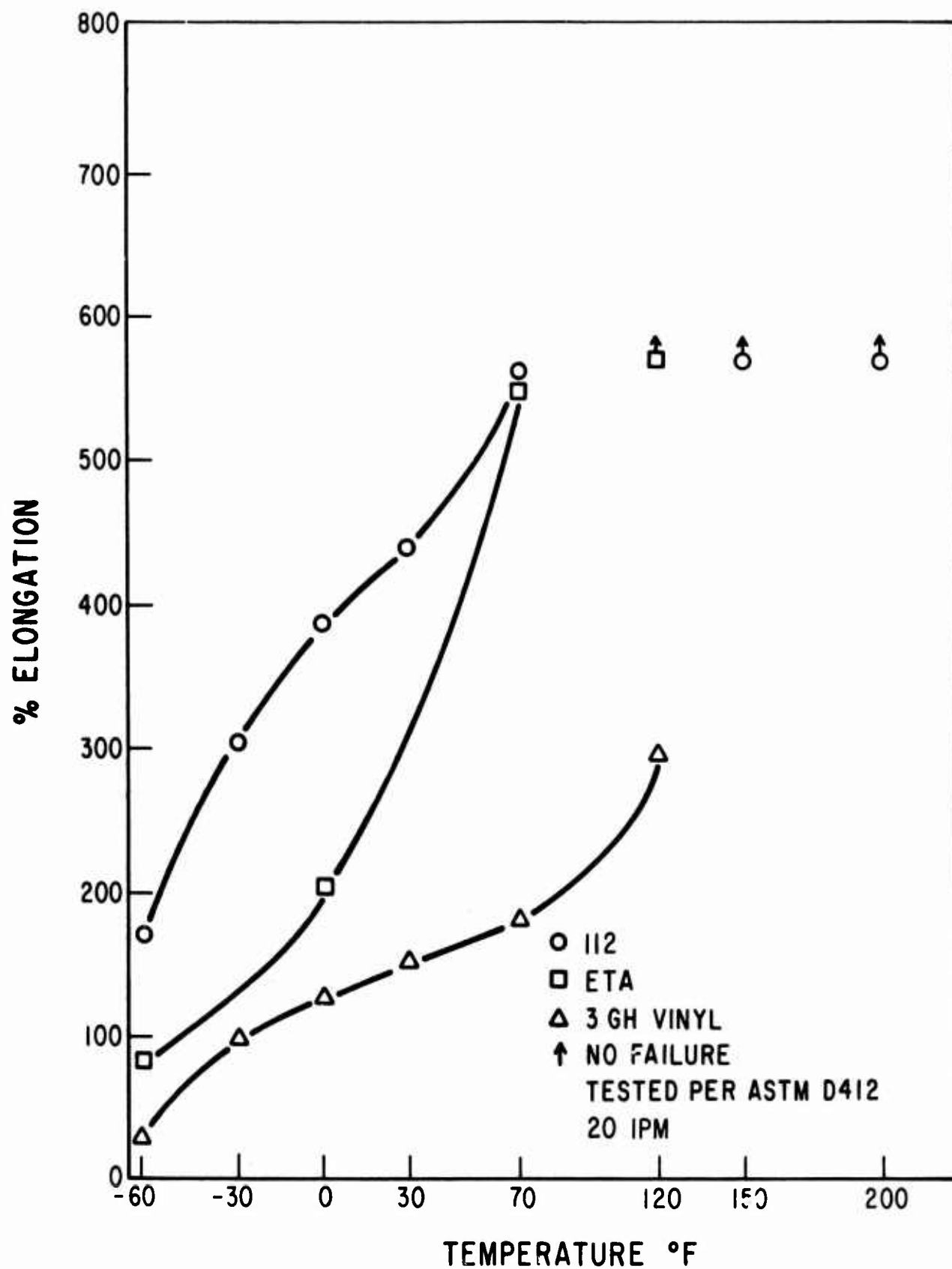


FIGURE 3. ELONGATION OF INTERLAYER MATERIALS

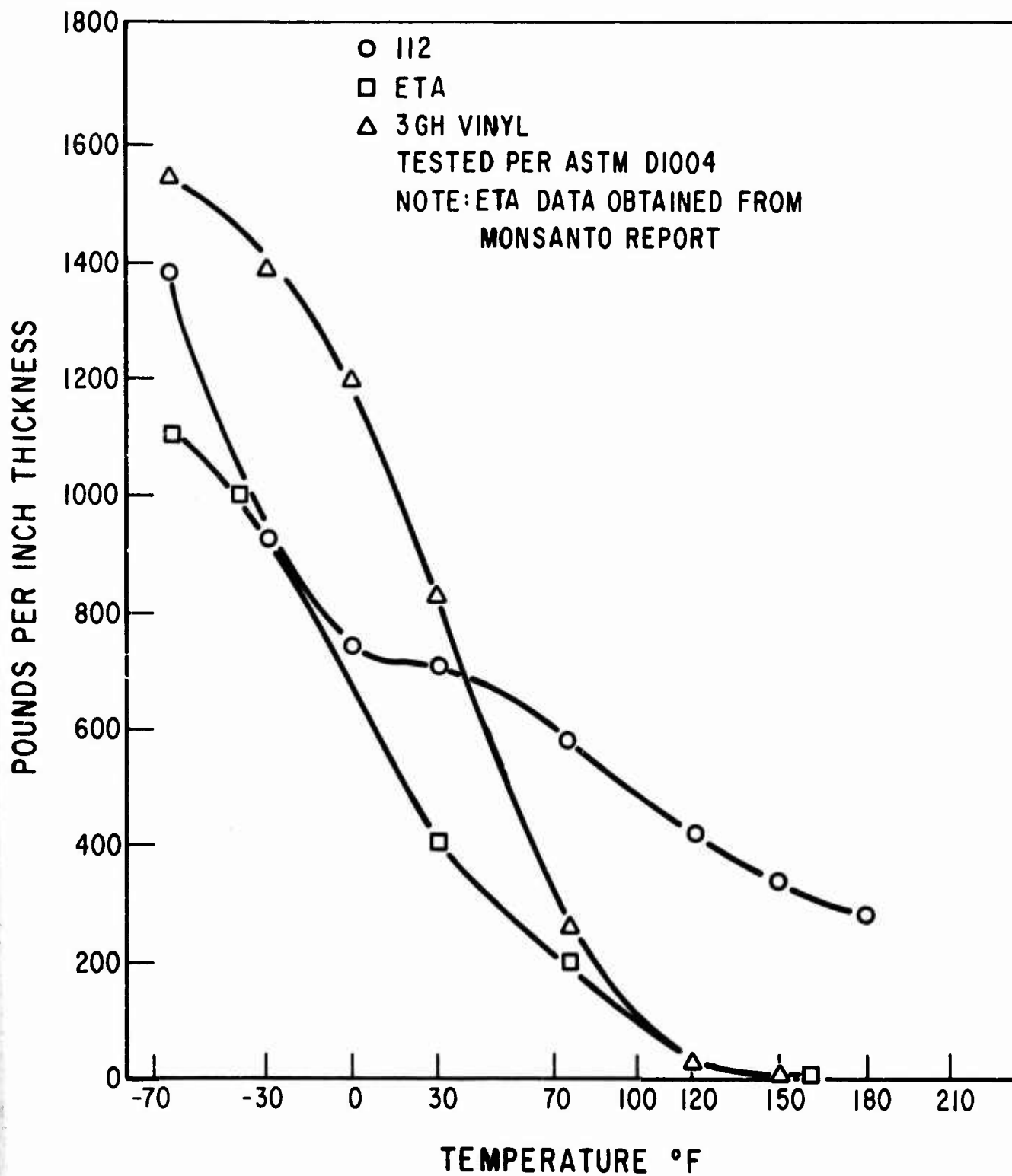


FIGURE 4. TEAR STRENGTH OF INTERLAYER MATERIALS

#### (12) Stress-Strain Data

A comparison of the stress-strain curves of 112 and 3GH Vinyl interlayers at temperatures from -30°F to 70°F is shown in Figure 5. These tests were conducted with a 1200% elongation tape extensometer and depict the better ductility of 112 over 3GH Vinyl. Stress-strain data on Ethylene Terpolymer could not be made due to an insufficient supply of this material.

Individual stress-strain curves of 112 at temperatures varying from -30°F to 150°F are shown in Figure 6.

#### (13) Compressive Shear Tests

The compressive shear properties of Monsanto Ethylene Terpolymer (ETA) and 112 were determined when laminated to polycarbonate, as-cast acrylic, and chemically tempered glass. In addition, the compressive shear strength of 3GH Vinyl was determined when laminated to as-cast acrylic and chemically tempered glass. Because the plasticizers in 3GH Vinyl attack polycarbonate, the shear strength of Vinyl to polycarbonate was not measured.

The tests were conducted in the temperature range of -65°F to 250°F, and as shown in Figure 7, the test samples had a .50" offset with a 1 square inch shear area. The thickness of the interlayer and adhesive used in these tests was .090" with the acrylic and polycarbonate thickness being .250" and the glass thickness being .110". The samples were soaked 20 minutes at each temperature prior to testing and were loaded at a cross-head speed of .20"/minute. The test data obtained represents an average of five tests per substrate per each temperature tested.

The shear properties of Ethylene Terpolymer, 112 and 3GH Vinyl to chemically tempered glass are shown in Figure 8. Exact shear strength was difficult to attain at all test temperatures due to glass breakage caused by poor edges. However, the data does depict the excellent shear properties of PPG 112 at temperatures from 75°F to 250°F, while the shear properties of Ethylene Terpolymer and 3GH Vinyl are below 175 psi at a test temperature of 150°F. The failure mode is important in these tests in that a cohesive failure indicates that the bond to the substrate is greater than the shear strength of the interlayer or adhesive. Conversely, an adhesive failure indicates that the bond to the substrate is weaker than the shear strength of the interlayer or adhesive. It is interesting to note that the failure mode of the Ethylene Terpolymer was mostly cohesive and that of 3GH Vinyl mostly adhesive at all test temperatures.

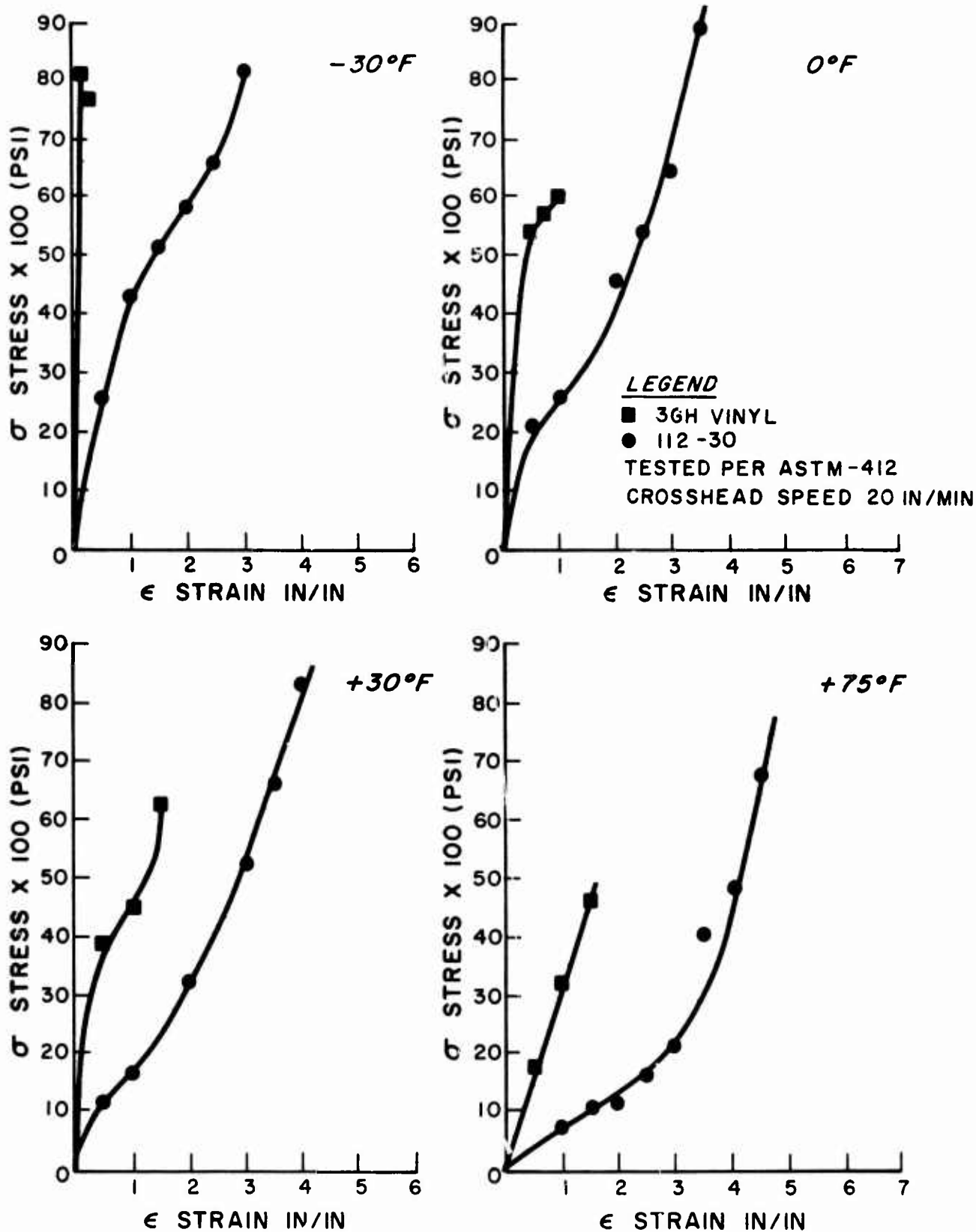


FIGURE 5. STRESS-STRAIN CURVES OF 112 AND 3GH VINYL AT VARIOUS TEMPERATURES



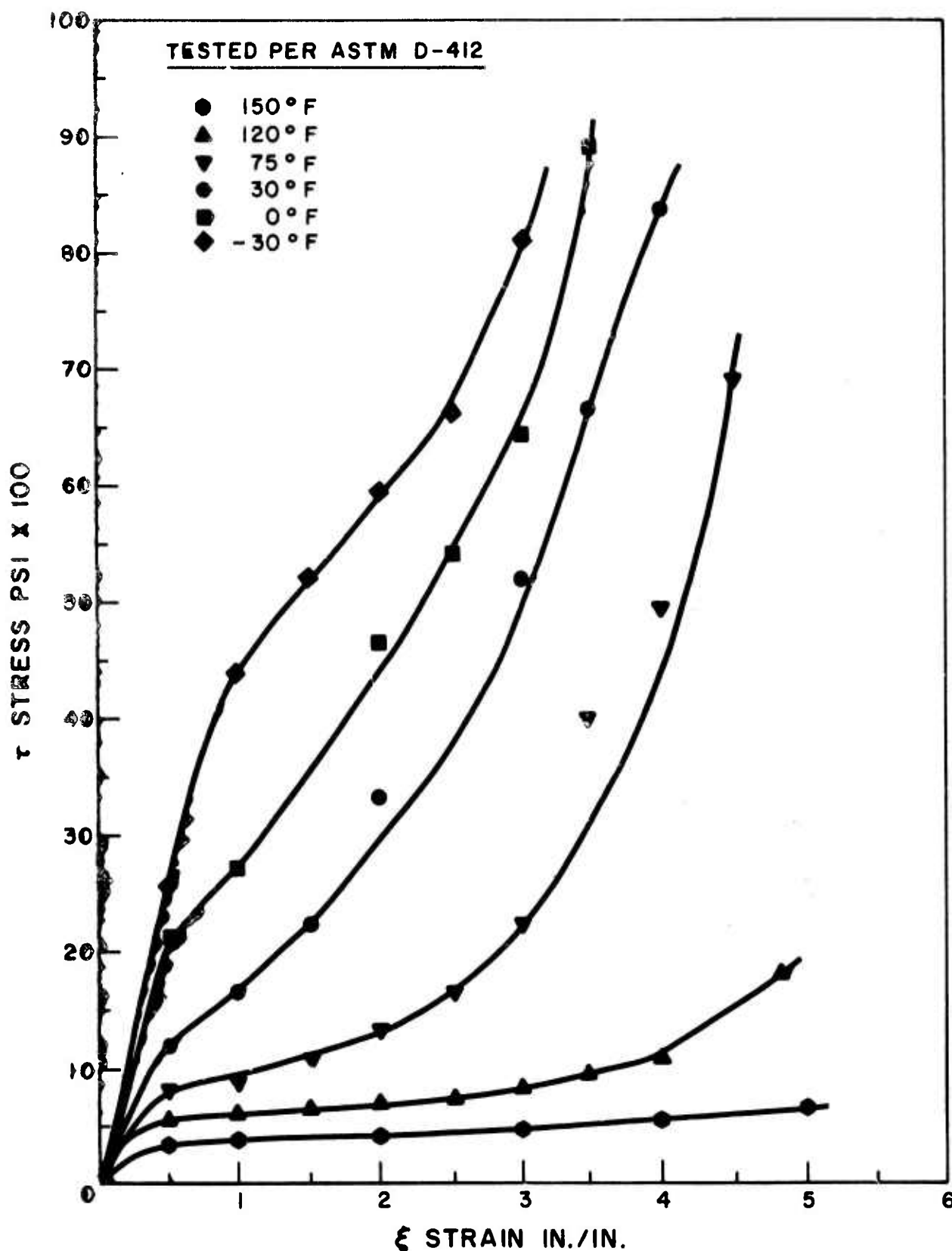
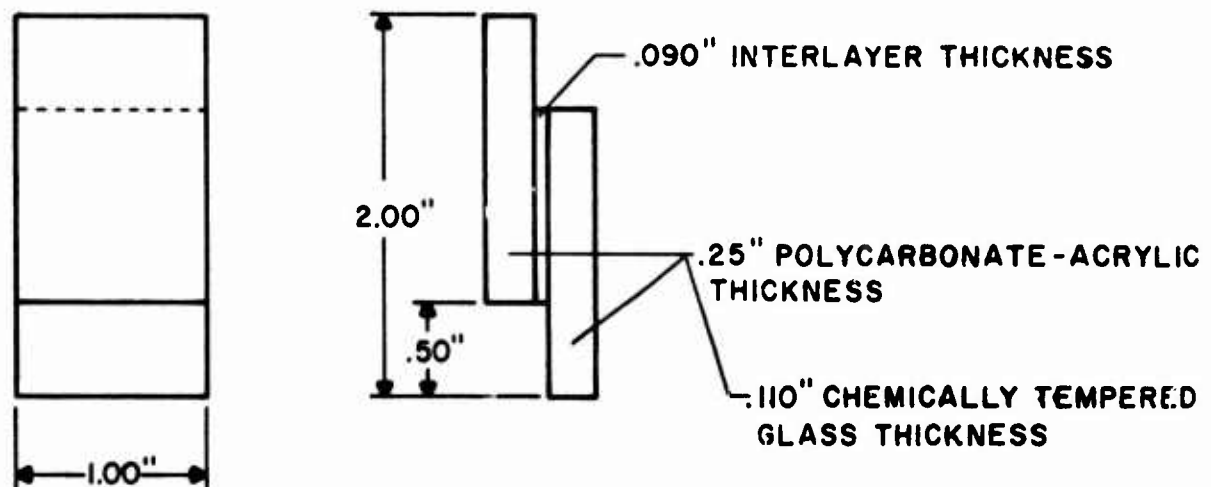


FIGURE 6. STRESS-STRAIN CURVES OF 112 INTERLAYER AT VARIOUS TEMPERATURES

## POLYCARBONATE-ACRYLIC GLASS SAMPLES



### TEST CONDITIONS

1. CROSSHEAD SPEED .20 INCHES PER MINUTE
2. CHART SPEED 1 INCH PER MINUTE
3. SAMPLES SOAKED 20 MINUTES AT TEMPERATURE PRIOR TO TESTING

FIGURE 7. COMPRESSIVE SHEAR TEST SAMPLES

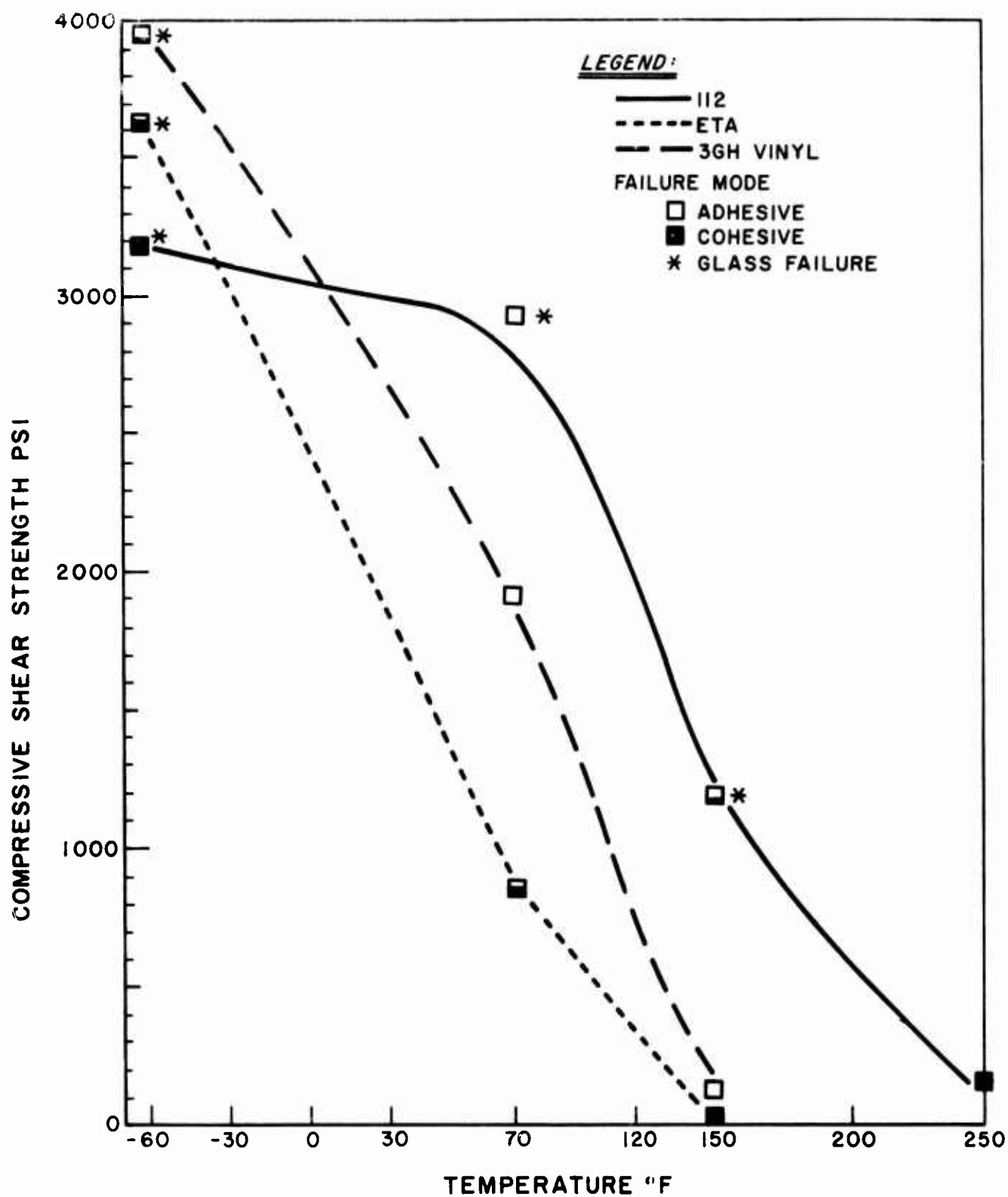


FIGURE 8. COMPRESSIVE SHEAR STRENGTH OF 3GH VINYL, ETA, AND I12 INTERLAYERS TO CHEMICALLY TEMPERED GLASS

The compressive shear strength of 112 and Ethylene Terpolymer to polycarbonate is depicted in Figure 9. As indicated by the data, the ETA has poor shear strength at a temperature of 150°F while the 112 has a shear strength of 150 psi at 250°F. It is worthy to note that at test temperatures below 120°F, the Ethylene Terpolymer failed adhesively and at 120°F and above, cohesive failures were obtained. This data depicts the poor shear properties of Ethylene Terpolymer at test temperatures above 120°F. The failure mode of 112 to polycarbonate indicates that at test temperatures above 120°F, the shear strength is higher than the adhesive strength. At 120°F and below, adhesive and cohesive failures were obtained, indicating that the adhesion and shear strength of 112 to polycarbonate were comparable.

The adhesion of Ethylene Terpolymer to as-cast acrylic is very poor. However, with the addition of N-1 cement, a PPG-developed adhesive for improving the adhesion of interlayers to acrylic surfaces, the adhesion can be greatly improved. Figure 10 indicates the shear properties of 112, ETA and 3GH Vinyl to as-cast acrylic. As experienced with the glass samples, exact shear strength could not be obtained at all test temperatures due to catastrophic acrylic failure. The data indicates the better shear strength of 3GH Vinyl at temperatures of 150°F and below. However, the failure mode of 112 to acrylic is completely adhesive at all test temperatures. This data implies that if better 112-to-acrylic adhesion could be obtained, higher loads to failure could be realized. The Ethylene Terpolymer shear strength in this test was once again very poor at test temperatures above 120°F.

#### (14) Peel Adhesion Tests

NASA Peel Adhesion Tests<sup>5</sup> were conducted on Ethylene Terpolymer laminated to polycarbonate and as-cast acrylic substrates and 112 laminated to glass, gold radar reflective coated and uncoated polycarbonate and acrylic substrates. This test is one measure of delamination resistance and basically consists of mechanically peeling a 1" wide strip of interlayer from 9" of substrate at an angle of 90°. The test samples were prepared by placing wire screen (60 x 60 mesh) between two .030" plies of interlayer, then laminating the interlayer to the plastic substrates. The wire mesh was used to give structural integrity to the interlayer, eliminating premature failures caused by the interlayer tearing or failing in tension.

---

<sup>5</sup>NASA Technical Brief 65-10173, "Peel Resistance of Adhesive Bonds Accurately Measured".

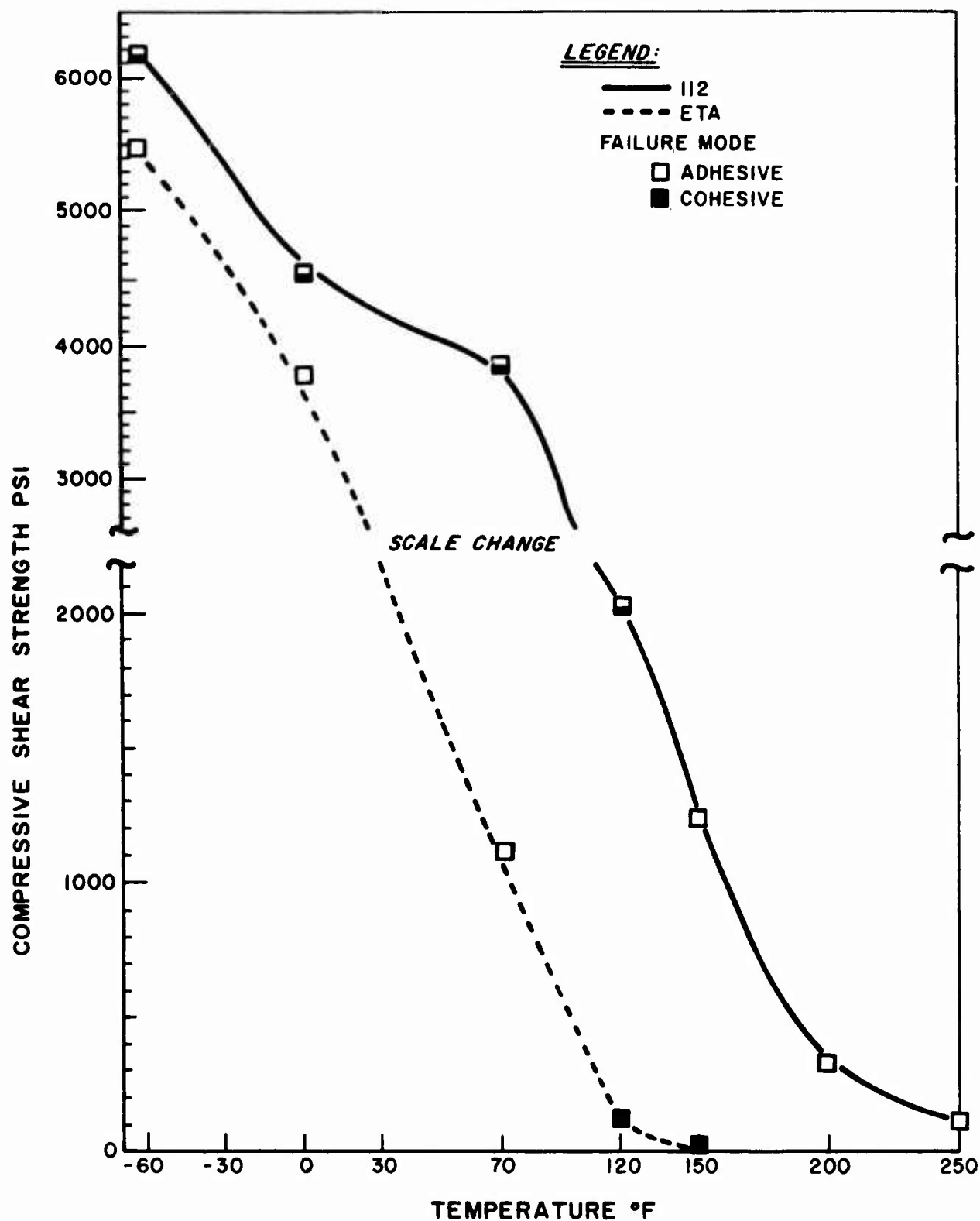


FIGURE 9. COMPRESSIVE SHEAR STRENGTH OF II2 AND ETA TO POLYCARBONATE

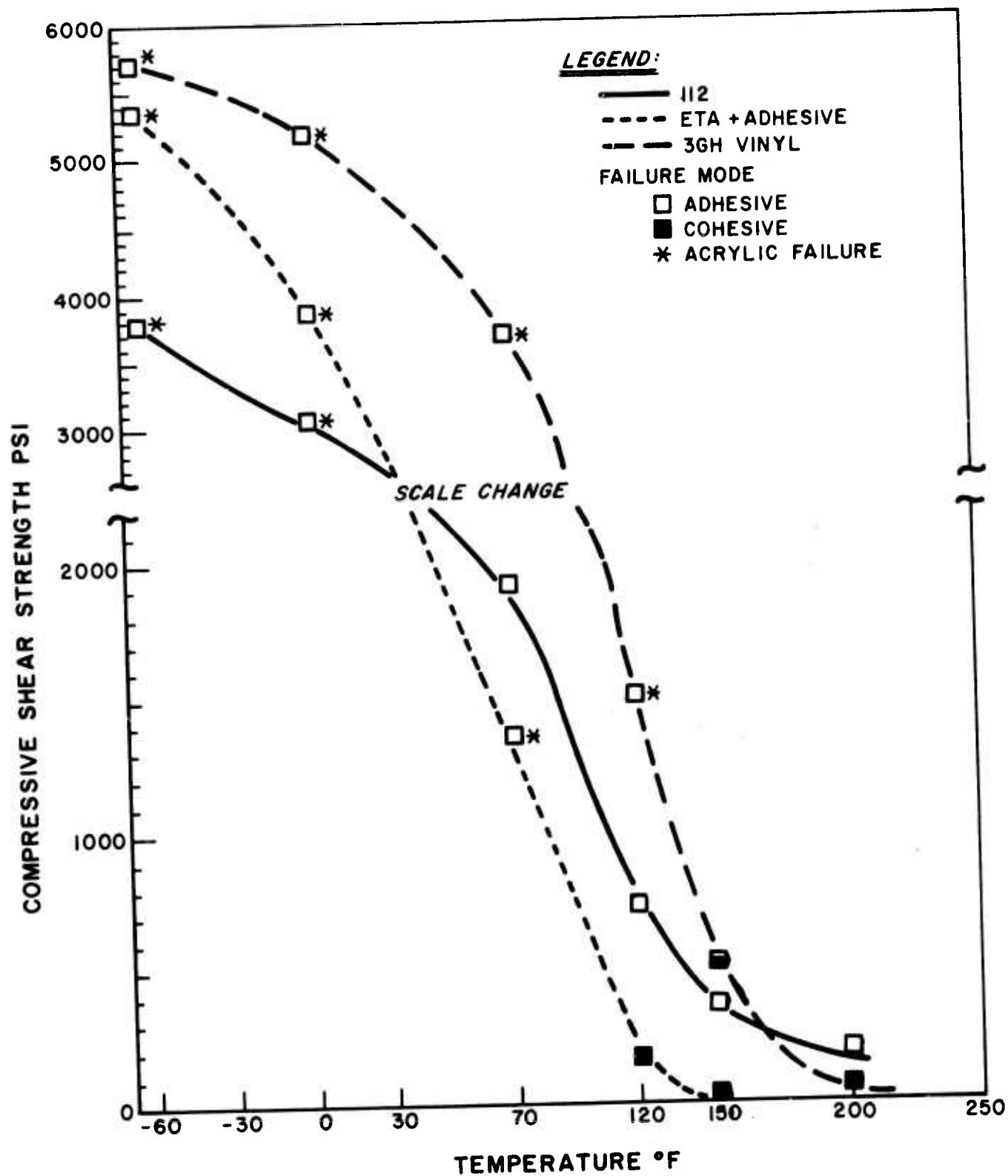


FIGURE 10. COMPRESSIVE SHEAR STRENGTH OF 3GH VINYL, ETA, AND I12 INTERLAYERS TO AS-CAST ACRYLIC

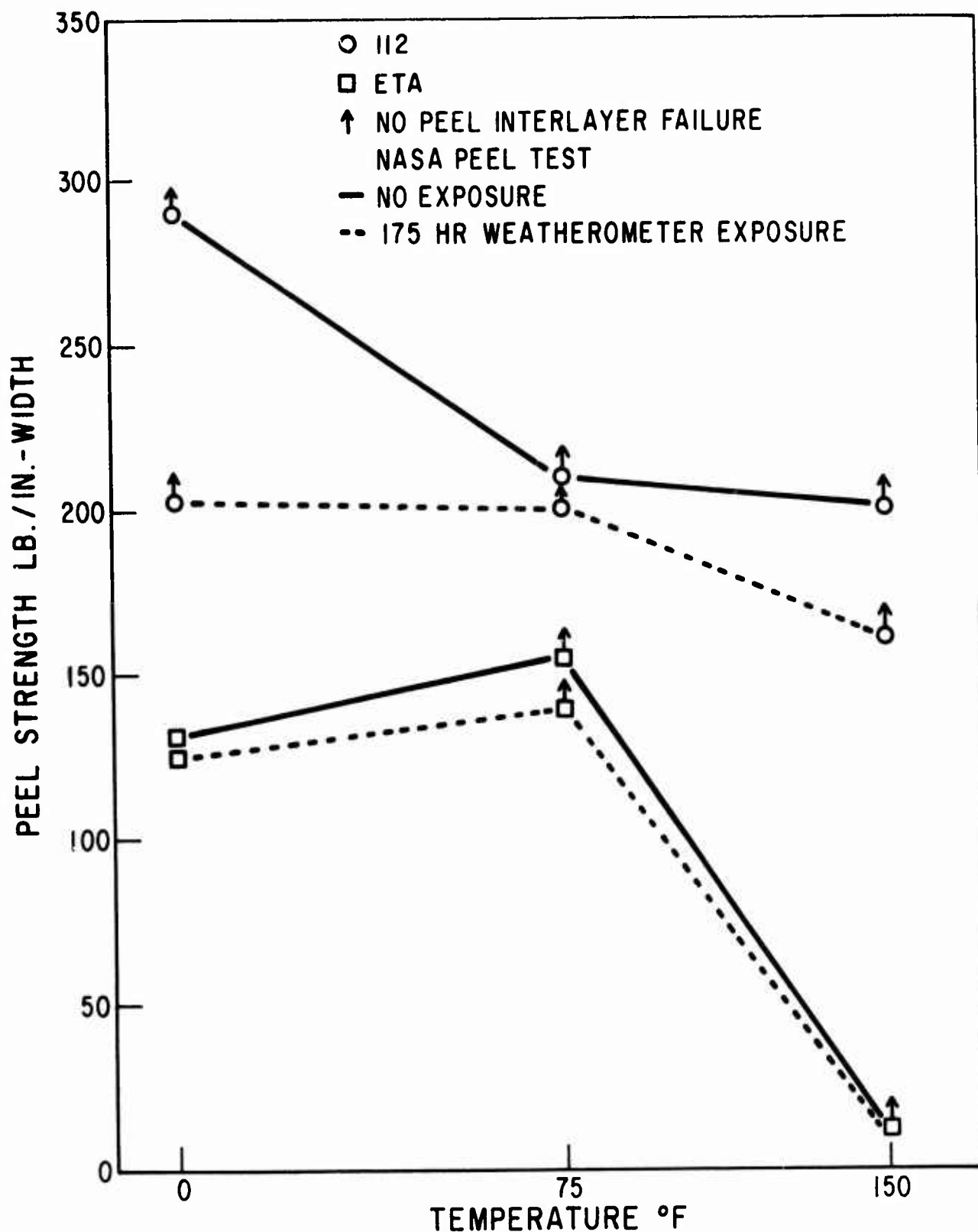


FIGURE II. PEEL ADHESION OF II2 AND ETA TO POLYCARBONATE



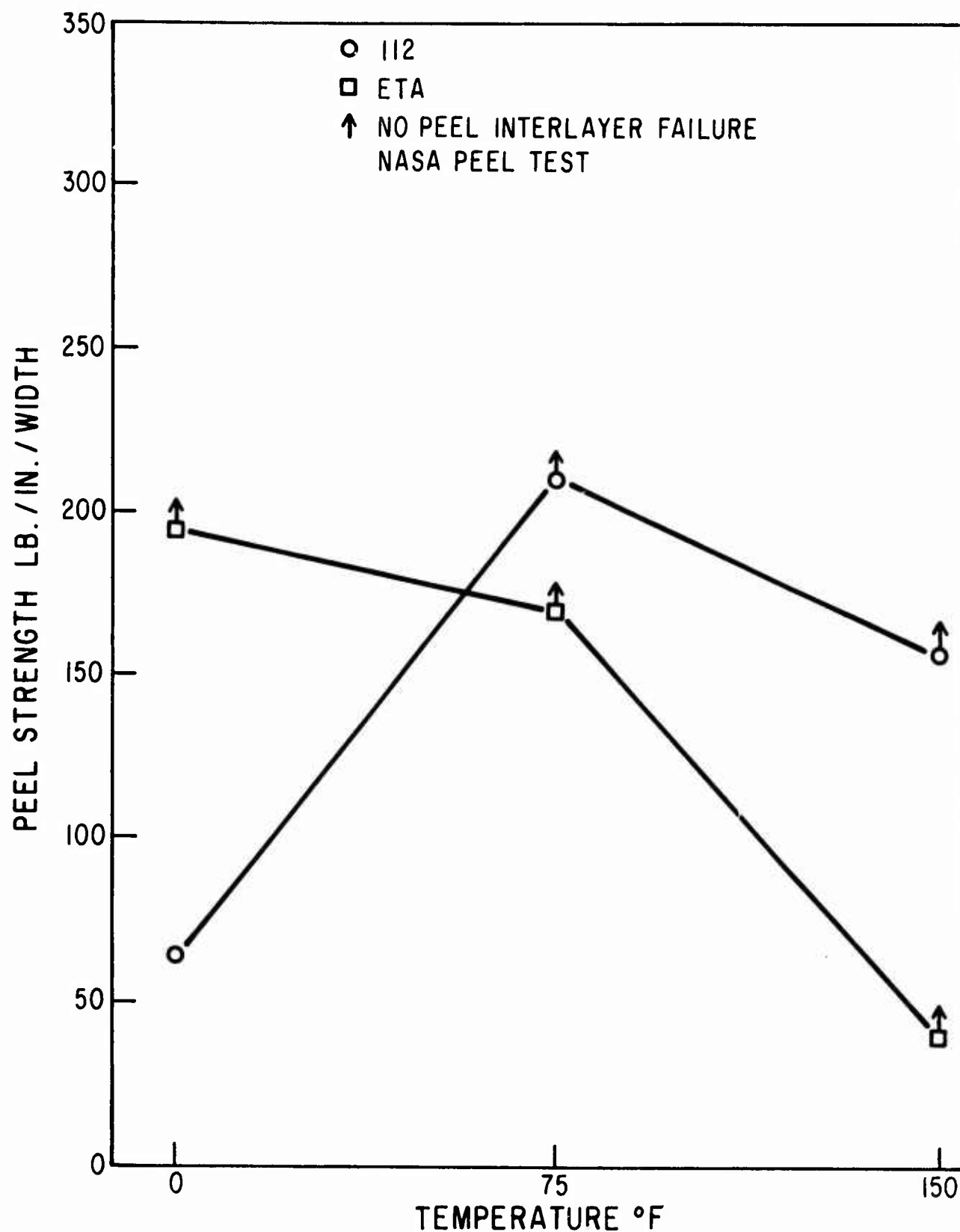


FIGURE 12. PEEL ADHESION OF I12 AND ETA INTERLAYERS TO AS-CAST ACRYLIC

(a) To Polycarbonate

The adhesion of Ethylene Terpolymer and 112 to polycarbonate at 0°, 75°, and 150°F with and without a 175 hour weatherometer exposure is depicted in Figure 11. The weatherometer samples had the polycarbonate surface exposed to the weatherometer conditions (120°F, 90-100% R.H. and constant ultraviolet), while the edges and interlayer surfaces were protected with aluminum tape. As shown by the data, the 112 interlayer could not be peeled from the polycarbonate surface with and without weatherometer exposure and adhesion results were greater than 160 lbs/in width at all test temperatures. These were the maximum loads attained due to mesh failure; therefore, the peel strength at these temperatures is greater than indicated.

At temperatures of 75° and 150°F, the Ethylene Terpolymer could not be peeled from the polycarbonate with and without weatherometer exposure, resulting in failure loads greater than 140 lbs/in width at 75° and 20 lbs/in width at 150°F. These were the maximum loads attained due to a failure in the mesh at 75°F, and a tensile failure of the Ethylene Terpolymer at 150°F. Therefore, in Figure 11, the peel strength at these temperatures is greater than indicated.

The adhesion strength of Ethylene Terpolymer and 112 to polycarbonate is considered excellent and gives an indication of the good delamination resistance of these interlayers to this substrate.

(b) To As-Cast Acrylic (Plex II)

NASA peel tests were also conducted on 112 and Ethylene Terpolymer laminated to as-cast acrylic. These tests were conducted using the same sample construction and testing technique as previously mentioned. As shown in Figure 12, the adhesion of 112 to as-cast acrylic is greater than 150 lbs/in width at 75° and 150°F. At these test temperatures, the interlayer could not be peeled from the acrylic, resulting in mesh failure. At 0°F, the adhesion of 112 is 60 lbs/in width.

The adhesion of Ethylene Terpolymer to as-cast acrylic was initially found to be very poor, resulting in delamination immediately after the samples were laminated. However, with the use of N-1 cement applied to

the acrylic, the adhesion was increased substantially. With the use of this adhesive, the interlayer could not be peeled from the acrylic substrate at all three test temperatures. At 0°F and 75°F, the adhesion was greater than 150 lbs/in width, and at 150°F, the adhesion was greater than 35 lbs/in width.

This excellent adhesion strength depicts the good delamination resistance of 112 to as-cast acrylic and Ethylene Terpolymer to as-cast acrylic with the application of an adhesive.

(c) To Chemically Strengthened Glass

The adhesion of 112 to chemically strengthened glass was established by contractor-conducted testing prior to this contract and found to be greater than 200 lbs/in width when tested at 75°F.

(d) To RCS-Gold-Coated Polycarbonate and Acrylic

Adhesion measurements were made on 112 laminated to .250" polycarbonate and Plex II acrylic substrates coated with 15 ohms/square radar reflective coating. These tests were conducted at 75°F with the data indicating a peel strength of 5 lb/in width to polycarbonate and approximately 1 lb/in width to the Plex II acrylic. The failure modes were important in these tests in that the interlayer failed adhesively to the radar coating on the polycarbonate substrates while the coating failed adhesively to the acrylic substrate.

The data indicates that the adhesion of the radar coating to acrylic is very poor and that the adhesion of the 112 to this coating is also poor. Since the samples having the coating applied to the polycarbonate did not fail at the polycarbonate coating interface, adhesion of the film to this substrate is greater than 5 lb/in width.

Due to the relatively poor adhesion of the 112 interlayer to the gold film, techniques to control the initiation of delamination are required in composites containing 112 and gold coated polycarbonate and these were incorporated in prototype windshield designs.

b. Summary

Due to the elastomeric characteristics of interlayer materials, a range in strength data was obtained. Specific data points represent the mean of all tests, and at some test temperatures the maximum and minimum strengths of these interlayers overlapped.

Of the three interlayers evaluated, PPG 112 had the best tensile strength, elongation, and ductility at test temperatures ranging from  $-65^{\circ}\text{F}$  to  $+200^{\circ}\text{F}$ . This interlayer was also capable of withstanding prolonged exposure at  $250^{\circ}\text{F}$  and approximately 50 hours at  $300^{\circ}\text{F}$  without producing any bubble formation or other undesirable optical characteristics. In addition to these superior properties, the compatibility, adhesion and shear strength to polycarbonate, Plex II acrylic, and glass made 112 the best available candidate to fulfill the stringent impact and temperature requirements of this program.

### 3. EDGE ATTACHMENT

Edge attachment development in Task I was handled much like the impact work with a material evaluation phase, followed by design optimization effort incorporating the most promising components. In Phase I, a test program was conducted to determine the ability of various edge reinforcement adhesives to withstand structural loads of high performance aircraft windshield. A goal of 870 pounds per lineal inch ultimate load was used to rate edging materials. This goal was selected since it is the ultimate edge load requirement for the F-111, assigned as the demonstration model for this program. The specimens used in this evaluation were 4.8 inches wide, thus the total acceptable load for each specimen was approximately 4200 pounds.

Since other Task I work indicated that the structural portion of the windshield cross-sections would be polycarbonate, the temperature used for the edge attachment tests was critical. For low temperature testing,  $-65^{\circ}\text{F}$  was used since it was required per performance specification. Concern was with the higher temperature ranges because of the reduction in strength and stiffness of polycarbonate at elevated temperatures. According to preliminary thermal testing and thermal gradient studies, (Section 4, Initial Thermal/Pressure Testing), soak temperatures of  $200^{\circ}\text{F}$  and  $260^{\circ}\text{F}$  were finally used for the edge attachment evaluation.

Figures 13 and 14 show the different cross-sections evaluated, configuration of the edge attachment cross-section, and the geometry of the loading details. In all cases, the test was conducted on an Instron machine using a crosshead speed of .05 inch per minute. All specimens were tested in single shear to represent the windshield mounting using a retainer and bushings to prevent overclamping of the structural members. The basic variable in this evaluation was the adhesive used to bond the edging reinforcement to the polycarbonate plies. The following materials available for this program at the time of the Task I materials evaluation phase, were considered as possible candidates because of their physical properties and compatibility with potential substrates:

Uralane 5739  
PPG 112 Interlayer  
Heat Vulcanizing (HV) Silicone  
RTV 630 Silicone

Table I gives the results obtained at each of the three test temperatures. Due to the nature of the structural material, the load at which yielding was first observed in addition to the ultimate load is reported.

The results showed the effect of test temperature on the load carrying capability of the edgemembers. Bolt hole elongation was the predominant failure. The RTV 630 and the Uralane 5739 materials appeared to be the best candidates, particularly for high temperature loading.

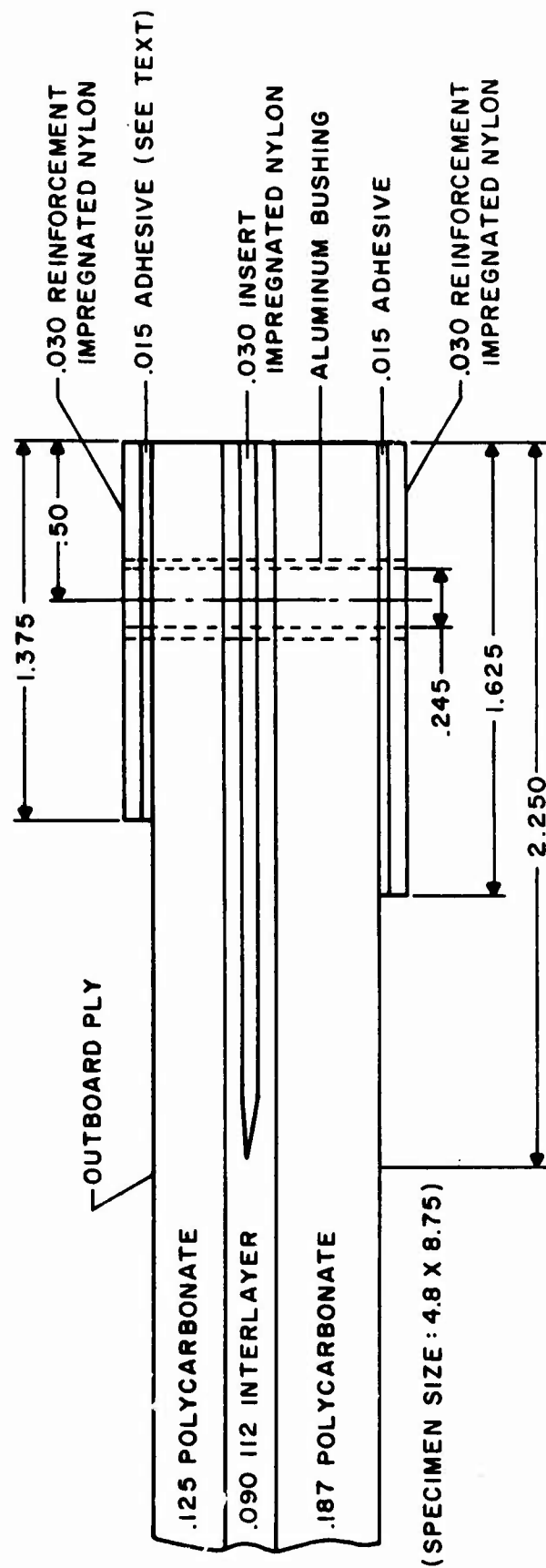


FIGURE 13. F-III EDGE REINFORCEMENT TEST SPECIMEN #1

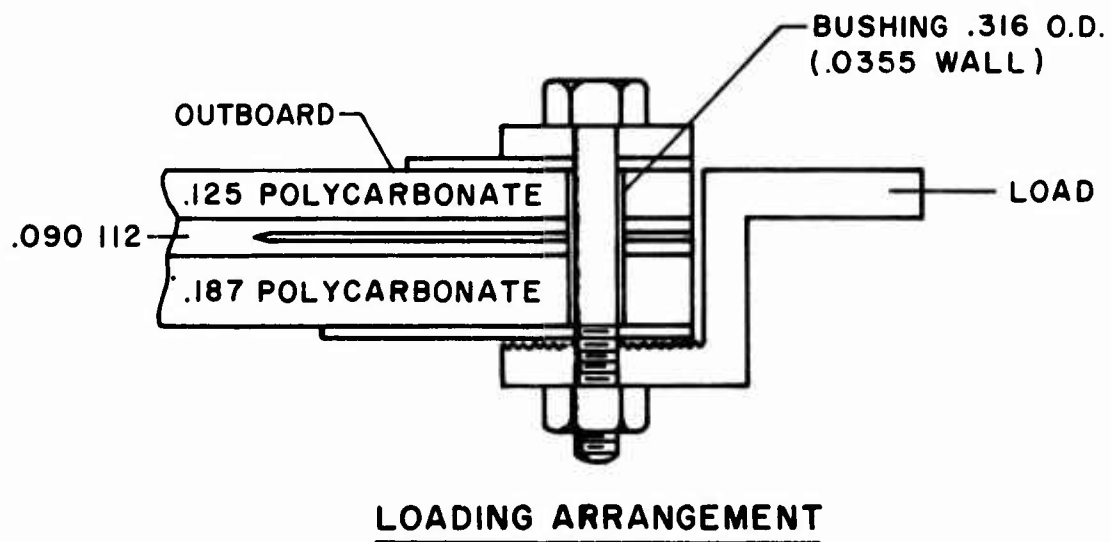
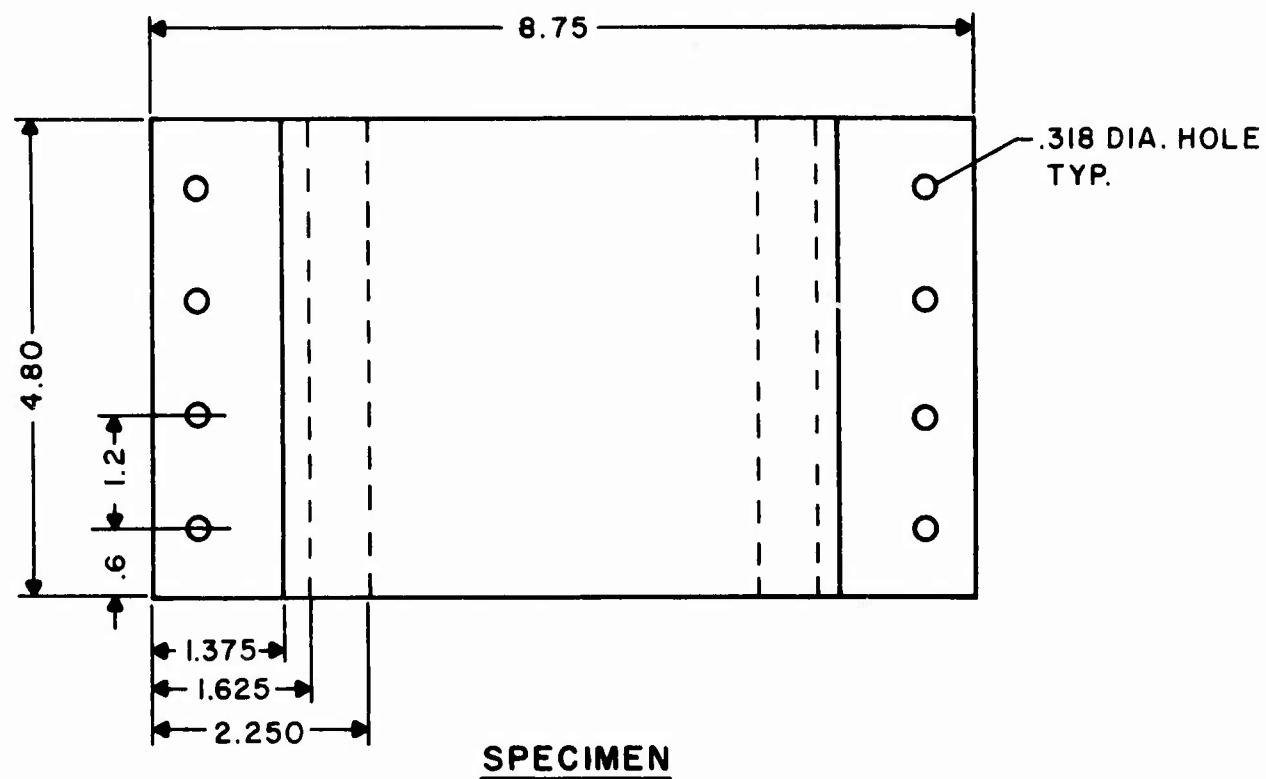


FIGURE 14. EDGE REINFORCEMENT SPECIMEN AND TEST SET-UP.



TABLE I - PRELIMINARY EDGE ATTACHMENT TENSILE TESTS

SAMPLE CONFIGURATION: 4.8" x 8.75" specimens with 2 reinforcement straps plus insert (Figures 13 and 14)

| Adhesive Type    | Temperature<br>(°F) | Yield Load<br>(lbs/in.) | Ultimate Load<br>(lbs/in.) | Failure                                                  | Remarks                   |
|------------------|---------------------|-------------------------|----------------------------|----------------------------------------------------------|---------------------------|
| Uralane 5739     | -65                 | 1770                    | 2080                       | None                                                     | Crazing of strap material |
| PPG 112          | -65                 | 1560                    | 2080                       | None                                                     | Crazing of strap material |
| HV Silicone      | -65                 | 1460                    | 2080                       | None                                                     | Crazing of strap material |
| RTV 630 Silicone | -65                 | 1810                    | 2080                       | None                                                     | Crazing of strap material |
| Uralane 5739     | 200                 | 1190                    | 1630                       | Bolt hole elongation                                     | Polycarbonate crazing     |
| PPG 112          | 200                 | 980                     | 1320                       | Strap adhesive<br>elongation and bolt<br>hole elongation | Polycarbonate crazing     |
| HV Silicone      | 200                 | 1150                    | 1580                       | Strap adhesive<br>elongation and bolt<br>hole elongation | Polycarbonate crazing     |
| RTV 630 Silicone | 200                 | 1210                    | 1750                       | Bolt hole elongation                                     | Polycarbonate crazing     |
| Uralane 5739     | 260                 | 900                     | 1100                       | Bolt hole elongation                                     | Polycarbonate crazing     |
| PPG 112          | 260                 | 540                     | 610                        | Strap adhesive<br>elongation                             | None                      |
| HV Silicone      | 260                 | 770                     | 970                        | Strap adhesive                                           | Polycarbonate crazing     |
| RTV 630 Silicone | 260                 | 890                     | 1170                       | Strap adhesive and<br>bolt hole elongation               | Polycarbonate crazing     |

Load limit of testing machine is 10,000 pounds equivalent to 2080 pounds/lineal inch.

Delamination was also found to occur at the elevated temperatures where there was excessive yielding and bolt hole elongation. This was particularly true where the adhesive elongated which then allowed a greater amount of load to be carried by the polycarbonate material at the bolt hole. Both the HV silicone and the 112 interlayer showed this behavior at both elevated temperatures.

Additional reinforcement to the interior surfaces of the structural polycarbonate plies was considered for added strength. The resulting specimens had four strap reinforcements, one bonded to each side of polycarbonate rather than two straps plus an insert as in Figures 13 and 14. The tensile test results for those samples are described in Table II. The last specimen listed in Table II, used a silicone prepreg for the adhesive. The prepreg became available during the program and was considered because of its viability and potential processing improvements.

In all the preliminary evaluations, the RTV 630 adhesive bonded satisfactorily to polycarbonate substrates with bond failure exceeding the yield of the polycarbonate substrates. The specimens with strap reinforcements bonded to each side of structural polycarbonate (Table II) were about 10% higher in tensile capability than with the insert type reinforcement (Table I). The silicone prepreg appeared promising for bonding application since bond strength was comparable and the application technique was much simpler for fabrication. However, with this system as with HV silicone, strap adhesion continued to be a problem throughout Task I.

In other material tests, bond strength for RTV 630 silicone adhesive was determined on specimens illustrated by the cross-section in Figure 15. For this test the requirement was 350 psi tensile shear bond strength at temperatures from -65°F to 220°F. The following bond strengths were obtained:

|                                                    |                               |
|----------------------------------------------------|-------------------------------|
| Test at RT                                         | 700 psi (average 4 specimens) |
| Test at 220°F                                      | 575 psi (average 2 specimens) |
| Test at 265°F                                      | 520 psi (average 2 specimens) |
| Test at RT (after 6 hrs<br>boiling water exposure) | 715 psi (average 1 specimen)  |

The peel strength of the RTV 630 to a polycarbonate substrate with SS-4120 primer was 15 lbs per inch width resulting in adhesive failure to polycarbonate substrate.

Although the bonding qualities of RTV 630 were satisfactory, the handling qualities were very poor because of two-component mixing, paste application, limited pot life, etc. Uralane 5739, which also provided acceptable bond, was also difficult to handle so that final selection

TABLE II - ADDITIONAL PRELIMINARY EDGE ATTACHMENT TENSILE TESTS

SAMPLE CONFIGURATION: 4.8" x 8.75" specimens with 4 reinforcement straps only (2 per ply) and no insert

| <u>Adhesive Type</u> | <u>Temperature<br/>(°F)</u> | <u>Yield Load<br/>(lbs/in)</u> | <u>Ultimate Load<br/>(lbs/in)</u> | <u>Failure</u>                                          | <u>Remarks</u>                           |
|----------------------|-----------------------------|--------------------------------|-----------------------------------|---------------------------------------------------------|------------------------------------------|
| HV Silicone          | 200                         | 940                            | 1390                              | Strap adhesive                                          | Slight delamination<br>slight PC crazing |
| RTV 630 Silicone     | 200                         | 1350                           | 1850                              | Bolt hole elongation;<br>bolt hole failure              | No delamination;<br>PC crazing           |
| HV Silicone          | 260                         | 660                            | 910                               | Bolt hole elongation;<br>strap adhesive                 | Slight delamination;<br>PC crazing       |
| RTV 630 Silicone     | 260                         | 1060                           | 1280                              | Slight bolt hole<br>elongation; slight<br>strap crazing | Slight delamination;<br>PC crazing       |
| Silicone Prepreg     | 260                         | 915                            | 1125                              | Bolt hole elongation;<br>strap adhesive                 | Slight delamination;<br>PC crazing       |

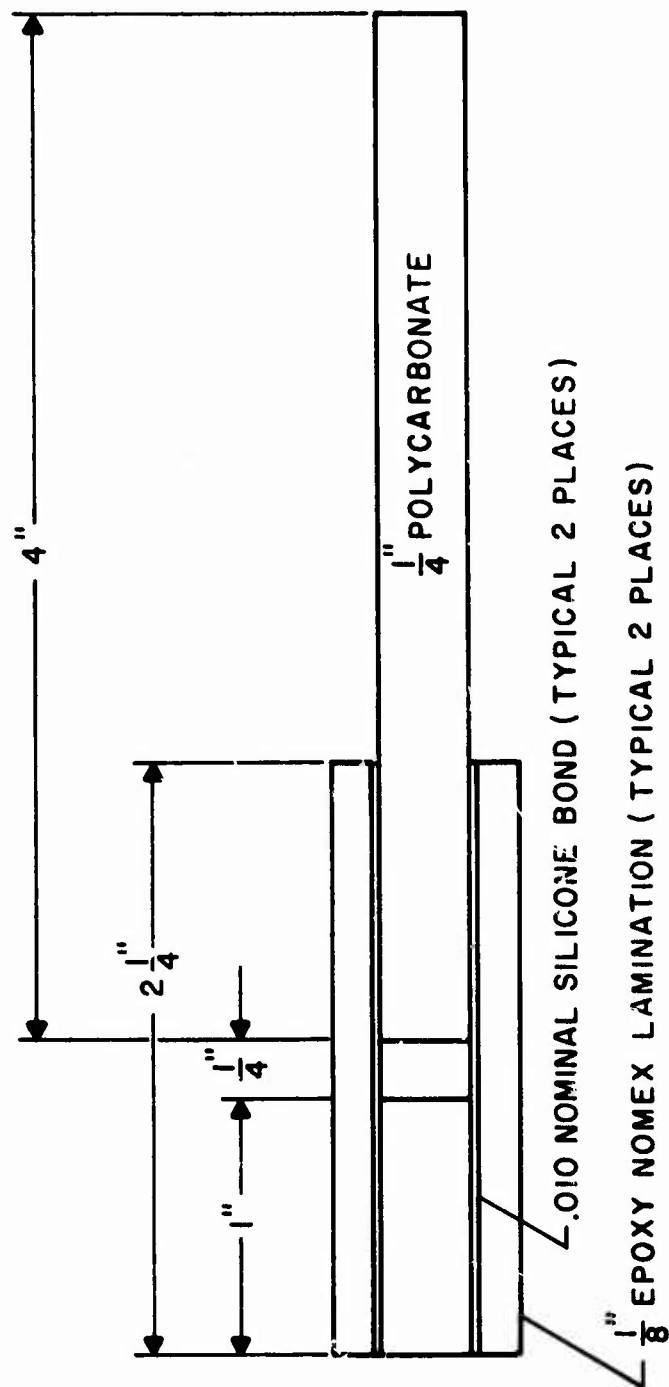


FIGURE 15. TENSILE SHEAR BOND SPECIMEN

was made for other reasons. The 5739 being a rigid system increased the chance for brittle crack propagation during bending while the 630 did not. The RTV 630, then, was the "lesser of evils" and efforts continued to find a system with acceptable edge strength which would be easier to apply.

The following conclusions were drawn from this portion of the study:

1. The required structural performance can be gained from the polycarbonate structural plies using impregnated nylon for bolt hole reinforcement bonded with either RTV 630 silicone or Uralane 5739 adhesives. Of these two, RTV 630 is preferable.
2. PPG 112 and HV silicone were not acceptable at the elevated temperature loading conditions.
3. An outboard retainer for the windshield mounting was recommended to enhance clamping to the frame structure without the use of tapered bushings.

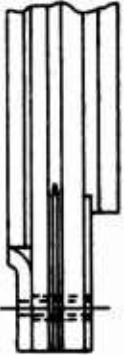
Inputs from the material evaluation were used in developing edgemember designs for optimized Task I bird impact panels. Tensile tests were then run on the basic cross-sections to facilitate final selection of a windshield edge attachment system for Task II use. Results for this second phase are summarized in Table III. Data for similar cross-sections which were tested in the preliminary phase have been included in the Table for comparison.

In the final test series, the full four plastic ply laminates with two extended plies and aluminum retainers were in the same strength range as the two-ply laminates. The primary difference was that specimens with the additional outer and inner lamina plies did not exhibit the PC surface crazing as experienced on the two-ply specimens.

The following conclusions were derived from the second phase tensile tests:

1. All tensile strength values including yield and ultimate values exceeded the objective goal of 870 pounds per lineal inch at all temperatures.
2. Ultimate tensile values, in general, increased with added reinforcement pieces. The bonded aluminum retainer, although not necessary as an edge reinforcement member, did perform similarly as a fabric reinforced laminate.

BIRD IMPACT CONFIGURATION  
PANEL REF.

|         |                                                                                       | TEMPERATURE      |                 |                  |                 | COMPONENTS |        |          |
|---------|---------------------------------------------------------------------------------------|------------------|-----------------|------------------|-----------------|------------|--------|----------|
|         |                                                                                       | 200°F            |                 | 260°F            |                 | INSERT     | STRAPS | RETAINER |
|         |                                                                                       | YIELD<br>LB./IN. | ULT.<br>LB./IN. | YIELD<br>LB./IN. | ULT.<br>LB./IN. |            |        |          |
|         |    | 1205<br>(-65°F)  | 1745<br>(2080)  | 865              | 1175            | 1          | 2      | 0        |
|         |    | 1350             | 1850            | 1060             | 1280            | 0          | 4      | 0        |
| 9030-17 |    | 1190             | 1400            | 890              | 1000            | 1          | 1      | ALUM.    |
| 9030-21 |   | 1250             | 1500            | 1080             | 1280            | 0          | 3      | ALUM.    |
| 9030-19 |  | 1250             | 1670            | 1060             | 1280            | 0          | 4      | 0        |
| 9030-18 |  | 1230             | 1740            | 1070             | 1310            | 0          | 4      | ALUM.    |

NOTE: REINFORCEMENT: EPOXY NOMEK BONDED WITH RTV 630.  
EDGE LOAD GOAL = 870 LBS. / LINEAL INCH.

TABLE III. TENSILE STRENGTH OF EDGE REINFORCEMENTS

3. Yield values were all about the same irrespective of added reinforcements.
4. Floating facing plies do not add significantly to the tensile strength of the overall laminate.
5. RTV 630 silicone bond system continued to be satisfactory for strength and bondability to all substrates including PC, epoxy-Nomex laminate and aluminum.

The basic edge reinforcement materials for the canopy were proven in the windshield program. The primary question, then, was the tensile edge strength capability of the two .125" PC structural ply design which met the bird impact requirement. Tests were run on the 4.8" tensile samples and the results, plus data from Table III, were as shown in Table IV:

TABLE IV - TENSILE STRENGTH OF DOUBLE PC PLY EDGEMEMBERS

Goal = 870 lbs/lineal inch

| <u>EXTENDED EDGE</u>        | <u>200°F</u> |                 | <u>260°F</u> |                 |
|-----------------------------|--------------|-----------------|--------------|-----------------|
|                             | <u>YIELD</u> | <u>ULTIMATE</u> | <u>YIELD</u> | <u>ULTIMATE</u> |
| .125" - .125"<br>(9031-3A)* | 1100         | 1290            | 790          | 910             |
| .125" - .188"<br>(9030-21)* | 1250         | 1500            | 1080         | 1280            |

\*Indicates similar Task I bird impact panel. See data sheets for shots WT-36 and WT-29 respectively in Appendix 1.

One can see that the .125" - .188" combination gave comparable strength at 260°F to the .125" - .125" plies at 200°F. However, a section with two .125" plies did just meet the 870 lbs/in ultimate tensile load requirement selected for this program under the rigorous 260°F soak condition.



#### 4. THERMAL/PRESSURE CAPABILITY

Bird tests had established the performance of two structural polycarbonate ply system with no preference for the outboard facing or floating ply. In essence, the outboard facing ply could be any material (i.e. - glass, acrylic, thermosetting plastic, etc.) since this ply added nothing to the impact capability of the construction. Hence, it became apparent that tests to evaluate effects of temperature and pressure would be useful to establish the outboard facing ply material.

In order to evaluate potential design considerations, the most severe tests as outlined by Addendum 1, Endurance Requirements were selected from the contract. The three tests considered to be the most severe and thus the best criteria for evaluation purposes were:

1. Maximum Burst Pressure/Temperature (18.8 psi, 383°F)
2. Maximum Crush Pressure (13.2 psi (avg.), 250°F)
3. Pressure Cycling (0 - 11.2 - 0 psi, 356°F)

For the latter two tests, the temperature of the outboard surface was to be controlled at a constant maximum throughout the test whereas the temperature for the initial test was the peak value achieved for the outboard surface. Figure 16 shows the actual temperature and pressure response required by this test. In all cases the inside ambient was controlled at 75°F. The primary objectives for conducting these tests were:

1. Establish the actual maximum temperatures that the structural members attain especially in the edge reinforcement region. These temperatures would then influence the outboard material selection and the upper temperature requirements considered necessary for acceptable edge reinforcing.
2. Determine the overall structural and optical quality when subjected to thermal and both static and cyclic temperature/pressure loads.

Since tests of full-scale transparencies were neither economical nor necessary and an actual test chamber was available, 15" circular samples were selected as standard specimens. Figure 17 shows a view of the test fixture with a 15" circular sample mounted in place. The sample was mounted with the outboard ply exposed to the electrical heating elements, and the inboard ply exposed to room temperature. A dial gage was positioned at the center of the panel contacting the inboard surface. The chamber cavity was pressurized and heated as required for the given test conditions. The inboard panel surface (top surface opposite the heated side in the test fixture) was cooled by controlling the ambient within the upper enclosure at 75°F. This was

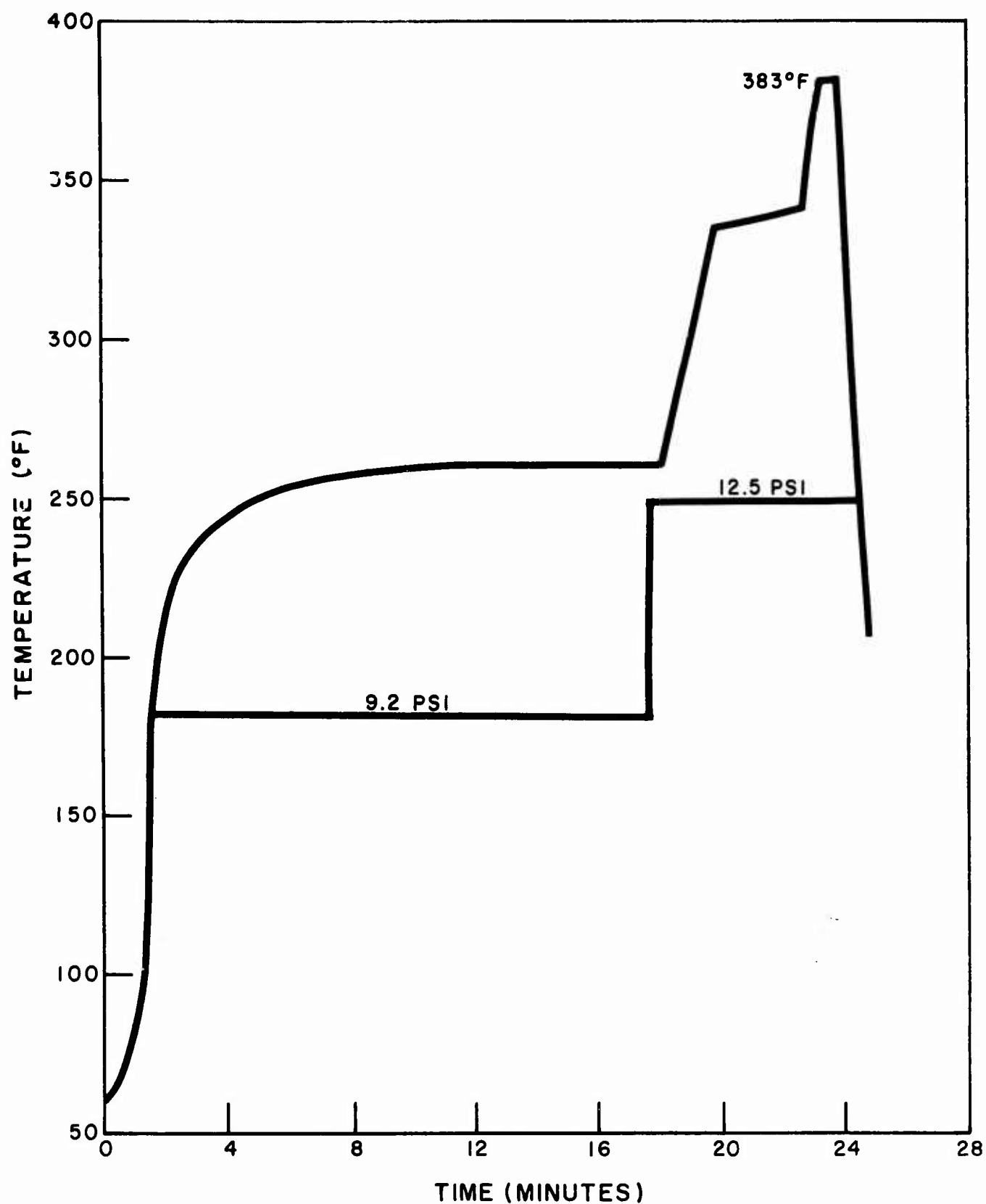


FIGURE 16. MAXIMUM BURST PRESSURE / TEMPERATURE TEST PROFILE.

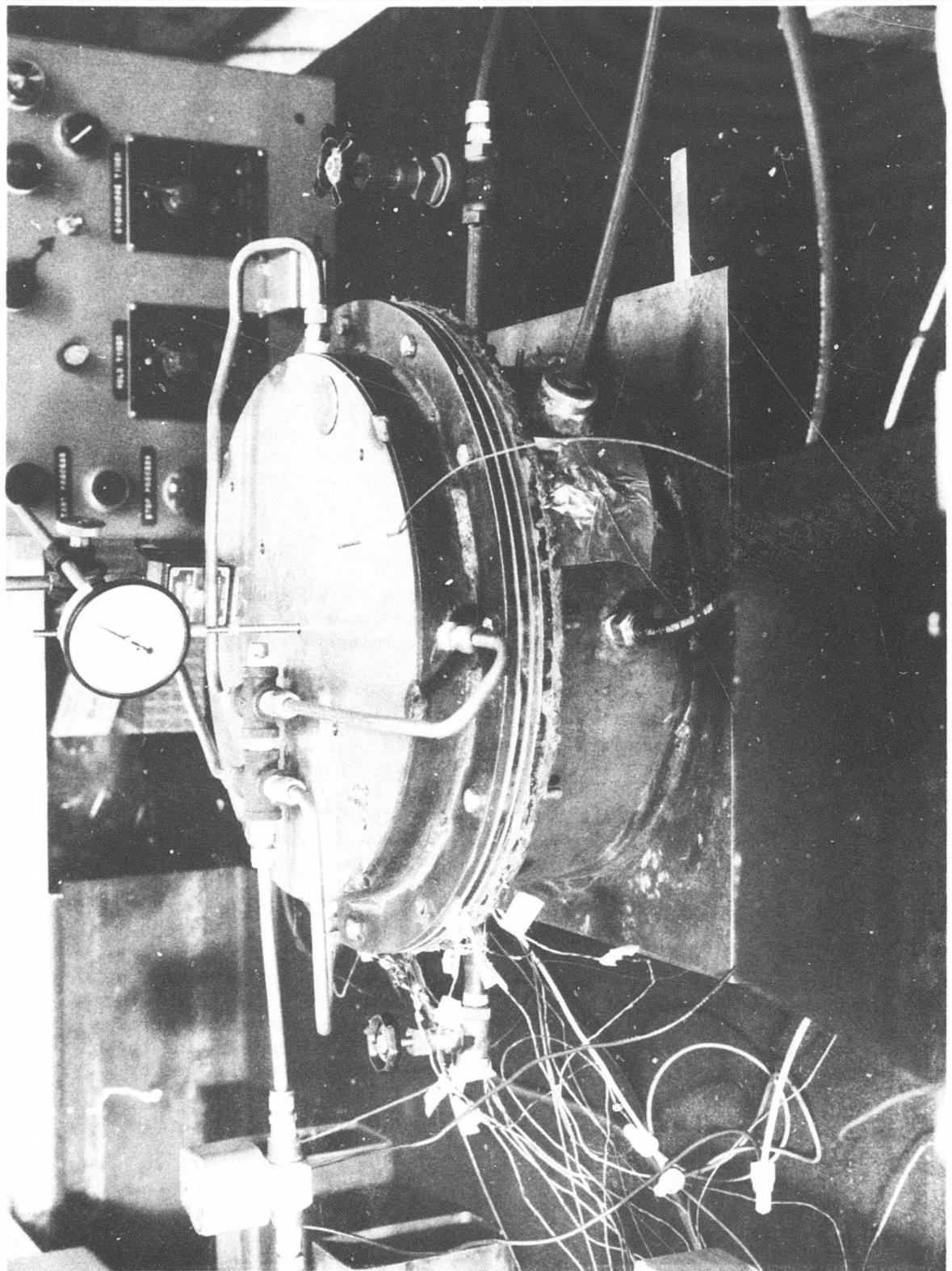


FIGURE 17. THERMAL/PRESSURE TEST FIXTURE

accomplished by introducing vaporized liquid nitrogen into this cavity. For all tests utilizing this facility, a positive inboard (relative to panel design) pressure was obtained by producing a vacuum in the lower heated chamber. Using the two 750 watt strip heaters and insulation around the edges, it was possible to reproduce the temperature rise shown in Figure 16 and obtain 260°F in six minutes.

a. Test Sample Description

Circular Samples, 15" in diameter, were fabricated per the conventional two-ply polycarbonate design with various outboard facing members. The different combinations utilized in this bench study are shown in Figure 18. As shown by the cross-sectional view, samples were laminated with iron-constantan thermocouples embedded at each interface. Thermocouples were aligned at the sample center and at a radial location in the edge section as shown by the plane view on Figure 18. The actual edge of the sample was extended 1 1/2" all around to obtain a support surface for the chamber walls. The edge thermocouples were located within the edge section 1/2" inside of the chamber wall contact area. Thus, both the edge and the center of the specimen were exposed to the various test conditions.

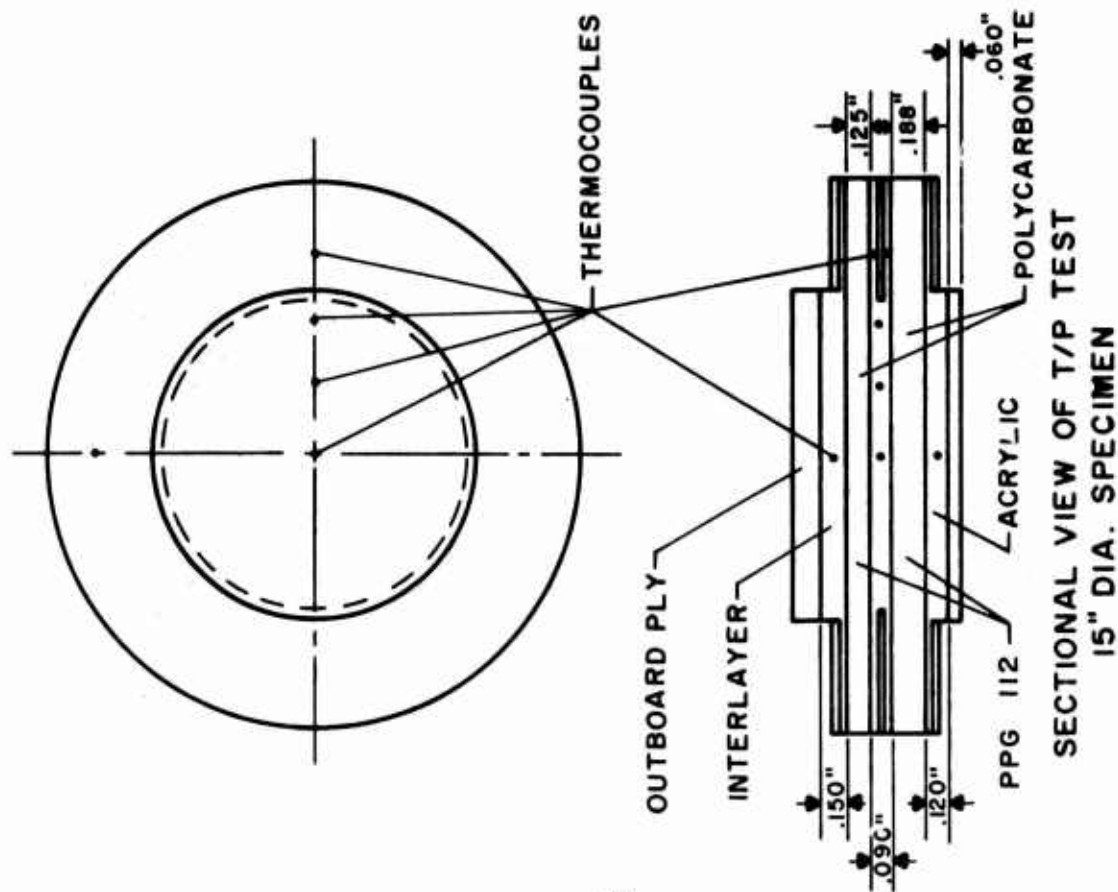
b. Initial Thermal/Pressure Testing

After some preliminary work to determine the equipment capability and sample reaction, the test scheme in Table V was proposed. The following paragraphs describe this preliminary testing and discuss the results.

TABLE V - 15" CIRCULAR SAMPLE TEST SCHEME

| <u>TEST CODE</u> | <u>PRESSURE (PSI)</u> | <u>MAXIMUM OUTBOARD<br/>TEMPERATURE (°F)</u> | <u>TIME (MINUTES)</u> |
|------------------|-----------------------|----------------------------------------------|-----------------------|
| A                | 11-12                 | 260                                          | 15                    |
| B                | 11-12                 | 300                                          | 10                    |
| C                | 11-12                 | 340                                          | 10                    |
| D-1              | 11-12                 | 360                                          | 10                    |
| D-2              | 11-12                 | 360                                          | 20                    |
| D-3              | 11-12                 | 360                                          | 30                    |

Tests were conducted on Sample No. 1 (Table VI) to establish the thermal capability of the test arrangement. Of primary concern were the heating rate, control and temperature uniformity across the surface. The initial attempts consisted of duplicating the temperature response of the outboard ply surface as defined by Figure 16.



| SAMPLE NO.                        | OUTBOARD PLY                      | INTERLAYER     |
|-----------------------------------|-----------------------------------|----------------|
| 1                                 | .060" ACRYLIC                     | .150" PPG 112  |
| 2                                 | .060" ACRYLIC                     | .150" PPG 112  |
| 3                                 | .060" ACRYLIC                     | .150" PPG 112  |
| 4                                 | .110" GLASS                       | .150" PPG 112  |
| 5                                 | .110" GLASS                       | .150" PPG 112  |
| 6                                 | .110" GLASS                       | .150" PPG 112  |
| 7                                 | .110" GLASS                       | .150" SILICONE |
| 8                                 | .125" CR - 39 *                   | .150" PPG 112  |
| 9                                 | .110" GLASS **                    | .150" PPG 112  |
| 10                                | .060" ACRYLIC +<br>.125" POLYCARB | .090" PPG 112  |
| 11                                | .060" ACRYLIC +<br>.188" POLYCARB | .090" PPG 112  |
| 12                                | .110" GLASS                       | .090" PPG 112  |
| * THERMOSETTING PLASTIC SHEET     |                                   |                |
| ** GLASS HELD TO SAMPLE BY EDGING |                                   |                |

FIGURE 18. DESIGN CONFIGURATIONS TESTED IN  
THERMAL / PRESSURE FACILITY



In the initial test, only one 750 watt heater was used. It required 21 minutes to bring the acrylic surface (exposed to heating element) to 260°F. Because of control problems, this temperature level was exceeded and the fifteen minute hold was actually maintained at 285°F. Due to the slow rate of heating and the control problems, further extension of the test schedule was discontinued. Figure 19 shows the temperature distributions achieved at the end of the 285°F soak for this specimen. As anticipated, the thermal gradient through the transparent central region approached linearity. The thermal conductivity of the transparent materials of this design do not differ much, so a linear gradient is reasonable. Conversely, the insulation character of the edge reinforcement caused significant differences in the thermal gradient through this edge section. The maximum temperature of 235°F on the outboard strap indicates some degree of heating nonuniformity associated with this thermal system. Some of this nonuniformity could have been caused by the concentrated heating system and the heat loss through the exposed edges.

Based on the average temperature achieved for this test and the potential insulation gained by the straps, a tentative temperature of 200°F was proposed as the upper soak limit of edge reinforcement tensile test samples (see Section II-3, Table I). A soak limit goal of 260°F was established for these samples to provide a safety margin.

A second test using specimen No. 1 was conducted with two 750 watt heaters and more insulation. This arrangement achieved the 260°F level in six minutes, but control problems developed causing the test to be discontinued.

Improvements were made in the control system and tests were continued with incorporation of pressure loading. Subsequent samples were tested at the 260°F temperature level without any pressure for fifteen minutes. If no effects developed, the next test repeated the 260°F outboard temperature with 9.2 psi internal pressure. Subsequent tests repeated this portion with exposure of 260°F with and without pressure followed by the 340°F outboard temperature for five minutes with or without 12.5 psi internal pressure. The initial tests on Sample Nos. 1 and 2 (acrylic-faced) and Nos. 4 and 5 (glass-faced) showed that the performance of the proposed designs were dependent on the combined loading of temperature and pressure with little or no effect produced by temperature without pressure. Initially, no attempt was made to keep the cabin temperature at 75°F. Hence, the first five tests for the acrylic-faced panels and the first three tests of the glass-faced panels as tabulated in Table VI show inboard temperatures of 135°F or higher. (The 100°F for the inboard temperature test A of panel 2 is believed to be in error.) Cooling the cavity of the inboard side with a maintained temperature of 75°F produced inboard ply temperatures of 100° to 110°F.

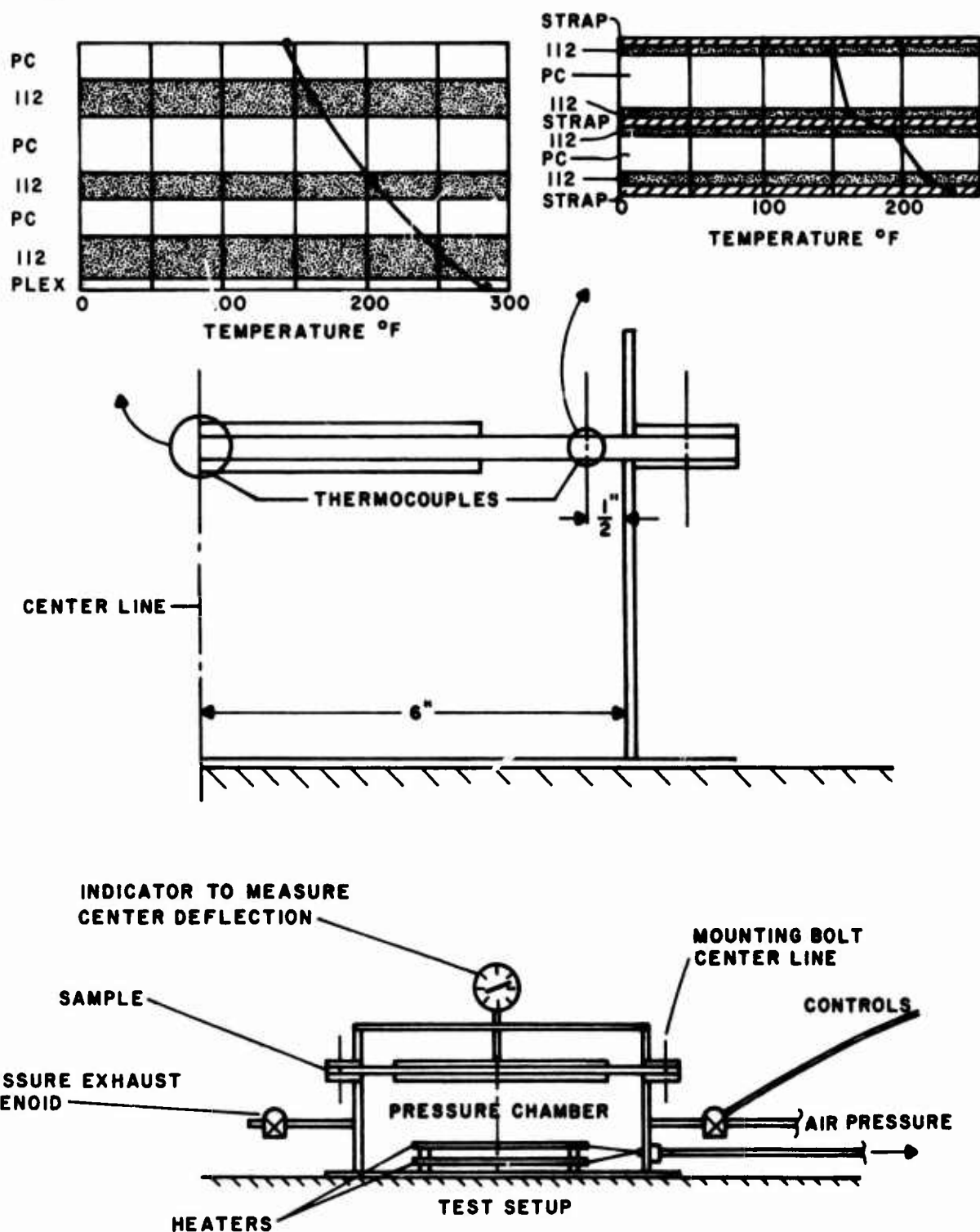


FIGURE 19. TEMPERATURE GRADIENT IN ACRYLIC-FACED DESIGN SPECIMEN NO. 1

TABLE VI - INITIAL TEMPERATURE/PRESSURE TEST RESULTS

ON 15" CIRCULAR PANELS

| SAMPLE<br>NO.               | TEST<br>CODE | TEMPERATURE      |                 | PRESSURE<br>(PSI) | CENTER                 | RESULTS                                  |
|-----------------------------|--------------|------------------|-----------------|-------------------|------------------------|------------------------------------------|
|                             |              | OUTBOARD<br>(°F) | INBOARD<br>(°F) |                   | DEFLECTION<br>(INCHES) |                                          |
| <u>ACRYLIC-FACED PANELS</u> |              |                  |                 |                   |                        |                                          |
| 1                           | A°***        | 285              | 145             | 0                 | --                     | No effects                               |
|                             | C°           | 460              | 174             | 0                 | --                     | Melted acrylic                           |
| 2                           | A°           | 260              | 143             | 0                 | .047                   | No effects                               |
|                             | A            | 260              | 100             | 9.2               | .399                   | Some I/L bubbles,<br>distorted           |
|                             | C            | 375              | 135             | 9.2               | .337                   | Interlayer bubbles                       |
|                             | C°           | 380              | 110**           | 0                 | .145                   | No effects                               |
|                             | C            | 400              | 110**           | 12.5              | .415                   | Deformed acrylic                         |
| <u>GLASS-FACED PANELS</u>   |              |                  |                 |                   |                        |                                          |
| 4                           | A°           | 270              | 155             | 0                 | --                     | Some delamination                        |
|                             | A            | 260              | 150             | 9.2               | .303                   | Delam, crystallized<br>V-gell-interlayer |
|                             | C°           | 395              | 180             | 0                 | .237                   | Dissolved V-gell<br>melted interlayer    |
|                             | C*           | 340              | 100**           | 9.2               | .339                   | I/L bubbles, delam                       |
| 5                           | D            | 355              | 100**           | 11.0              | .452                   | I/L bubbles, delam                       |

\*After Test No. C°, the glass face and outboard interlayer were removed and the interlayer replaced

\*\*Inboard surface cooled by maintaining the inside cavity at 75°F

\*\*\*Superscript ° indicates temperature without inboard pressure



Maintaining the outboard surface temperature at 260°F for fifteen minutes with 9.2 psi internal pressure caused severe delamination of the glass ply and the formation of some crystallized particles in the outermost interlayer. (Some of this delamination was associated with an oversight in the panel assembly.) Similar tests of the acrylic-faced panel produced some small bubbles in the outermost interlayer. However, some degree of optics degradation was observed after this test. Subsequent test codes C° and C (Table VI) at higher temperatures caused further glass delamination and bubbling of the outermost interlayer for the glass-faced panels. It was apparent at this point that the design of the glass-faced panels was susceptible to delamination since the glass was not held in place by a strap. Since the glass was more rigid than the rest of the composite, it tried to stay flat while the plastic surface was going convex. Also, some of the bubble formation in the outermost interlayer could have been associated with these delamination forces causing the glass to separate from the panel.

The acrylic-faced panels also showed interlayer bubbles at the higher temperature/pressure exposures comparable to the glass-faced design. Bubbles formed in the interlayer that subsequently helped to cause acrylic deformation. The photographs in Figure 20 show the optical effect of the damage caused by these tests. The photographs present a view of the standard 1" gridboard through panel No. 5 inclined at the F-111 windshield installation angle of 22°. Comparison of the Figure 20(b) photograph with the as-fabricated condition in Figure 20(a) graph illustrates the detrimental effects of the tests.

#### c. Final Thermal/Pressure Testing

Based on the initial test results, modifications to the basic acrylic and glass-faced constructions were designed and parts fabricated. Initial modifications consisted of using a silicone material as the outermost interlayer for a glass-faced construction (Sample No. 7) and a thermosetting plastic CR-39® as a substitute for the outboard acrylic on the all-plastic design (Sample No. 8). Except for these changes, Sample Nos. 7 and 8, were similar to previous circular samples. Neither of these samples showed any improvement with actual failures occurring early in the proposed test sequence.

Sample No. 7, glass-faced with silicone outermost interlayer, did not have acceptable adhesion to the glass surface. This sample subjected to an internal pressure of 11 psi, showed gross delamination at the silicone-glass interface when the outboard glass surface reached 140°F. Hence, Sample No. 7 never achieved the first test exposure of 260°F at 11-12 psi.

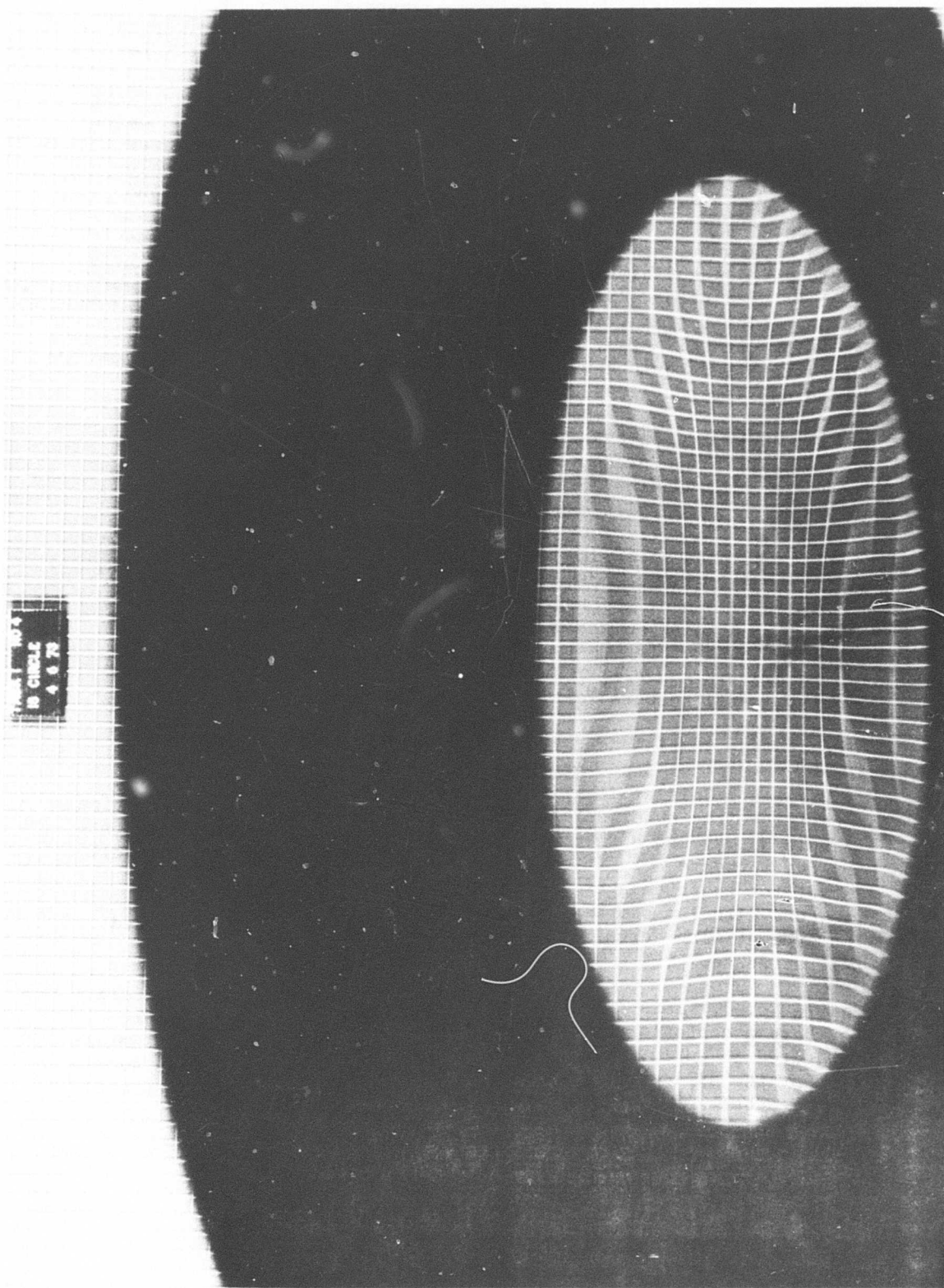


FIGURE 20(a). THERMAL SAMPLE NO. 5 BEFORE TEST



FIGURE 20(b). THERMAL SAMPLE NO. 5 AFTER TEST



Although Sample No. 8, the CR-39-faced panel, did achieve the first stage of the test sequence of 260°F at 11-12 psi, the sample did not perform successfully. Bubbles formed at the CR-39 interlayer surface, and the outboard CR-39 ply fractured and deformed. In essence, this material did not surpass the performance of acrylic.

The gross interlayer bubble formation exhibited by glass-faced samples was attributed at least partially to the stiffness of glass compared with the remaining plastic structure. It was reasoned that internal pressure loads causing deflections approaching 1/2" produced additional peel stresses especially at the interlayer edge between the rigid glass face and the more flexible plastic. To substantiate this reasoning, Sample No. 9 which was identical to previous glass-faced samples except for glass edge attachment that extended to the edge, was tested. An additional sample with glass on both sides extending to the edge, Sample No. 12, was also fabricated and tested.

Earlier tests indicated the acrylic-faced panels could not sustain the thermal/pressure exposures with the outboard acrylic showing heat deformation after interlayer bubble formation at the acrylic surface. To improve this performance, acrylic fused to polycarbonate was substituted as the outboard ply. This addition of polycarbonate was designed to improve the acrylic stiffness and increase thermal insulation to protect the interlayer. As shown in Figure 18, 1/8" and 3/16" polycarbonate were used to fabricate Sample Nos. 10 and 11. Results of tests of these latest designs are tabulated in Table VII.

The latest modifications of holding the glass and acrylic fused to polycarbonate as the outboard face yielded significant improvements in combined thermal/pressure load performance. The glass-faced Sample No. 9 sustained a total time of 60 minutes at 360°F, 11-12 psi which was the best performance achieved by any design. After the last test at 360°F, 11-12 psi for 30 minutes, some small bubbles formed in the outermost interlayer. These bubbles are outlined on the photograph Figure 21. Conversely, Sample No. 12 with glass on both sides exhibited a poor performance that could not be explained.

Utilization of fused acrylic-polycarbonate facing also showed a significant improvement when compared to the acrylic-faced design. No effects were produced in the acrylic-3/16" polycarbonate-faced panel No. 11 until the next to the last test was conducted. In test D-2, the 360°F exposure for 20 minutes, acrylic deformation and some interlayer bubbles developed. Some of the interlayer bubbles, as shown in Figure 22, were considerably larger than the

TABLE VII - RESULTS OF FINAL TEMPERATURE/PRESSURE TESTS ON 15" CIRCULAR PANELS

| Construction     | Sample No. | Test | T <sub>0</sub> (°F) | T <sub>I</sub> (°F) | PSI/Total Min | T <sub>A</sub> (°F) | Max. Defl. (Center) | Results                                                                                                                                                                            |
|------------------|------------|------|---------------------|---------------------|---------------|---------------------|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CR-39 - 112      | 8          | A    | 280                 | 111                 | 11.4/17       | 172                 | .369                | Small bubbles in I/L<br>CR-39 broke; piece fell off                                                                                                                                |
|                  |            | B    | 315                 | 121                 | 11.4/10       | 178                 | .353                |                                                                                                                                                                                    |
| Glass - 112      | 9          | A    | 277                 | 131                 | 11.5/16       | 168                 | .120                | No effects (trapped air<br>voids due to lamination)<br>No effects<br>No effects<br>No effects<br>10% growth in original<br>voids (no new areas)<br>40 I/L bubbles, voids<br>growth |
|                  |            | B    | 301                 | 139                 | 11.5/10       | 264                 | .116                |                                                                                                                                                                                    |
|                  |            | C    | 345                 | 123                 | 11.5/10       | 308                 | .141                |                                                                                                                                                                                    |
|                  |            | D-1  | 364                 | 132                 | 11.5/10       | 316                 | .159                |                                                                                                                                                                                    |
|                  |            | D-2  | 368                 | 208                 | 11.5/21       | 343                 | .157                |                                                                                                                                                                                    |
|                  |            | D-3  | 370                 | 132                 | 11.5/31       | 340                 | .142                |                                                                                                                                                                                    |
| Acrylic/PC - 112 | 10         | A    | 265                 | 116                 | 11.2/15       | 192                 | .340                | No effects<br>No effects<br>Slight acrylic deformation<br>I/L bubbles, acrylic deformed                                                                                            |
|                  |            | B    | 300                 | 90                  | 11.2/10       | 210                 | .354                |                                                                                                                                                                                    |
|                  |            | C    | 335                 | 130                 | 11.3/10       | 244                 | .405                |                                                                                                                                                                                    |
|                  |            | D-1  | 365                 | 143                 | 11.3/10       | 276                 | .421                |                                                                                                                                                                                    |
|                  |            | A    | 267                 | 112                 | 11.2/15       | 192                 | .326                |                                                                                                                                                                                    |
|                  |            | B    | 330                 | 100                 | 11.4/11       | 205                 | .354                |                                                                                                                                                                                    |
|                  |            | C    | 341                 | 106                 | 11.4/10       | 227                 | .385                |                                                                                                                                                                                    |
|                  |            | D-1  | 370                 | 98                  | 11.4/11       | 230                 | .401                |                                                                                                                                                                                    |
| Glass - 112      | 12         | D-2  | 374                 | 113                 | 11.5/20       | 263                 | .591                | No effects<br>No effects<br>No effects<br>No effects<br>Damaged surface and I/L                                                                                                    |
|                  |            | B    | 207                 | 107                 | 11.2/10       | 263                 | .138                |                                                                                                                                                                                    |
|                  |            | C    | 344                 | -                   | 11.5/12       | 300                 | .149                |                                                                                                                                                                                    |
|                  |            | D-1  | 367                 | -                   | 11.2/11       | 316                 | .142                |                                                                                                                                                                                    |
|                  |            |      |                     |                     |               |                     |                     |                                                                                                                                                                                    |

NOTES: T<sub>0</sub> = Maximum Constant Outboard Surface Temperature

T<sub>I</sub> = Maximum Inboard Surface Temperature During Test With Inboard Ambient at +75°F

T<sub>A</sub> = Maximum Temperature During Test in Outermost Interlayer Ply

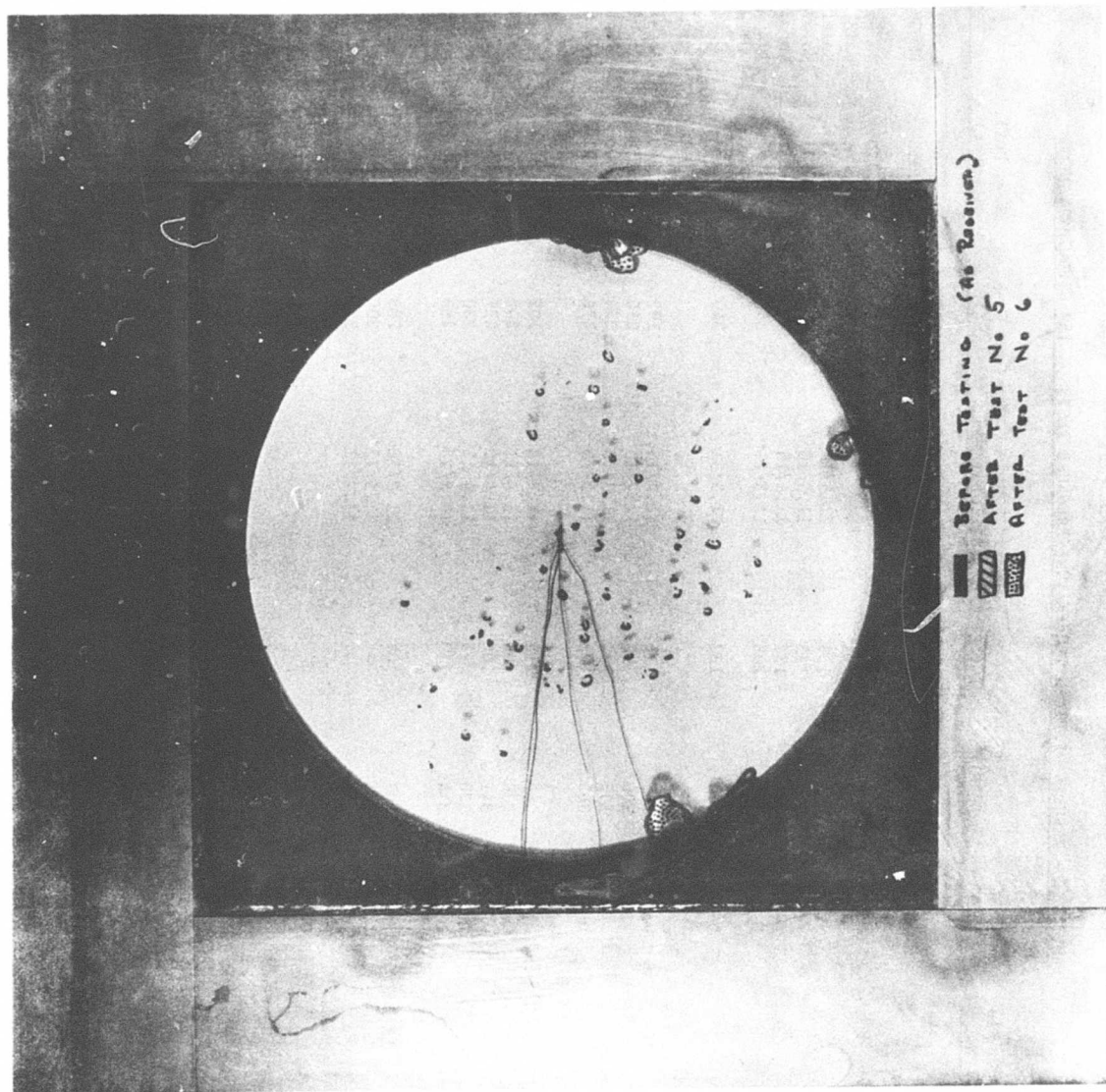
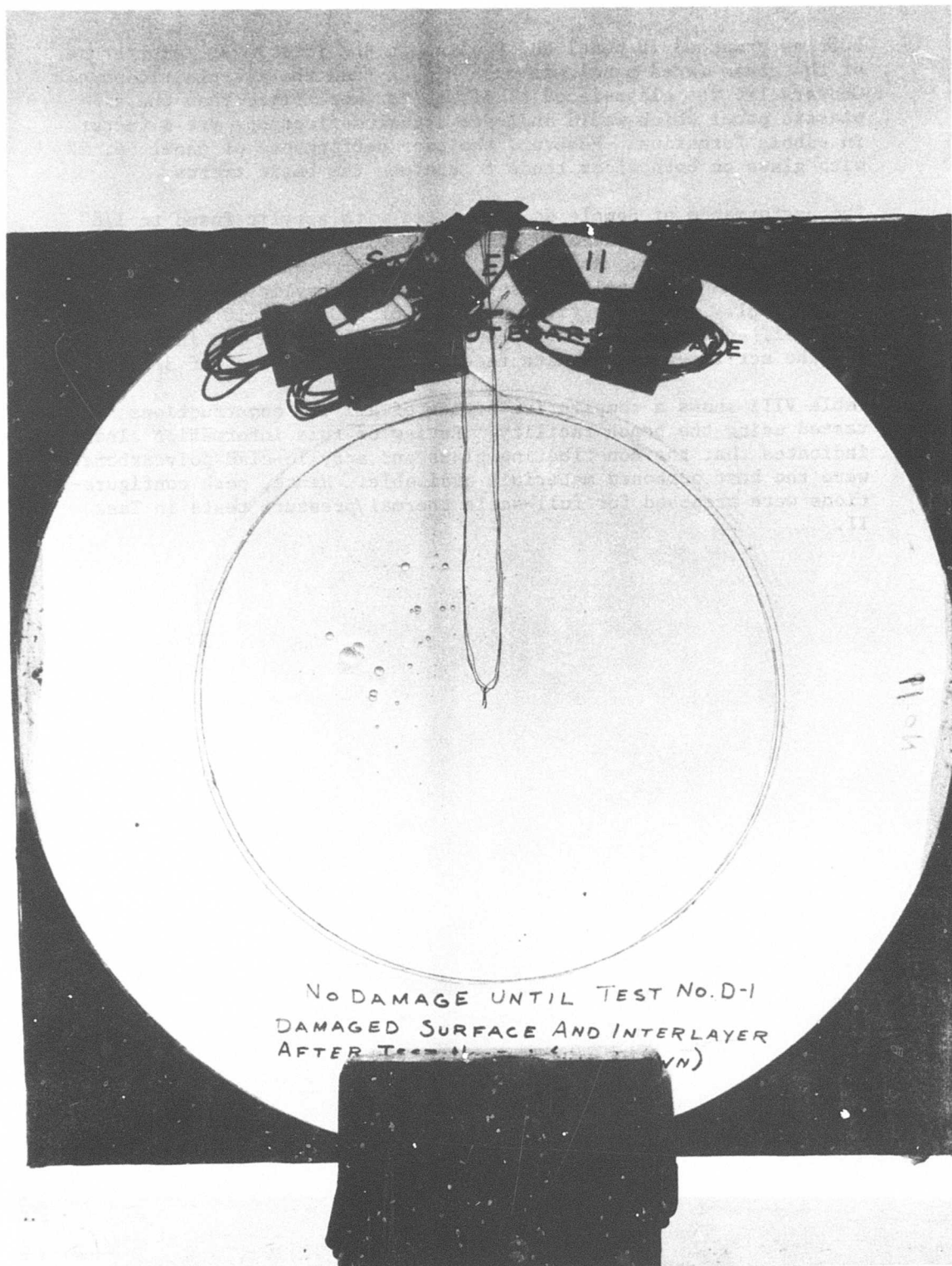


FIGURE 21. BUBBLES AND DELAMINATION IN GLASS-FACED PANEL NO. 9  
AFTER COMPLETION OF T/P TEST (THROUGH D-3)



**FIGURE 22. BUBBLES IN ACRYLIC & POLYCARBONATE-FACED PANEL NO. 11 AFTER COMPLETION OF TEST D-2.**



bubbles produced in panel No. 9 although the interlayer temperature of the glass-faced panel was much higher than the all-plastic panel. Conversely, the glass-faced panel was far more rigid than the all-plastic panel which would indicate actual deflections are a factor in bubble formation. However, the poor performance of panel No. 12 with glass on both sides tends to confuse the basic trends.

The performance of Sample No. 10, faced with acrylic fused to 1/8" polycarbonate, was generally consistent with panel No. 11 using 3/16" polycarbonate. As expected, interlayer bubble formation developed one test earlier than the thicker acrylic-polycarbonate faced panel. After the first exposure of 360°F for 10 minutes, test D-1, approximately thirty bubbles developed in the interlayer and the acrylic-polycarbonate face had a permanent set of 3/16".

Table VIII shows a comparative review of all the constructions tested using the bench facility. Review of this information clearly indicates that the non-floating glass and acrylic-clad polycarbonate were the best outboard materials available. Hence, both configurations were proposed for full-scale thermal/pressure tests in Task II.

TABLE VIII - RELATIVE TEMPERATURE/PRESSURE PERFORMANCE OF OUTBOARD CONSTRUCTIONS  
LAMINATED TO THE PROPOSED TWO STRUCTURAL PLY POLYCARBONATE DESIGN

| PANEL<br>NO. | OUTBOARD CONSTRUCTION       |                | TEST CAUSING<br>DETIMENTAL EFFECT | TEMP.<br>(°F) | PRESSURE<br>(PSI) | TOTAL TIME<br>(MIN) |
|--------------|-----------------------------|----------------|-----------------------------------|---------------|-------------------|---------------------|
|              | TRANSPARENT PLY             | INTERLAYER     |                                   |               |                   |                     |
| 2            | .060" Acrylic               | .150" 112      | C                                 | 375           | 9.2               | 5                   |
| 4            | .110" Glass                 | .150" 112      | C                                 | 340           | 9.2               | 5                   |
| 7            | .110" Glass                 | .150" Silicone | A                                 | 140           | 11                | 0                   |
| 8            | .125" CR-39*                | .150" 112      | B                                 | 315           | 11                | 10                  |
| 9            | .110" Glass**               | .150" 112      | D-3                               | 370           | 11.5              | 61                  |
| 10           | .060" Acrylic +<br>.125" PC | .090" 112      | D-1                               | 365           | 11.4              | 10                  |
| 11           | .060" Acrylic +<br>.188" PC | .090" 112      | D-2                               | 374           | 11.5              | 30                  |
| 12           | .110" Glass**               | .090" 112      | D-1                               | 367           | 11.2              | 11                  |

\*Thermosetting plastic material, Allyl Diglycol Carbonate

\*\*Edge attachment of glass or glass itself extended to the outer edge of sample (not floating)

## 5. IMPACT RESISTANCE

Two methods were employed in determining impact resistance in Task I. Preliminary screening of interlayers, structural materials and coatings was accomplished via a laboratory impact cannon which is used to fire a 150 gram urethane-faced titanium missile at 12" x 12" targets at speeds up to 390 knots. Standard penetration curves have been generated prior to this contract for various materials and laminates as shown in Figure 23. As confirmed by these curves, polycarbonate (PC) is the only state-of-the-art material capable of providing the required impact resistance within the weight and thickness limitations for canopies and windshields.

One of the continuing problems with field use of PC transparencies is the poor abrasion and chemical resistance of PC. The air cannon screening involved preliminary tests to determine the relative performance of various methods of protecting the PC. Cladding the PC by fusing as-cast acrylic does provide abrasion and chemical protection, but as Figure 23 shows, the impact strength is reduced by cracks which originate in the acrylic. Another method is to interpose an interlayer or adhesive between the PC and a protective ply which yields penetration limits close to that of the PC ply itself. A third is to apply an abrasion resistant coating to the PC.

One group of screening tests involved PC plus three potential abrasion-resistant coatings. Nominal 286 kt impacts were made with the 150 gram missile on .250" PC with MR 4000, Abcrite and O-I 650 coating on two sides and with O-I 650 on one side. Only Abcrite-coated PC stopped the missile and formed a ductile bulge. PC with O-I 650 on one side bulged then failed and the others exhibited complete brittle failure. Inspection of shipments of Abcrite, however, shows poor adhesion to the substrate. For this reason, and the fact that MR 4000 is only available on as-extruded LEXAN,<sup>®</sup> O-I 650 was chosen for limited evaluation in preliminary bird impact tests.

The effect of coatings on the impact resistance of PC also included preliminary missile impacts on 12" x 12" x .125" specimens of PC with the L-O-F 15 ohms/square gold film applied to one surface. In order to simulate end-use conditions, samples were exposed to standard laminating time-temperature-pressure conditions. Missile velocities were 246 to 253 kt, approximating the known penetration velocity for as-received, uncoated .125" PC. Impacts on either the coated or uncoated surfaces showed no evidence of embrittlement with ductile penetrations in both cases.

As mentioned above, the addition of an interlayer or adhesive between the protective ply and the PC structural ply serves to stop crack propagation, thereby resulting in a transparency with both durability and impact resistance. However, this is true only as long as the interlayer maintains its elastomeric properties. Since one of the bird impact

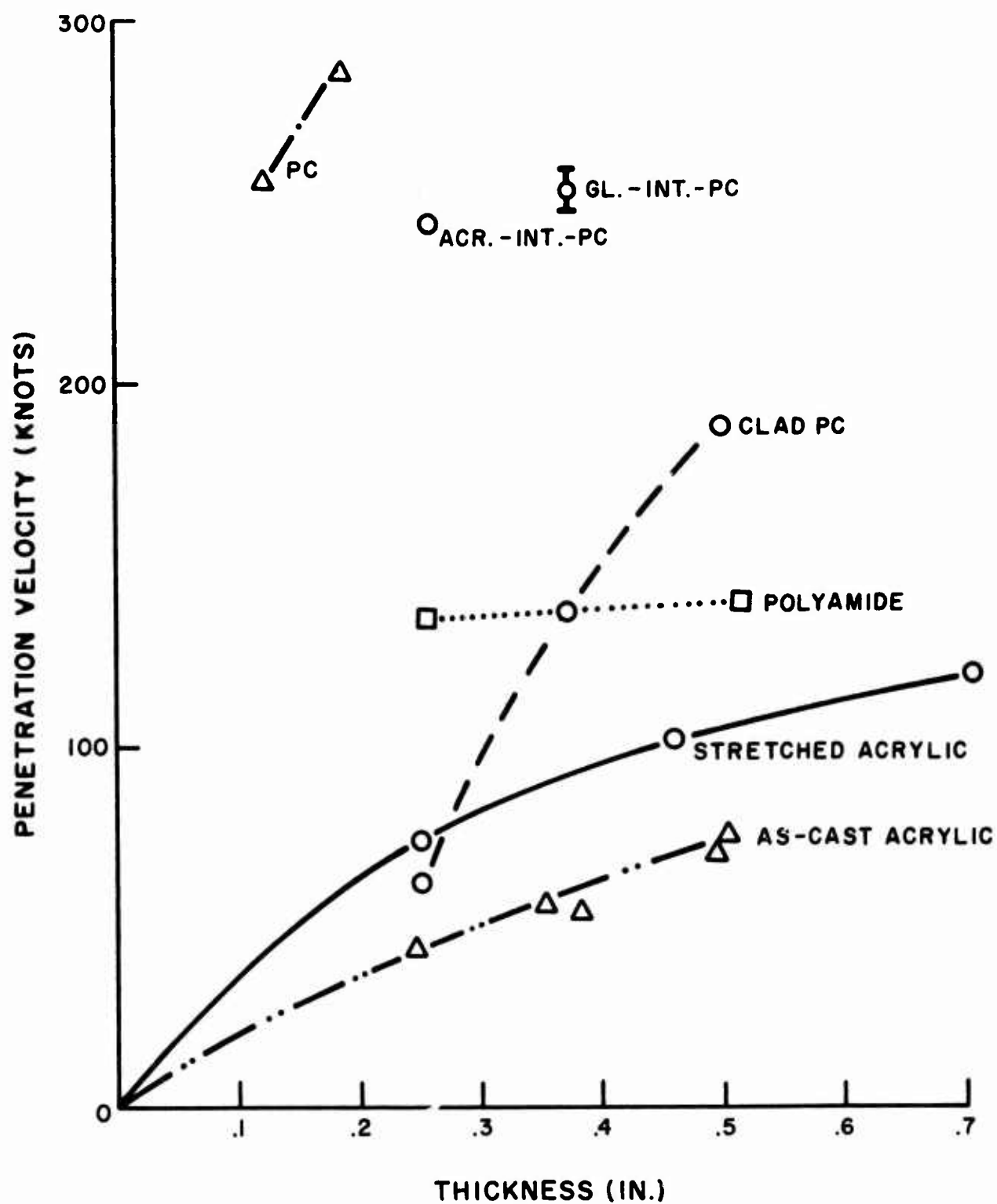


FIGURE 23. RESISTANCE TO 150 GM. MISSILE PENETRATION

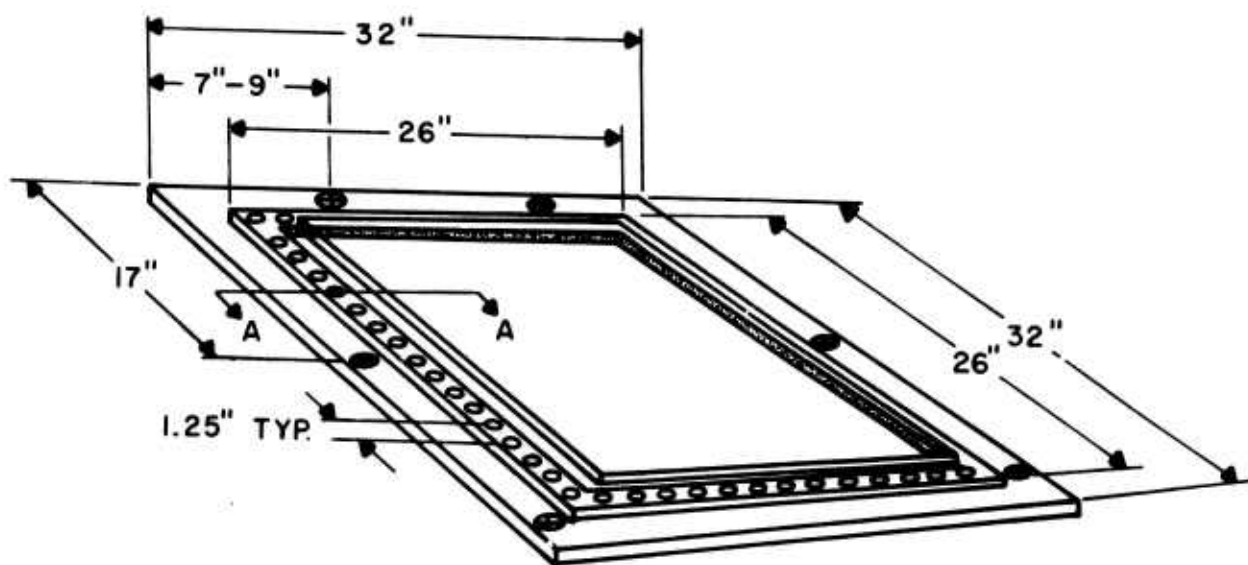
requirements involved a gradient of -30°F outboard ambient to room temperature inboard, it was felt that some of the currently available interlayer/adhesives would be too brittle to prevent crack propagation. To fix this range for candidate interlayers, a series of air cannon impacts was used to evaluate low temperature embrittlement. Here, 12" x 12" specimens of .110" HERCULITE® II glass - .090" interlayer - .125" PC were impacted at a nominal 243 kt, just below the penetration velocity for this combination. Interlayer temperature was varied and the temperatures at which the missile was stopped or just penetrated determined the embrittlement range. In preliminary screenings, silicones were superior although plagued with adhesion problems. PPG CIP-64, currently used in the F-111, exhibited an embrittlement range between approximately +40°F and 50°F. Of those considered applicable for this program, two materials, PPG 112 and Monsanto Research Corporation Ethylene Terpolymer, exhibited the most promising embrittlement ranges. For comparison, data was also gathered for phosphate plasticized polyvinyl butyral (TCP Vinyl). This experimental vinyl was chosen for its compatibility with PC, unlike 3GH Vinyl in which the plasticizer attacks PC. As shown, the "low temperature" embrittlement range is actually above room temperature and is much higher than other candidate materials.

TABLE IX. - INTERLAYER EMBRITTLEMENT RANGE

| <u>INTERLAYER</u>   | <u>MISSILE<br/>PENETRATED</u> | <u>MISSILE<br/>HELD</u> |
|---------------------|-------------------------------|-------------------------|
| TCP Vinyl           | 86°F                          | 121°F                   |
| PPG 112             | 11°F                          | 18°F                    |
| Ethylene Terpolymer | 16°F                          | 24°F                    |

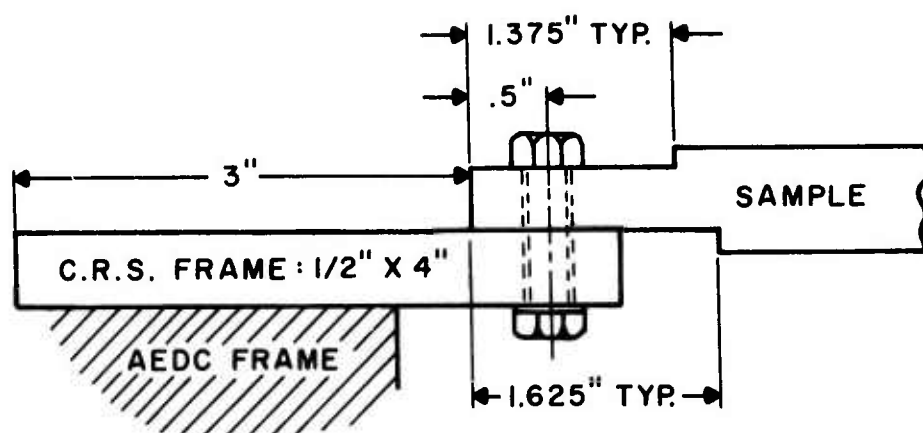
In addition to the air cannon test work, the primary evaluation of impact resistance in Task 1 was made via room temperature bird impacts on flat 26" x 26" panels. This phase of the program was conducted at Arnold Engineering Development Center (AEDC), Tullahoma, Tennessee.<sup>6</sup> All impacts were center strikes with 4 lb birds. A sketch of a typical panel and an edge mounting section appears in Figure 24. The panels were bolted to a 1/2" x 4" steel frame which was clamped to the rigid AEDC support, as shown in Figures 25 and 26. Figure 25 is an overall view of the impact area configuration for windshields mounted at 22° from the line of flight of the bird. Figure 26 gives a close-up view of a panel bolted to the steel mounting frame which is subsequently clamped to the target holder. The canopy test apparatus was identical to that used for windshields except that the support structure was modified to give an angle of incidence of 13.2° from the line of flight of the bird.

<sup>6</sup>For a complete description of the AEDC flight impact simulator, see: E. J. Sanders. "The AEDC Bird Impact Test Facility," AFML-TR-73-126, Conference on Transparent Aircraft Enclosures, June, 1973.



**NOTE:**

● = FINAL CLAMP LOCATIONS



**SECTION A-A**

**FIGURE 24. TASK I BIRD IMPACT SAMPLE  
AND MOUNTING FRAME**



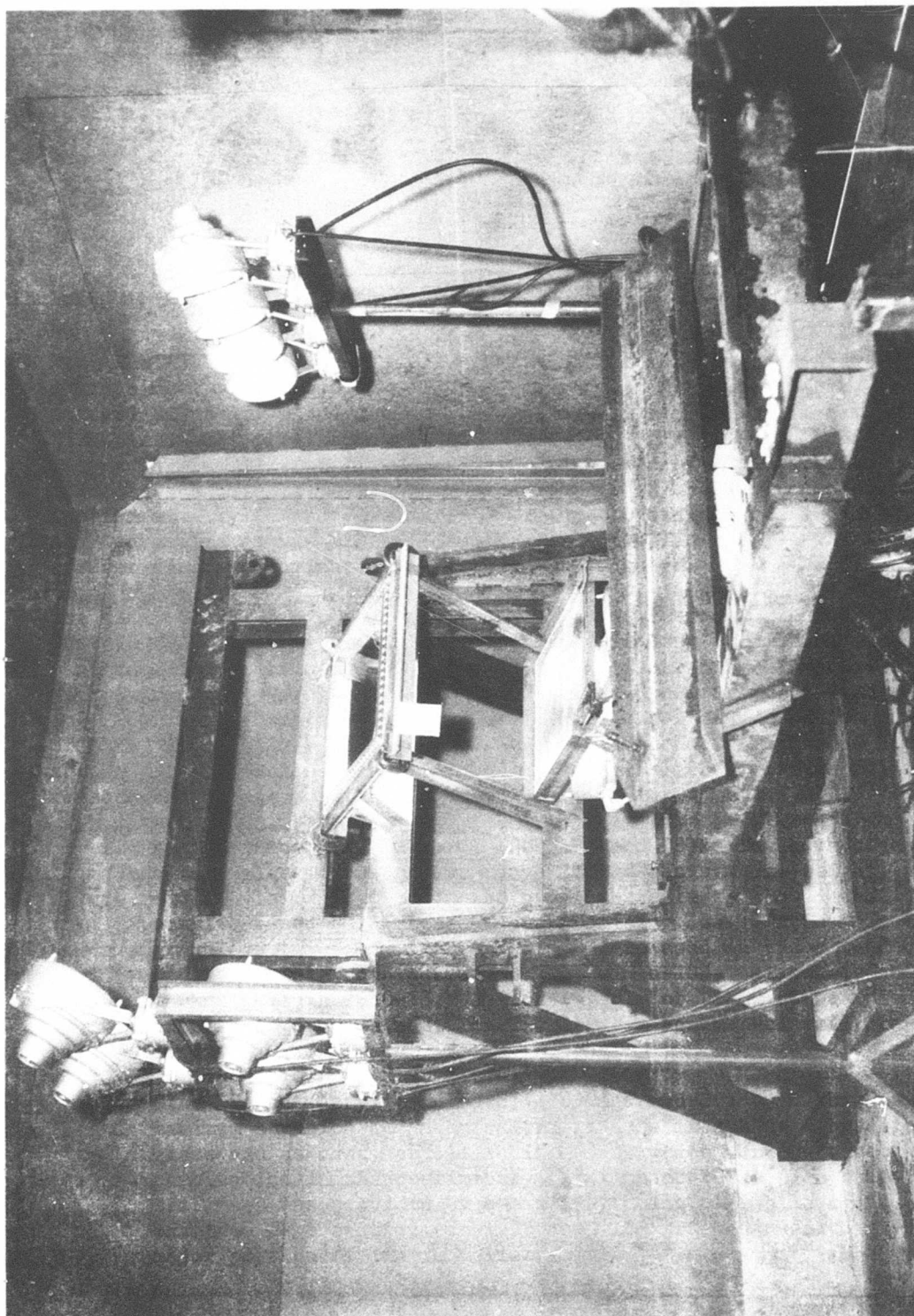


FIGURE 25. PRELIMINARY TASK I FLAT PANEL BIRD IMPACT TARGET AREA

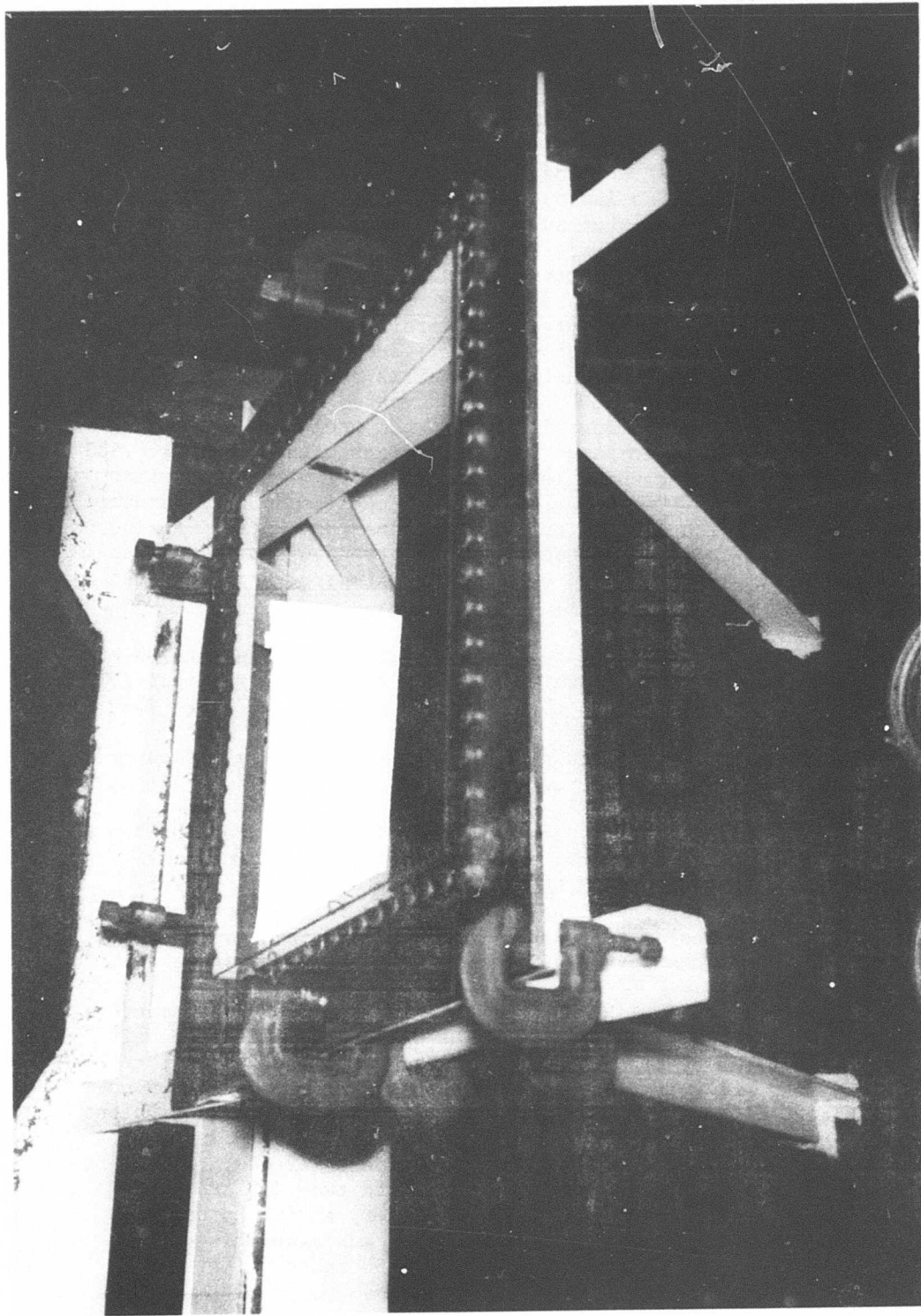


FIGURE 26. TASK I CANOPY BIRD IMPACT PANEL AND MOUNTING

Task I bird impact tests consisted of two groups. The first was designed to make comparisons between materials and cross-sections reflecting inputs from the material evaluation, laboratory impacts and PPG's experience in the 4 lb/500 kt impact range. The results from the preliminary bird impacts were combined with candidate edgemember designs to produce optimized cross-sections for a second series of bird shots.

Preliminary windshield constructions ranged from those based on relatively thick monolithic PC to laminates of various PC ply thicknesses. In this series of specimens, when surface protection was provided, a "hard" coating, glass, as-cast acrylic or stretched acrylic was selected based on experience or the laboratory materials evaluation. Specific cross-sections were picked to show effects of ply thickness, composition and arrangement with panels of equivalent overall thickness. As listed in Table X, four basic thickness groups were selected. The first consisted of monolithic .750" PC. The second series of eight panels, with a nominal thickness range of .850" - .870", compared monolithic .625" PC, laminated .250" PC and laminated .125" PC components. The third group, 6A, 7A, 13A and 14A compared thicker designs with monolithic .688" and .750" PC to laminated combination of .125" and .188" PC. The last group made use of the .500" maximum outboard extension and was therefore the thickest, ranging from 1.025" to 1.090" nominal thickness. Again, monolithic and laminated PC components were compared but in this group a floating .125" PC ply was placed between the outboard facing ply and the first extended PC mounting ply.

Detailed results for the first 18 tests are described on the data sheets in Appendix 1. However, the laminated group is summarized in Figures 27, 28 and 29 which correspond to the order and grouping of Table X.

Several basic conclusions were drawn which influenced the selection of optimized Task I test panel constructions.

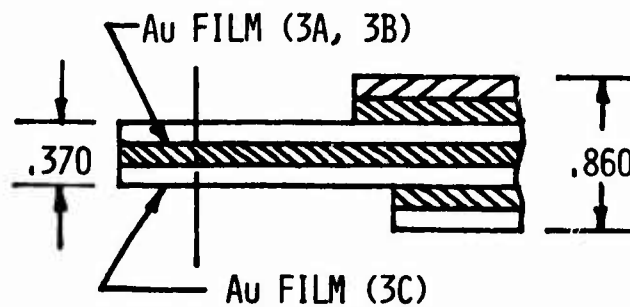
1. Even with center impacts, the panel support system can influence results. In initial shots, clamp restraint and sharp frame edges caused unexpected failures along the aft edge. In subsequent tests, support structure edges (test frames or module mounting surfaces) were rounded to minimize shearing, and the clamping locations were stabilized for the top edge and sides.
2. In general, the likelihood of brittle failure was proportional to PC structural ply thickness. The Group 1 monolithic panels were destroyed by impacts even 44 knots below the 500 knot requirement. Likewise in the other groups, the panels with monolithic PC plies exhibited catastrophic failures while equivalent panels with thin plies prevented penetration. Group 2 provided perhaps the best comparison of ply thickness effects. Sample 5B was blown apart at 447 knots while 8A with two .250" PC plies was sheared or cracked around the periphery at 497 knots. The design with two .125" PC plies, however, sustained hits up to 525 knots and was not penetrated until 538 knots.

TABLE X - CONSTRUCTIONS FOR TASK I PRELIMINARY BIRD IMPACT TESTS

| <u>UP</u> | <u>SAMPLE</u> | <u>SHOT NO.</u> | <u>CONSTRUCTION (IMPACT-FACING SURFACE LISTED FIRST)</u>                                                                 |
|-----------|---------------|-----------------|--------------------------------------------------------------------------------------------------------------------------|
|           | 1A            | WT-17           | .750" PC (.375" PC extended edge section)                                                                                |
|           | 2A            | WT-12           | .750" PC (coated both sides with OI 650) (.375" PC extended edge<br>-----)                                               |
|           | 3A,3B         | WT-2,5          | .125" Acrylic - .120" IL - .125" PC (15 ohms/sq gold film)* -<br>.120" IL* - .125" PC* - .120" IL - .125" PC             |
|           | 3C            | WT-7            | .125" Acrylic - .120" IL - .125" PC* - .120" IL* - .125" PC*<br>(15 ohms/sq gold film) - .120" IL - .125" PC             |
|           | 4A,4B         | WT-3,1          | Same as Code 3, without 15 ohms/sq gold coating                                                                          |
|           | 8A            | WT-6            | .110" Glass - .120" IL - .250" PC - .120" IL* - .250" PC<br>(.125" PC - .120" IL - .125" PC extended edge)               |
|           | 5A,5B         | WT-4,16         | .125" Acrylic - .120" IL - .625" PC (.375" PC extended edge)<br>-----)                                                   |
|           | 6A            | WT-14           | .125" Acrylic - .090" IL - .750 PC (.375" PC extended edge)                                                              |
|           | 7A            | WT-18           | .125" Acrylic - .120" IL - .188" PC* - .090" IL - .188" PC* -<br>.120" IL - .125" PC                                     |
|           | 13A           | WT-9            | .060" Acrylic/.093" PC - .120" IL - .125" PC* - .090" IL* -<br>.188" PC* - .120" IL - .125" PC                           |
|           | 14A           | WT-15           | .060" Acrylic/.093" PC - .120" IL - .688" PC (.438" PC<br>extended edge)<br>-----)                                       |
|           | 9A            | WT-11           | .110" Glass - .120" IL - .125" PC - .120" IL - .125" PC* -<br>.120" IL* - .125" PC* - .120" IL - .060" Acrylic           |
|           | 10A           | WT-13           | Same as Code 9 but with 15 ohms/sq gold film on glass                                                                    |
|           | 11A           | WT-8            | .110" Glass - .120" IL - .625" PC - .120" IL - .060" Acrylic<br>(.375" PC extended edge)                                 |
|           | 12A           | WT-10           | .110" Glass - .120" IL - .125" PC - .120" IL - .125" PC* -<br>.120" IL* - .125" PC* - .120" IL - .125" Stretched Acrylic |

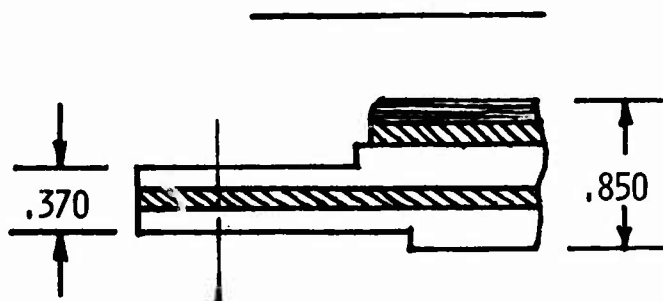
Include in extended edge section.



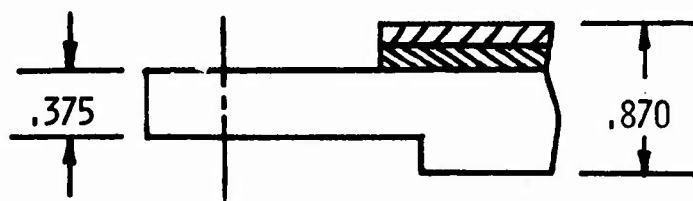


|      |    |        |        |                          |
|------|----|--------|--------|--------------------------|
| WT-2 | 3A | FAILED | 447 KT | PUNCHED THRU TOP (FRAME) |
| WT-5 | 3B | OK     | 525    | NO SHEARING OR PC DAMAGE |
| WT-7 | 3C | FAILED | 538    | SHEARED TOP EDGE         |

|      |    |        |        |                         |
|------|----|--------|--------|-------------------------|
| WT-3 | 4A | OK     | 510 KT | NO PC DAMAGE            |
| WT-1 | 4B | FAILED | 504    | 1ST SHOT - CUT BY FRAME |

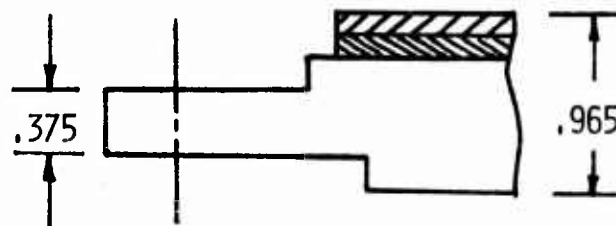


|      |    |        |        |                               |
|------|----|--------|--------|-------------------------------|
| WT-6 | 8A | FAILED | 497 KT | SHEARED AT TOP, CRACKED EDGES |
|------|----|--------|--------|-------------------------------|

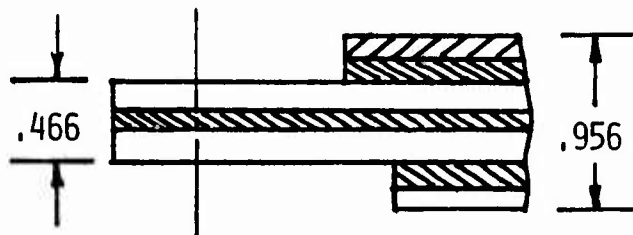


|       |    |        |        |                 |
|-------|----|--------|--------|-----------------|
| WT-4  | 5A | FAILED | 483 KT | BLEW OUT CENTER |
| WT-16 | 5B | FAILED | 447    | " " "           |

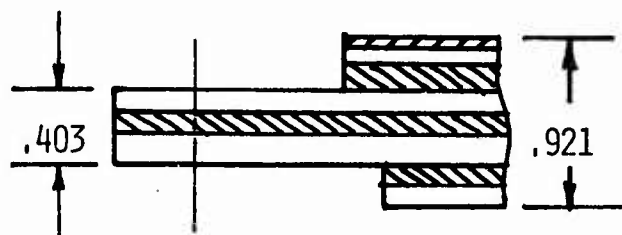
FIGURE 27. SUMMARY OF TASK I PRELIMINARY BIRD IMPACTS (GROUP 2)



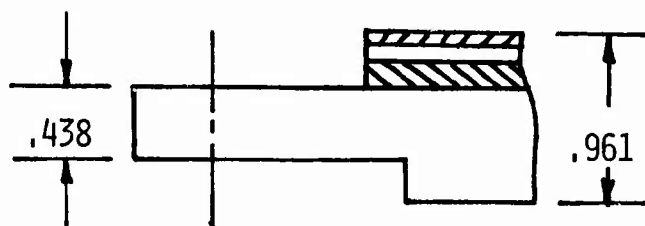
WT-14 6A FAILED 511 KT BLEW OUT CENTER



WT-18 7A OK 507 KT NO PC DAMAGE



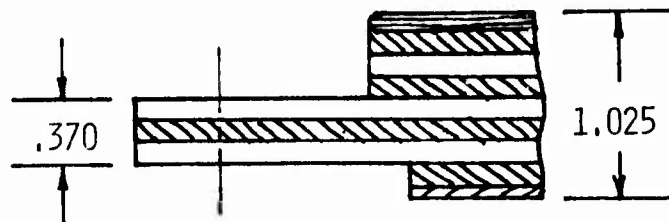
WT-9 13A OK 499 KT NO SERIOUS DAMAGE



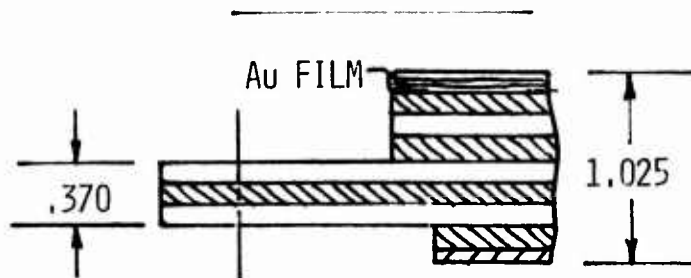
WT-15 14A FAILED 478 KT BLEW OUT CENTER

FIGURE 28. SUMMARY OF TASK I PRELIMINARY BIRD IMPACTS (GROUP 3)

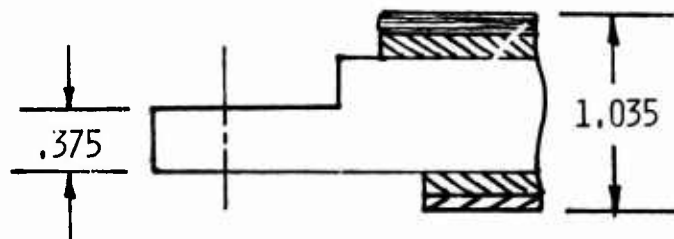




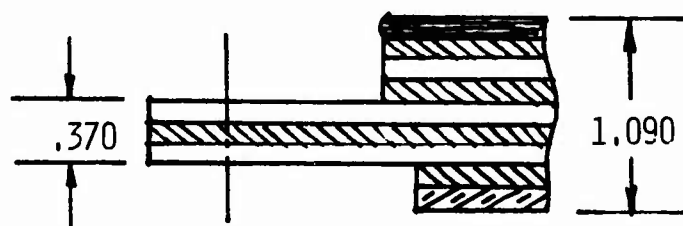
WT-11 9A OK 517 KT PC CRACK AT TOP (CRAZING) PLEX OK



WT-13 10A OK 491 KT PC CRACK AT TOP. GOLD FILM OK. PLEX OK



WT-8 11A FAILED 509 KT BLEW OUT CENTER



WT-10 12A OK 512 KT PC CRACK AT TOP. DANGEROUS S/A SPALL

FIGURE 29. SUMMARY OF TASK I PRELIMINARY BIRD IMPACTS (GROUP 4)

3. The other thickness effect was demonstrated in Group 4. The stiff outboard section of glass and an extra PC ply did not improve the penetration over thinner designs. In fact, PC cracking indicated that the opposite was true. Therefore, it was not necessary or even advantageous to pursue constructions which took advantage of the .500" allowable deviation from mold line.
4. A floating ply of PC inboard did not adversely affect penetration resistance, although no evaluation could be made as to the degree of improvement. One thickness iteration of unattached PC inboard was included in optimized flat panels.
5. The gold 15 ohms/square radar reflecting film worked well on both glass and PC. Adhesion of the film to substrates and of all 112 interlayer to the film was good in all cases. In general, results were equivalent for similar specimens with and without coating, as a result:
  - (a) Location of the film can be determined by its effect on optics, resistance to arcing or other reasons.
  - (b) For cost savings, the film was eliminated from the balance of Task I bird impact test specimens.
6. As far as bird impact resistance was concerned, there was little difference between glass, acrylic or fused acrylic/PC outboard. The final choice of a facing ply was then possible on the basis of other criteria, such as abrasion and thermal resistance, expansion mismatch, residual visibility, etc. Both glass and acrylic were selected for optimized flat panel specimens.
7. As-cast acrylic could be used as an inboard abrasion ply with no serious spalling or degradation of penetration resistance provided PPG N-1 cement or equivalent was used. Stretched acrylic, on the other hand, was unacceptable either with or without the use of adhesives. Large, sharp spall pieces were ejected at measured speeds up to 269 ft/sec during deflection of samples which used stretched acrylic as an inboard floating ply.
8. A two PC ply edge section with thicknesses of .125" and .188" provided the best penetration resistance for the center impacts at the required 500 knots.

Two other panels were produced with preliminary constructions, but tested later. These panels listed in Table XI were originally intended for investigating the effect of LCOS restraint during deflection.

TABLE XI - LCOS RESTRAINT PANEL CONSTRUCTIONS

| <u>SAMPLE</u> | <u>SHOT NO.</u> | <u>CONSTRUCTION</u>                                                                                                           |
|---------------|-----------------|-------------------------------------------------------------------------------------------------------------------------------|
| 15A           | WT-31           | .125" Acrylic - .120" IL - .125" PC - .120" IL -<br>.125" PC* - .120" IL* - .125" PC* - .120" IL -<br>.125" Stretched Acrylic |
| 16A           | WT-30           | .125" Acrylic - .120" IL - .125" PC - .120" IL -<br>.125" PC* - .120" IL* - .125" PC* - .120" IL -<br>.125" PC                |

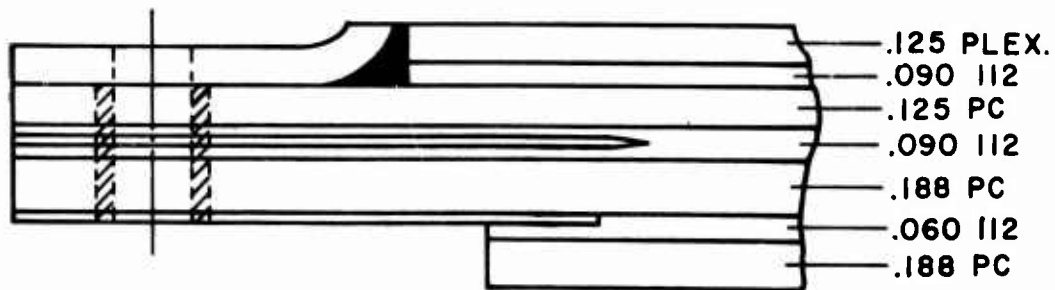
\*Included in extended edge section

Specimen 15A was used to confirm spall characteristics and again, large, sharp pieces were ejected from the inboard surface during impact. The inboard PC of 16A was damaged with a chisel to simulate LCOS damage. Although cracks originated within the ply during deflection, they were stopped by the 112 interlayer and did not cause any adverse effect on bird resistance. It is interesting to note that the laminated outboard section of acrylic and PC used in 15A and 16A did not result in structural PC cracking as was exhibited with panels 9A, 10A and 12A which used a stiffer floating laminate of glass and PC outboard.

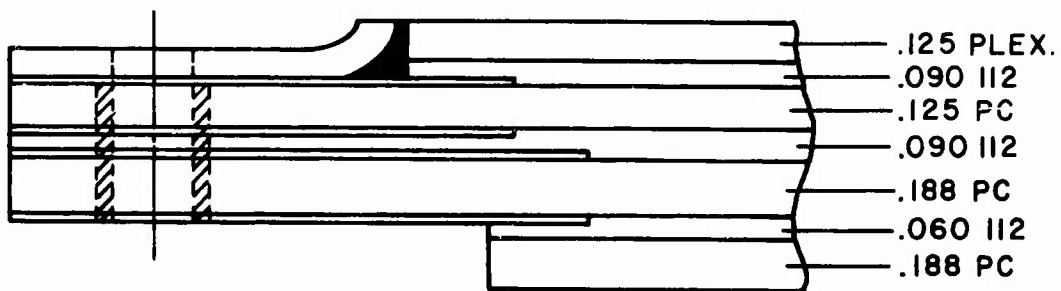
The final Task I windshield bird impact tests were conducted on optimized, flat 26" x 26" panels which, unlike the preliminary specimens, included candidate edge attachments. Three basic constructions (five sample configurations) were developed using inputs from preliminary bird shooting and from the edge attachment, structural and material evaluation portions of this effort. Edge sections of the designs shown in Figure 30 and in the individual data sheets in Appendix 1 were selected for the following reasons:

1. Acrylic-Faced (PC Inboard) (9030-17 and 18) - The advantages of an all-plastic design are many--impact resistance, weight, residual visibility, etc. The preliminary tests showed that an acrylic-faced PC laminate was a promising design type. In this group, PC plies of .125" and .188" were used in the extended section. This combination met the dimensional allowance and worked well in 9030-13. A floating ply of .188" PC was used inboard to provide additional stiffness against thermal/pressure loads.
2. Glass-Faced (Acrylic Inboard) (9030-19 and 20) - In this design, maximum abrasion and chemical resistance is achieved by using glass and as-cast acrylic facing plies which were an acceptable combination in the preliminary bird impact tests. In this case, stiffness was provided by the glass facing ply while again, an extended edge section of .125" and .188" PC was used to gain the major portion of impact resistance.

9030-17A,B,C



9030-18 A,B



9030-19A,B

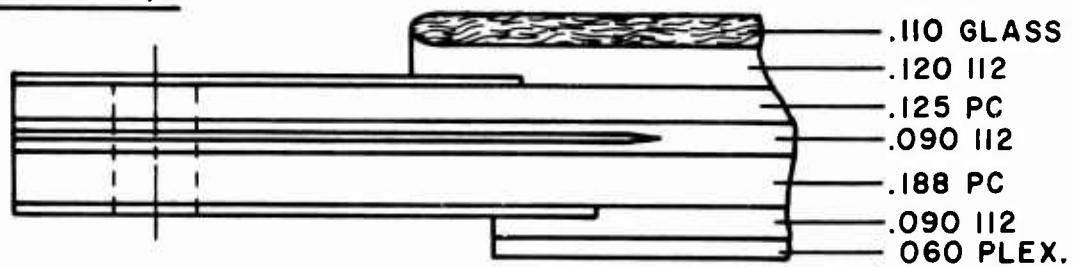
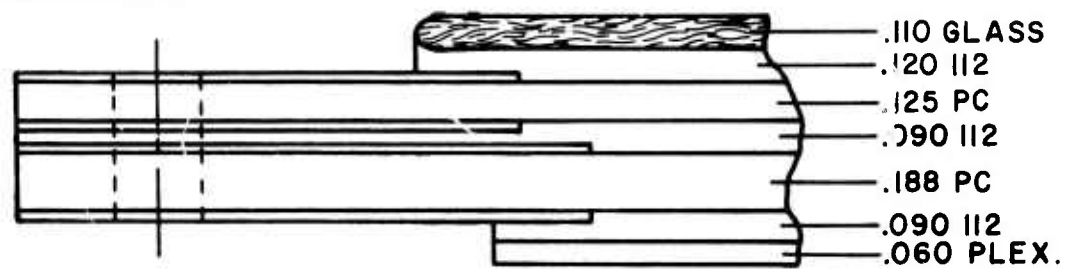


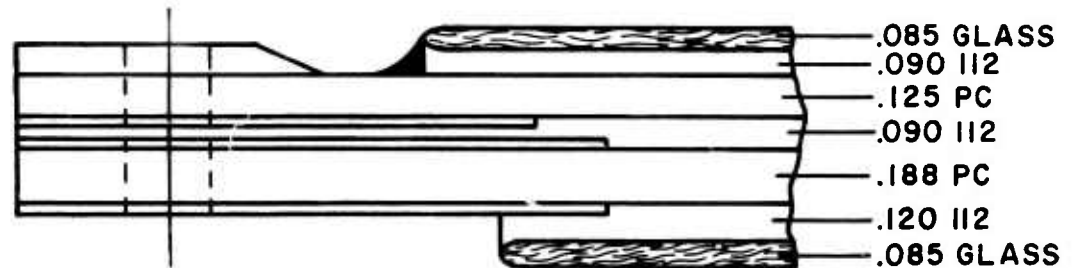
FIGURE 30. TASK I BIRD IMPACT TEST PANELS  
WITH EDGE ATTACHMENTS.

## FIGURE 30. CONTINUED

### 9030-20A,B



### 9030-21A,B



3. Glass-Faced (Glass Inboard) (9030-21) - Problems with glass-faced plastic designs in fabrication and service originate from the 10:1 ratio of coefficients of thermal expansion of plastics to glass. The 9030-21 design with glass on both exposed surfaces introduced a balanced cross-section and also maximum surface durability. Stiffness in service would be comparable to the existing glass windshield, yet during impact, failure of the glass plies would permit the necessary deflection. Failure of the inboard ply would create spall which was to be evaluated for severity during this test series.

Several edge attachment variations were made between and within the three material arrangement groups. As can be seen in Figure 30, combination of straps, inserts, retainers and bushings (spacers) were included. These were cross-referenced with tensile samples in the edge attachment program, as discussed in Task I, Section 3. The retainers were produced from soft aluminum and in groups 17 and 18 were bent as shown in Figure 30. In Group 21 which was tested after retainer "peeling" caused failure in the other groups due to direction of hydrostatic pressure down through the edge, the retainer was either removed (21B) or modified (21A) to include a taper as shown on the data sheet for WT-29 in Appendix 1. Epoxy-Nomex was used for both PC reinforcement straps and inserts with thicknesses and sizes as detailed in Appendix 1. Strap and retainer bonding was via nominal .010" RTV 630. Where tested, aluminum bushings were used.

Detailed data for each of the eleven shots can be found in the data sheets for WT-19 to 29 in Appendix 1 and the deflection data is available in Appendix 2. Several general conclusions were drawn which influenced selection of materials and the construction for the Task II windshield design.

1. Edge Attachment - Although there was no major difference in bird impact resistance between types of reinforcement (straps vs insert), the edge attachment did place severe loading on the bolts, particularly at the rear edge. In several cases, bolt failure led to collapse of the edge during deflection. It was expected that this would amplify the importance of impact location during windshield testing in Task II, and high strength bolts were selected for Task II.

Retainer geometry must be selected to prevent funneling of the hydrodynamic pressure down into the edge, causing shearing of the extended plies. This can be accomplished by geometry of the retainer and elimination of a free edge where peeling can begin.



As far as bird impact resistance was concerned, the RTV 630 adhesive performed well. In general, adhesion of the straps and inserts to 112, or polycarbonate (using RTV 630), was better during impact than the inter-laminar strength of the epoxy-Nomex reinforcement.

2. Transparency Construction - Based on both groups of Task I bird impact tests, two bolted structural plies of .125" and .188" PC with various floating facing plies were sufficient to meet the center 500 knot requirement. The facing plies, however, continued to show offsetting advantages and disadvantages in the final Task I windshield tests.

Specifically:

- a. Failure of chemically strengthened glass plies during impact deflection resulted in the ejection of spall particles and also complete loss of visibility. In the Task I tests, the spall left normal to the bulge inboard surface at average speeds from 296 to 315 ft/sec. Particles were embedded in styrofoam witness plates placed up to 40" below the target point.
- b. Inboard PC - In the first series of tests, a floating inboard ply of .125" PC performed well with no degradation of residual visibility. In the second series of tests, the use of a .188" PC floating ply appeared to create a center section which was too stiff, causing edge shearing. This problem would increase for impacts close to the panel edge.

The balance of unique advantages and disadvantages for the all-plastic and glass-plastic systems was also apparent in the other Task I activities, particularly the thermal/pressure evaluation (Section 4). All tradeoffs were taken into account in recommending constructions for Task II and the following comments summarize plus and minus factors exhibited by the two basic design types.

1. All-Plastic - Results showed that different plastic-faced laminates with thin PC structural plies would provide the necessary bird impact resistance. In addition, considering the current state-of-the-art in protective coatings, thin as-cast acrylic can also serve as an inboard ply and worked successfully under bird impact with no spall problems. In stopping the bird, all-plastic cross-sections retained useful visibility after impact, minimizing the chance for mission completion.

The primary problem according to our data was the degradation of visibility and structural integrity resulting from softening and plastic deformation of acrylic under extremes of temperature and pressure. An outboard ply of fused acrylic and polycarbonate

which was also acceptable during bird impact did give better resistance to F-111 temperature and pressure conditions. The higher heat deflection temperature of the polycarbonate provided extra support for the acrylic while a fused outboard section which is thicker than a monolithic ply causes a corresponding larger temperature drop between the outboard ambient and first interlayer. This, of course, imposes a weight penalty for a thicker, non-structural facing ply.

The important point, however, is that there were several alternatives available. By choosing one material at the beginning of Task II, the final design would not be irrevocably fixed and could reflect changes dictated by thermal and impact tests on full-size windshields.

2. Glass-Faced - Maximum abrasion and chemical resistance was achieved with glass outboard. Interior polycarbonate plies still provided the required impact resistance during flat panel bird impacts. However, fabrication and service problems would exist if glass were used on only one face because of the 10:1 ratio of coefficients of thermal expansion of plastics to glass. The "bimetallic effect" causes shape change as a function of temperature. For example, glass-faced test panels in Task I showed up to 9/16" residual bow over the 26" span at room temperature and windshields would experience even greater change. Concurrently, and especially when the "unbalanced" transparency is restrained, high peel stresses are created at the glass-interlayer interface with the potential for delamination or glass breakage. A design with glass on both faces introduces a "balanced" cross-section and maximizes surface durability. Stiffness in service would be comparable to the existing glass F-111 windshield, yet, as occurred during successful bird impact tests, failure of the glass plies permitted the necessary deflection. Failure of the chemically strengthened glass did have parallel disadvantages since there was no residual visibility after impact and spall was ejected from the inboard face.

One positive point for glass, of course, is its relative insensitivity to temperature when compared with plastic facing materials. Although the glass itself was not affected by temperature/pressure loads, its stiffness and relatively high thermal conductivity did accentuate interlayer problems including separation and bubbling at the extreme thermal/pressure test conditions.

Basically, the Task I tests indicated two areas which were found to have the potential for affecting the overall success in meeting windshield requirements and a Task II program was proposed accordingly. First, it was agreed that preliminary temperature/pressure tests should be conducted on full-size windshields in Task II rather than in Task III when designs would be fixed. Second, since two types of designs (all-plastic

and glass-faced) appeared to have merit and drawbacks for thermal, durability and bird impact resistance, the recommended plan proposed testing both types in Task II. In it, a primary all-plastic design was to receive the bulk of the investigation, but an alternate glass-faced one was included to undergo both thermal and bird impact tests.

Both recommended Task II test windshield designs relied on an extended edge section of .125" and .188" PC plies which met the 500 knot impact requirement. The constructions which were proposed and made for Task II and comments on the edgemembers follow, with sketches of the edge sections shown in Figures 31 and 32.

1. Primary Design (Figure 31) (All-Plastic)

.060" as-cast acrylic + .125" PC (fused) - .090" 112 - .125" PC - .090" 112 - .188" PC - .090" 112 - .060" as-cast acrylic

Areal Density = 5.16 lbs/ft<sup>2</sup>

The straps were to be .020" x 2.00" impregnated nylon (Nomex) bonded with RTV 630 or equivalent. A .125" aluminum retainer was to be used outboard with rectangular geometry on the forward arch, beam and sill. On the aft arch, the proposed retainer was tapered, as shown, to eliminate the chance of "tunneling" by bird tissue.

2. Alternate Design (Figure 32) (Glass-Faced)

.085" chemically strengthened glass - .090" 112 - .125" PC - .090" 112 - .188" PC - .090" 112 - .085" chemically strengthened glass

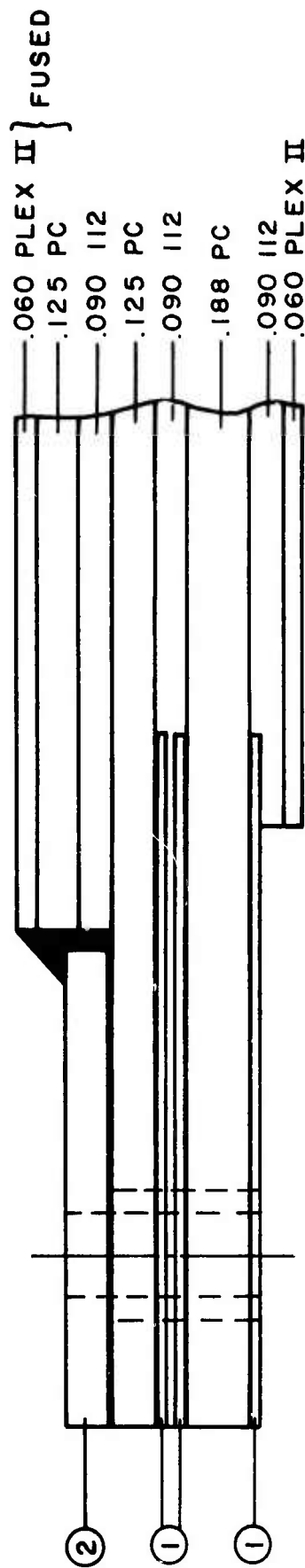
Areal Density = 5.76 lbs/ft<sup>2</sup>

In this design, the outboard glass ply was to be held around its periphery with a strap of .020" aluminum bonded to the inboard surface of the glass with a flexible adhesive such as RTV 630. On three sides, the beam, sill and forward arch, the glass was also to be held by an outboard .020" strap bonded to the glass and to a spacer/retainer with RTV. The outboard ply attachment was to be adhered to a .040" impregnated nylon spacer. The other three straps were proposed to be .020" x 2.00" impregnated nylon bonded with nominal .010" RTV 630 or equivalent.

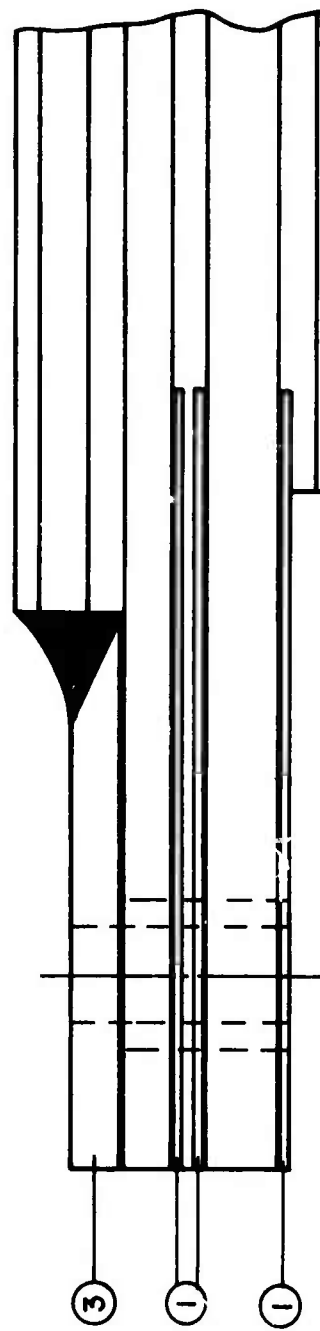
In the figures, the codes correspond to the following edge attachment details:

- (1) = .020" x 2" epoxy-Nomex strap bonded with nominal .010" RTV 630 or equivalent
- (2) = .125" x 1.375" aluminum retainer bonded with RTV 630
- (3) = .125" x 1.375" aluminum retainer (tapered as shown) bonded with nominal .010" RTV 630
- (4) = .020" x 2" aluminum strap bonded to glass and (5) spacer/retainer with nominal .010" RTV 630
- (5) = .080" x 1.375" aluminum spacer/retainer; tapered as shown and gap filled with RTV 630
- (6) = .040" x 1.375" epoxy-Nomex spacer bonded to (4) strap and .125" PC using nominal .010" RTV 630
- (7) = .020" x 2" (plus .030" x .250" additional) epoxy-Nomex strap bonded with nominal .010" RTV 630

# PRIMARY DESIGN



A) BEAM, SILL, FWD ARCH

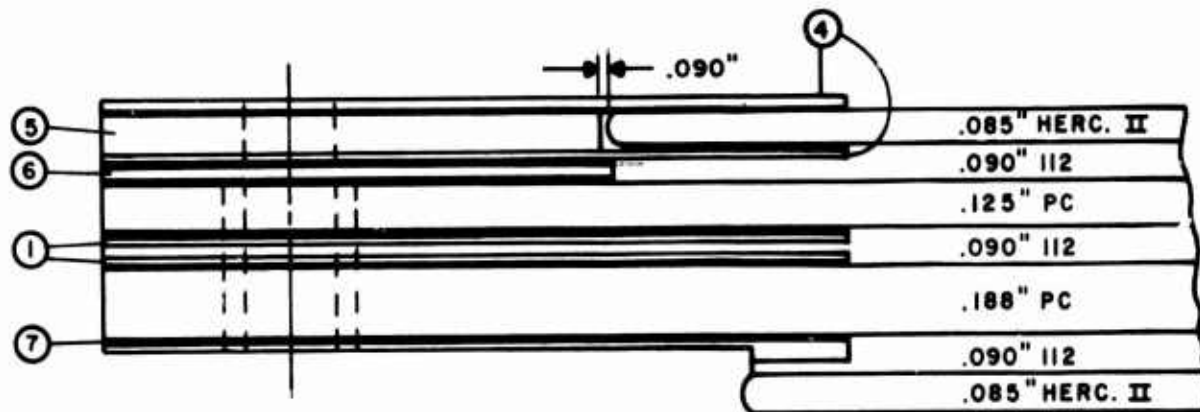


B) AFT ARCH

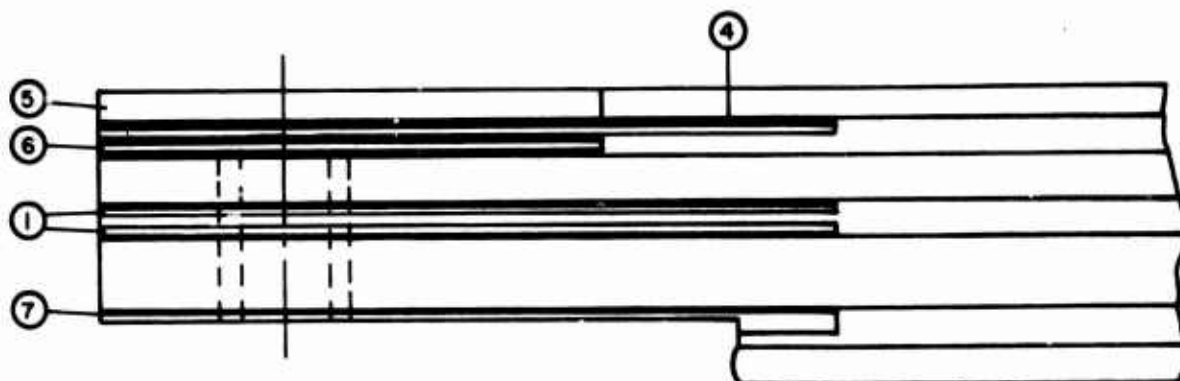
SAME CONSTRUCTION  
AS ABOVE

FIGURE 31. PRELIMINARY TASK II WINDSHIELDS

# ALTERNATE DESIGN



A) BEAM, SILL, FWD ARCH



B) AFT ARCH

SAME CONSTRUCTION  
AS (A), ABOVE

RE 32. PRELIMINARY TASK II WINDSHIELDS



Task I canopy bird impacts followed the same format as that used for the windshields. The first series was intended to define basic limits on materials and cross-sections, while the second series pursued optimization, including edge attachments. Since formalization of the canopy program placed it behind the windshield at the start, canopy constructions benefited from this spin-off. Another restriction of the number of possible canopy designs was the dimensional requirements for the canopy.

The preliminary constructions which are shown in detail in the data sheets for WT-32 to WT-35 in Appendix 1 were as follows:

TABLE XII - CONSTRUCTIONS FOR TASK I PRELIMINARY CANOPY BIRD IMPACTS

| <u>SAMPLE</u> | <u>SHOT NO.</u> | <u>CONSTRUCTION (IMPACT SURFACE LISTED FIRST)</u>                                                           |
|---------------|-----------------|-------------------------------------------------------------------------------------------------------------|
| 9031-1A,1B    | WT-32,34        | .125" Acrylic - .060" 112 IL - .125" PC* -<br>.090" 112 IL* - .188" PC*                                     |
| 9031-2A,2B    | WT-33,35        | .125" Acrylic - .060" 112 IL - .125" PC* -<br>.030" 112 IL* - .125" PC* - .060" 112 IL* -<br>.060" Acrylic* |

\*Included in extended edge section

The 500 knot impact requirement was surpassed with two extended structural plies of .125" PC. This permits the use of .060" as-cast inboard for physical isolation of the PC rather than an abrasion-resistant coating if a .125" - .188" PC ply combination is used. The use of the acrylic inboard does, however, tend to reduce residual visibility after impact. The four preliminary canopy panels all prevented penetration from 485 knots to 536 knots with nearly identical center thickness (.585" vs. .588") and areal density (3.64 vs. 3.66 lbs/ft<sup>2</sup>). The goal on the optimized parts, therefore, was to evaluate more diverse designs which would be lighter or thinner in addition to testing complete structures with edge attachments. Edge reinforcement and facing ply selection incorporated results for Task I windshields. Sections of the final Task I canopy designs are shown in Figure 33, and the following comments indicate the rationale in their selection:

1. 9031-3A - This design incorporated the same PC ply arrangement as 9031-2 which met the bird requirement. However, in light of the thermal/pressure tests, the monolithic as-cast acrylic of 9031-2 was replaced by an outboard facing ply of fused acrylic/PC. To reduce weight (to 3.46 lbs/ft<sup>2</sup>) and thickness, the inboard inter-layer and as-cast acrylic of 9031-2 have been eliminated and the now-exposed PC ply was coated with O-I 650. Edge reinforcement was via four .020" x 2" epoxy-Nomex straps (1) similar to those used for the windshield samples.

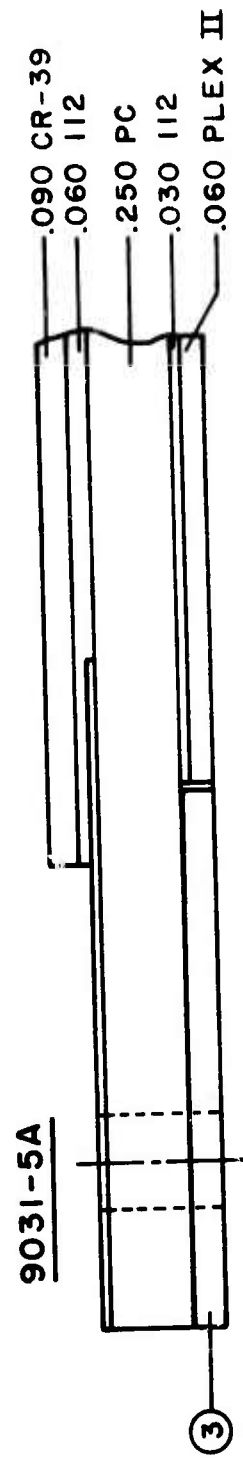
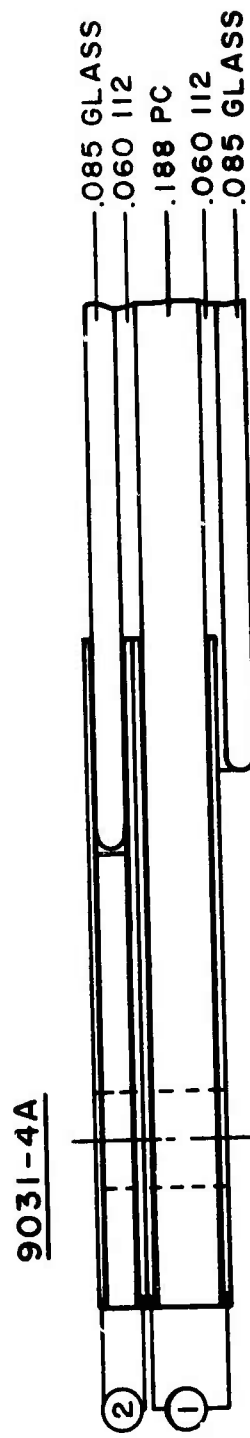
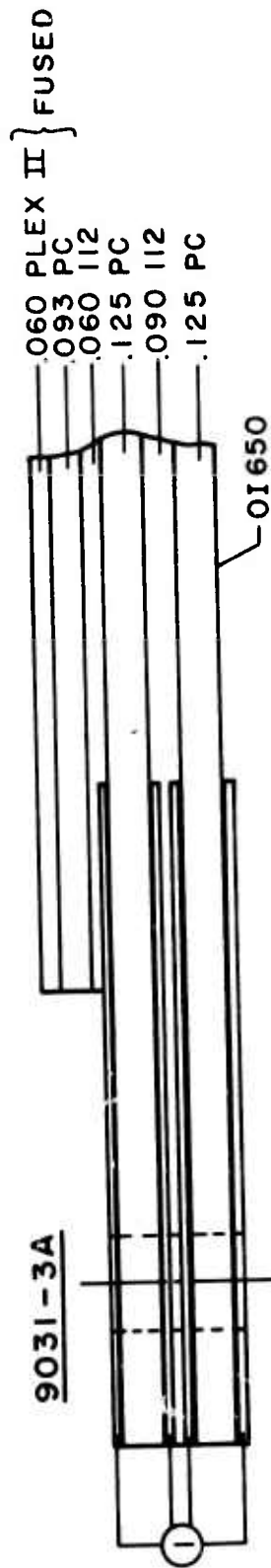


FIGURE 33. FINAL CANOPY FLAT PANELS.

2. 9031-4A - Thermal/pressure tests indicated that a glass facing ply may be necessary. The 9031-4A specimen was an attempt to be under the .500" thickness limit with a panel providing a balanced glass design and bird impact resistance. Even so, this is the heaviest of the proposed canopy designs at 4.04 lbs/ft<sup>2</sup>. In service, this design would exhibit stiffness at least comparable to the present F-111 1578 configuration glass canopy. The outboard glass had 2" titanium straps (2) configured similarly to the "A" light in the present glass F-111 transparencies except that the outboard strap was deleted from the aft edge. The PC reinforcement was .020" x 2" epoxy-Nomex.
3. 9031-5A - The last design was the lightest of the candidate canopy constructions (3.11 lbs/ft<sup>2</sup>) and also was under .500" center thickness. It incorporated a high level of abrasion resistance for a plastic-faced design with an outboard ply of allyl diglycol carbonate (CR-39). A comparison of the stiffer monolithic .250" PC used here and the doublet of .125" PC used in 9031-3A was included to indicate whether the poor performance of monolithic PC exhibited in the windshield program extends to thin plies at shallower angles.

Only two edge reinforcements were used in -5A. They included .020" x 2" epoxy-Nomex strap (1) and a .080" x 1.625" inboard epoxy-Nomex spacer which is labeled (3) in the sketch. In all three designs, the edge reinforcement material was bonded to the PC with nominal .010" RTV 630.

The three final flat Task I canopy specimens were subjected to nominal 500 knot impacts, as described in the data sheets for shots WT-36 to WT-38 in Appendix 1. In general, results were as expected based on previous flat windshield and canopy panels. In the plastic panels, the failure of 9031-5A corroborated the poor performance of relatively thick monolithic PC structural plies witnessed in the windshield testing. Two plies of .125" PC, on the other hand, were again adequate to meet the 500 knot requirement at 13.2° installation angle.

The glass-faced design, 9031-4A, did prevent penetration at 526 knots with a single structural ply of .188" PC. Although it takes advantage of the ductility of the PC during impact, the glass-faced plastic would provide structural stiffness comparable to the present design in normal service. However, this unique combination is offset by higher weight than all-plastic panels and the spall and loss of visibility attributable to breakage of the chemically strengthened glass during bird impact.

All candidate edge attachment systems performed as expected and no new conclusions were drawn from these tests. The RTV 630 and epoxy-Nomex reinforcement continued to provide the necessary impact support for plastic plies.

In recommending optimized constructions for Task II canopy then, several possible choices evolved.

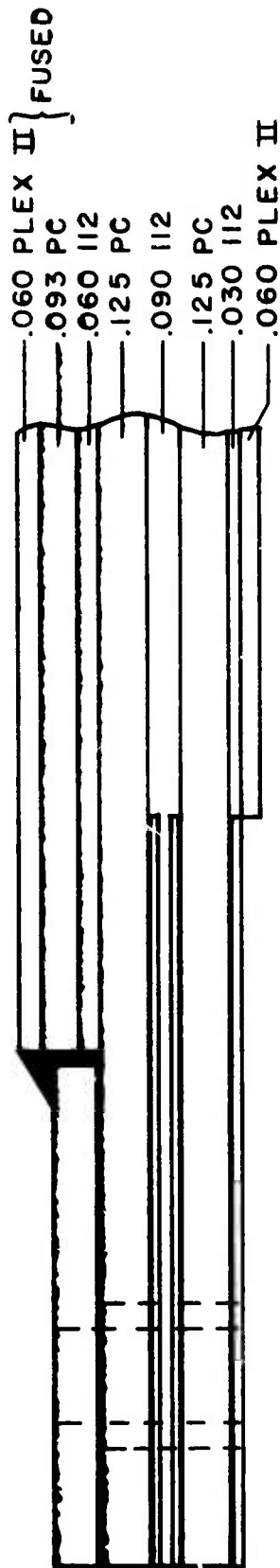
1. All-Plastic, Single Structural Ply - A plastic-faced design with a single .188" PC ply might meet the bird requirement, but it would be questionable structurally, particularly for edge loading. Also, there is no fail-safe capability with the single ply.
2. All-Plastic, Double Structural Ply - In preliminary flat panel tests, both .125" - .125" and .125" - .188" PC ply combinations have passed 500 knot impacts. In addition, the two ply, four-side edge reinforcement used in these constructions met the 870 lbs/in tensile load requirement from -65°F to +260°F.

Double PC ply constructions have stopped 4 lb birds at 500 knots with different facing plies. Like the windshield, this granted the freedom to select the outboard ply for optimum thermal resistance and choose the inboard material (plastic ply or coating) for durability and cost.

3. Glass-Faced, Single Structural Ply - This design was actually a modification of the present glass canopy with the addition of a PC ply for bird impact resistance. Its good thermal and structural capabilities are offset by weight, spall and loss of residual visibility.

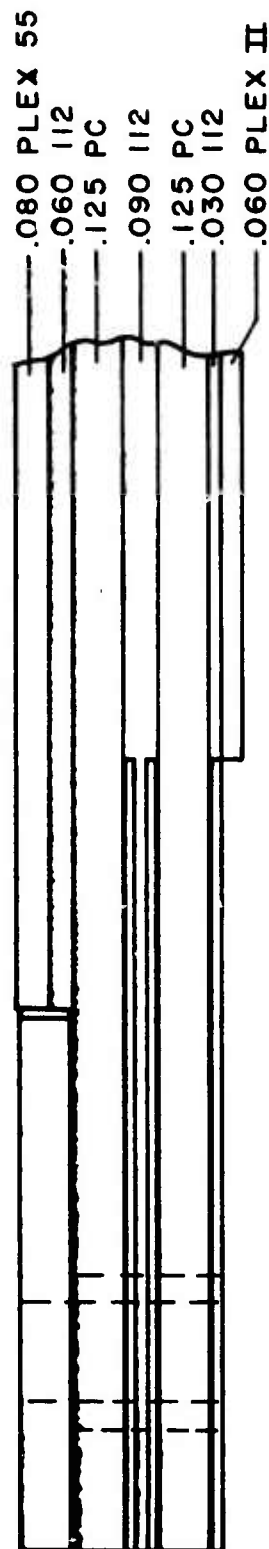
Based on these observations and other results of canopy and windshield tests to date, two constructions were submitted for use in preliminary Task II bird impact tests on full-size left-hand canopies. The constructions were identical except for facing plies. As shown in Figure 34, they include double structural plies of .125" PC which sustained 500 knot impacts successfully. Both had .060" as-cast acrylic as the inboard ply since it was felt that this will provide better overall protection than current state-of-the-art coatings. Facing plies were either monolithic .080" as-cast acrylic as in (B) or, if required for thermal protection, fused acrylic/PC as in (A). For edge attachment, the outboard edge contained a .125" x 1.375" aluminum retainer and reinforcement of .020" x 2" epoxy-Nomex. As was the case on the flat panels, all reinforcements were bonded to the PC using nominal .010" RTV 630. As with the windshields, aluminum bushings were included in the bolt holes to transfer bolt loads from the retainer to the mounting surface.

9031-6A



(A)

9031-7A



(B)

FIGURE 34. RECOMMENDED PRELIMINARY TASK II CANOPIES

## SECTION III

### TASK II

#### 1. INTRODUCTION

The primary objective of Task II was to establish a basis to recommend a specific detailed windshield design to meet the contract requirements. To accomplish this, the major effort was to evaluate the response of developmental, full-size F-111 windshields and canopies of approved constructions to bird impacts at different locations at speed between 500 knots and Mach 1.2. As a result of Task I work, a secondary but concurrent effort investigated the effect of required F-111 temperature and pressure profiles.

As before, the different areas of activity in bird impact testing and thermal/pressure evaluation are discussed separately. The Task II section is concluded with the windshield and canopy designs selected for Task III prototype production.



## 2. THERMAL/PRESSURE CAPABILITY

To further evaluate the thermal and pressure capability of the designs established in Task I, tests of full-scale windshields were conducted. Again, as in Task I, it was not practical to conduct all the tests defined as Endurance Requirements, so the most severe tests were selected. This included the maximum Burst Pressure/Temperature, Maximum Crush Pressure and Pressure Cycling (Type II). Since laminated structures become more rigid with lower temperatures, elevated temperature tests were assumed to be the severe test conditions.

### a. Test Facility

Since an F-111 production pressure fixture with cyclic response to 20 psi existed, it was only necessary to devise a temperature system for the proposed tests. Based on past experience and the rapid temperature response required, a heat blanket system was selected. Figure 35 shows the construction of the thermal system utilized. The thermal blanket, through a percentage off-on controller, heated the outboard surface of the windshield attached to a production proof-pressure fixture. Preliminary tests using an expendable plastic windshield indicated uniform contact of the blanket to the outboard surface was necessary to achieve quick heat response. A repeatable system was designed to accomplish this contact using an outboard surface rubber cover under vacuum. A sheet of 1/8" silicone was placed between the part and the blanket to eliminate any contact mark-off. The fiberglass surface and stitches of the blanket readily damaged the acrylic surface at 260°F in the preliminary test. This was attributed to the 260°F outboard surface temperature and the vacuum necessary for temperature uniformity and repeatability. Hence, a vacuum of 1 psi was maintained for all subsequent tests. Higher vacuum to 10 psi showed no significant advantage in temperature uniformity. Although the heating response obtained approached the desired rate of 260°F in six minutes, no method for quick cooling was possible. Hence, temperature cyclic tests were not conducted.

### b. Test Procedure

After the thermal system was finalized, a standard test plan was devised. Table XIII shows this proposed test scheme that was standardized by actual tests of the expendable all-plastic windshield No. 22. Tests 1, 2, 3, 5, and 6 are similar to tests conducted on 15" samples in Task I.

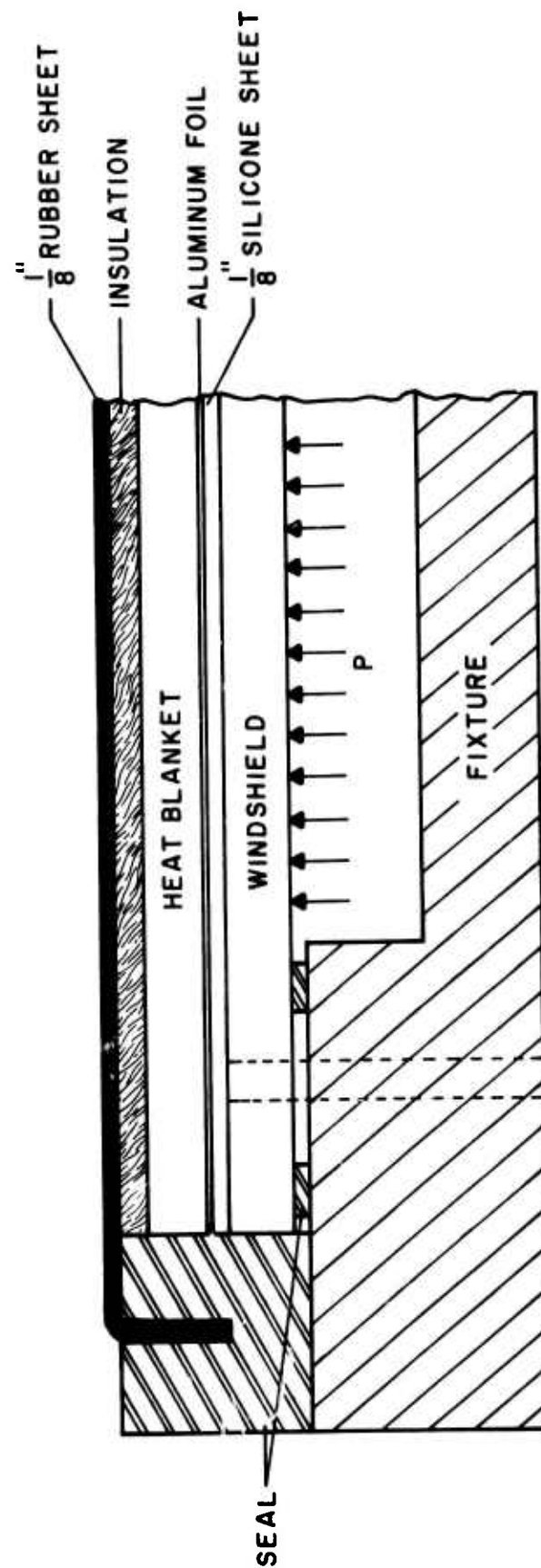


FIGURE 35. SCHEMATIC OF THERMAL SYSTEM USED IN  
FULL SCALE THERMAL PRESSURE TEST

TABLE XIII - TEST PLAN

| <u>TEST NO.</u> | <u>PRESSURE (PSI)</u> | <u>TEMPERATURE (°F)</u> | <u>TIME (MIN.)</u> | <u>CYCLES</u> |
|-----------------|-----------------------|-------------------------|--------------------|---------------|
| 1               | 16-20                 | Room Temp.              | 30                 | 1             |
| 2               | 12.5                  | 260                     | 15                 | 1             |
| 3               | 12.5                  | 300                     | 10                 | 1             |
| 4               | 12.5                  | 260                     | 15                 | 1             |
|                 | 12.5                  | 340                     | 5                  | 1             |
| 5               | 12.5                  | 340                     | 10                 | 1             |
| 6               | 12.5                  | 360                     | 10                 | 1             |
| 7               | 12.5                  | Room Temp.              | 5                  | 10            |
| 8               | 12.5                  | 360                     | 5                  | 5             |
| 9               | 12.5                  | 360                     | 5                  | 10            |

For each test as outlined above the windshield was attached to the pressure fixture with conventional fasteners. The 3/16" screws along the arches were tightened to achieve contact between the part and fixture. The 1/4" bolts along the rails were tightened to a torque of 50 inch-pounds. The prescribed F-111 torquing procedures were followed. The build-up was then accomplished as detailed in Figure 35. After making all the required connections, actual tests were conducted.

Before each static test the heating blanket enclosure was subjected to the maximum vacuum of 5 to 10 psig. After all leaks were sealed, the vacuum in the outboard enclosure was reduced to 1 psig. At the beginning of each static test, the prescribed internal cavity was pressurized to the prescribed load of 12.5, 16 or 20 psig. This pressure was maintained throughout each test. The heating blanket was energized to heat the outboard surface at the maximum rate. Depending on the actual prescribed temperature level, it was achieved within six to ten minutes. After completing the prescribed exposure time at a given temperature and pressure, power to the heating blanket was turned off and the pressure in the chamber was relieved. The outboard thermal system was then dismantled to enhance cooling. After an inspection of the part, the thermal system was replaced for the next test.

c. Sample Description

Figures 31 and 32, Section II-5, show the design of the two left-hand windshields tested. Based on the results of Task I, two windshields were made: an all-plastic windshield with acrylic fused to 1/8" polycarbonate as the outboard ply and a windshield with glass as both facing plies. To enhance fabrication, an aluminum spacer was utilized on the all-glass design, panel No. 29. Each windshield had iron-constantan thermocouples embedded within the interlayers. These thermocouples were positioned at the geometric center.

Prior to the actual tests, 1/8" strain gages were applied to the inboard surface at critical locations as shown in Figure 36. Because of the strain gage adhesive limitations, no gages were applied to the outboard surface. The temperature at various locations on both surfaces was measured by attached thermocouples. These thermocouple locations are also shown on Figure 36.

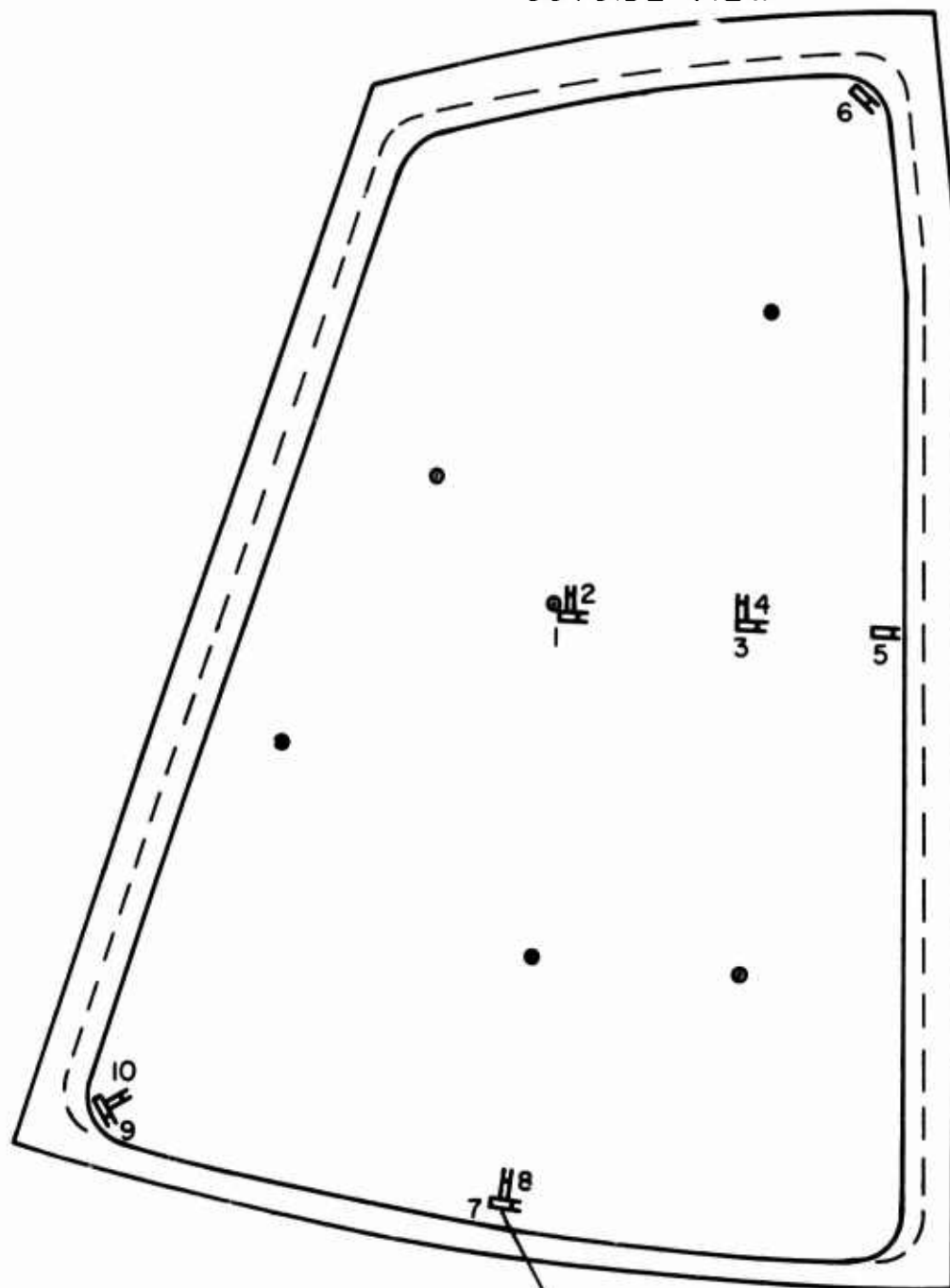
d. Test Set-Up

Figure 37 shows the complete windshield test set-up. The uniform contact of the blanket to the outboard surface of windshield No. 28 can be noted by the conformance of the outside rubber sheet. The deflection of the windshield was determined from the gage mounted at the center of the panel. In order to achieve access to the outboard surface of the windshield, a hole was designed in the blanket. Although this hole permitted deflection measurements, it drastically reduced the thermal capability of the blanket in the central area. Hence, temperatures as sensed by the embedded thermocouples were erratic and not valid maximums for the particular interlayers. The temperature controller, temperature recorder and strain recorder are in the background. The valve at the right foreground was used to control the vacuum in the heating system enclosure.

e. Test Results

Results of the thermal/pressure tests are tabulated on Table XIV. All-plastic panel No. 28 successfully withstood 20 psi internal pressure for 30 minutes without any adverse effects. A creep of .008" occurred at this pressure hold with deflections increasing from .228 to .236". The maximum stress did not exceed 1000 psi.

# OUTSIDE VIEW



## KEY:

- OUTBOARD AND INBOARD THERMOCOUPLES
- OUTBOARD THERMOCOUPLE ONLY
- H STRAIN GAGE

1/8" STRAIN GAGE BONDED TO INBOARD SURFACE

FIGURE 36. STRAIN GAGE AND THERMOCOUPLE LOCATIONS ON WINDSHIELDS NO. 28 AND 29 SUBJECTED TO THERMAL / PRESSURE TEST.



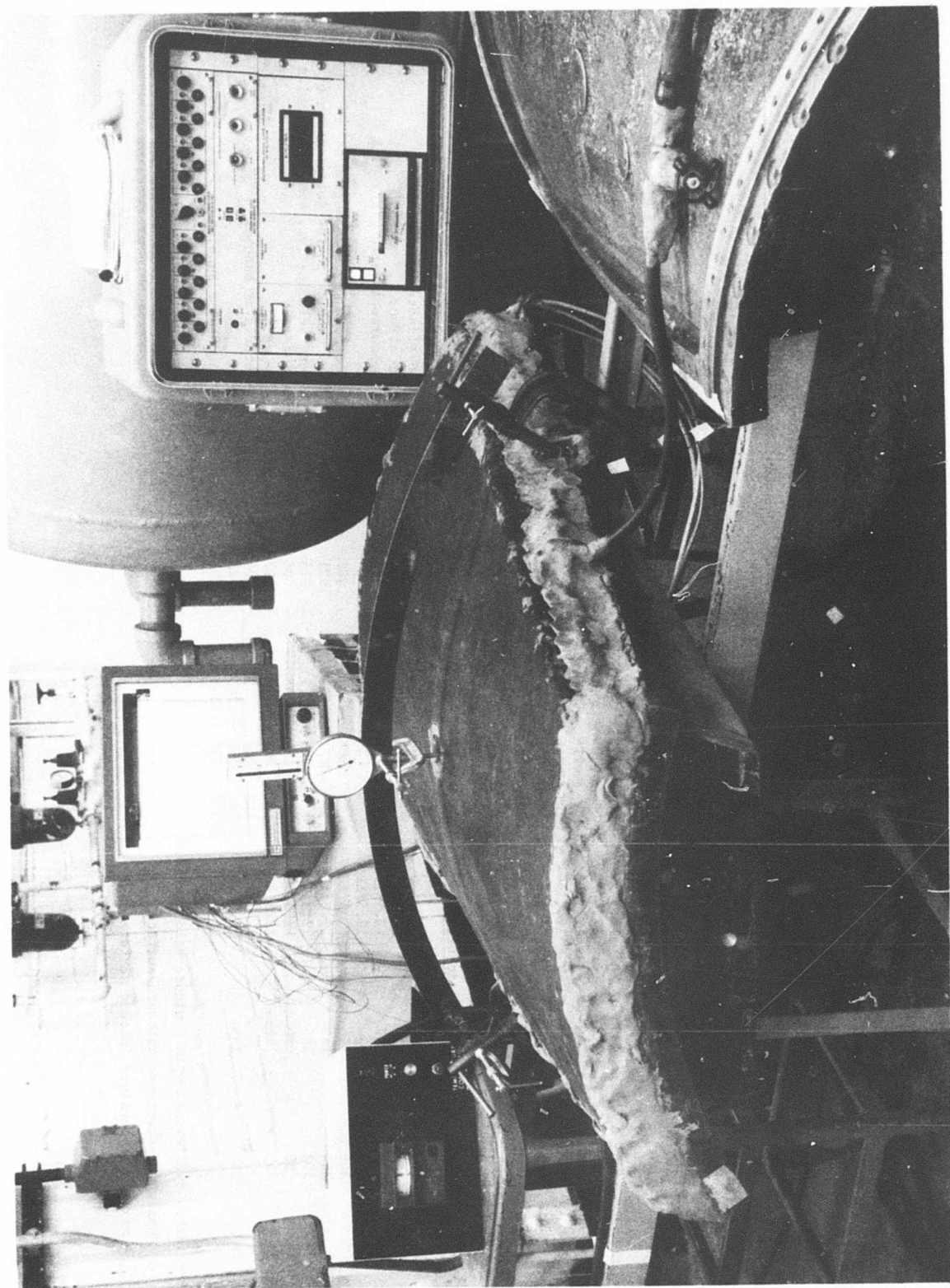


FIGURE 37. FULL-SIZE THERMAL/PRESSURE TEST SET-UP



TABLE XIV - RESULTS OF THERMAL/PRESSURE TESTS

| Test No.                                          | T <sub>0</sub> (°F) | T <sub>1</sub> (°F) | PSI/Total Min | Center Deflection (Ins) | Creep (Ins) | Max. Stress @ Location (PSI) | Results                                         |
|---------------------------------------------------|---------------------|---------------------|---------------|-------------------------|-------------|------------------------------|-------------------------------------------------|
| <b>Panel No. 28 All-Plastic Design</b>            |                     |                     |               |                         |             |                              |                                                 |
| 1                                                 | 80                  | 80                  | 20 /36        | .228 - .236             | .008        | - 600 @ 6                    | No effect                                       |
| 2                                                 | 290                 | 148                 | 12.5/18       | .232 - .320             | .088        | 700 @ 5                      | I/B Plex cracked; O/B surface stained           |
| 3                                                 | 315                 | 142                 | 12.5/14       | .289 - .377             | .088        | 900 @ 5                      | Indentations O/B surface                        |
| 4                                                 | 260                 | --                  | 12.5/17       | .243 - .352             | .109        | --                           | --                                              |
| 5                                                 | 349                 | 180                 | 12.5/8        | .391 - .427             | .036        | 900 @ 5                      | No effect                                       |
| 6                                                 | 350                 | 135                 | 12.5/12       | .313 - .427             | .114        | 1,000 @ 5                    | No effect                                       |
| 7*                                                | 367                 | 174                 | 12.5/15       | .404 - .508             | .104        | 1,200 @ 5                    | Interlayer bubbles, aft corner                  |
| 8*                                                | 80                  | 80                  | 12.5/50       | .215 - .220             | .005        | - 500 @ 6                    | No effect                                       |
|                                                   | 354                 | 196                 | 12.5/40       | 1st .346 - .363         | .017        | 1,000 @ 3                    | Interlayer bubbles                              |
|                                                   |                     |                     |               | 5th .531 - .546         | .015        | 1,200 @ 3                    |                                                 |
| 9*                                                | 352                 | 212                 | 12.5/80       | 1st .383 - .398         | .015        | 1,100 @ 3                    | More bubbles and associated acrylic deformation |
|                                                   |                     |                     |               | 10th .633 - .644        | .011        | -1,000 @ 9                   |                                                 |
| <b>Panel No. 29 Balanced Glass-Plastic Design</b> |                     |                     |               |                         |             |                              |                                                 |
| 1                                                 | 80                  | 80                  | 16 /30        | .194 - .194             | .000        | - 8,500 @ 7                  | No effect                                       |
| 2                                                 | 263                 | 170                 | 12.5/27       | .196 - .216             | .020        | -11,800 @ 8                  | No effect                                       |
| 3                                                 | 305                 | 167                 | 12.5/15       | .183 - .248             | .065        | -12,700 @ 8                  | Delamination along aft arch                     |
| 4                                                 | 260                 | --                  | 12.5/19       | --                      | --          | --                           | --                                              |
| 5                                                 | 346                 | 196                 | 12.5/10       | .186 - .274             | .088        | -15,900 @ 8                  | Increase in delamination                        |
| 6                                                 | 344                 | 189                 | 12.5/17       | .272 - .293             | .021        | -17,400 @ 8                  | Few bubbles inside delamination area            |
| 7*                                                | 362                 | 185                 | 12.5/15       | .266 - .291             | .025        | -18,200 @ 8                  | More delamination, some new bubbles             |
| 8*                                                | 80                  | 80                  | 12.5/50       | .181 - .185             | .004        | - 7,400 @ 7                  | No effect                                       |
|                                                   | 359                 | 226                 | 12.5/40       | 1st .226 - .253         | .027        | - 9,800 @ 8                  | --                                              |
|                                                   |                     |                     |               | 5th .302 - .306         | .004        | -13,500 @ 8                  | Interlayer bubbles                              |
| 9*                                                | 362                 | 235                 | 12.5/80       | 1st .238 - .263         | .025        | -10,100 @ 8                  | --                                              |
|                                                   |                     |                     |               | 10th .344 - .345        | .001        | - 8,900 @ 8                  | Interlayer bubbles                              |

\*Pressure cyclic test with 5 minute holds at 12.5 psi

T<sub>0</sub> = Maximum temperature outboard surfaceT<sub>1</sub> = Maximum temperature inboard surface

The first temperature exposure test to a maximum of 260°F as measured in the aft arch region for a total time of 18 minutes caused considerably more creep approaching .10". At the beginning of the actual test the inboard acrylic ply cracked. This fracture originated at the edge near the center of the aft arch and traveled across the panel to the forward arch. Although no interlayer bubbles or acrylic deformation were obtained, the silicone sheet stained the outboard surface. This stain corresponded with the heating element locations in the blanket. Because of this stain, it was not possible to evaluate effects on optics. In addition to the stain, some small indentations were produced in the outboard acrylic surface by small foreign particles. These imperfections were more noticeable after the next test at 300°F. As further increases in temperature were achieved, the stained areas were found to be slightly depressed below the adjacent surface. Bubbles did not develop in the outboard interlayer until the acrylic surface was exposed to 360°F for 15 minutes. During this test (No. 6), bubbles ranging from 1/8" to 1/4" in diameter formed in the interlayer 2" to 5" from the aft arch. This agrees well with Task I results.

Subsequent cyclic pressure at the temperature of 360°F produced many more interlayer bubbles. A total time of 120 minutes at 360°F, and cyclic pressure loading to 12.5 psi produced numerous bubbles that accumulated and consequently deformed the acrylic. The panel continued to bulge during this test sequence with an initial deflection of .383" on the first cycle and a final deflection of .644" on the tenth cycle. Based on the outboard and inboard temperatures, the outermost interlayer was above 300°F.

Results for the alternate design (glass both sides) were somewhat better. After no effects were caused by the first two tests at room temperature and 260°F, delamination developed in the third test at 300°F. Delamination of the outboard glass ply from the interlayer extending 3" into the daylight opening developed along the central region of the aft arch. Subsequent test 4 produced an increase in this delamination. However, a thermocouple placed in this region indicated temperatures in this area were 35-50° above the control thermocouples. Since the all-plastic panel did not show any significant bubbling in this area, it was rationalized that this hot spot was a recent occurrence and not present during the earlier tests of the all-plastic panel No. 28. The next test at 340°F caused a few bubbles to form inside the delamination area. The number of bubbles correspondingly increased with the 360°F exposure of test 6. Again this agrees with Task I results. Bubbles formed in the glass face panel before the all-plastic design. In this test the aft arch delamination area heating rate exceeded the control temperature rate, but the delamination area did not substantially exceed the maximum of 360°F.

The last two tests caused more bubbles to form in the outboard interlayer of the glass-plastic windshield (panel No. 29), but these bubbles remained isolated and did not grow and subsequently combined as experienced by the all-plastic panel, No. 28. This better performance without large bubbles for the glass-plastic design is attributed to the rigid glass facing, even though the higher thermal conductivity of the glass caused the interlayer to achieve somewhat higher temperatures than the plastic panel. A comparison of the bubble formation and associated effects for the two designs is shown by Figure 38. The first photograph shows the effect caused by bubble formation and associated acrylic-clad polycarbonate deformation. Conversely, the less severe damage of the glass-plastic panel is shown in the second photograph, Figure 38(b).

The first cycle creep of .025" to .027" for the glass-plastic design was substantially more than the all-plastic. This was attributed to a higher structural ply temperature. Later cycles for the glass-plastic design showed drastic reductions in creep with only .001" in the tenth cycle.

#### f. Discussion

In comparison, bubbles formed earlier in the outboard interlayer of the glass-plastic design No. 29. This was due to the higher conductivity and smaller thickness of the outboard glass ply compared with the acrylic-clad polycarbonate ply. The outboard glass was .085" compared with a total thickness of .185" for the acrylic-clad polycarbonate. Also, the inboard surface temperature of the glass-plastic panel, No. 29, was consistently higher than the same temperature for the all-plastic part, No. 28. Although the glass-plastic design was somewhat higher in temperature than the all-plastic design, the glass-plastic part was more rigid with substantially less creep than the all-plastic design for similar temperatures. The all-plastic design also exhibited some permanent deformation (increased curvature). The indentations and other surface damage produced in the acrylic outboard ply indicated another potential problem with this facing material.

In general, the results indicate that the outermost interlayer cannot withstand the prolonged constant temperature exposure achieved by 360°F outboard with cyclic pressure. This appears to be true for either design. For the acrylic-faced version, interlayer bubbles led to acrylic deformation whereas the glass-faced design problems were delamination and bubbles. However, it must be remembered that these tests were conducted without any cooling of the inboard surface. Therefore, extended exposures approached a steady state condition with a small gradient through the thickness. Since the test set-up did not control the interior cavity at 75°F consistent with the endurance requirement, the actual tests were more severe

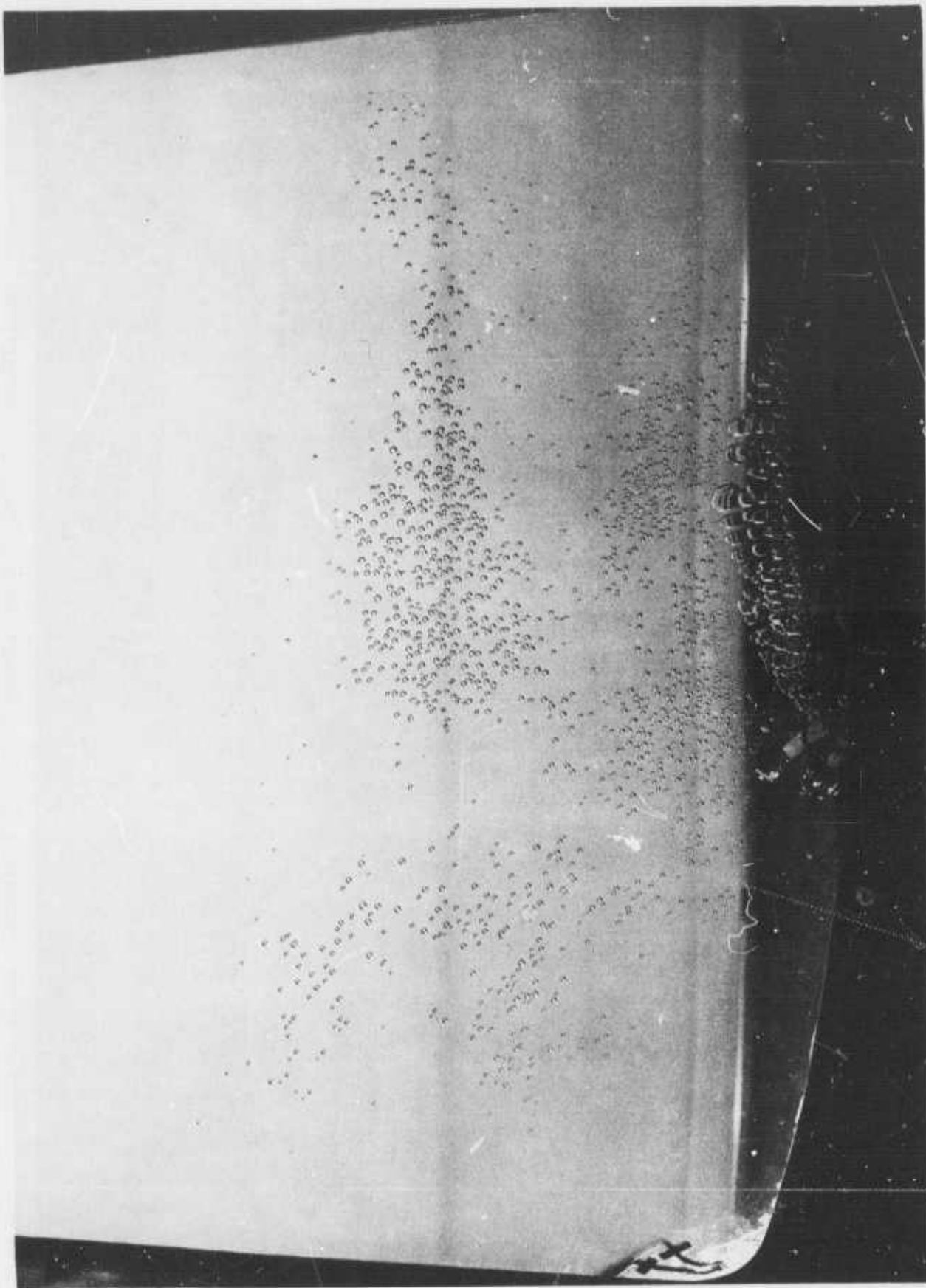


FIGURE 38(a). BUBBLES AND DELAMINATION IN GLASS-FACED WINDSHIELD NO. 29  
CAUSED BY THERMAL/PRESSURE TEST

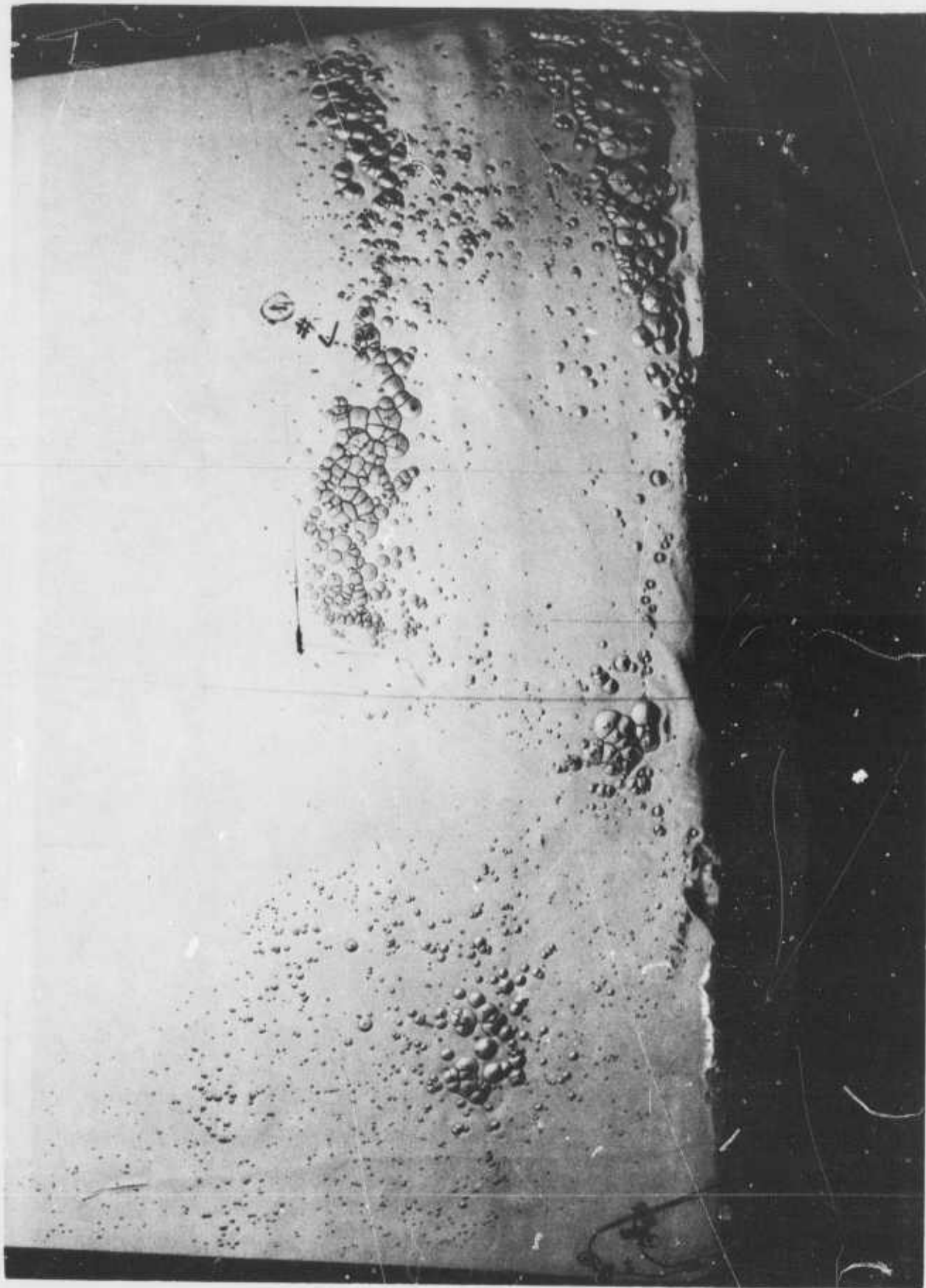


FIGURE 38(b). BUBBLES AND ACRYLIC DAMAGE IN ALL-PLASTIC WINDSHIELD NO. 28  
CAUSED BY THERMAL/PRESSURE TEST



than specified. Although this was the case, it is felt that neither design would successfully pass the specified one life-time test, especially with the optics requirement. In this test, the glass-plastic candidate was better than the all-plastic with a .185" outer combination of .060" acrylic and 1/8" PC. For an all-plastic design, a fused ply of .060" acrylic and 3/16" PC would be required.



### 3. TASK II BIRD IMPACT TESTS

Task II bird impacts were made on full-size F-111 windshields and canopies. As in Task I, all tests were made using 4 lb birds fired from the AEDC launcher. As will be discussed in some detail, various impact locations and mounting conditions were employed for the windshield program. All windshield tests were conducted at ambient "room temperature" conditions. The canopies, mounted in F-111 module hatches, were shot in the forward arch-beam corner in both ambient temperature and low temperature gradient environments.

The windshield portion of Task II deviated somewhat from the program originally planned. Additional tests were required to evaluate the effect of mounting structure and to develop an optimized module arch-windshield system which would prevent penetration in the aft beam corner. In order to describe the total problem, this report will document not only Task II bird impacts, but related tests conducted both by the Air Force and by PPG INDUSTRIES.

The preliminary phase of Task II included shots at five windshields of the Primary construction discussed in Section II-5 and shown in Figure 31. Panels were mounted in a rigid test frame, shown in Figure 39, and oriented to simulate the module installation. The goal of this series was to establish the worst impact location and to verify the Task I design recommendations. Impacts were made in the center, along the beam close to the forward arch, and in the aft arch-beam corner. Figure 40 summarizes the locations and results while detailed comments can be seen in the data sheets for WT-39 through WT-43 in Appendix 1.

Before discussing the effect of mounting and impact location, some conclusions were drawn about the windshield construction which related to the basic Primary design.

1. The main structural plies of .125" and .188" PC provided a high level of impact resistance, particularly in the panel center where plastic deformation was a maximum.
2. The facing ply of fused .060" as-cast acrylic and .125" PC acted as a single brittle ply, as expected, but did not lead to any structural failure during impact. As a result, a facing ply of .060" acrylic and .188" PC, which showed promise for thermal resistance, was recommended to be tested for bird impact effects.
3. Under impact in the 500 knot range, the inboard acrylic cracked but was held by the interlayer. Near the goal of Mach 1.2, impacts led to large localized deflections which caused minor spalling of several small pieces of the acrylic from the bulged area.

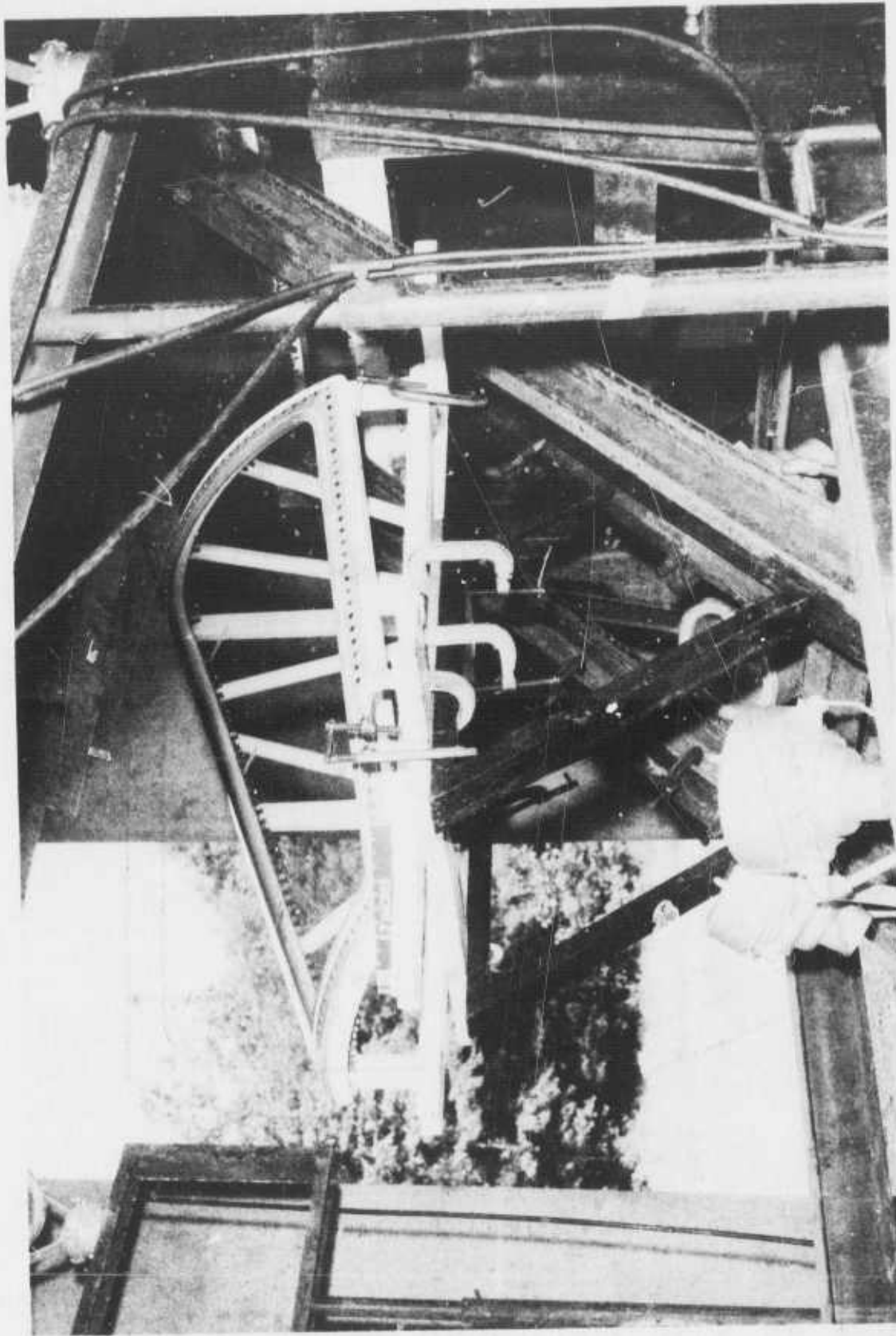
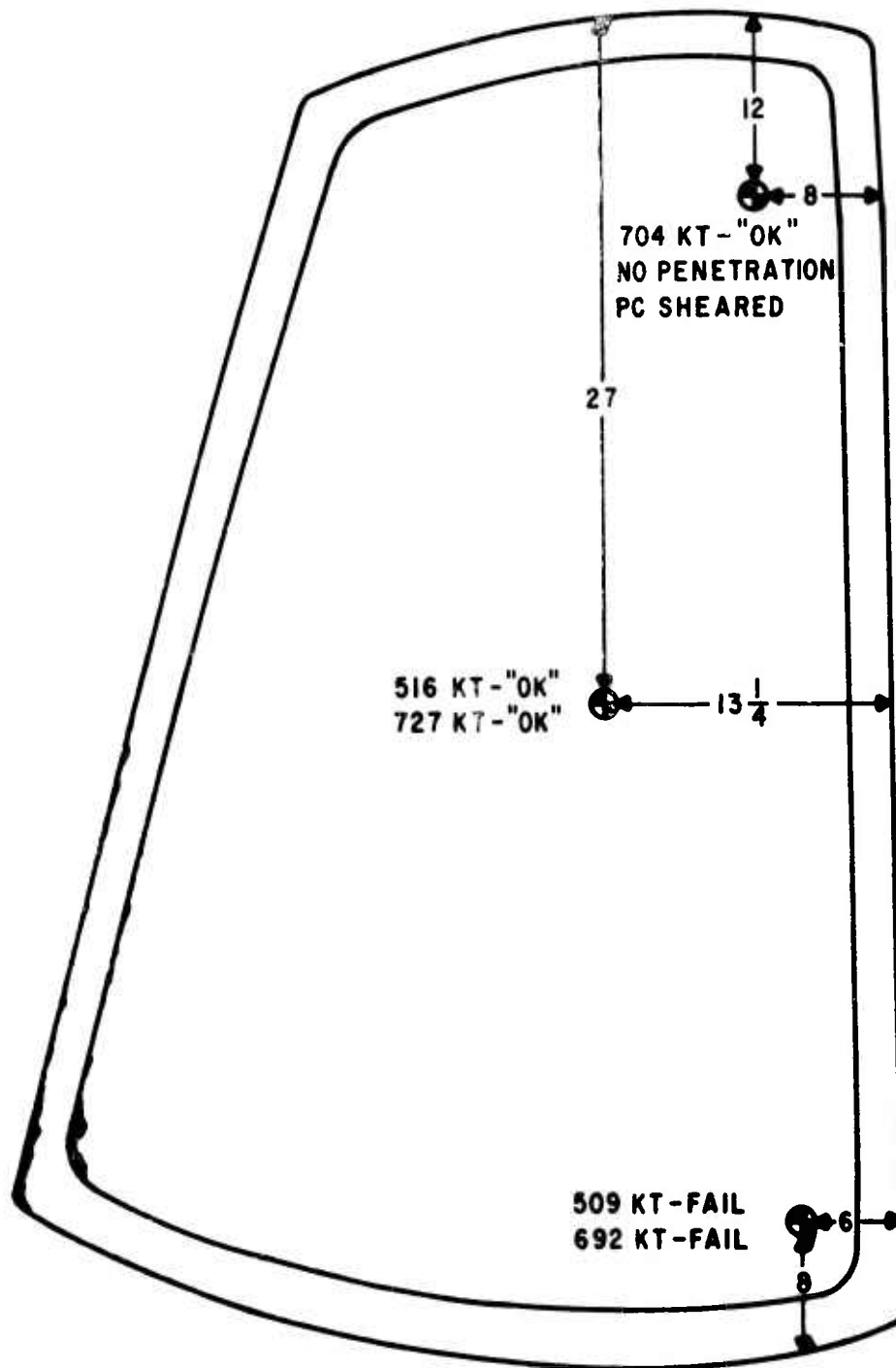


FIGURE 39. TASK II BIRD IMPACT TEST WINDSHIELD IN RIGID FRAME



**NOTE:**

SEE FIGURE 31. FOR CONSTRUCTION DETAILS.

**FIGURE 40. WINDSHIELD BIRD IMPACTS IN FRAME.**

Even with the extreme local bulging from high speed impacts, there was no crack propagation from the inboard acrylic through the innermost .090" 112 interlayer. Therefore, this interlayer was reduced to .060" to partially offset the addition of .062" PC in the facing ply.

4. The edge system in general, and the retainer, bushings, bolts and ply reinforcement in particular, performed their required tasks, indicating no need for modification at that time.
5. As expected, large center deflections were experienced with thin laminated cross-sections.

The more important factor in these tests, which had an effect on program direction, was related to impact location and mounting structure.

1. The primary windshield construction provided different protection levels ranging from the goal of Mach 1.2, for impacts near the center to below the 500 knot requirement in the aft arch-beam corner, which was established as the worst location. The forward arch-beam corner was also shown to be a problem area with an impact resulting in extensive shearing of the PC structural plies but no bird tissue penetration.
2. Shearing of the polycarbonate structural plies was related to the proximity of impact location to a restraining edge or edges. This observation reemphasized the potential for panel failure due to restraining by the gun sight. It was recommended that a test with an actual Lead Computing Optical Sight (LCOS) be made. This was accomplished under Air Force auspices, and is discussed in Appendix 3.
3. High-speed motion pictures showed that there was negligible deflection of the frame during shot WT-43 in the aft arch-beam corner. The use of a stiff frame was chosen for durability and to place maximum load on the transparency. However, in retrospect it is now generally agreed that this approach may be acceptable for center shots but it is very unrealistic for determining actual penetration resistance in a location which will ultimately be mated to an existing airframe structure. Experiences outside of but associated with this program confirmed that different results could occur with aft beam corner impacts on windshields in different mounting structures:

- (a) In July 1972, PPG conducted tests at ambient temperature with 4 lb birds on full-sized F-111 windshields similar in cross-section to 9030-13A (WT-9) with as-cast acrylic outboard. The windshields were mounted in a frame, shown in Figure 41, which was less rigid than the second generation frame used in the preliminary Task II tests. In the PPG tests, a windshield was not penetrated by a 495 knot impact approximately 6" from the beam edge and 14" from the aft arch edge. High-speed motion pictures<sup>7</sup> show more frame deflection than with WT-43.
- (b) In November 1972, the Air Force made 4 lb bird impacts<sup>8</sup> on two windshields of the same basic construction as discussed in (a). The windshields were mounted in a standard F-111 crew module, i.e., without any modification to the transparency support structure. A 531 knot impact approximately 8" from both the beam and aft arch caused a section of the arch mounting structure to fail, resulting in penetration by the bird. In this test, designated FM-2, the windshield itself was not penetrated and its structural damage was limited to tearing of bolt holes in the area of arch failure. The extensive failure of the module arch led to a program, awarded to McDonnell Douglas under Contract F33615-73-C-3142, to develop a suitable arch reinforcement which is documented in AFFDL-TR-74-40.

With the flexible frame and module test results in mind, it was decided that the primary Task II windshield construction should be checked in a more realistic structure before design changes were undertaken. To do this, a corner impact (WT-44) was made on windshield 9030-25 mounted in a module as in Figure 42, with arch stiffening suggested by McDonnell Douglas and fabricated by AEDC. As indicated by the data sheet in Appendix 1, a corner shear failure at 503 knots was similar, although less severe than the previous failure of 9030-24 (WT-43), which was impacted at 509 knots in the rigid test frame. Sections were cut from these windshields and returned to PPG Glass Research for an immediate failure analysis to assist in selecting possible solutions to these edge shearing failures.

---

<sup>7</sup>PPG Technical Proposal AC-113072, Scenes 10 and 11, November 30, 1972.

<sup>8</sup>E. J. Sanders, Investigation of the Effects of Bird Impacts on the F-111 Crew Module, p. 11, LTR-AEDC-VKF-ASA-1-73, March 1973.



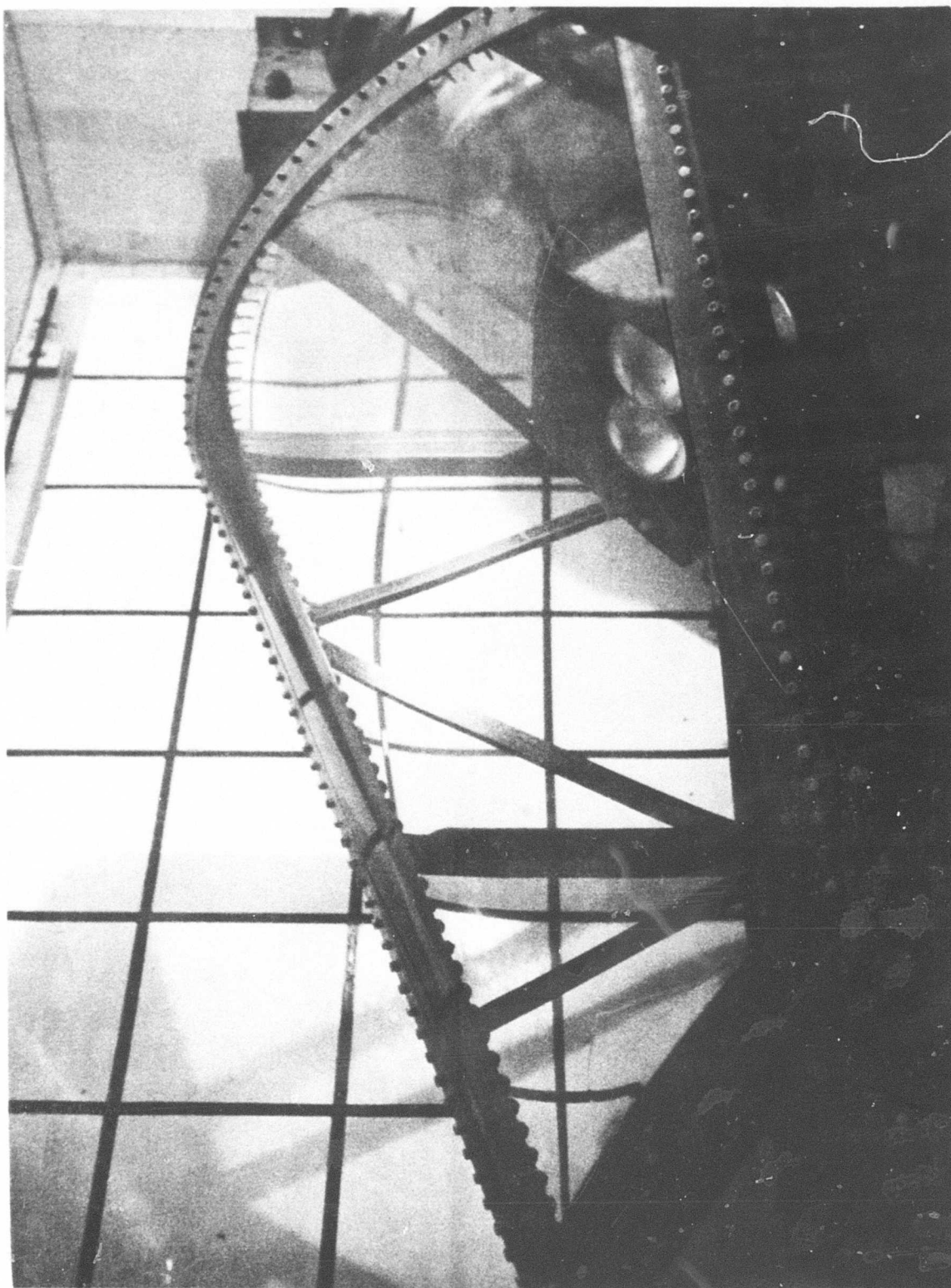


FIGURE 41. PPG TEST FRAME USED DURING IN-HOUSE TEST AT NRC



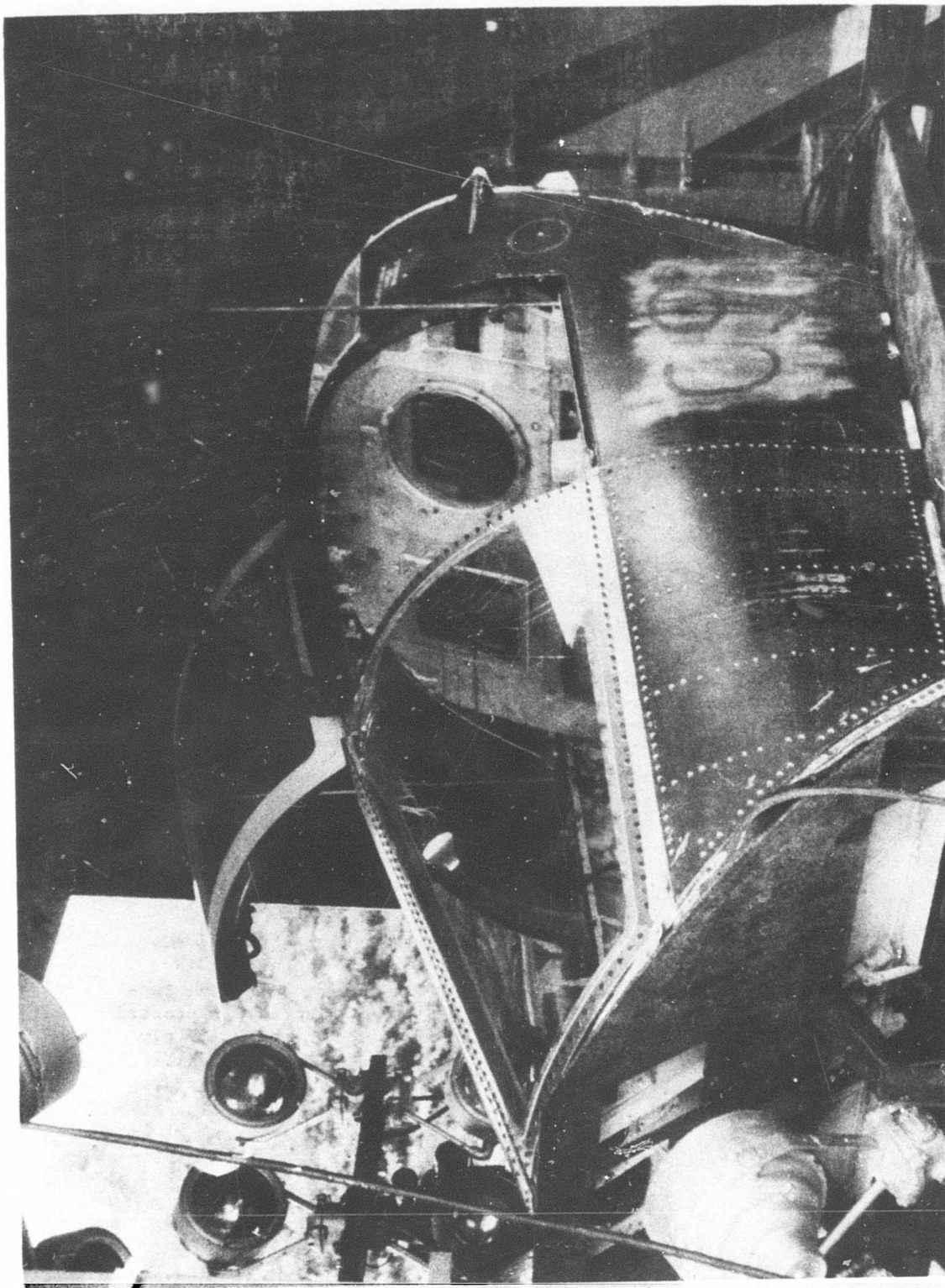


FIGURE 42. F-111 CREW MODULE USED FOR TASK II BIRD IMPACTS

## 1. Module Impact (WT-44)

The primary fracture occurred in the 3/16" PC (inside) ply along the aft edge. The origin was approximately 3" long in line with the edge of the arch mounting surface. It was located completely between the second and third gussets which had been used by AEDC to stiffen the arch reinforcement. The fracture started from the inside surface next to the arch ledge, and was apparently a shear failure.

A secondary fracture in the 3/16" PC originated in the aft beam corner. The origin, like the primary, was located on the inside surface. The fracture face of the origin indicated a low stress failure which implies that this corner offered little resistance to the impact load. It should be noted that this corner failure was not the result of the projecting first gusset which contacted the inside surface during impact. This restraint did result in a local failure but it was not related to the three primary failure origins in the 3/16" PC ply.

The third failure in the 3/16" PC ply was along the aft arch, 11" from the beam corner. Unlike the primary origin, this was not located directly in line with the edge of the arch ledge but was approximately 1/8" aft from this line. A second difference was that the origin occurred on the impact side of the 3/16" ply. The fracture face exhibited some plastic deformation before failure, indicating some resistance to the impact.

The fractures in the 3/16" ply were stopped by the 112 interlayer separating the two extended plies. This permitted the 1/8" PC ply to carry some of the impact load before being overpowered by the impact. The large amount of yielding prior to failure, plus the fact that the origin was located on the impact-facing (tension) surface, indicate that this ply carried more bending and tensile load than the 3/16" ply. This is also borne out by the amount of deformation around bolt holes 4-11 in the 1/8" PC which is not present in the 3/16" PC ply.

## 2. Frame Impact (WT-43)

The fracture origin of the 3/16" PC in windshield 9030-24 was along the aft edge at the arch end of the beam corner radius. It occurred on the inside surface (next to the mounting surface), in line with the outboard floating section, and probably started from some surface defect or damage. The rest of the 3/16" ply appeared to have provided some impact resistance which resulted in tearing along the support frame with origins on the inside surface.

The 1/8" PC fracture origin was located on the impact-facing surface generally coincident with the main origin in the 3/16" ply. This ply did not appear to have carried as much load as the 1/8" ply in panel 9030-25. In general, it was the opinion that windshield 9030-24 (WT-43) in the frame was slightly poorer in resisting the equivalent impact than 9030-25 (WT-44) tested in the modified module.

The foregoing analysis indicated a failure mode common to both windshields, regardless of the support, which had to be overcome to prevent penetration during edge shots. In both cases, shearing started from the inside surface of the 3/16" PC structural ply at or near the edge of the arch support surface. As a result, this ply carried essentially no load. Although the fracture was isolated by the 112 interlayer, the 1/8" PC ply could not absorb the bulk of the energy and it then failed.

Two routes were followed to overcome the failures in the aft beam corner. First, it was the consensus of Air Force, PPG and McDonnell Douglas personnel that modification of the rigid test frame to simulate the EI and dynamics of the arch would be time-consuming, expensive and inaccurate at a critical point in the program. Therefore, it was decided to combine the tests of the transparencies and the interim arch modification in a crew module. Second, two design changes were considered to overcome the shearing and excessive ply loading.

1. Increase the bending radius over the support by rounding the edge of the arch ledge and adding a metal support strip under the windshield edge attachment.
2. Increase the tensile load-carrying capability of the extended edge section.

Figure 43 shows cross-sections of three windshields which incorporated the design changes which were tested in the module. The first construction shown is essentially the same as 9030-24 and 9030-25 with the exception of thicker PC in the fused outboard ply. The changes for this iteration including rounding the sharp corner on the existing arch section and addition of a .025" x 1.25" titanium support strip. The titanium strip, tapered as shown, was not a load carrying part of the edge attachment but served to prevent shearing over the frame. The right-hand windshield in the center of the Figure had the same overall thickness as the primary design but with different internal ply arrangement. Here, the outboard fused ply included .125" PC while the .125" PC structural ply in the primary design was replaced with a .188" PC ply. This panel had a .020" x 1.625" 301 stainless steel support strip between the edge attachment and the module. The third panel at the bottom of Figure 43, had no support strip but contained a third full-size structural ply of .125" PC. All three designs continued to use the retainer, epoxy-Nomex reinforcement and RTV 630 used successfully on the earlier windshields.

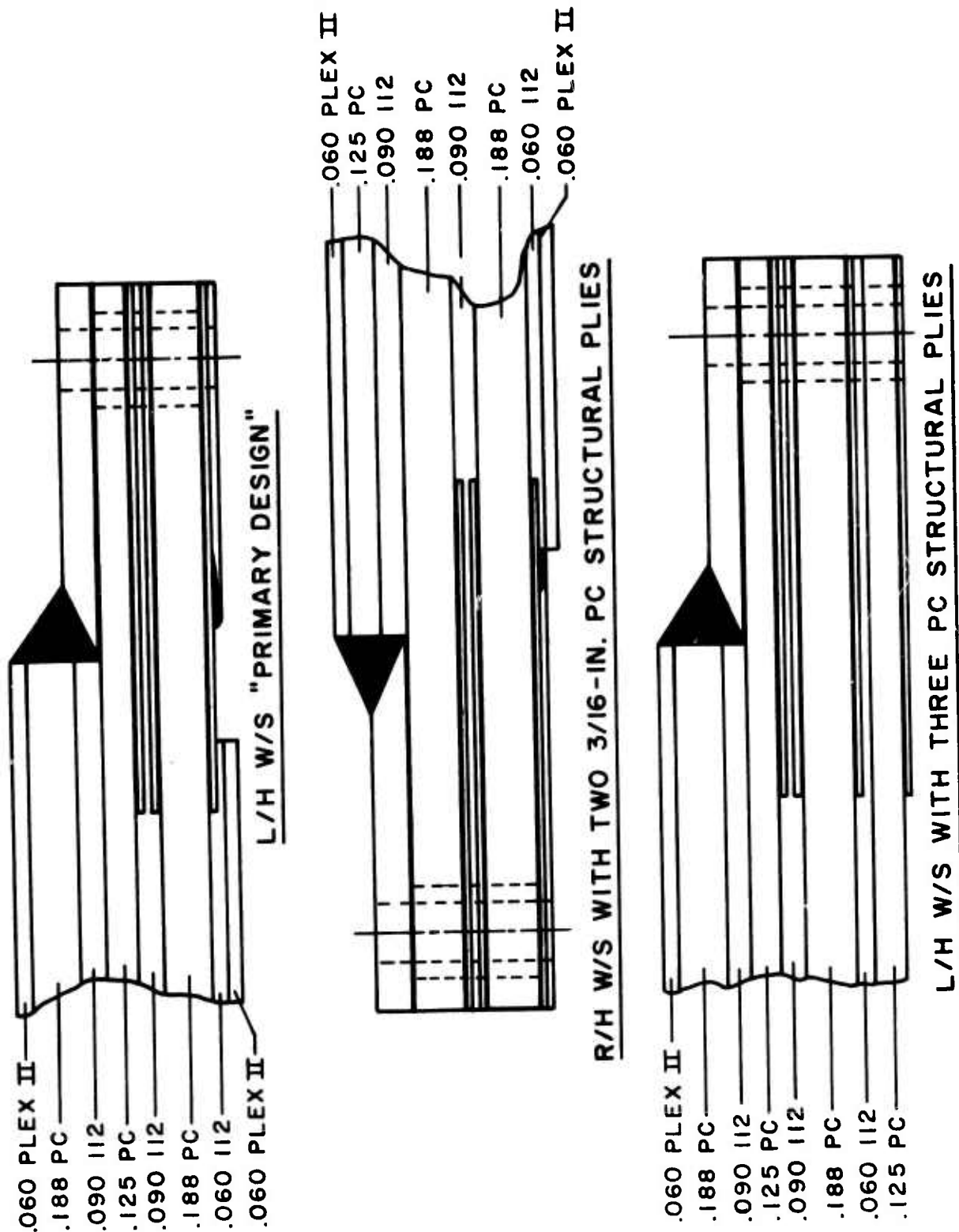


FIGURE 43. MODIFIED WINDSHIELDS FOR MODULE TESTING



The three revised windshields were tested in a crew module which, in addition to rounding of the mounting surface, included McDonnell Douglas interim arch fittings. The reinforcements extended approximately 13" from the beam edge along the aft arch of each panel.

Detailed observations for the tests WT-47 to -49 can be seen in the data sheets in Appendix 1. For immediate comparison, module impacts are summarized in the following Table XV while portions of the panels appear in the photograph in Figure 44.

As shown in Figure 44, there were improvements over WT-44 in the performance of windshields with two extended PC structural plies (tests WT-47 and -49), even at higher impact energy. But, the changes since WT-44 were insufficient to prevent penetration. Fracture analyses of sections of the two windshields tested with support strips and rounded ends on the arch mounting flange revealed that the catastrophic shearing of the inboard PC ply which occurred in WT-44 had been eliminated. In WT-47, the fracture of the inboard PC ply began from numerous origins on both surfaces. In WT-49, the origins in the inboard PC were from the outboard (tension) surface. In both cases, the failures of the inboard PC were still coincident with the end of the arch flange. The outboard extended PC ply of both windshields failed in tension from origins near the bolt holes. Overall, however, there was only slight difference between WT-47 and -49 insofar as the extent of impact damage experienced.

All windshield shots, of course, were influenced by the performance of the arch reinforcement supplied by McDonnell Douglas. In light of the slight deformation of the arch in the impact area, it was apparent that the rigidity of the modified arch influenced the extent of failure in WT-47 and -49. The critical role played by the arch was demonstrated by WT-50 which repeated the conditions of Air Force module test FM-2, discussed previously, with the exception of the additional arch support. In FM-2, the "old" windshield with no edge reinforcement was not penetrated, but a section of the arch failed, permitting much of the bird to enter the module. In WT-50, the same windshield construction which survived in FM-2 was penetrated with more severe damage than any of the sections shown in Figure 44. It was apparent that a better windshield/arch combination was necessary between the extremes of FM-2 and WT-50. Toward this end, McDonnell recommended that .070" be milled off the inboard surface of the flange of the left-hand interim fitting for subsequent testing.

A windshield with a third extended ply of .125" PC survived a 520 knot impact in the aft beam corner in WT-48. The impact resulted in no serious structural damage to the transparency (see Figure 44) or reinforced arch. Therefore, a windshield/arch combination existed which met the bird impact requirement in the worst location. At 61.3 lbs, this design was within the contract weight requirement but other difficulties, such as interfacing with mold line, low light transmittance, and an exposed inboard PC ply, indicated a need for optimization.

TABLE XV - SUMMARY OF INITIAL CORNER IMPACTS IN MODULE

| <u>Test</u> | <u>Facing Ply<br/>(Plex/PC)</u> | <u>Extended Edge</u>        | <u>Support</u> | <u>Arch</u>   | <u>Speed<br/>(KT)</u> | <u>Result</u> |
|-------------|---------------------------------|-----------------------------|----------------|---------------|-----------------------|---------------|
| WT-44       | .060/.125                       | .125 PC - .188 PC           | --             | Gusseted AEDC | 503                   | Failed        |
| WT-47       | .060/.188                       | .125 PC - .188 PC           | .025 T1        | Interim Fix   | 528                   | Failed        |
| WT-48       | .060/.188                       | .125 PC - .188 PC - .125 PC | --             | "             | 520                   | OK            |
| WT-49       | .060/.125                       | .188 PC - .188 PC           | .020 SS        | "             | 515                   | Failed        |



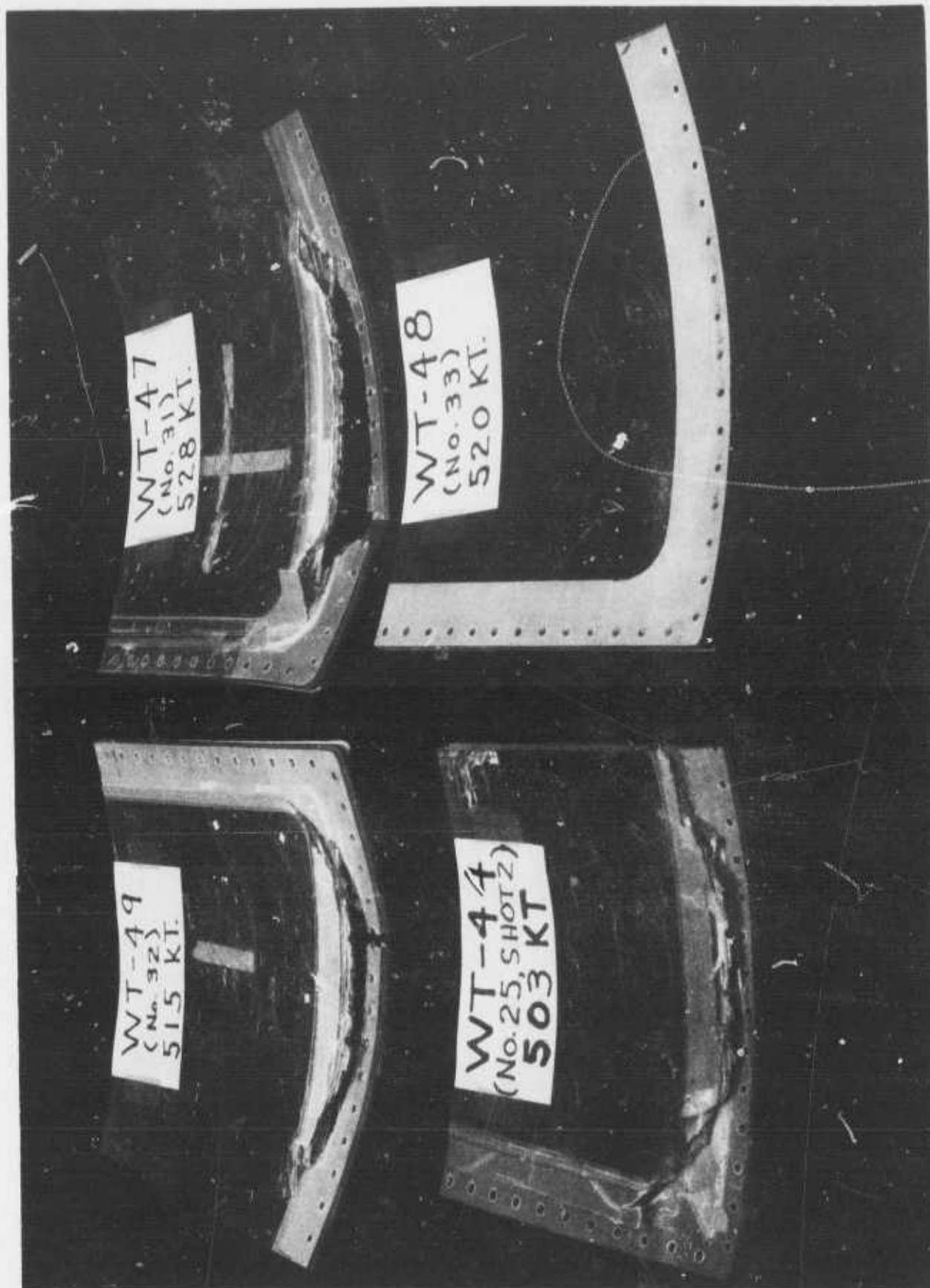


FIGURE 44. AFT BEAM WINDSHIELD SECTIONS; NOMINAL 500 KT. IMPACTS IN F-111 MODULE

Following the work discussed above, a review was held between PPG, McDonnell Douglas and the Air Force to discuss the results and coordinate future activity. Since optimized arch-windshield combinations needed to be evaluated for impact resistance in the aft beam corner, the final iterations were made on the three remaining Task II windshields. These tests were made in lieu of the temperature extreme windshield shots which were included in the Test Plan but deleted at the instruction of the Air Force.

Two of the windshields proposed for final Task II bird impacts were three PC ply windshields which had thinner edge sections than 9030-33 but included .060" as-cast acrylic inboard for maximum durability. These designs, shown in Figure 45, provided a direct comparison with 9030-33 (WT-40); therefore, the basic edge attachment and facing ply section were retained. In Figure 45, (1) is the aluminum retainer and (2) is the .020" x 2" epoxy-Nomex reinforcement used before. A titanium support strip (3) was placed between the panel and the mounting surfaces to increase the bending radius.

The final windshield design incorporated changes in the two PC ply design intended to strengthen the edge in the critical aft beam impact area. As can be seen in Figure 46, a .025" x 2" titanium insert (3) was added between the epoxy-Nomex straps (2) along the beam and aft arch. Along the rear arch, the inboard reinforcement (4) was .025" titanium rather than the .020" epoxy-Nomex used elsewhere. Other than a titanium support strip (5), these strengthening items were not used on the forward arch and sill of this panel because of the reduced bird impact severity, to simplify fabrication and to reduce weight. In addition, the .125" and .188" plies were reversed from 9030-31 and previous panels. The purpose of this was to minimize the impact bending stress of the inboard ply and increase the tensile load-carrying capability of the outboard (now .188") ply.

Since an optimized windshield/arch combination was desired, the three windshields were matched with three levels of arch reinforcement. Two of the combinations are shown in Figure 45, while Table XVI lists in sequence the windshields and arches that were evaluated in the series, with the results for each.

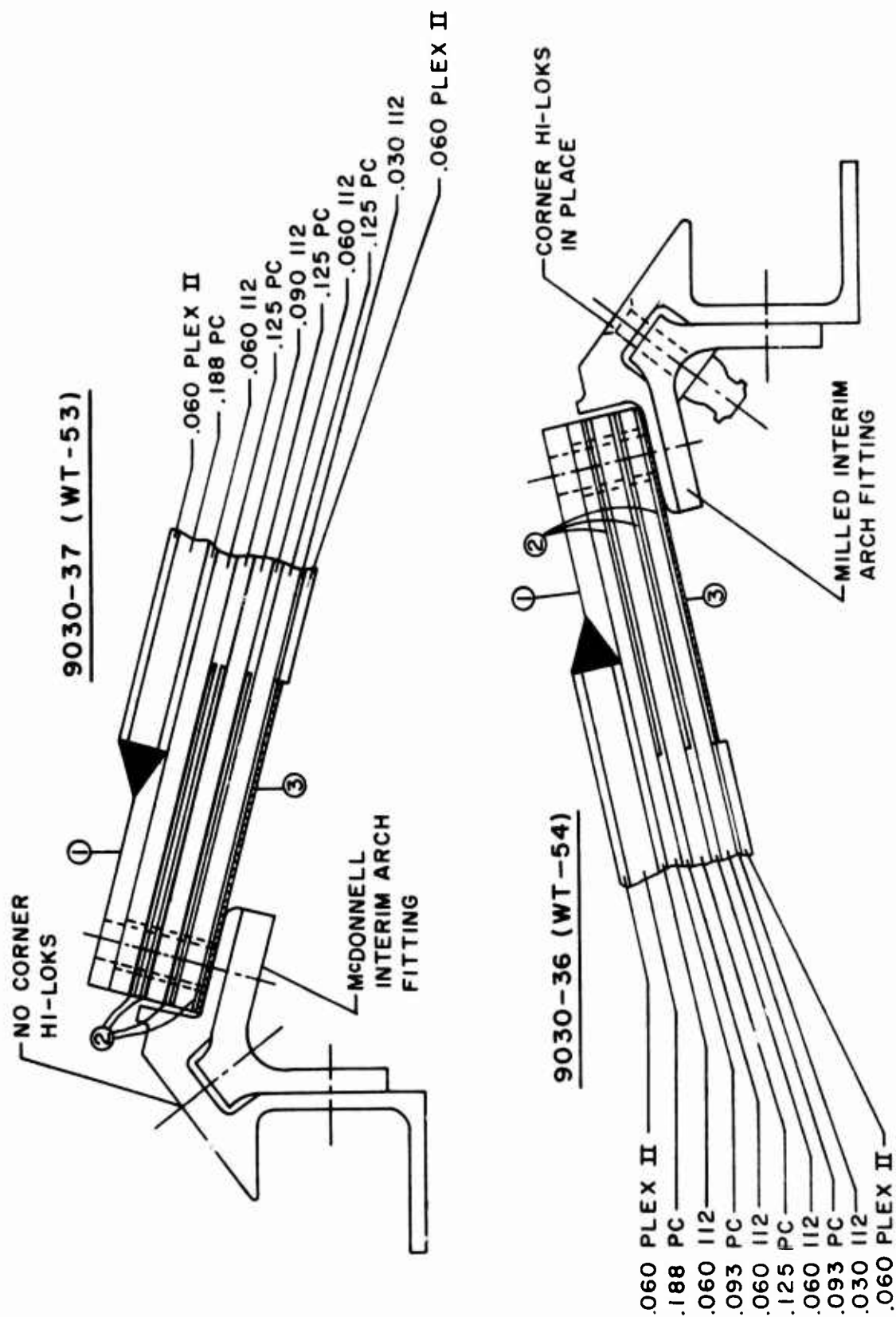
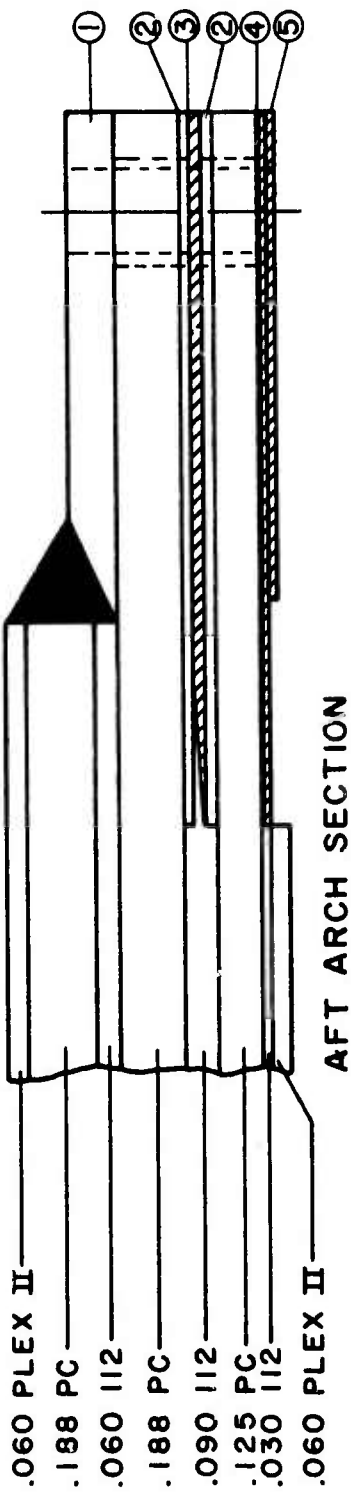
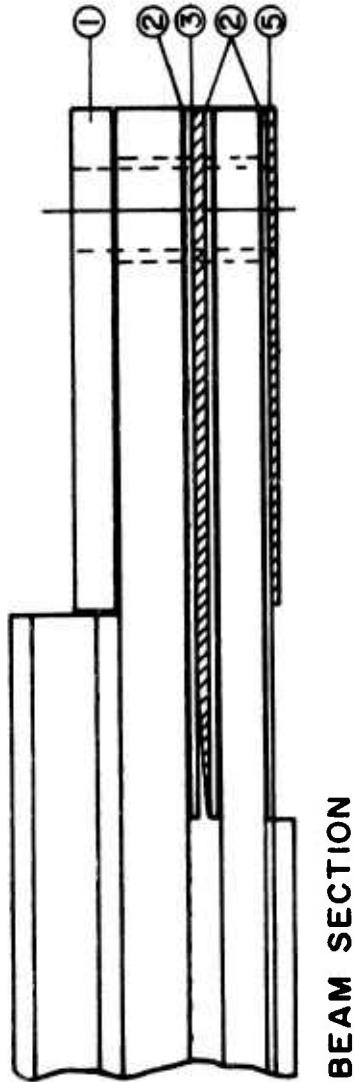


FIGURE 45. WINDSHIELD - ARCH COMBINATIONS

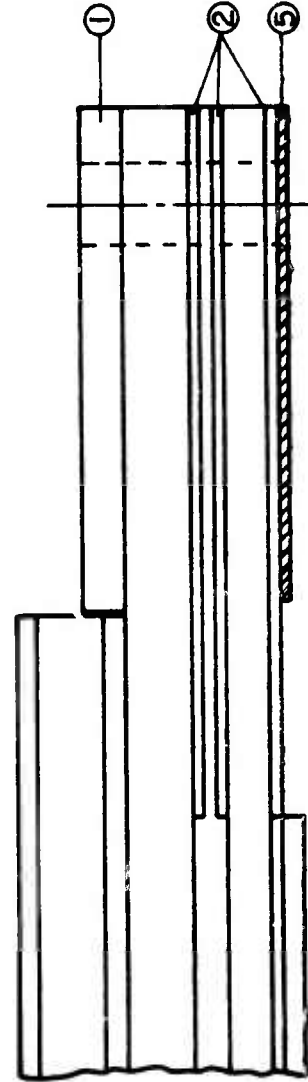
9030 - 38 (015 W/S)



AFT ARCH SECTION



BEAM SECTION



FWD. ARCH AND SILL SECTION

FIGURE 46. TWO-PC-PLY WINDSHIELD

TABLE XVI - FINAL WINDSHIELD TESTS - TASK II

| <u>Test</u> | <u>Panel Construction</u>                    | <u>Arch Reinforcement</u>                            | <u>Speed</u> | <u>Result</u> |
|-------------|----------------------------------------------|------------------------------------------------------|--------------|---------------|
| WT-53       | Medium 3-Ply                                 | (Used) - Not milled, Hi-Loks removed. Added section* | 516 KT       | OK            |
| WT-54       | Thin 3-Ply                                   | (Used) - Milled with all fasteners in place.         | 521 KT       | OK            |
| WT-59       | "Primary" with 1/8" and 3/16" plies reversed | (New) - Milled with corner Hi-Loks removed.          | 458 KT       | Failed        |

\*See text

Both windshields with three PC structural plies survived aft beam corner impacts from 4 lb birds at 516 knots and 521 knots. Support included the same McDonnell Douglas interim fitting as used in WT-49 and WT-50 with two changes. First, the corner Hi-Lok fasteners were removed. Also, a second reinforcement had been added to strengthen the arch flange which had cracked during previous shots. This fitting, fabricated by AEDC/ARO with McDonnell Douglas engineering support, including .25" steel webs, began at the end of the McDonnell interim fitting and extended support 7.6" farther down the arch. With this combination, there was more residual indentation of the inboard PC ply in line with the arch mounting flange than occurred with WT-48. However, there was sufficient rotation of the arch and support by the titanium edge attachment strip (which deformed enough to crack), that no PC shearing occurred.

For WT-54, the horizontal leg of the left-hand fitting was milled at PPG INDUSTRIES, Works No. 5, to reduce its thickness from .200" to a nominal of .130". In contrast to WT-53, the corner Hi-Lok fasteners were used for WT-54. With this combination of arch reinforcement and the thinner windshield with three PC structural plies, a relatively high energy impact was defeated. There was no serious structural damage to the windshield. There was more permanent rotation and deflection of the arch than with any previous successful corner impact. As a result of this damage plus the cumulative effects of two previous shots on the left-hand side, it was the consensus of PPG, McDonnell Douglas and the Air Force representatives that another test should be made. It was decided to replace the arch while AEDC attempted to straighten the titanium arch reinforcements. Reworking of the interim arch fittings proved unsuccessful and a new milled reinforcement was manufactured for WT-59, the final windshield shot.

In spite of the design changes discussed, plus a more flexible mounting, the aft beam corner impact area of 9030-38 was penetrated at a lower-than-requested bird speed of 458 knots. The failure, if anything, was more severe than the previous shots on two-ply designs. Analysis of the failure showed that the design was overpowered, exceeding the ultimate strength of the extended PC plies.

WT-59 completed the Task II windshield bird impacts which included nine shots in the critical aft beam corner. Because of the importance of the corner impacts in the test program and in service, Table XIII summarizes all such tests including those which were part of independent PPG and Air Force programs.

In summary, the main Task II windshield test effort involved bird impact optimization of not just the windshield, as defined in the Statement of Work, but of an interrelated windshield-arch system. Conclusions drawn from this program of aft beam corner impacts on windshields in modified modules affected not only Task III windshield recommendations, but the overall retrofit effort.

1. An outer fused ply of .060" as-cast acrylic and .188" PC, dictated by thermal requirements, would not adversely affect bird resistance.
2. Designs with two extended PC plies were not capable of sustaining aft beam corner impacts without penetration. All demonstrated a mode of failure with shearing of the innermost extended ply which caused tensile failure of the other ply.
3. Panels with three extended PC plies did meet the 500 knot requirement in the aft beam corner. In most cases, the three ply designs exceeded mold line at the edges, implying the need for aerodynamic fairings.
4. A titanium or stainless steel support strip between the windshield and mounting surface tended to reduce edge shearing.
5. Edge shearing was also reduced by grinding the top center of the mounting surfaces in the module to increase the bending radius.
6. Windshield arch reinforcement was as critical to bird impact resistance as design of the windshield itself. An optimized level of stiffness was necessary between limits which caused either transparency or arch failure.
7. Optimization of system to meet specific requirements (aft beam corner impacts) required actual hardware rather than test frames.



TABLE XVII - AFT-BEAM CORNER BIRD IMPACT TESTS ON F-111 WINDSHIELDS

Conditions:

All tests at room temperature on complete windshields oriented with the beam edge 22° to the line of flight of the 4 lb birds.

| Test and Panel No.        | Panel Construction                                                                                             | Mounting Conditions                           | Impact Results     | Remarks                                                                      |
|---------------------------|----------------------------------------------------------------------------------------------------------------|-----------------------------------------------|--------------------|------------------------------------------------------------------------------|
| 0772-10<br>PPG Test       | "Old" design<br>(1/8 - 3/16 edge)<br>PC floating I/B<br>with I/B stainless<br>Z-bar only edge<br>reinforcement | PPG test frame                                | OK @ 495 KT        | Frame deflected; slight<br>damage to PC plies; no<br>penetration             |
| FM-2<br>Air Force<br>Test | "Old" design; no<br>Z-bar under edge;<br>no edge reinforcement                                                 | Unmodified<br>module                          | W/S OK @<br>531 KT | Although W/S OK, arch<br>section failed allowing<br>penetration into cockpit |
| WT-42<br>9030-23          | 2 PC ply edge<br>(1/8 - 3/16)                                                                                  | Rigid frame                                   | Failed @ 692 KT    | Minimal frame deflection                                                     |
| WT-43<br>9030-24          | 2 PC ply edge<br>(1/8 - 3/16)                                                                                  | Rigid frame                                   | Failed @ 509 KT    | Minimal frame deflection                                                     |
| WT-44<br>9030-25          | 2 PC ply edge                                                                                                  | Module with<br>gusseted arch<br>reinforcement | Failed @ 503 KT    | Shearing in line with<br>edge of mounting flange                             |

TABLE XVII (cont'd)

| <u>Test and Panel No.</u>  | <u>Panel Construction</u>                                  | <u>Mounting Conditions</u>                                         | <u>Impact Results</u> | <u>Remarks</u>                                                                            |
|----------------------------|------------------------------------------------------------|--------------------------------------------------------------------|-----------------------|-------------------------------------------------------------------------------------------|
| WT-47<br>9030-31           | Same<br>Ti support strip                                   | Module with<br>interim fitting                                     | Failed @ 528 KT       | Better resistance than<br>WT-44; only slight arch<br>deflection or rotation               |
| WT-48<br>9030-33           | 3 PC ply edge<br>(1/8 - 3/16 - 1/8)<br>Ti support strip    | Module with<br>interim fitting                                     | OK @ 520 KT           | No serious damage to<br>61.5 lb panel                                                     |
| WT-49<br>9030-32           | 2 PC ply edge<br>(3/16 - 3/16)                             | Module with<br>interim fitting                                     | Failed @ 515 KT       | Only slightly better than<br>1/8 - 3/16; W/S failed;<br>arch slightly damaged             |
| WT-50<br>Air Force<br>Test | "Old" design<br>like FM-2                                  | Module with<br>interim fitting                                     | Failed @ 529 KT       | Comparison with FM-2<br>shows effect of arch<br>reinforcement                             |
| WT-53<br>9030-37           | 3 PC ply edge<br>(1/8 - 1/8 - 1/8)                         | Module with<br>interim fitting<br>(no corner Hi-<br>Loks)          | OK @ 516 KT           | No significant structural<br>damage to 61 lb W/S; some<br>arch deflection and<br>rotation |
| WT-54<br>9030-36           | 3 PC ply edge<br>(.093 - 1/8 - .093)                       | Module with<br>milled interim<br>fitting                           | OK @ 521 KT           | No significant structural<br>damage to 55 lb W/S; most<br>arch deflection and<br>rotation |
| WT-59<br>9030-38           | 2 PC ply edge<br>(3/16 - 1/8) +<br>insert and Ti<br>straps | Module with new<br>milled interim<br>fitting; no<br>corner Hi-Loks | Failed @ 458 KT       | Damage more severe than<br>other 2 PC edge ply<br>designs                                 |

Initial Task II bird impact tests were made on full-size prototype canopies of the constructions in Figure 34 in Section II-5. Because of the limited projected area of the F-111 canopy in the installed position, impact points were based on those used for the Air Force's FM series,<sup>9</sup> but approximately 2" closer to the canopy center beam. Both canopies were mounted in standard F-111 hatches. As the data sheets for WT-51 and -52 in Appendix 1 show, the canopies prevented penetration at 509 knots and 684 knots. The high-speed shot at Mach 1.04 resembles windshields tested under similar conditions with a residual bulge and minor acrylic spall from the end of the bulge. For the 500 knot requirement in the FM series location, the cross-section can be expected to be more a function of weight or structural/thermal and durability considerations than strictly bird impact resistance.

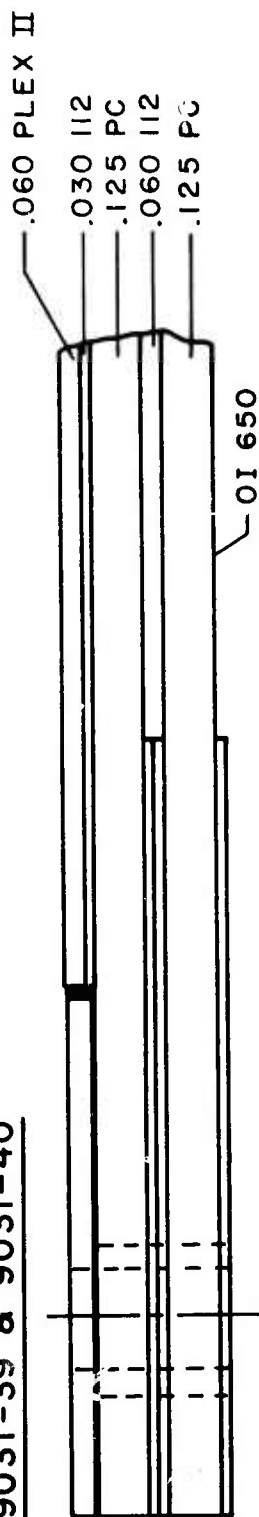
The possibility of weight reduction and low temperature impact resistance was considered in developing constructions for final Task II canopy bird impacts. In this group, gross weight reduction was proposed by elimination of the acrylic facings in favor of "hard" coatings. It was PPG's opinion that industry experience with current coatings precluded the use of current abrasion resistant coatings on the outboard surface. However, two panels with minimum weight and thickness were included with coatings inboard. Shown in Figure 47, 9031-39 and -40 have a thin abrasion ply of as-cast acrylic outboard and O-I 650 coating inboard. O-I 650 yielded maximum adhesion to the substrate in Task I tests, but with some PC embrittlement. In Task I, a 26" x 26" flat panel, 9031-3A with O-I 650 inboard, survived a 497 knot impact (WT-36), with no damage to the inboard PC ply. It should also be noted, however, that based on Task I thermal tests, the .060" acrylic facing section would probably not meet the contract thermal/pressure requirements.

High temperature exposures under this contract and the AEDC wind tunnel tests sponsored by the Air Force showed that maximum temperature resistance was provided by fused acrylic and PC. Canopy 9031-41 was heavier than -39 and -40 (36.6 lbs versus 25.9 lbs panel weight) but promised better thermal resistance. The bottom cross-section in Figure 47 shows a design with maximum abrasion and thermal resistance, but also maximum weight at 39.4 lbs. Since this design was closest to the windshield construction, it was selected for initial impact testing at low temperature.

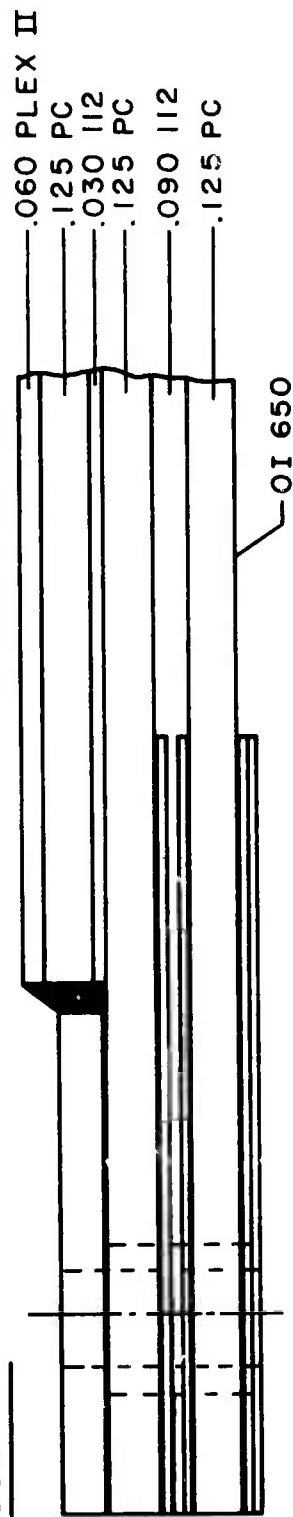
---

<sup>9</sup>Ibid, Figure 11, p. 21.

9031-39 & 9031-40



9031-41



9031-42

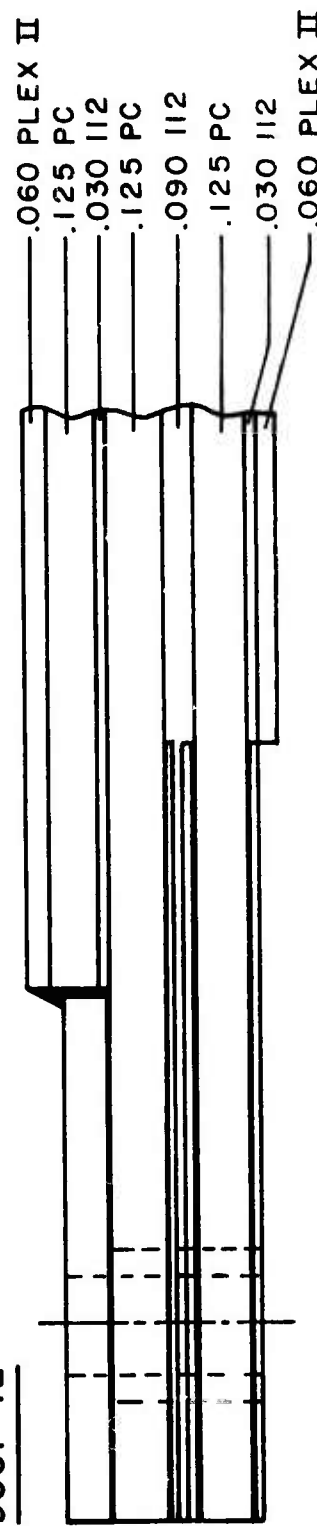


FIGURE 47. FINAL TASK II CANOPIES

As can be seen in the data sheets for WT-55 and WT-56 in Appendix 1, 9031-41 and 9031-40 survived nominal 500 knot room temperature impacts. Although successful, the general condition of the canopies and the cracking of PC plies indicated that these panels were close to their penetration limits. Two factors may have accentuated the damage. First, the strikes were closer to the beam edge than during preliminary shots. Second, the PC cracking may have been related to the time-temperature exposure of the PC during cure of the O-I 650. The coating itself did not act as a source of PC fractures even though it exhibited typical strain-induced brittle cracking in areas of maximum deflection. Canopy 9031-41 exhibited a sharp, nonuniform bulge in the impact area due to failure of the outboard structural PC ply. Post test analysis of the panel indicated that the unusual failure may have been the result of a crack in the fused ply propagating through a thin (approximately .020") area of the outermost 112 interlayer.

The purpose of the final Task II canopy tests was to evaluate the penetration resistance under  $-30^{\circ}\text{F}$  outboard ambient to  $+75^{\circ}\text{F}$  inboard ambient temperature gradient conditions. Both shots were marred by equipment and facility problems indicated on the data sheets in Appendix 1.

The first low temperature gradient test was made on 9031-42, the canopy design most like the two PC ply windshields. After difficulties in obtaining the proper outboard ambient temperature, equipment changes by AEDC did provide the required  $-30^{\circ}\text{F}$  as measured by a chart recorder which monitored all ambient and surface conditions. When the panel reached steady state, it was shot in the same location as the previous two canopy shots, i.e., 8" from the beam, 12" from the forward arch. The impact resulted in a penetration with a football-shaped plug blown inward. Inspection of the fractures shows that they started in the front ply and continued through the canopy unimpeded by the interlayers. This is typical of failures at temperatures below the  $+20^{\circ}\text{F}$  to  $+10^{\circ}\text{F}$  embrittlement range of 112 interlayer. The shape of the flap is almost identical to that formed when one of PPG's in-house test windshields was penetrated under  $+2^{\circ}\text{F}$  soak conditions.

After the test it was discovered that AEDC's recorder had not been calibrated and that indicated temperatures were approximately  $11^{\circ}\text{F}$  higher than actuals, so that the outboard ambient was at least  $-39^{\circ}\text{F}$ . The temperature gradient (WT-57, Appendix 1) including the revised surface temperatures show interlayer temperatures, particularly between the structural plies, below the 112 embrittlement range. Therefore, one would expect penetration at these lower-than-required temperatures.

The second low temperature canopy shot, WT-58, was made on the lightest canopy cross-section. In this test, temperature measurement was not a problem, but rather the bird package struck part of the temperature enclosure framework which did not fall completely beyond the bird's line of flight. As a result, the actual impact point and condition of the bird package are not known. In spite of these factors which would tend to reduce the chance of penetration, 9031-39 did exhibit some cracking through the laminate which permitted tissue to enter the module. The recorded temperature for the center 112 was 22.6°F which, experience has shown, is above the embrittlement range for this interlayer system.

It is possible that the low temperature embrittlement of the 112 may have been accompanied by brittleness of the PC. As with the other two canopies in this series coated with O-I 650, the time-temperature effect of the 230°F coating cure may have resulted in some loss of PC impact strength as in Task I.

For convenience, the six Task II canopy bird impacts are summarized in Figure 48. The following general conclusions were drawn from this series, which influenced the design recommended for Task III production.

1. Unlike the windshield, the existing canopy hatch is an adequate mounting structure for absorbing bird impact loads on the transparency.
2. As found in Task I, a pair of two .125" PC structural plies is adequate to meet the 500 knot bird impact requirement. Protection is possible close to the goal of Mach 1.2.
3. High-speed impacts with attendant large deflections may cause minor acrylic spall from the area of maximum bulge. This agrees with windshield conclusions.
4. The use of O-I 650 for inboard abrasion protection may reduce PC impact resistance. However, quantitative bird data was not obtained.
5. The constructions tested will not meet the 500 knot protection requirement under -30°F outboard ambient to +75°F inboard ambient temperature gradient conditions.



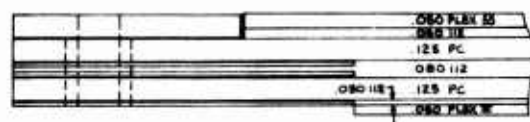
CONDITIONS: ALL CANOPIES INSTALLED IN F-111 MODULE HATCHES  
IMPACTS WITH 4-POUND BIRDS

9031-6A



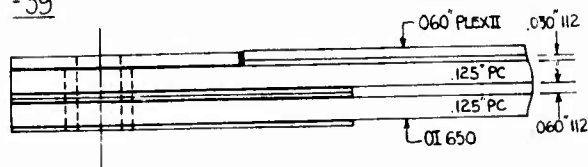
684 KT OK ROOM TEMPERATURE  
12" FROM BEAM

-7A



509 KT OK ROOM TEMPERATURE

-39



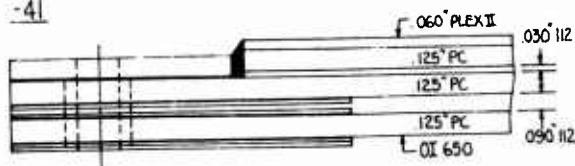
520 KT (FAILED) -30°F O/B AMB.  
BIRD HIT FRAME

9031 40



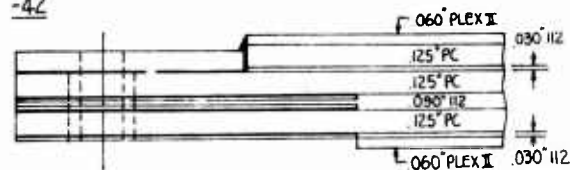
500 KT OK ROOM TEMPERATURE

-41



513 KT OK ROOM TEMPERATURE  
8" FROM BEAM

-42



516 KT FAILED <-39°F O/B AMB.

FIGURE 48. TASK II CANOPY BIRD IMPACTS

#### 4. RECOMMENDED WINDSHIELD AND CANOPY DESIGNS

Conclusions stated in the previous sections were the basis of recommendations for Task III windshield and canopy designs. The basic constructions were proposed and approved at a Program Review Meeting held at Wright-Patterson Air Force Base in October 1973.

The recommended Task III prototype windshield configuration in Figure 49 differs in several important respects from the Primary Task II test design shown in Figure 31. As the aft arch section shows, the most obvious is the three PC structural ply construction plus arch reinforcement dictated by the aft beam impact loading. The three .125" ply section was not the thinnest which survived aft beam corner impacts; however, it was chosen because of Air Force reservations about potential optics problems with .093" PC. For the outboard ply, Task II static thermal/pressure tests and Air Force wind tunnel work indicated that a fused outer ply of .060" as-cast acrylic plus .188" PC would provide the highest practical level of thermal protection. As explained before, .060" as-cast acrylic was selected as the inboard facing surface to provide isolation of the PC plies and to overcome drawbacks of state-of-the-art protective coatings.

The aft arch section in Figure 49 also defines the edgemember arrangement recommended for Task III windshields. As with Task II parts, an outboard retainer was proposed, but for Task III, these were tapered to facilitate matching with fairings required to blend the thicker edge section with nominal mold line. The following taper slopes were based on McDonnell Douglas recommendations.

1. Forward Arch - 7.5°. This angle permitted blending with the forward arch fairing.
2. Sill - 10°. A larger taper was required to clear sill fairing angle support. The 10° angle permits .060" clearance.
3. Aft Arch and Beam - 5°. On the aft arch, the 5° slope would permit blending the windshield and canopy retainers via a tapered filler.

While the beam, sill and forward arch retainers were flush with the edge of the fused facing ply, the aft arch incorporated a second taper as shown. Several possibilities were considered for filling the gap created by this taper with the final choice being a filler of Product Research Company PR1750 polysulfide. The retainers were made using 2024-T3 aluminum.

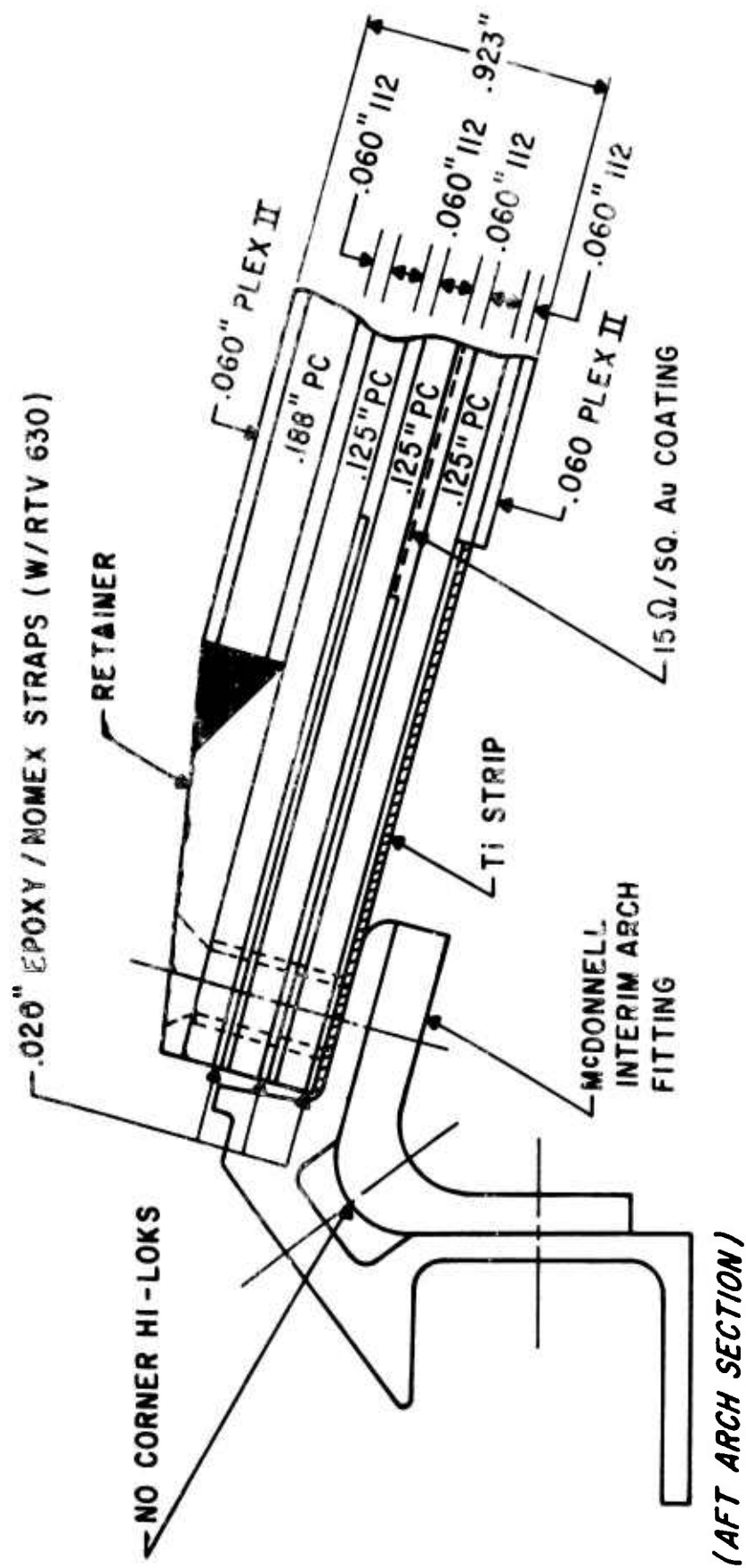


FIGURE 49. RECOMMENDED WINDSHIELD

Structural reinforcement for each of the PC plies was to be provided by .020" epoxy-Nomex "straps" bonded with nominal .010" RTV 630 to the inboard surface of each ply. This reinforcement differed slightly from that used in the panel with three .125" PC plies shot in WT-53. However, the reinforcement arrangement proposed for Task III was used for windshield 9030-36 which survived a 521 knot corner impact in test WT-54. By using the single reinforcement on the second PC ply, the second interlayer was reduced to .060".

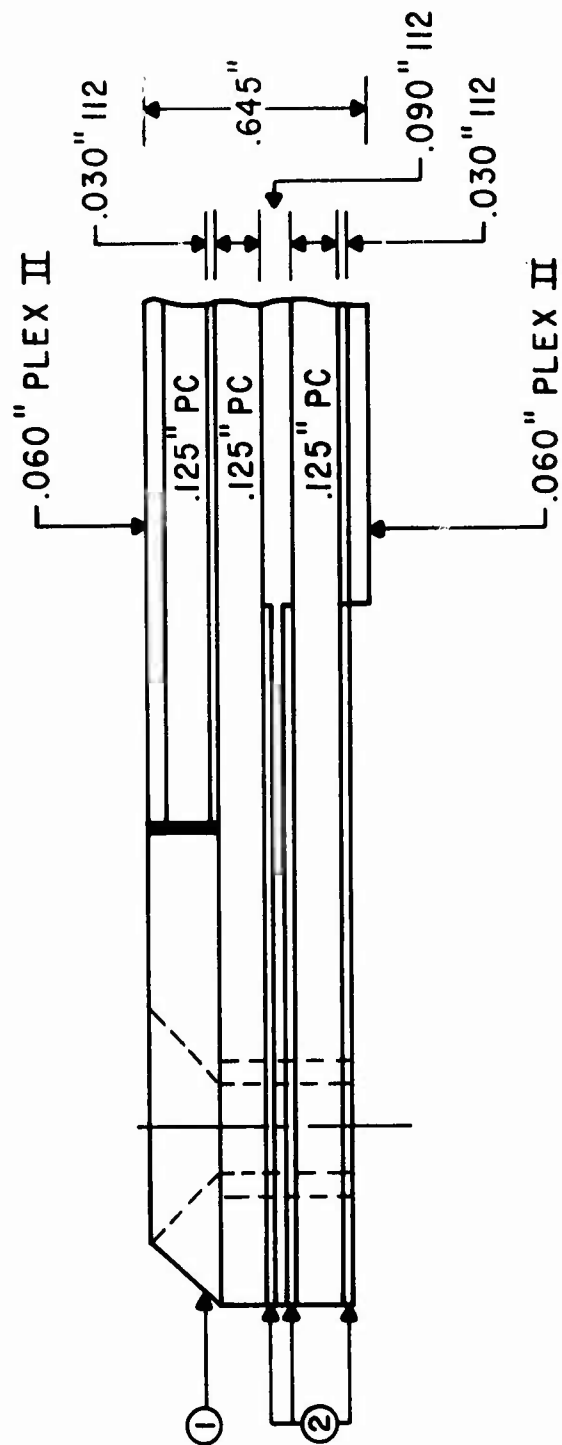
Other edge attachment items included a .025" titanium support strip or inboard retainer attached superficially to the innermost strap to provide bending support during impact deflection. Mounting loads between the retainer and support strip were carried by tempered aluminum "bushings."

In the proposed windshield design, the 15 ohms per square coating was to be applied to the inboard (concave) surface of the middle PC structural ply. The strap on this ply was slightly undersize to permit the film to extend beyond the daylight opening. Grounding was via bus bars to the airframe through bushings along the aft arch.

A typical section of the recommended canopy design, presented at the Program Review, can be seen in Figure 50. This basic design was tested for bird impact in Task II and as discussed in the previous part, the two structural plies of .125" PC have proven more than adequate in meeting the 500 knot requirement at room temperature. As important as bird impact in structural ply selection was the 870 lbs/lineal inch tensile edge loading requirement. Tests indicated that at 260°F soak, the ply and reinforcement arrangement shown was the minimum which would provide the tensile load capability.

As with the windshield, the canopy used an outboard retainer to distribute the mounting loads to the bushings. In order to clear the fasteners, a maximum canopy retainer slope of only 2° would have been possible. Therefore, a rectangular retainer was selected and a chamfer was added to the periphery. In an actual retrofit application, the forward arch chamfer would not be applied in lieu of an additional aerodynamic fairing to be added to this canopy hatch between the windshield and canopy transparencies.

With the structural ply arrangement and edge reinforcement fixed, the rest of the cross-section was based on a tradeoff between surface protection and weight. In the recommended design, PPG opted a maximum reasonable durability. For the same reasons as for the windshield, a fused outboard ply was suggested. In this case, .060" as-cast acrylic plus .125" PC would provide somewhat less protection than the .060"/.188" combination used in the windshield, but saved approximately 4 lbs per canopy over the thicker outer ply.



① ALUMINUM RETAINER

② .020" EPOXY / NOMEX STRAPS ( BONDED W/RTV 630 )

FIGURE 50. RECOMMENDED CANOPY CONSTRUCTION

Two methods of inboard surface protection were considered for the canopy. Both thin as-cast acrylic and abrasion resistant coatings were used in Tasks I and II and each have advantages and disadvantages as detailed elsewhere in this report. Thin as-cast acrylic was chosen for the inboard facing ply because it provides maximum long-term protection for the interior plies and also because of the numerous field difficulties being encountered with current state-of-the-art coatings. At the Program Review, Air Force and SMAMA representatives concurred with this decision even though it resulted in a projected panel weight of approximately 40 lbs.

At Air Force request, the 15 ohms per square gold film was deleted from F-111 canopies. This permitted a greater number of Task III prototype windshields to be produced with the coating than originally proposed.



## SECTION IV

### TASK III

#### 1. INTRODUCTION

The objective of Task III was the construction of hard tooling and subsequent delivery of prototype windshields and canopies. Specifically, the following parts were made and delivered to the Air Force for qualification testing.

##### a. Structurally Acceptable Units

Ten windshields (five L/H and five R/H) and four canopies (two L/H and two R/H) were to be delivered in which optics were on a best efforts basis. These parts will be utilized by the Air Force for bird impact qualification tests. One set of revised windshield fairings (P/N 12K3206) was also provided along with this group.

##### b. Ready-To-Fly Units

Eight windshields (four L/H and four R/H) and two canopies (one L/H and one R/H) were to be delivered which met all structural requirements and also current production optical requirements. Again, one set of modified windshield fairings was delivered with this group.

The bulk of this section of the report will be devoted to a description of the physical characteristics of the 18 windshields and 6 canopies and how they compare with contract requirements.

Task III did not include any test work funded by the contract; however, some edge attachment data has been generated by PPG's on-going evaluations and is included here for general information.

## 2. PROTOTYPE FABRICATION AND DELIVERY

In practice, Task III was a two-stage, overlapping effort of tooling production and prototype part fabrication. Modification of existing tools or construction of new hardware occurred prior to and concurrent with panel assembly. A specific discussion and list of tooling has been covered by other submissions to the Air Force<sup>10</sup> and it will not be discussed in this Final Report.

Most of the questions about assembly and structural integrity were answered in Task II; however, some testing was done to verify the effects of changes between test sample edge attachments and those of recommended designs.

Tensile load data generated in Tasks I and II was based on an edge attachment with two polycarbonate (PC) structural plies. Since the Task III windshield cross-section incorporated three plies of .125" PC rather than the .125" - .188" PC combination, but the same number of reinforcements, tensile tests were completed on 4.8" x 8" specimens of both edge designs. Table XVIII lists the results for windshields and canopies and provides a comparison with earlier data, showing that comparable results were achieved at 260°F. Although the windshield continued to exceed requirements, the canopy still was just above the ultimate 870 lbs/in load requirement with little safety margin.

TABLE XVIII - ULTIMATE TENSILE LOADING OF TASK III EDGE DESIGNS

| <u>Edge Type</u>              | <u>Yield<br/>(Lbs/In)</u> | <u>Ultimate<br/>(Lbs/In)</u> |
|-------------------------------|---------------------------|------------------------------|
| Task II W/S (1/8-3/16 PC)*    | 1080                      | 1280                         |
| Task III W/S (1/8-1/8-1/8 PC) | 1050                      | 1240                         |
| Task II C/P (1/8-1/8 PC)*     | 790                       | 910                          |
| Task III C/P (1/8-1/8 PC)     | 830                       | 1030                         |

\*From Table IV

---

<sup>10</sup>Letter from J. F. Wilson, PPG, to H. A. Warren, Jr., WPAFB, dated 28 March 1974, Subject: Contract No. F33615-74-C-3077 Developmental F-111 Windshields and Canopies.

Although physical characteristics of Task II test panels were evaluated, Task III prototypes were the first to include a complete documentation, particularly on the three PC ply windshield design. From Task II, it was apparent that prototypes produced under this contract would not meet the contract distortion and deviation requirements which were even more stringent than those imposed on current production parts. This was discussed at the October 1973 Program Review and at that meeting, verbal go-ahead was given to use current F-111 production optical requirements for distortion and deviation as the criteria for evaluating Task III optics. Therefore, the distortion and deviation data presented in Tables XIX, XX and XXI are based on these criteria. The Tables present pertinent information on optical and structural panels grouped as specified in the Introduction.

Task III optical windshields met the numerical requirements of Sections 5.1, Optical Distortion, and 5.3, Optical Deviation, of the current Acceptance Test Procedure (ATP) for F-111 Windshields and Canopies.<sup>11</sup>

These windshields did not meet the subjective interpretation of Section 5.2, Visual Optical, which relates to immediately apparent bending, blurring, divergency, convergency or jumping of grid lines. The number of specific exceptions per panel has been included in the "comments" columns of Tables XIX and XX. They range from 2 to 9 cases with the R/H panels generally better than L/H parts, due primarily to the relative quality of laminating tooling. Figures 51 and 52 show gridboard photos of two windshields which demonstrate both the type of optical defects and generally distortion-free center panel areas encountered in the prototype windshield development. Figure 51 shows a left-hand windshield (401611 RF) which meets the ATP requirements for Mark I and Mark II deviation plus lensing and displacement. Items which fall outside Section 5.2 for this windshield are the forward arch bands which encroach on the critical area and a bull's-eye located in the forward beam-side portion of the critical area. In Figure 52, fewer and less severe distortion bands are present in the forward critical area of this right-hand windshield (401612 RF). However, this optical delivery part, which again meets the ATP deviation, lensing and displacement requirements, does exhibit aft arch roll-off present on most of the prototype windshields.

---

<sup>11</sup>"Acceptance Test Procedure 501-2 for F-111 Windshield and Canopy Transparencies," pp. 4 and 5, 18 June 1971.

TABLE XIX - TASK III STRUCTURAL WINDSHIELDS

| Serial No. | Type | Destination | Deviation*<br>(MK I) (MK II) | Lensing* | Displ. | L.T.<br>(%) | Haze<br>(%) | Weight<br>(Lb) | Comments                                                              |
|------------|------|-------------|------------------------------|----------|--------|-------------|-------------|----------------|-----------------------------------------------------------------------|
| 401594 RF  | 015  | Holloman    | OK                           | OK       | OK     | 59.1        | 2.1         | 60.5           | 5 out of spec items per ATP Section 5.2*                              |
| 401607 RF  | 016  | "           | --                           | OUT      | OUT    | 59.0        | 2.7         | 59.3           | 4 ATP Section 5.2 items                                               |
| 401615 RF  | 015  | AEDC        | OK                           | OK       | OUT    | 58.9        | 1.7         | --             | 7 ATP Section 5.2 items                                               |
| 401618 RF  | 015  | "           | OK                           | OK       | OK     | 59.6        | 2.2         | --             | Damaged I/B Plex; originally an optical unit; 9 ATP Section 5.2 items |
| 403666 RF  | 015  | "           | --                           | --       | OK     | --          | --          | --             | 6 ATP Section 5.2 items                                               |
| 402627 RF  | 016  | "           | --                           | OUT      | OUT    | 57.7        | 2.3         | --             | 18 ATP Section 5.2 items                                              |
| 401609 RF  | 016  | "           | --                           | OK**     | OUT**  | 58.5        | 2.8         | --             | 4 ATP Section 5.2 items                                               |
| 403680 RF  | 016  | "           | --                           | --       | OUT    | --          | --          | --             | 8 ATP Section 5.2 items                                               |
| 401617 RF  | 015  | WPAFB       | OK                           | OK       | OUT    | 59.5        | 2.3         | --             | 8 ATP Section 5.2 items                                               |
| 401593 RF  | 016  | "           | --                           | OK       | OK     | --          | --          | 60.6           | 7 ATP Section 5.2 items                                               |

\*Defined according to "Acceptance Test Procedure 501-2 for F-111 Windshield and Canopy Transparencies."

\*\*Marginal, i.e., just OK or just OUT.

TABLE XX - TASK III OPTICAL WINDSHIELDS

| Serial No. | Type | Destination | Deviation* |       | Lensing* | Displ.* | L.T.<br>(%) | Haze<br>(%) | Comments                                                     |
|------------|------|-------------|------------|-------|----------|---------|-------------|-------------|--------------------------------------------------------------|
| 401616 RF  | 015  | Brooks AFB  | OK         | OUT   | OK       | OK      | 59.8        | 3.9         | 7 out of spec items per ATP Section 5.2*                     |
| 401589 RF  | 015  | "           | OK         | OK    | OK       | OK      | 57.3        | 1.2         | Original 015 viewed by A.F., 7 ATP Section 5.2 items         |
| 401610 RF  | 015  | "           | OUT        | OUT   | OK       | OK      | 57.4        | 1.7         | Replacement, defects noted, 7 ATP Section 5.2 items          |
| 401611 RF  | 015  | "           | OK         | OK    | OK       | OK      | 59.8        | 3.3         | 9 ATP Section 5.2 items, photo is Figure 51                  |
| 402628 RF  | 016  | "           | --         | OUT** | OK       | OK      | 58.4        | 2.0         | Viewed by A.F., weight = 62.3 lbs<br>3 ATP Section 5.2 items |
| 401613 RF  | 016  | "           | --         | OK    | OK       | OK      | 58.9        | 2.1         | 2 ATP Section 5.2 items                                      |
| 401612 RF  | 016  | "           | --         | OK    | OK       | OK      | 58.4        | 3.0         | Viewed by A.F., 2 ATP Section 5.2 items, Figure 52           |
| 402626 RF  | 016  | "           | --         | OK    | OK       | OK      | 59.6        | 1.9         | 3 ATP Section 5.2 items                                      |

\*Defined according to "Acceptance Test Procedure 501-2 for F-111 Windshield and Canopy Transparencies."

\*\*Marginal, i.e., just OK or just OUT.

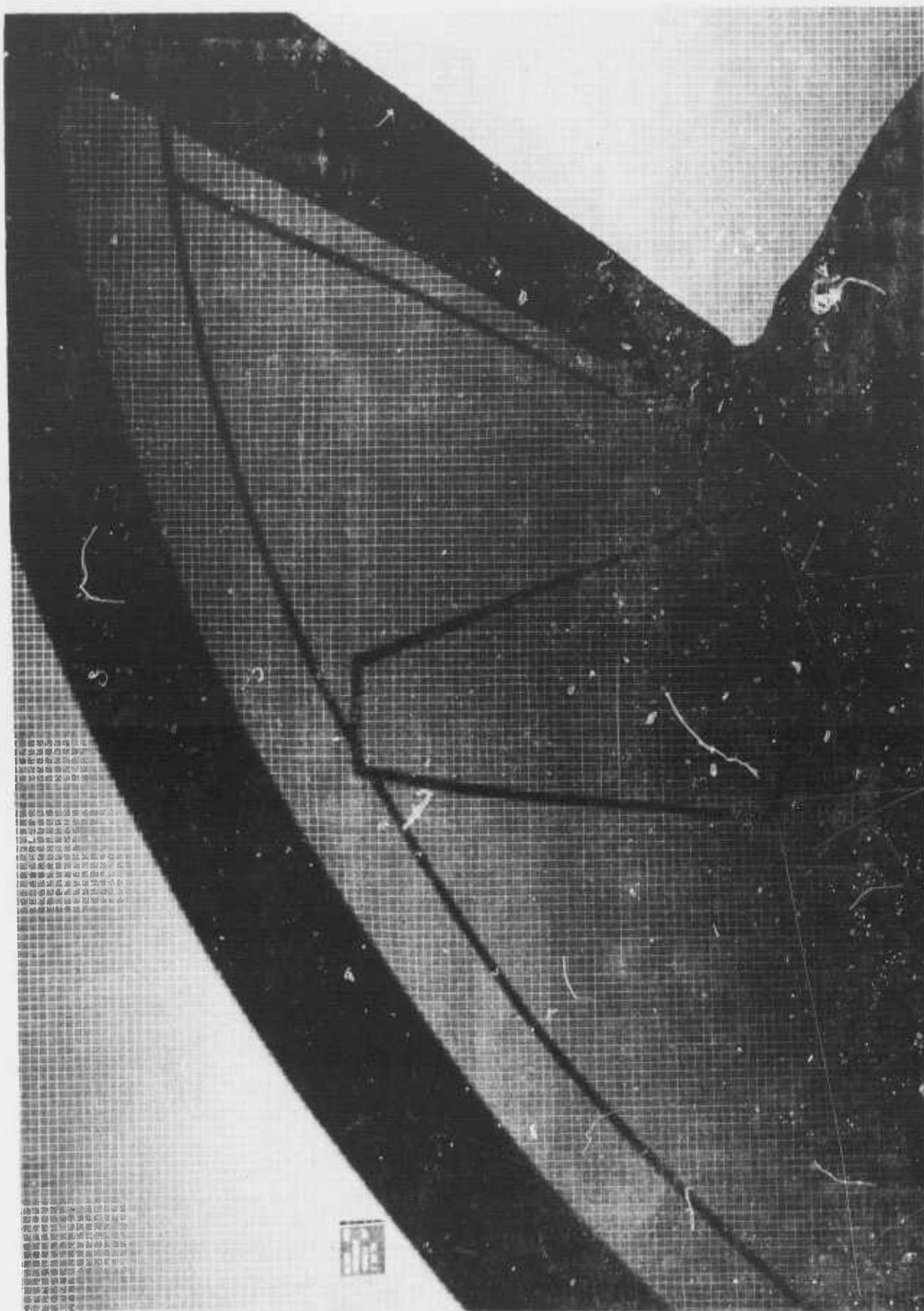


FIGURE 51. TASK III L/H WINDSHIELD (401611 RF) GRIDBOARD PHOTO



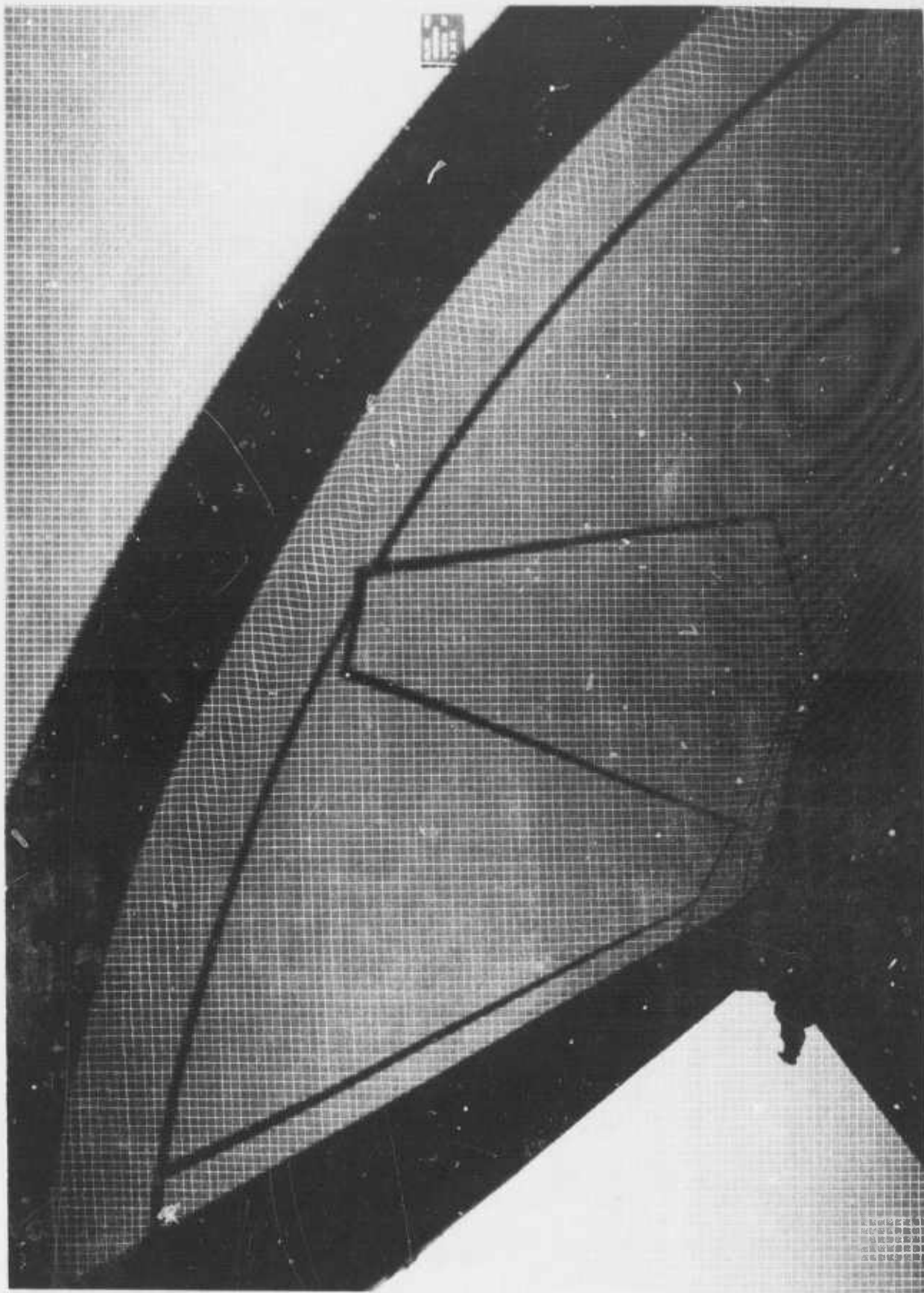


FIGURE 52. TASK III R/H WINDSHIELD (401612 RF) GRIDBOARD PHOTO

Those familiar with early 1080 glass F-111 windshields will note a similarity to the first eighteen F-111 retrofit prototypes. There has been an overall improving trend in optical quality during Task III and efforts are continuing in-house and on an additional eight prototype parts being produced under Contract F33615-74-C-3077. Since these efforts are underway at the time of this writing, details will not be covered in the Final Report; however, areas under investigation include assembly and finishing procedures, laminating tooling and laminating conditions.

Air Force representatives (Captain D. C. Chapin and Major W. F. Provines) visited PPG INDUSTRIES, Works No. 23, twice during Task III to inspect prototype optics. During the second visit by Captain Chapin and Major Provines, multiple images were compared between a production glass windshield and a Task III plastic windshield. Two to three bright secondary images could be seen on the glass part. Only a second image was visible on the Task III windshield and it was much dimmer than that of the glass part.

Another important item from Tables XIX and XX, light transmittance, can be compared with Statement of Work requirements, and Task II predictions. At the end of Task II, windshield transmittance was expected to be 69-71% minus 10-14% for the 15 ohms/sq gold film. Initial windshield data with the Task III 112 interlayer, but not gold film, was 70.5% transmittance as expected. However, the transmittance loss for the gold film on PC offset interlayer improvements. The average for Task III windshields was 58.8% and in no individual cases did any part meet the 60% requirement. Haze ranged from 1.2% to 3.9% with an average of 2.35%. In all cases, the windshields met the requirement of 4% and the average approached the 2% goal of the contract.

Table XXI indicates that the Task III prototype canopies at approximately 42 lbs are heavier than projected based on the 39.4 lb weight of Task II canopy 9031-42. The difference was due to increased retainer thickness and acrylic thicknesses greater than nominal. Of course, both are higher than the 30 lb Statement of Work requirement as a result of the weight of facing plies included for durability. Light transmittance (76.7% average) and haze (2.2% average) both surpass the requirements of 60% and 4% respectively. As with windshields, canopies meet the numerical ATP requirements for production F-111 parts, but do exhibit some apparent visual distortion as specified in Section 5.2 of the ATP. Canopies, however, are closer to production standards than windshields in this area.

TABLE XXI - TASK III OPTICAL AND STRUCTURAL CANOPIES

| Serial No.                  | Type | Destination | Zone I*<br>(>1:10) (>1:6)  | Zone II*<br>(>1:10) (>1:6) | L.T.<br>(%) | Haze<br>(%) | Weight<br>(lb) | Comments            |
|-----------------------------|------|-------------|----------------------------|----------------------------|-------------|-------------|----------------|---------------------|
| <b>A. STRUCTURAL PANELS</b> |      |             |                            |                            |             |             |                |                     |
| 402636 RF                   | 017  | Holloman    | 0                          | 0                          | 0           | 77.6        | 42.5           | Viewed by Air Force |
| 402645 RF                   | 018  | "           | 0                          | 0                          | 0           | 76.1        | 41.8           |                     |
| 403663 RF                   | 017  | WPAFB       | OPTICAL DATA NOT AVAILABLE |                            |             |             |                |                     |
| 402644 RF                   | 018  | "           | 0                          | 0                          | 0           | 76.4        | --             | Scuff in O/B Plex   |
| <b>B. OPTICAL PANELS</b>    |      |             |                            |                            |             |             |                |                     |
| 402648 RF                   | 017  | Brooks AFB  | 0                          | 0                          | 0           | 77.5        | --             |                     |
| 402647 RF                   | 018  | "           | 0                          | 0                          | 0           | 76.1        | 42.0           |                     |

\*Defined according to "Acceptance Test Procedure 501-2 for F-111 Windshield and Canopy Transparencies."

The Task III prototype transparency data reported herein was not intended to be a complete study of the 24 windshields and canopies. A complete test program was planned for the parts at the destinations indicated in Tables XIX, XX and XXI. Structural windshields and canopies sent to Holloman Air Force Base were installed in a module for rocket sled bird impacts. Six structural windshields were subjected to cannon-fired bird impacts at Arnold Engineering Development Center. One shipset of structural parts underwent ultimate thermal/pressure testing at Wright-Patterson Air Force Base. The ten optical windshields and canopies were delivered to Brooks Air Force Base for a complete optics evaluation. After this phase, the optical parts were tested at Wright-Patterson Air Force Base for one lifetime of cyclic thermal/pressure testing followed by retesting of optical characteristics and bird impacts.

### 3. PERFORMANCE SUMMARY

Tasks II and III were to yield windshield and canopy designs which would provide bird resistance yet function as serviceable F-111 transparencies. This section summarizes briefly how the prototypes compared with Statement of Work requirements, as discussed in detail elsewhere and identifies possible problem areas.

Tables XXII and XXIII are item-by-item lists of requirements or goals and performance levels achieved during the program, detailed in applicable sections. Windshields were within allowable limits for mold line deviation, weight and haze. The average light transmittance was below the required value by 1.2%.

After much development work, a combination of windshield and support structure was defined which will meet the 500 knot room temperature impact requirement. The windshield should provide higher levels of protection, approaching Mach 1.2 at mid-panel; however, it is unlikely that any practical combination could provide Mach 1.2 bird resistance in the aft beam corner.

Thermal/pressure tests on full-size windshields indicated that neither a .085" glass-faced or .060" acrylic plus .125" PC fused plastic-faced section would survive the maximum temperature/pressure combinations as originally specified in the F-111 Qualification profiles. However, successful wind tunnel tests on samples with .060" acrylic - .188" PC facing, plus Air Force reevaluation of test parameters, indicate at least a better chance for meeting them with a bird resistant windshield.

As far as optics are concerned, the subjective effect of distortion is the main problem area. The Task III optical windshields met the numerical criteria for lensing and displacement; however, there was still visually apparent bending of grid lines, particularly in the forward arch area and extreme aft arch edge. This subject must receive the main thrust of development effort as parts are produced beyond the initial 18 prototypes.

Table XXIII, the canopy summary, shows that the approved design exceeded the outboard mold line deviation slightly and the weight requirement by a large amount (12 lbs). The weight was added by facing plies which were agreed were required to provide the necessary thermal protection for the outermost 112 interlayer and abrasion protection for the polycarbonate structural plies. The two .125" plies were found to provide a high level of room temperature bird impact protection, approaching the Mach 1.2 goal, at the shallow canopy installation angle. The 500 knot protection was not achieved with an outboard temperature of 9° below the -30°F low temperature extreme listed.

There was no temperature/pressure testing on prototype canopies. Limiting factors in tests to be run at Wright-Patterson Air Force Base are expected to be .060" acrylic - .125" PC outboard ply and the marginal ultimate tensile capability of the edge attachment.

Without the gold 15 ohms/sq coating, prototype canopies easily met the 60% transmittance requirement. This could be a human factors problem when contrasted with the approximately 18% lower windshield transmittance. As with windshields, canopies met the current production numerical requirements for distortion and deviation but did encounter instances where grid line distortion exceeded subjective limits. In general, however, the Task III prototype canopies were closer to production optical quality than the Task III windshields.



TABLE XXII - PERFORMANCE SUMMARY - WINDSHIELD

| STATEMENT OF WORK                                                                                                                                                                                                                                                                                                                                                    | ACTUAL                                                                                                                                                                                                                                                                      |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| I. <u>MOLD LINE DEVIATION</u>                                                                                                                                                                                                                                                                                                                                        | I. <u>MOLD LINE DEVIATION - BLEND WITH MCAIR FARINGS</u>                                                                                                                                                                                                                    |
| A. 0.23" I/B<br>B. 0.50" O/B                                                                                                                                                                                                                                                                                                                                         | A. 0.06" I/B<br>B. 0.49" O/B                                                                                                                                                                                                                                                |
| II. <u>BIRD IMPACT (4 LB BIRD)</u>                                                                                                                                                                                                                                                                                                                                   | II. <u>BIRD IMPACT (4 LB BIRD)</u>                                                                                                                                                                                                                                          |
| A. Requirement<br><br>1. 500 KT @ RT<br>2. 500 KT @ -30°F to +75°F<br>3. 500 KT @ +200°F to +75°F<br><br>B. Goal<br><br>1. Mach 1.2                                                                                                                                                                                                                                  | A. Verified in Modified Module - Aft Beam Corner<br><br>1. 520 KT @ RT - OK<br>2. Testing Eliminated<br>3. Testing Eliminated<br><br>B. Goal<br><br>1. Center Impact<br><br>a) Mach 1.1 (727 KT) @ RT - OK (2 Ply Design)                                                   |
| III. <u>PRESSURE-TEMPERATURE</u>                                                                                                                                                                                                                                                                                                                                     | III. <u>FULL SIZE WINDSHIELD TESTS</u>                                                                                                                                                                                                                                      |
| A. Four Life-Times                                                                                                                                                                                                                                                                                                                                                   | A. To Be Evaluated at WPAFB<br><br>1. Failed 360°F O/B, 12.5 psi (Task II)<br><br>2. Fused O/B OK, 10 Cycles at Mach 2.4 (Air Force Tests)                                                                                                                                  |
| IV. <u>WEIGHT</u>                                                                                                                                                                                                                                                                                                                                                    | IV. <u>WEIGHT</u>                                                                                                                                                                                                                                                           |
| A. 69 Lbs                                                                                                                                                                                                                                                                                                                                                            | A. 61 Lbs                                                                                                                                                                                                                                                                   |
| V. <u>OPTICS</u>                                                                                                                                                                                                                                                                                                                                                     | V. <u>OPTICS</u>                                                                                                                                                                                                                                                            |
| A. Transmittance: 60%<br><br>B. Haze: 4.0%<br><br>C. Deviation:<br><br>1. Originally<br>a) Optical Sight: 6' of Arc<br>b) Balance: 8'<br><br>2. Changed to More Stringent and Easier Interpreted ATP 501-2 Requirements<br><br>D. Distortion:<br><br>1. FZM-12-10952A, Section VII<br><br>2. Changed to More Stringent and Easier Interpreted ATP 501-2 Requirements | A. Transmittance: 58.8% Average<br><br>B. Haze: 2.4% Average<br><br>C. Deviation:<br><br>1. Meets Current ATP Numerical Requirements<br><br><br><br><br><br>D. Distortion:<br><br>1. Meets Current ATP Numerical Requirements; Does Not Meet Sec. 5.2 for Visual Distortion |

TABLE XXIII - PERFORMANCE SUMMARY - CANOPY

| <u>STATEMENT OF WORK</u>                                                   | <u>ACTUAL</u>                                                                             |
|----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| I. <u>MOLD LINE DEVIATION</u>                                              | I. <u>MOLD LINE DEVIATION</u>                                                             |
| A. 0.20" O/B                                                               | A. 0.22" O/B                                                                              |
| B. 0.00" I/B                                                               | B. 0.06" I/B                                                                              |
| II. <u>BIRD IMPACT (4 LB BIRD)</u>                                         | II. <u>BIRD IMPACT (4 LB BIRD)</u>                                                        |
| A. Requirement                                                             | A.                                                                                        |
| 1. 500 KT @ RT                                                             | 1. OK @ 509 KT @ RT                                                                       |
| 2. 500 KT @ -30°F to +75°F                                                 | 2. Failed @ -30°F O/B & 513 KT                                                            |
| 3. 500 KT @ +200°F to +75°F                                                | 3. Not Tested                                                                             |
| B. Goal                                                                    | B. Goal                                                                                   |
| 1. Mach 1.2                                                                | 1. OK @ 684 KT (Mach 1.04)                                                                |
| III. <u>PRESSURE-TEMPERATURE</u>                                           | III. <u>PRESSURE-TEMPERATURE</u>                                                          |
| A. Four Life-Times per Windshield S.O.W.                                   | A. Best Chance - To Be Evaluated at WPAFB                                                 |
| IV. <u>WEIGHT</u>                                                          | IV. <u>WEIGHT</u>                                                                         |
| A. 30 Lbs                                                                  | A. 42 Lbs                                                                                 |
| V. <u>OPTICS</u>                                                           | V. <u>OPTICS</u>                                                                          |
| A. Light Transmittance: 60%                                                | A. Light Transmittance: 76.7% Avg.                                                        |
| B. Haze: 4.0%                                                              | B. Haze: 2.2% Avg.                                                                        |
| C. Deviation:                                                              | C. & D. Deviation and Distortion                                                          |
| 1. Originally - 4' of Arc                                                  | 1. Meets Current ATP Numerical Requirements: Does Not Meet Sec. 5.2 for Visual Distortion |
| 2. Changed to More Stringent and Easier Interpreted ATP 501-2 Requirements |                                                                                           |
| D. Distortion                                                              |                                                                                           |
| 1. 1 in 20 Gridslope                                                       |                                                                                           |
| 2. Changed to More Stringent and Easier Interpreted ATP 501-2 Requirements |                                                                                           |

## APPENDIX 1

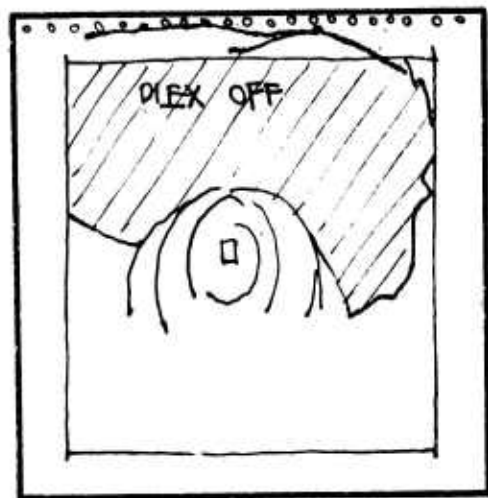
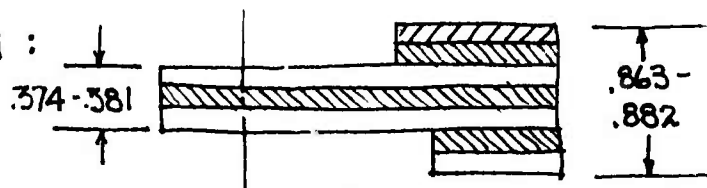
Following are data sheets recorded for each of the bird impact tests conducted during Task I and II of this program. They are arranged in order of test (WT) number with the sample identification at the top of the sheet.

SAMPLE CODE : 9030-4B

CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .125" PC - .120" 1/L - .125" PC -  
.120" 1/L - .125" PC

THICKNESS : .860" AREAL DENSITY : 5.36 LB./FT<sup>2</sup> PANEL WT. : 22.5 LB.

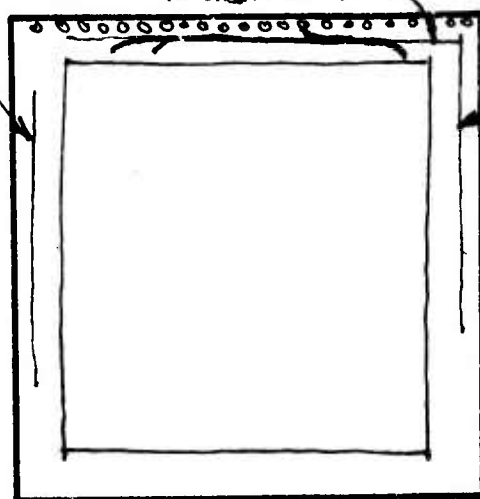
EDGE SECTION :



(FRONT)

FRAME CUTS

← SHEARED →



(REAR)

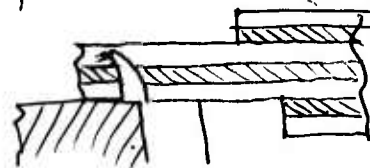
RESULTS ON 3-26-73 @ ? °F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-1 SPEED : INTENDED : 850 FPS  
PRELIM : 844 " BIRD WT. : 4.17 LB.  
FINAL : 851.5 FPS

REMARKS : PLAT (8±0) (504 kt) (46,926 FT-LB)

BIRD PENETRATED. TOP EDGE SHEARED ALLOWING TISSUE TO PASS THRU. CRACK IN LINE WITH MOUNTING FRAME. FRAME CORNERS VERY SHARP & ACTUALLY CUT INTO PC, EVEN ON SIDES.

PLY IN CONTACT WITH FRAME FAILED NORMAL TO SURFACE AND PROPAGATION BECAME OBLIQUE THRU OTHER PLYS, AS SHOWN.

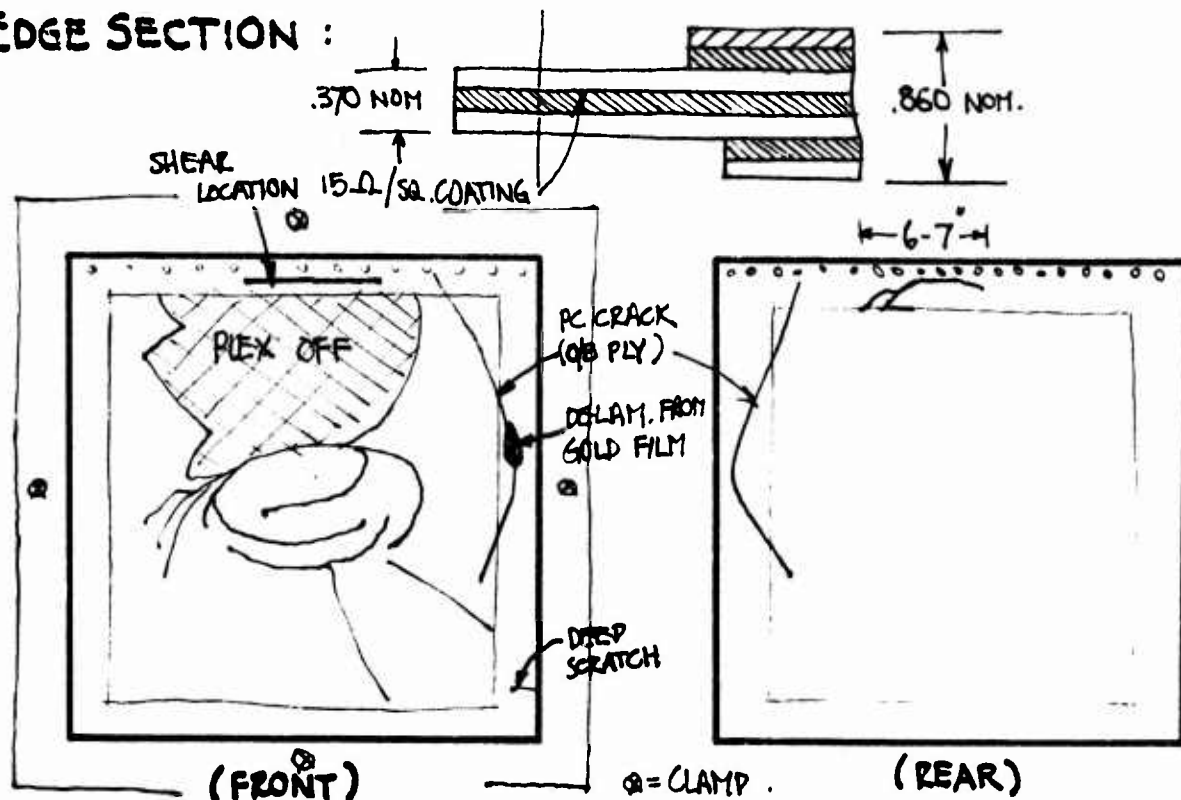


SAMPLE CODE : 9030-3A (WT-2)

CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .125" PC (15-2/52) - .120" 1/L - .125" PC - .120" 1/L - .125" PC

THICKNESS : .860" AREAL DENSITY : 5.36 LB./FT<sup>2</sup> PANEL WT. : 22.5 LB.

EDGE SECTION :



RESULTS ON 3-26-73 @ °F AND 23° INSTALLATION ANGLE

SHOT NO. : 2

SPEED :

INTENDED 750 FPS.

PRELIM. 747 "

FINAL . 758.1 FPS

BIRD WT. : 4.00 LB.

REMARKS :  $\delta \approx -1/8^\circ$

(447 KT)

(35,398 FT-LB)

**BIRD PENETRATED.** TISSUE THROUGH 6-7" CUT PUNCHED THROUGH IN LINE WITH FRAME. FRAME CHAMFERED & ROUNDED WITH EMERY CLOTH, (NEEDS MORE). FRAME DID NOT CUT PC, BUT LOAD AT TOP EDGE IMPOSED BY FRAME STILL EXCESSIVE.

CRACK IN O/B PLY OF PC, IN LINE WITH FRAME. ENDS (BEGINS?) AT TOP EDGE BOLT HOLE, SLIGHT DELAM. (2-3 IN<sup>2</sup>) WHERE CRACK STOPPED AT GOLD FILM INTERFACE. NO OTHER LOSS OF ADHESION ANYWHERE ELSE INCLUDING PENETRATION AREA.

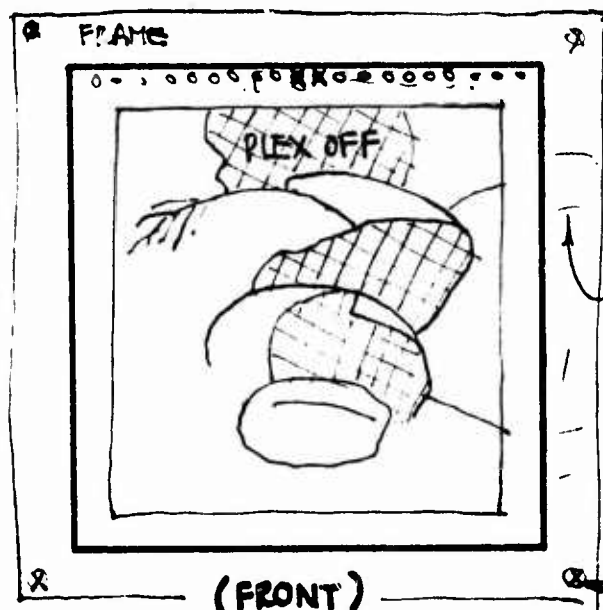
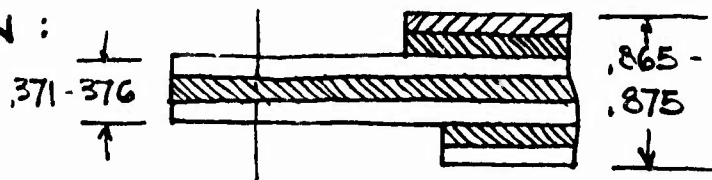
TOP CLAMP COULD BE RESTRAINING BIRD.

SAMPLE CODE : 9030-4A

CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .125" PC - .120" 1/L -  
.125" PC - .120" 1/L - .125" PC

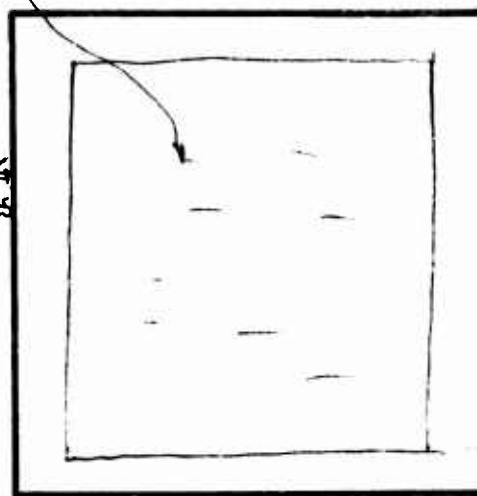
THICKNESS : .860" AREAL DENSITY : 5.36 LB./FT<sup>2</sup> PANEL WT. : 22.5 LB.

EDGE SECTION :



EDGE  
HANDLING  
SCRATCHES

FINE SCRATCHES ON 1/8 PC PRIOR TO TEST



RESULTS ON 3 -27-73 @ °F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-3 SPEED: INTENDED : 750 FPS  
PRELIM : ~ 830 BIRD WT. : 4.00 LB  
ACTUAL FINAL 861.5 FPS

REMARKS : (FLAT) (510 kt) (46,016 FT-LB)

BIRD DID NOT PENETRATE. TWO BOLTS GONE FROM CENTER OF TOP EDGE. SLIGHT TOP EDGE FRAME ROTATION. SLIGHTLY LOWER IMPACT PT.

PC DEFORMED WHERE IT MOVED OVER FRAME IN CENTER OF TOP EDGE, ALTHOUGH THERE WAS NO FAILURE OF THE PC ANYWHERE IN THE PANEL. THE EXTENDED PORTION OF THE TOP EDGE DEFORMED LIKE THE FRAME. FOR THIS SHOTS, CLAMPS WERE IN CORNERS OF MOUNTING FRAME. SIDE FRAME RAILS LIFTED ~ 1/16". TOP EDGE CORNER OF THE FRAME WAS BEVELED & ROUNDED MORE THAN LAST SHOT.

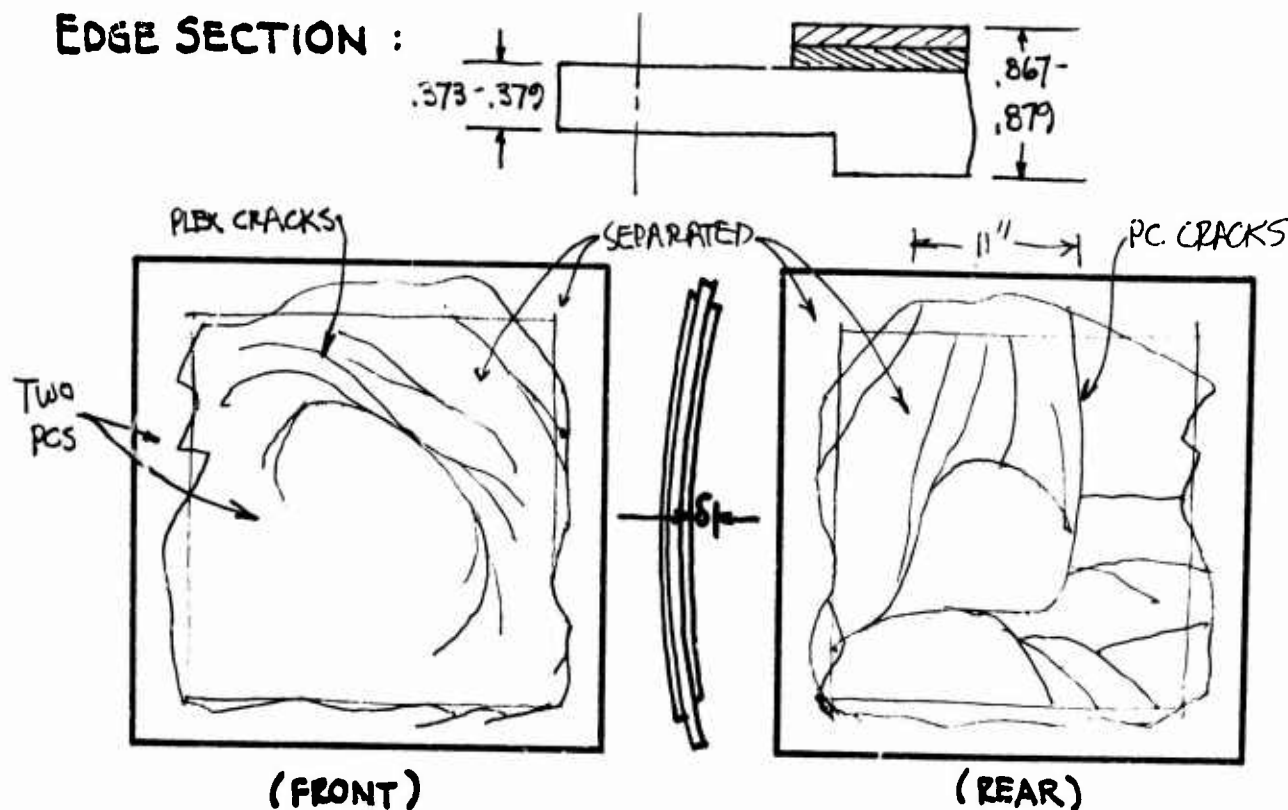


SAMPLE CODE : 9030-5A

CONSTRUCTION : .125" ACrylic - .120" 1/L - .625" PC

THICKNESS : .870" AREAL DENSITY : 5.41 LB./FT<sup>2</sup> PANEL WT. : 22.5 LB.

EDGE SECTION :



RESULTS ON 3 -27-73 @ °F AND 23 ° INSTALLATION ANGLE

SHOT NO.: WT-4 SPEED: INTENDED : 750 FPS  
ACTUAL : 800 " BIRD WT. : 4.06 LB

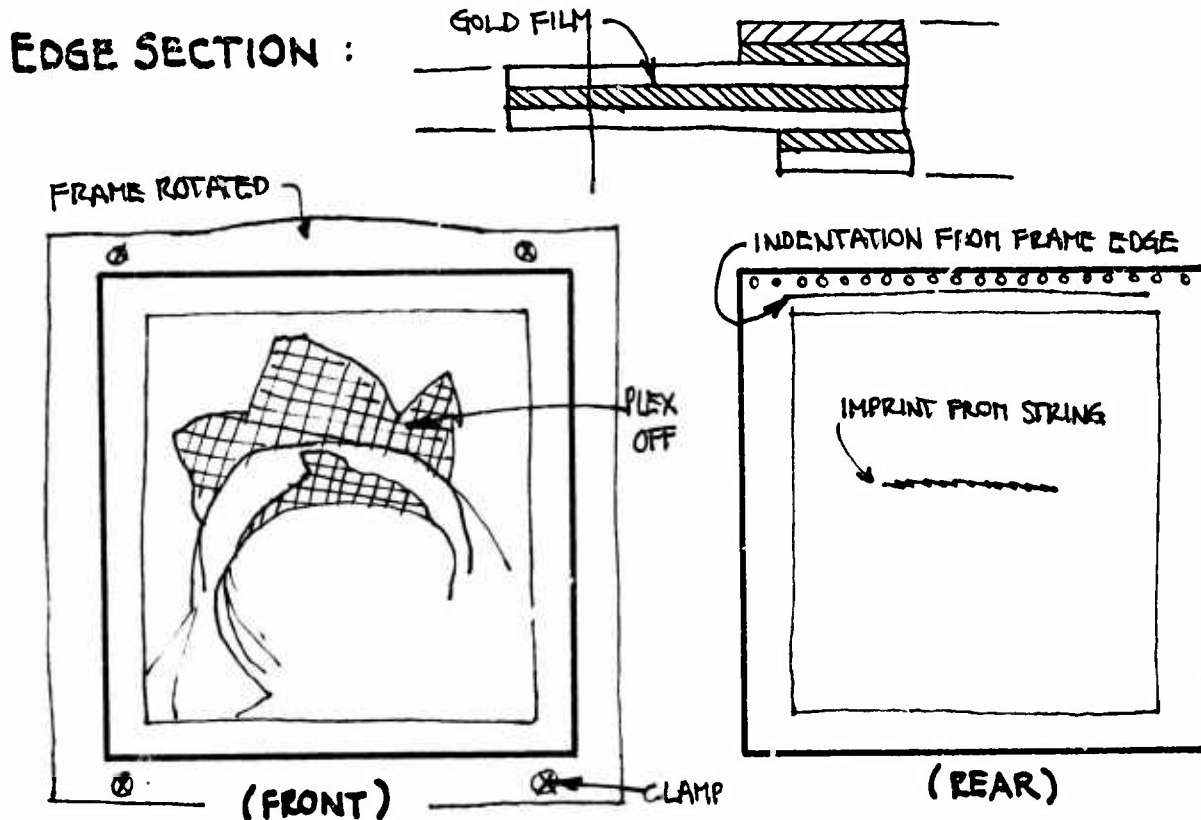
REMARKS :  $d = 5/16"$  RED RUBBER ON EDGE  
FINAL : 815.9 FPS (483 kt) (41,948 FT-LB)

BIRD PENETRATED. ENTIRE CENTER PORTION SHEARED & BLEW OUT. NO PLEX REMOVED FROM FRONT. PC AND PLEX CRACKS ARE NOT COINCIDENT, BEING STOPPED BY 11Z IN BOTH CASES. TOP EDGE SHEARING IN LINE WITH FRAME IN CENTRAL 11" SPACE & IN A LINE WITH FUSED 1/3 SECTION OVER REST OF TOP EDGE. MOST "ZIPPER" SHEARING ON OTHER 3 EDGES IN LINE WITH FRAME (& RESULTANT HIGH BENDING STRESS.)

SAMPLE CODE : 9030-3B

CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .125" PC - (15-2/sq FILM) -  
.120" 1/L - .125" PC - .120" 1/L - .125" PC

THICKNESS : .860" AREAL DENSITY : 53.6 LB./FT<sup>2</sup> PANEL WT. : 22 LB.



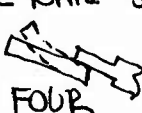
RESULTS ON 3-28-73 @ ~50 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-5 SPEED : INTENDED : 850 fps. BIRD WT. : 3.9% LB  
ACTUAL : 887.0 fps.

REMARKS :  $\delta \approx 0$  (FLAT)

(525 kt)

(48,35% FT-LB)

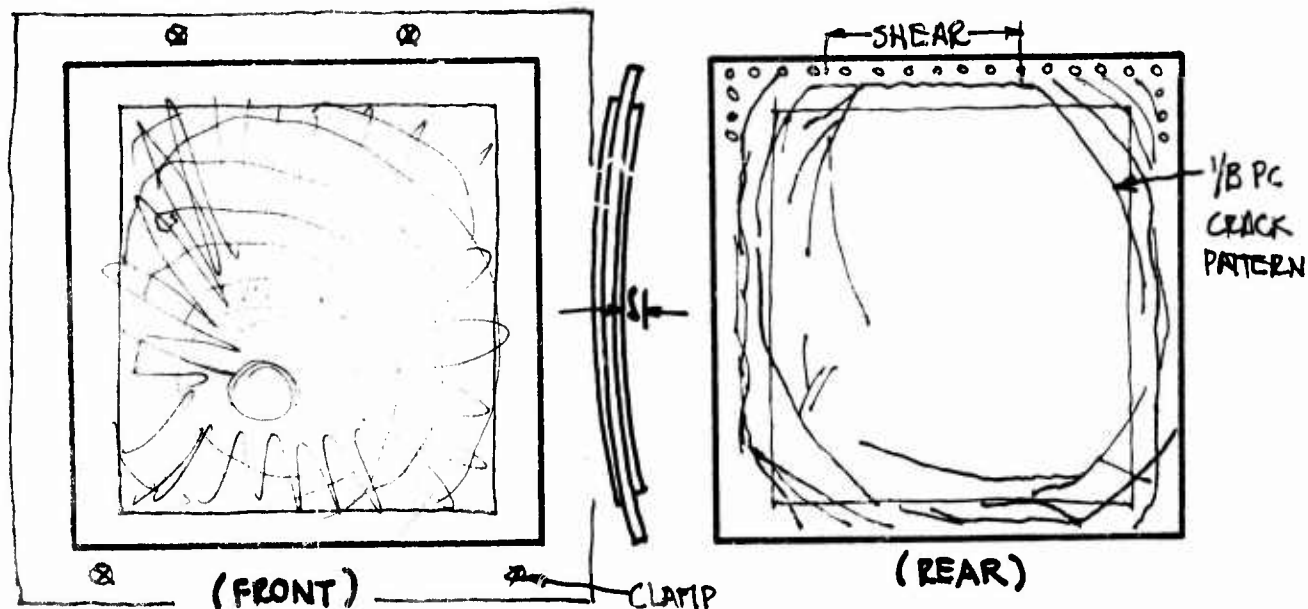
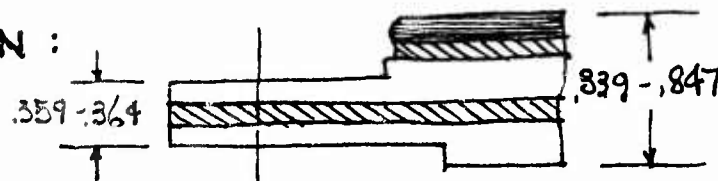
BIRD DID NOT PENETRATE. GOLD FILM HELD WELL WITH NO APPARENT DELAMINATION. TOP FRAME RAIL SHOWS PERMANENT ROTATION TOWARD IMPACT DEFLECTION. I.E., . THERE IS MORE BOLT HOLE DEFORMATION ALONG TOP EDGE THAN 1st FOUR SHOTS AND MORE LIKE PREVIOUS WORK ON SIMILAR PANELS. NEGLIGIBLE TOP EDGE ROTATION IN PANEL AFTER TEST. NO PC CRACKING ANYWHERE IN PANEL. SIMILAR TO 4A (SHOT WT-3). X-RAYS SHOW 45° YAW.

SAMPLE CODE : 9030 - 8A

CONSTRUCTION : .110" HERCULITE<sup>®</sup> II - .120" 1/L - .250" PC - .120" 1/L -  
.250" PC.

THICKNESS : .850" AREAL DENSITY : 5.99 LB./FT<sup>2</sup> PANEL WT. : 25 LB.

EDGE SECTION :



RESULTS ON 3 - 26 - 73 @ 55-60°F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-6 SPEED : INTENDED : 830 FPS  
FINAL : 839.2 " BIRD WT. : 4.15 LB.  
(497 kt) (45,362 FT-LB)

REMARKS :  $\delta = 1/2"$

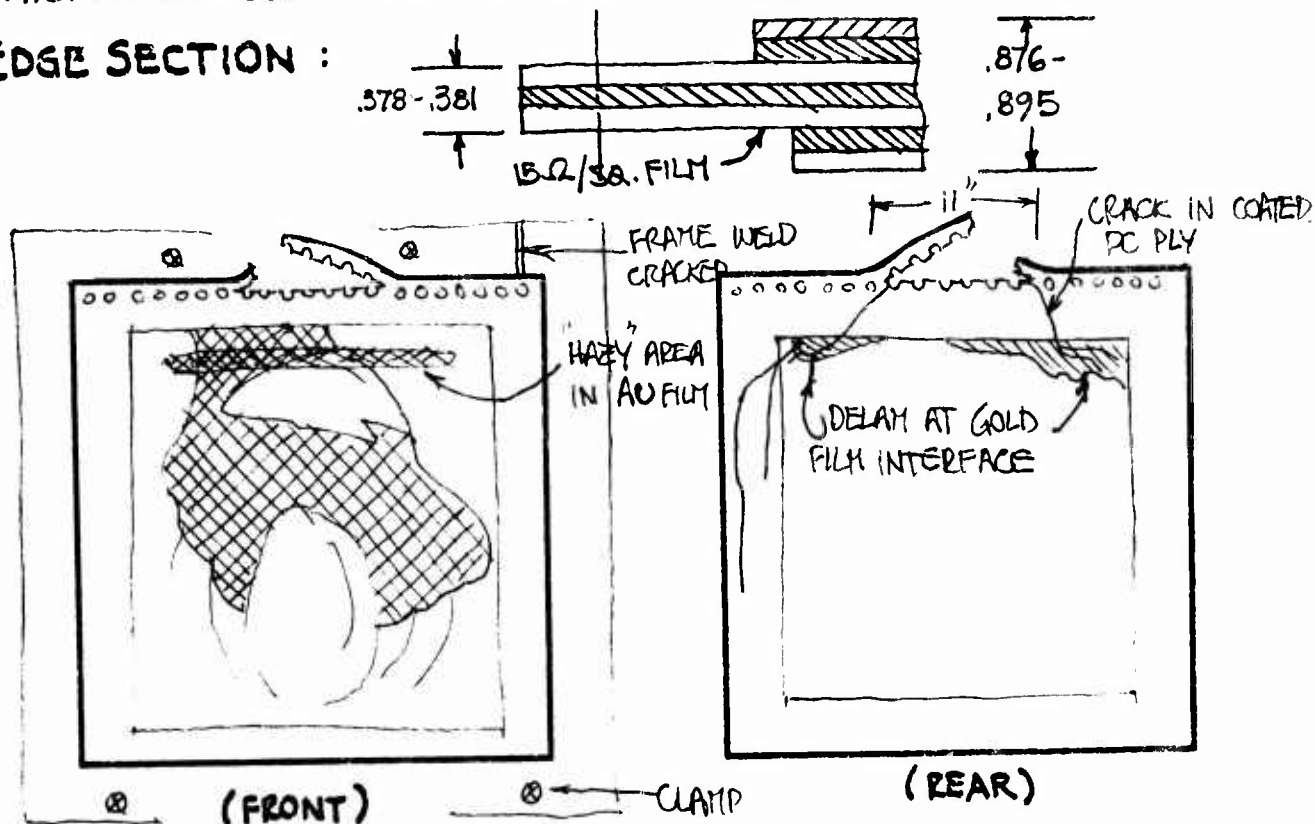
BIRD PENETRATED, TOP EDGE SHEARING. BOTH PLYS OF PC CRACKED.  
0% RESIDUAL VISIBILITY. BIRD TISSUE (FEATHERS, ETC.) STUCK IN  
SHEARED SECTION (OPENING ~18" LONG) CRACK PATTERNS IN TWO PC  
PLYS ARE SIMILAR BUT NOT COINCIDENT. GOOD GLASS-112 ADHESION,  
SOME PC CRACKING COINCIDES WITH FRAME EDGE. IT PROBABLY ORIGINATED  
ALONG TOP & PROPAGATED ALONG HIGH STRESS DUE TO BENDING OVER FRAME.

SAMPLE CODE : 9030-3C

CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .125" PC - .120" 1/L - .125" PC  
(150/50 GOLD FILM) - .120" 1/L - .125" PC

THICKNESS : .860" AREAL DENSITY : 5.36 LB./FT<sup>2</sup> PANEL WT. : 22.75 LB.

EDGE SECTION :



RESULTS ON 3-28-73 @ 64.5 °F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-7 SPEED: INTENDED: 850 FPS BIRD WT. : 4.18 LB  
FINAL : 908.2 "  
(538 Kt) (53.4% FT-LB)

REMARKS :  $\delta = -.116"$

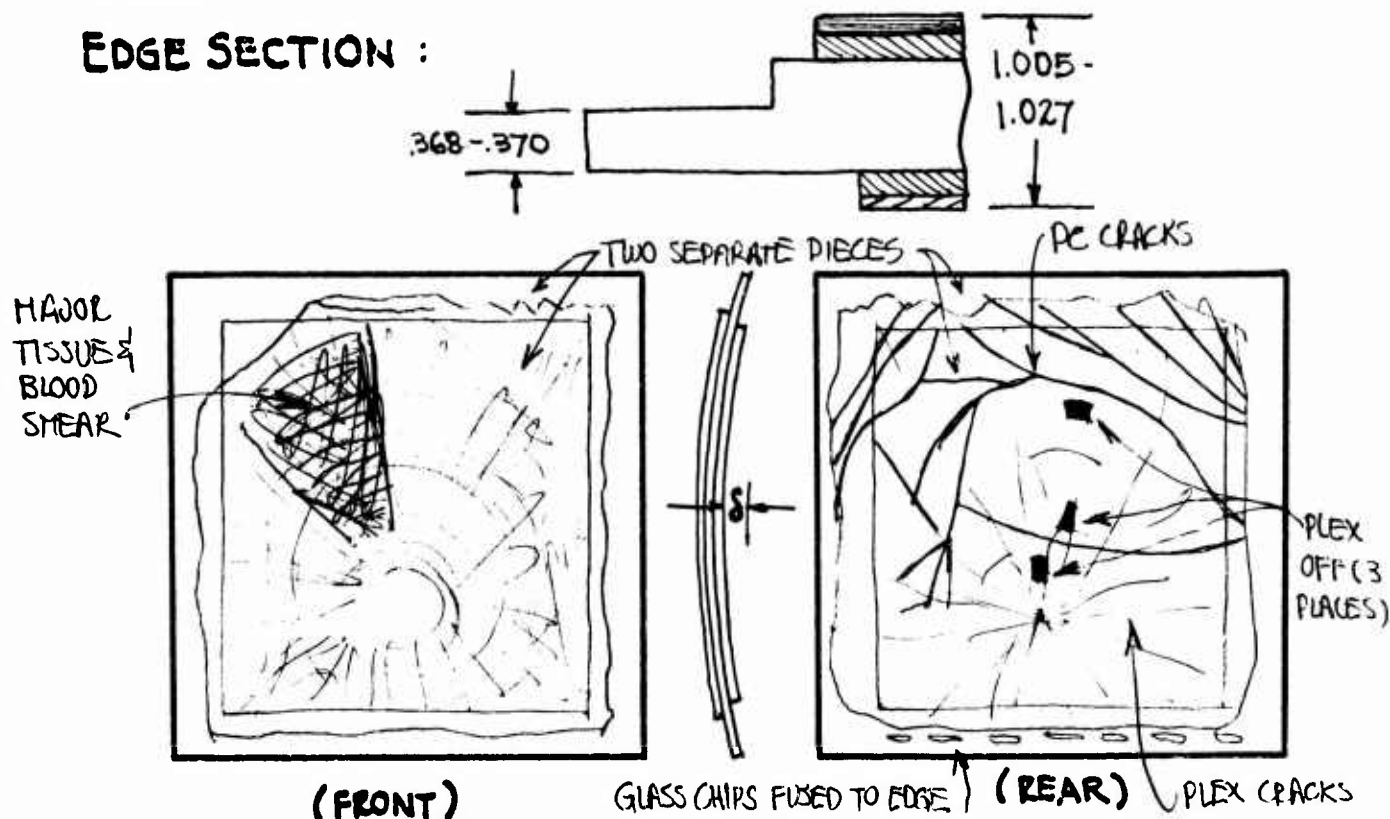
BIRD PENETRATED MUCH LIKE 3A (SHOT WT-2). JUST ABOVE PENETRATION LIMIT. EDGE SHEARED OVER 11" OF TOP EDGE WITH CRACK IN 2<sup>ND</sup> PC PLY CONTINUING TOWARD SIDES. THE CRACK RESULTED IN SLIGHT DELAMINATION AT THE GOLD FILM INTERFACE AS SHOWN. THERE WAS NO OTHER LOSS OF ADHESION TO THE GOLD FILM ANYWHERE ON THE PANEL. CONSIDERABLE DEFLECTION (WITH RESIDUAL INDENTATION) OVER FRAME BEFORE EDGE FAILED BETWEEN BOLTS FOR AN 11" DISTANCE.

SAMPLE CODE : 9030-11A

CONSTRUCTION : .110" HERCULITE II - .120" 1/4 - .625" PC - .120" 1/4 - .060" ACRYLIC

THICKNESS : .1035" AREAL DENSITY : 7.14 LB./FT<sup>2</sup> PANEL WT. : 29.75 LB.

EDGE SECTION :



RESULTS ON 3-28-73 @ 60-65°F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-8 SPEED : INTENDED : 850 FPS BIRD WT. : 4.18 LB.  
FINAL : 858.8 "

REMARKS :  $\delta = 5/16"$  (5085 KT) (47,850 FT-LB)

BIRD PENETRATED. CENTER SECTION BLEW OUT LIKE 5A (SHOT WT-4). TOP EDGE SHEARING COINCIDES WITH BOTH OFFSETS BETWEEN EDGE AND FACING SECTIONS AND FRAME. MOST OTHER SHEARING COINCIDES WITH FRAME. PC CRACKED, 0% RESIDUAL VISIBILITY.

INBOARD ACRYLIC CRACKED WITH ORIGIN AT IMPACT PT., AND ALL CRACKS STOP AT IIZ SURFACE. GOOD ADHESION THROUGHOUT ONLY 3 SMALL PIECES OF PLEX (~2 W<sup>2</sup>) WERE BLOWN OFF THE INBOARD SURFACE. VERY SLIGHT DELAM AROUND PC CRACKS.

BLOOD SHEAR & PC FRACTURE PATTERN INDICATES. MAY HAVE YAWED.

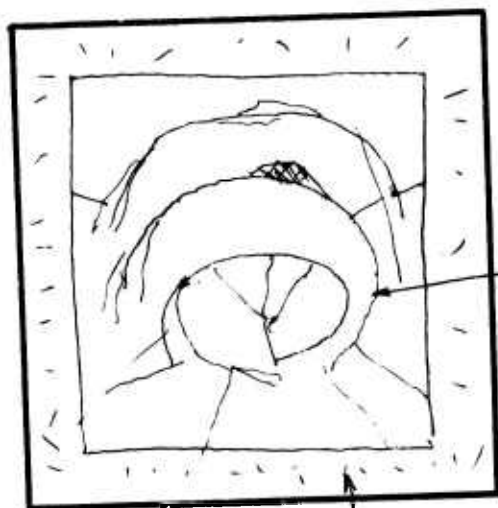
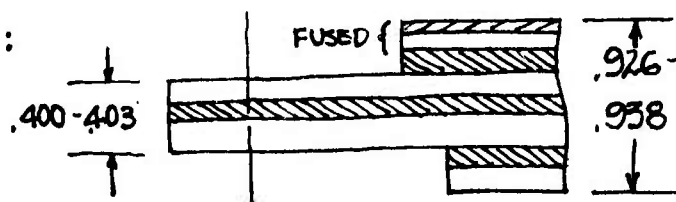


SAMPLE CODE : 9030-13A

CONSTRUCTION : .060" ACRYLIC / .093" PC - .120" 1/2 L - .125" PC - .090" 1/2 L -  
.188" PC - .120" 1/2 L - .125" PC

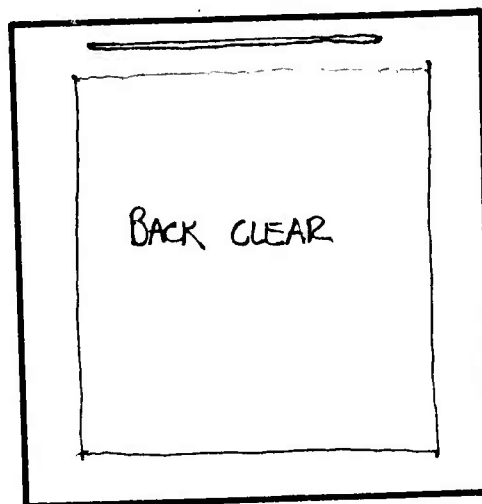
THICKNESS : .921" AREAL DENSITY : 574 LB./FT<sup>2</sup> PANEL WT. : 24.25 LB.

EDGE SECTION :



(FRONT)

EDGE SCRATCHES FROM  
HANDLING - NO EFFECT



(REAR)

RESULTS ON 3 -29-73 @ ~60 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-9 SPEED : INTENDED : 850 FPS  
FINAL : 842.6 " BIRD WT. : 4.00 LB.  
(499 Kt) (44,877 FT-LB)

REMARKS :  $\delta = 0$  (FLAT)

BIRD DID NOT PENETRATE. NOT EVEN CLOSE, OUTBOARD FUSED  
PLEX/PC PLY CRACKED BUT NOT REMOVED EXCEPT FOR 2-3 IN<sup>2</sup> AS  
SHOWN. OUTBOARD PLY SHOWS CRACKS THRU ACRYLIC & PC BUT STOPPING  
AT 1/2. GOOD RESIDUAL VISIBILITY (BEST OF 9 SO FAR). NO PC  
CRACKING. NO SIGNIFICANT RESIDUAL PANEL DEFORMATION.

OVERALL CONDITION AS EXPECTED, BASED ON IN-HOUSE WORK.

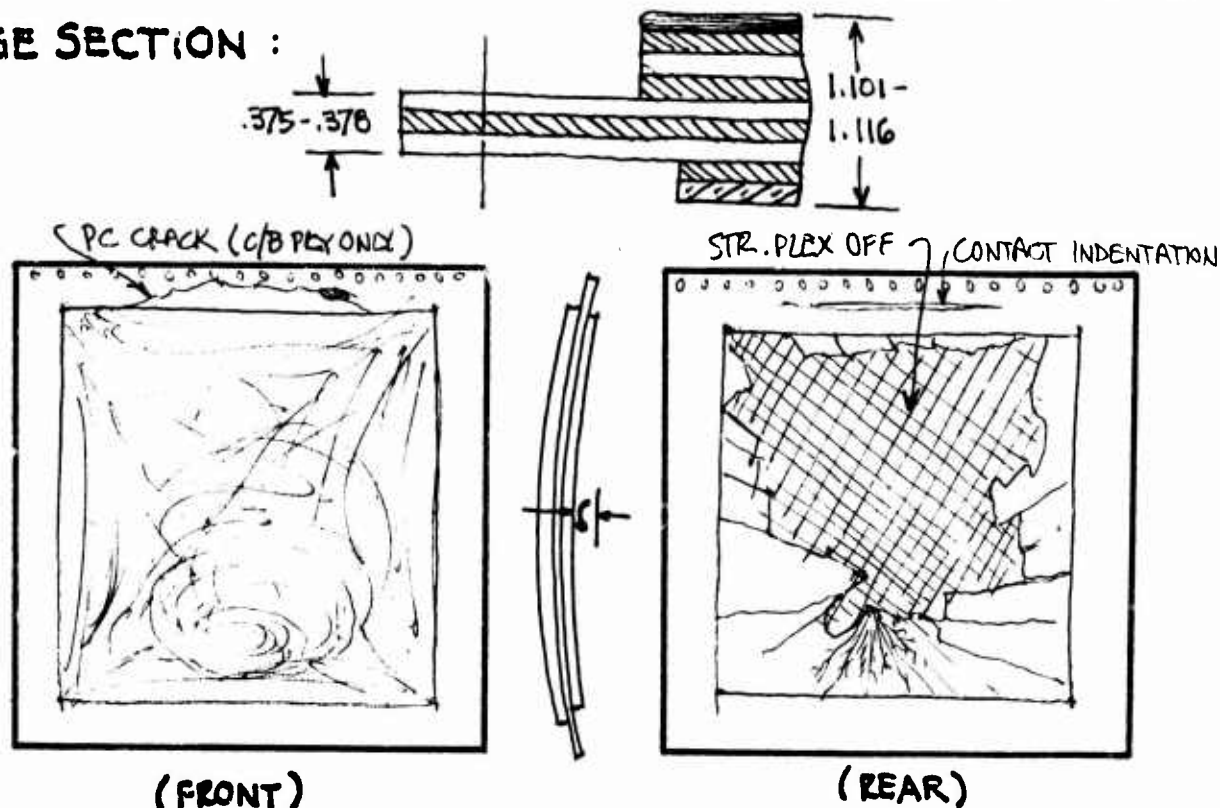


SAMPLE CODE : 9030-12A

CONSTRUCTION : .110" HERCULITE II - .120" 1/L - .125" PC - .120" 1/L - .125" PC -  
.120" 1/L - .125" PC - .120" 1/L - .125" STR. ACRYLIC

THICKNESS : 1.090" AREAL DENSITY : 7.48 LB./FT<sup>2</sup> PANEL WT. : 30.5 LB.

EDGE SECTION :



(FRONT)

(REAR)

RESULTS ON 3 -29-73 @ 65°F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-10 SPEED: INTENDED: 850 FPS  
TENTATIVE: 83.9" BIRD WT. : 4.0 LB  
FINAL: 862.5" (511 KT) (46,185 FT-LB)

REMARKS : 1/2" SAMPLE SUBJECTED TO 3 AUTOCLAVE CYCLES.

BIRD DID NOT PENETRATE BUT STRETCHED ACRYLIC SPALL WAS EJECTED FROM THE INBOARD SURFACE, 80% OF S/A WAS REMOVED, PRIMARILY IN LONG SPLINES. SPALL PIECES SHOW TYPICAL RAZOR-EDGE LAMINAR FAILURE.

INBOARD PC SHOWS INDENTATION AND OUTBOARD PC (ACTUALLY MIDDLE PLY) CRACKED (10" LONG) WHERE BENT OVER FRAME. THERE WAS A SMALL DELAMINATION SPOT WHERE THE PC CRACK STOPPED AT THE 11/2 SURFACE. 0° RESIDUAL VISIBILITY.

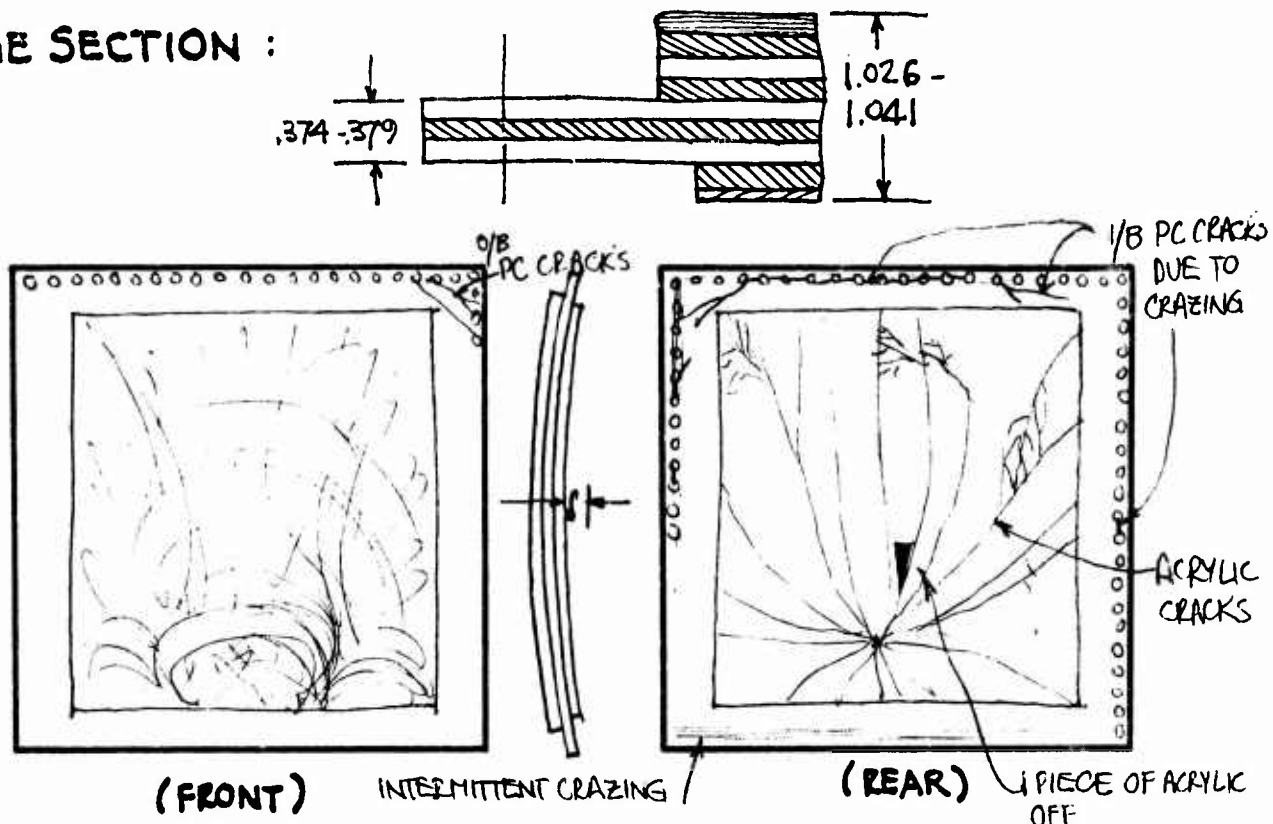
SPALL SPEEDS (AEDC) : 269 FPS FOR 1.51" X .66" SPALL  
191 FPS FOR 1.84" X 1.03" "

SAMPLE CODE : 9030-9A

CONSTRUCTION : .110" HERCULITE II - .120" 1/L - .125" PC - .120" 1/L - .125" PC -  
.120" 1/L - .125" PC - .120" 1/L - .125" AS-CAST ACRYLIC.

THICKNESS : 1.025" AREAL DENSITY : 7.08 LB./FT<sup>2</sup> PANEL WT. : 29.5 LB.

EDGE SECTION :



RESULTS ON 3-29-73 @ 60-65 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-II SPEED : INTENDED : 850 FPS  
TENTATIVE : 874.6 " BIRD WT. : 4.12 LB  
FINAL : 868.1 "

REMARKS :  $\delta = 9/16"$  (514 KT) (48,189 FT-LB)

BIRD DID NOT PENETRATE. 0° RESIDUAL VISIBILITY. CORNER CRACK IN 2<sup>nd</sup> PC PLY (O/B IN EDGE). CRACKS BETWEEN BOLT HOLES ON TOP EDGE OVER FULL WIDTH OF 3<sup>rd</sup> PC PLY (1/8 IN EDGE) & SEVERAL CRACKS ALSO ON SIDES BETWEEN BOLT HOLES. INBOARD CRACKS DUE TO CRAZING WHICH RESULTED FROM IMPROPER EDGE SPACER DURING FABRICATION. THESE PROBABLY OCCURED ON REBOUND.

ACRYLIC CRACKED BUT 99% OF AS-CAST MATERIAL REMAINED ADHERED WITH ONLY ONE SMALL PIECE OFF NEAR IMPACT PT.

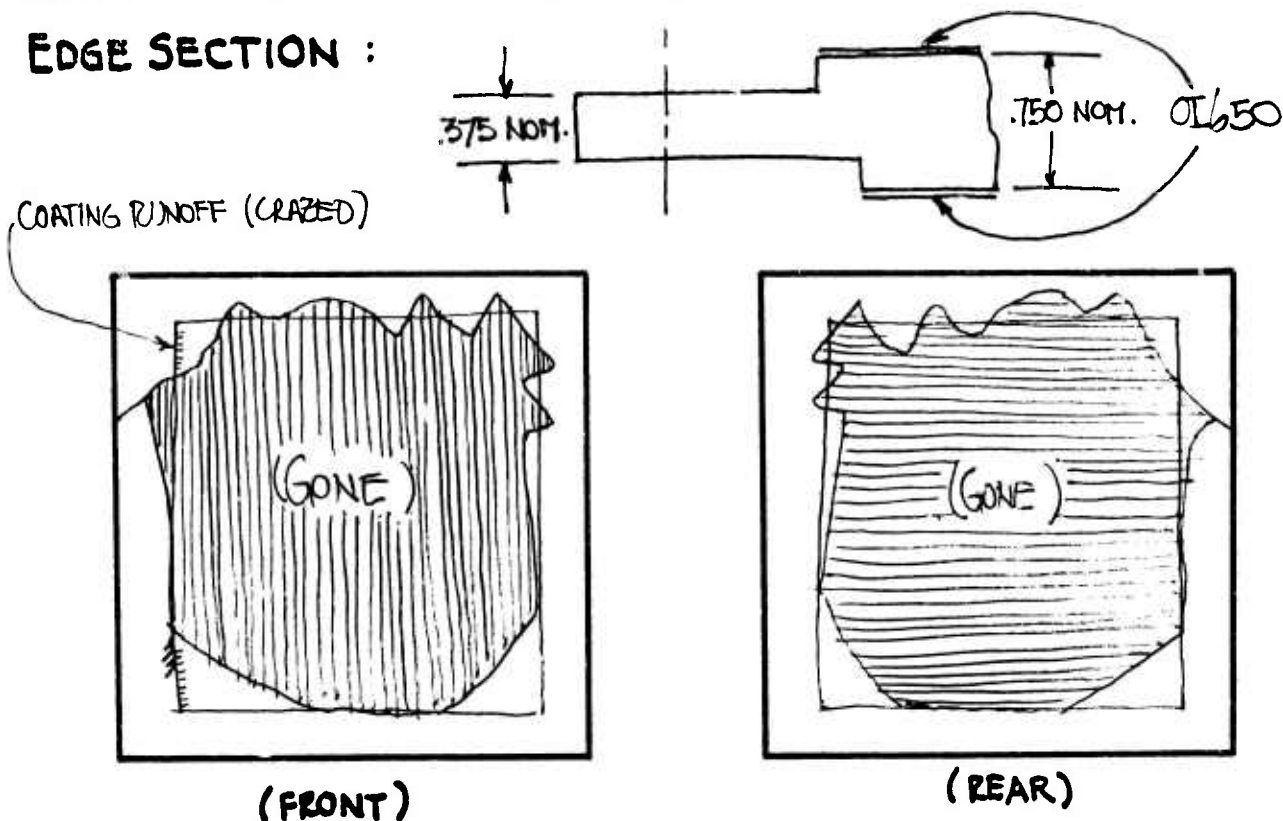
IMPACT CLOSE TO BOTTOM EDGE.

SAMPLE CODE : 9030-2A

CONSTRUCTION : .750" PC COATED BOTH SIDES WITH OI650.

THICKNESS : .750" AREAL DENSITY : 4.68 LB./FT<sup>2</sup> PANEL WT. : 20.25 LB.

EDGE SECTION :



RESULTS ON 3 -29-73 @ ~15 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-12 SPEED : INTENDED : 800 FPS  
TENTATIVE : 820.5 BIRD WT. : 4.15 LB.

REMARKS :  $\delta = -\frac{1}{16}$ " FINAL : 835.7" (495 kt) (44,985 FT-LB)

BIRD PENETRATED. SAMPLE SHATTERED INTO NUMEROUS SMALL PIECES, MOST SMALLER THAN 6" x 6". FAILURE ON TOP EDGE EQUALLY DIVIDED BETWEEN IN LINE WITH FRAME AND IN LINE WITH CORNERS FORMED BY OUTBOARD AND INBOARD SECTIONS. MOST OTHER EDGE FAILURE CONNECTS DISCONTINUITY (CORNER) FORMED BY OUTBOARD AND INBOARD SECTIONS. PORTION REMAINING IN FRAME IN ONE PIECE - GOOD FUSION.

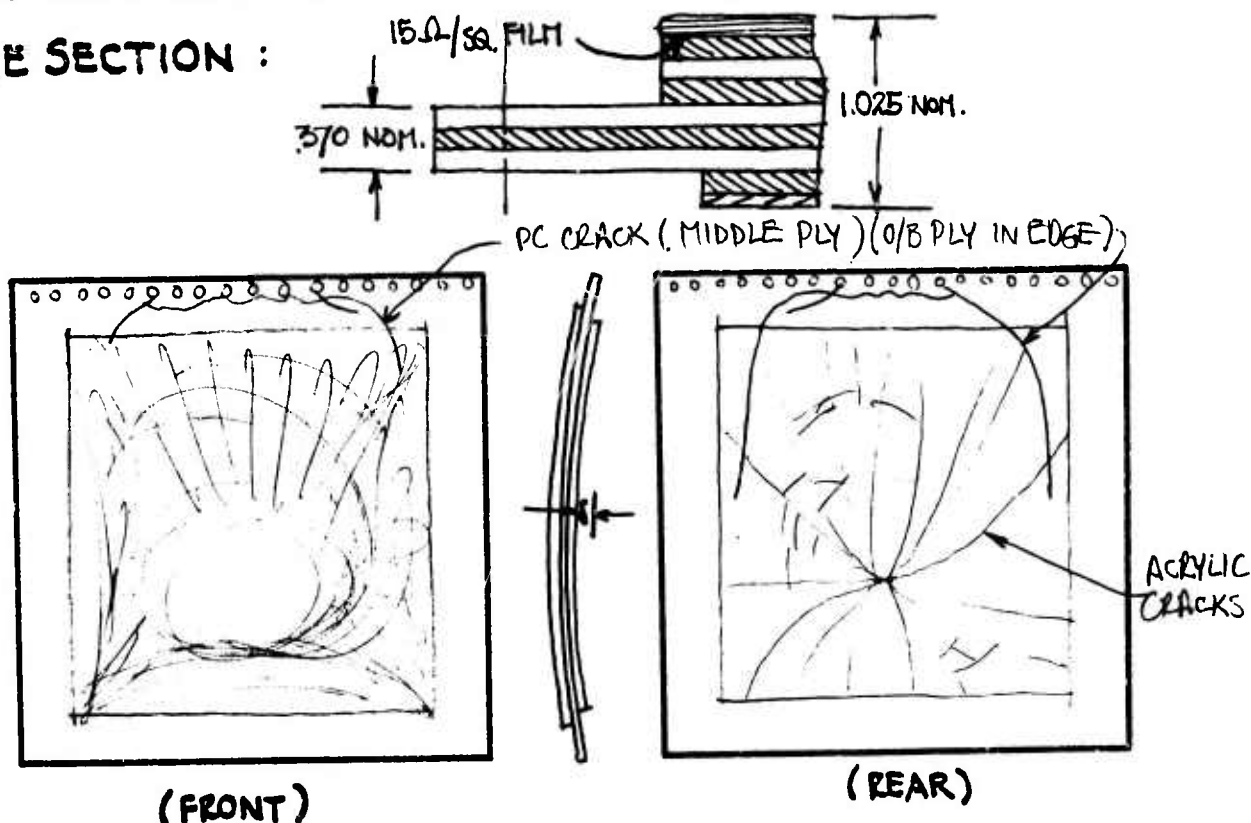
FAILURE REMINISCENT OF ACRYLIC-CLAD 3/4" PC WINDSHIELD TESTED 12-71.

SAMPLE CODE : 9030-10A

CONSTRUCTION : .110" HERCULE II (15.2/SG FILM) - .120" 1/L - .125" PC - .120" 1/L  
.125" PC - .120" 1/L - .125" PC - .120" 1/L - .060" AS-CAST ACRYLIC.

THICKNESS : 1.025" AREAL DENSITY : 7.08 LB./FT<sup>2</sup> PANEL WT. : 29.25 LB.

EDGE SECTION :



RESULTS ON 3 -29-73 @ ~65 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-13 SPEED : INTENDED : 850 FPS  
PRELIM. : 829.6 " BIRD WT. : 4.18 LB.  
FINAL : 821.1 " (48 KT) (43,740 FT-LB)

REMARKS :  $\delta = 7/16$ " OCCASIONAL DIFFICULTY IN DRILLING. (O/B PLY)

BIRD DID NOT PENETRATE. ADHESION TO GOLD COATED GLASS COMPARABLE TO UNCOATED PANELS. CRACK IN MIDDLE PLY IN LINE WITH DEFORMATION OVER FRAME ALONG TOP EDGE. CRACK MAY CORROBORATE EMBRITTLEMENT INDICATED BY HARD DRILLING.

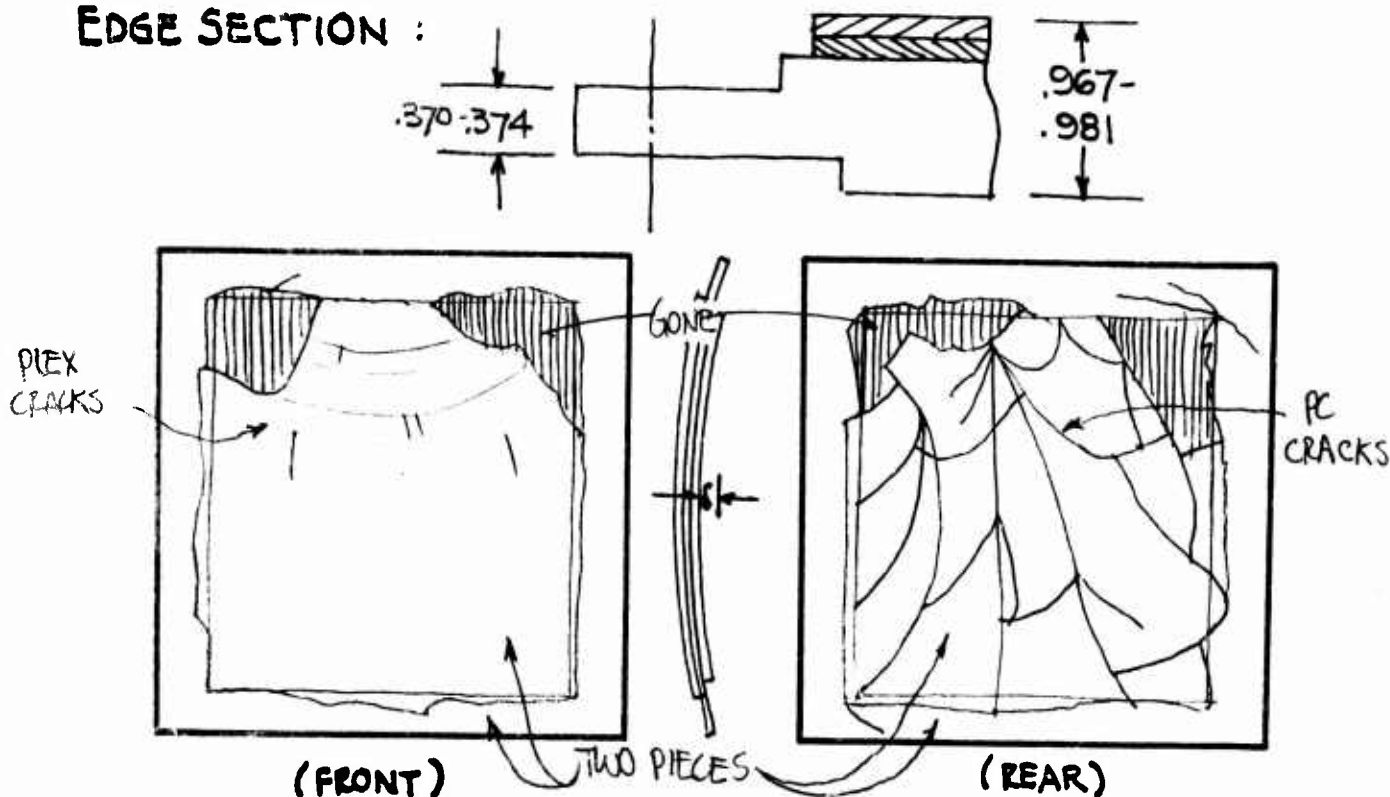
TYPICAL ACRYLIC CRACK PATTERN, NO OBSERVABLE ACRYLIC SPAULING. OVERALL PERFORMANCE SIMILAR TO 9A (SHOT WT-11).

SAMPLE CODE : 9030-6A

CONSTRUCTION : .125" ACRYLIC - .090" 1/2 - .750" PC

THICKNESS : .965" AREAL DENSITY : 6.01 LB./FT<sup>2</sup> PANEL WT. : 2525 LB.

EDGE SECTION :



RESULTS ON 3-29-73 @ 60 ± 5 ° F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-14 SPEED : INTENDED : 850 FPS  
PRELIM : 862.8 " BIRD WT. : 3.91 LB.

REMARKS :  $\delta = 3/16$ "  
ACTUAL : 847.7 "  
(502 kt) (43,609 FT-LB)

BIRD PENETRATED. ENTIRE CENTER OF PANEL BLEW OUT. TOP CENTER SHEARING IN LINE WITH OFFSET INBOARD AND OUTBOARD SECTIONS. THICK PC PLY SEVERELY SHATTERED. GOOD FUSION. PC AND ACRYLIC CRACKS ORIGINATE AT TOP EDGE WITH NO DAMAGE AT IMPACT POINT - UNUSUAL. PROBABLY DUE TO RIGIDITY OF 3/4" PC PLY.

NO OBSERVABLE CRACK PROPAGATION THRU .090" 1/2 IN REMAINING PORTION

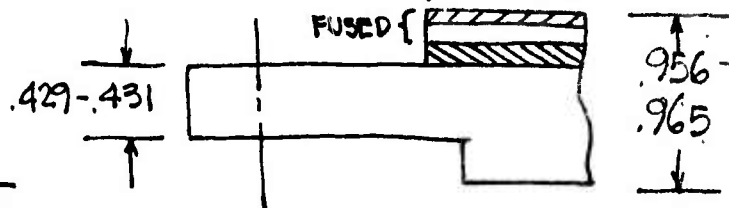


SAMPLE CODE : 9030-14A

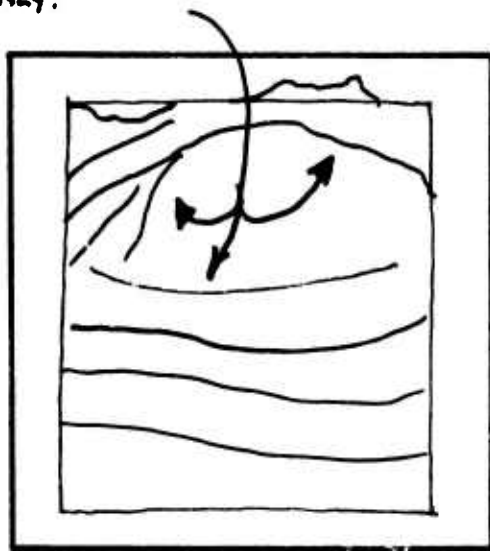
CONSTRUCTION : .060" ACrylic/.093" PC - .120" 1/L - .688" PC

THICKNESS : .961" AREAL DENSITY : 5.99 LB./FT<sup>2</sup> PANEL WT. : 25 LB.

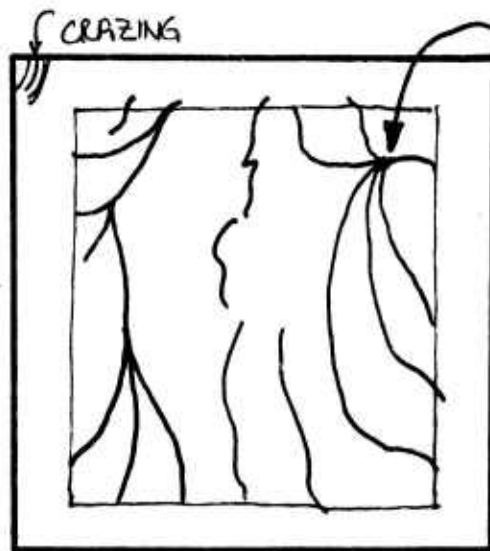
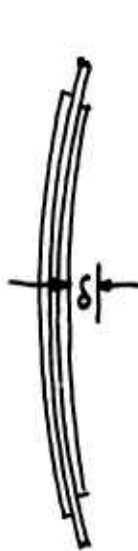
EDGE SECTION :



LIGHT CRACKING IN FRONT  
PLY ONLY.



(FRONT)



ORIGIN  
???

(REAR)

RESULTS ON 3 -29-73 @ - °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-15 SPEED : INTENDED : 780 FPS  
PRELIM. : 807.9 " BIRD WT. : 3.97 LB.  
FINAL : 819.4 "

REMARKS :  $\delta = 3/8"$  (485 kt) (41,372 FT-LB)

BIRD PENETRATED. ENTIRE CENTER SECTION BLOWN OUT.  
SHEARING ON TOP EDGE APPROX. 75 % COINCIDENT WITH BACK  
FUSED SECTION. FUSION VERY GOOD. NO APPARENT DE-LAM.  
CRACKING ON BACK SIDE SEVERE BUT NO PIECES BLOWN LOOSE.

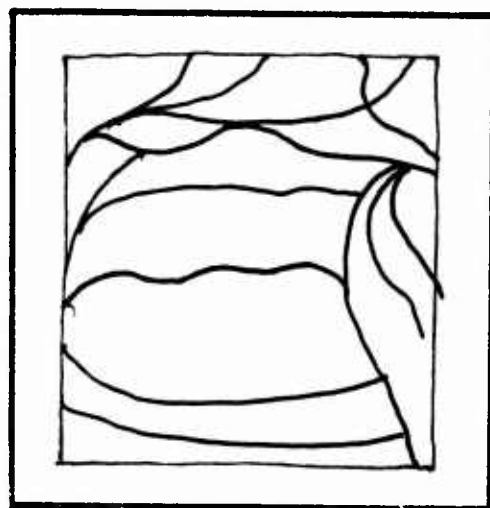
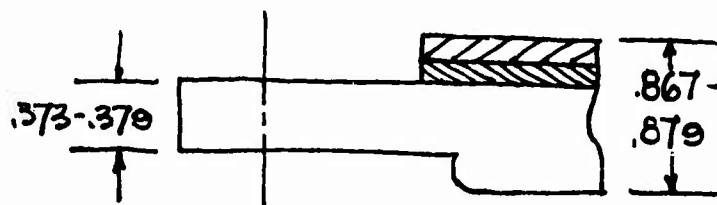


SAMPLE CODE : 9030-5B

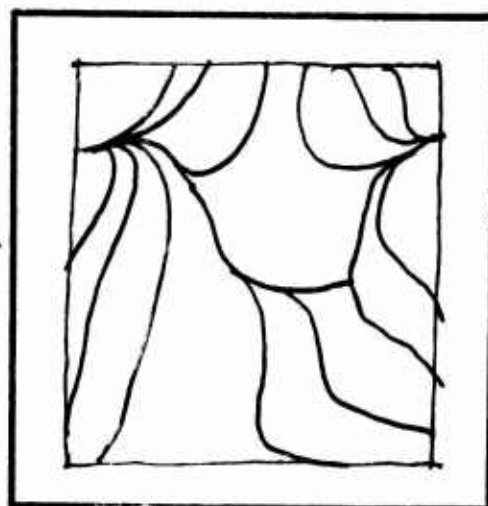
CONSTRUCTION : .125" ACRYLIC - .120" 1/4 - .625" PC

THICKNESS : .870" AREAL DENSITY : 5.41 LB./FT<sup>2</sup> PANEL WT. : 23 LB.

EDGE SECTION :



(FRONT)



(REAR)

RESULTS ON 3-29-73 @ ? °F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-16 SPEED : INTENDED : 750 FPS BIRD WT. : 4.18 LB.  
PRELIM : 753.3 "

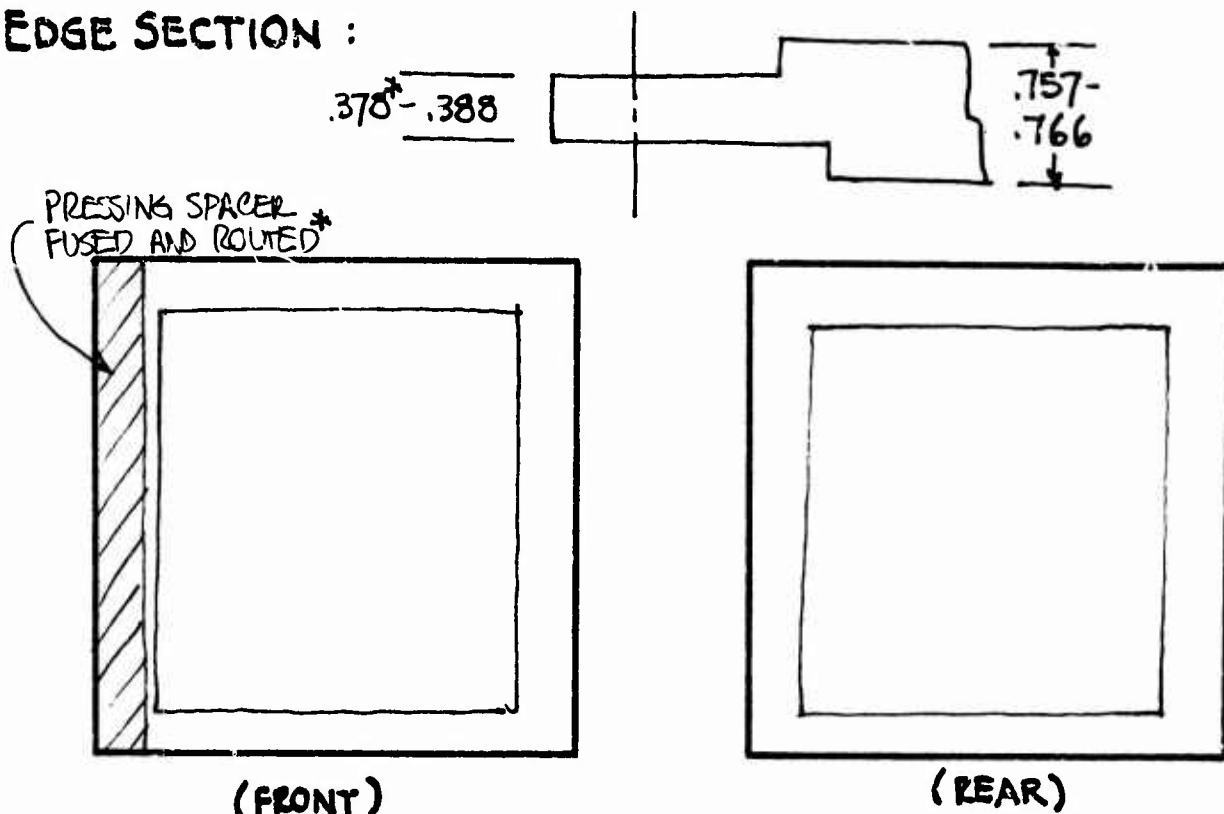
REMARKS :  $\delta = 5/16"$  FINAL : 774.5"  
(439Kt) (38,916 FT-LB)

BIRD PENETRATED. ENTIRE CENTER SECTION BLOWN OUT.  
TOP EDGE SHEARED OUT COINCIDENT WITH BACK FUSED PLY.  
GOOD FUSION. NO PIECES BLOWN LOOSE FROM FUSED FACES.

SAMPLE CODE : 9030-1A  
CONSTRUCTION : .750" PC

THICKNESS : .750" AREAL DENSITY : 4.68 LB./FT<sup>2</sup> PANEL WT. : 20.5 LB.

EDGE SECTION :



RESULTS ON 3-30-73 @ 64 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-17 SPEED : INTENDED : 750 FPS  
ACTUAL : 770.0 " BIRD WT. : 4.18 LB

REMARKS :  $\frac{1}{2}$  D (FLAT) FINAL " (NO X-RAYS) (38,466 FT-LB)  
(456 KT)

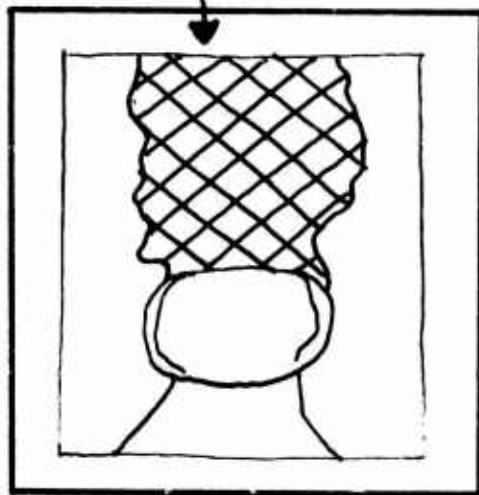
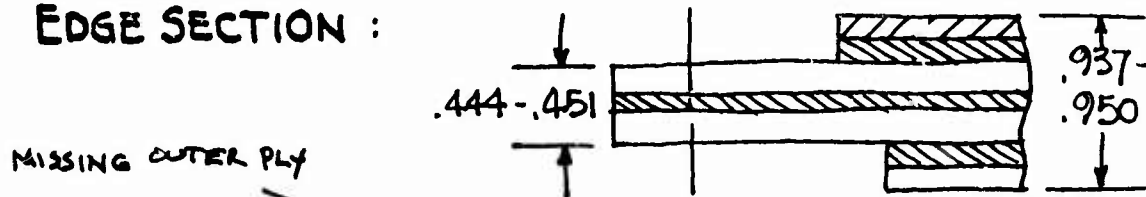
BIRD PENETRATED. SAMPLE CENTER SECTION BLOWN  
OUT INTO APPROX. 20 VARYING SIZE PIECES. APPROX. 75% OF  
SHEARING ALONG FUSED BACK PLY EDGE. GOOD FUSION.

SAMPLE CODE : 9030-7A

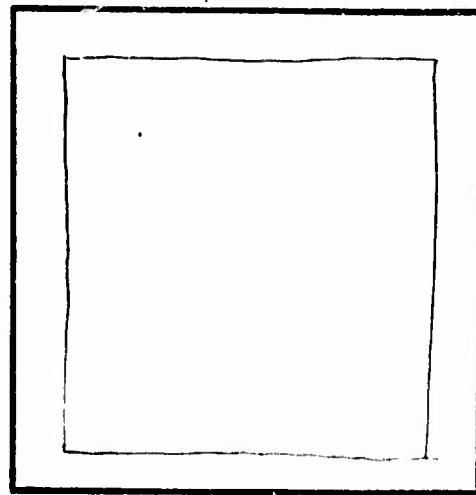
CONSTRUCTION : .125" ACRYLIC - .120" 1/L - .188" PC - .090" 1/L - .188" PC -  
.120" 1/L - .125" PC

THICKNESS : .936" AREAL DENSITY : 5.96 LB./FT<sup>2</sup> PANEL WT. : 23.75 LB.

EDGE SECTION :



(FRONT)



(REAR)

RESULTS ON 3-30-73 @ 64 °F AND 23 ° INSTALLATION ANGLE

SHOT NO. : WT-18 SPEED : INTENDED : 850 FPS  
PRELIM. : 857.5 " BIRD WT. : 4.00 LB.

REMARKS : J30

FINAL : 854.7 "

(506 kt)

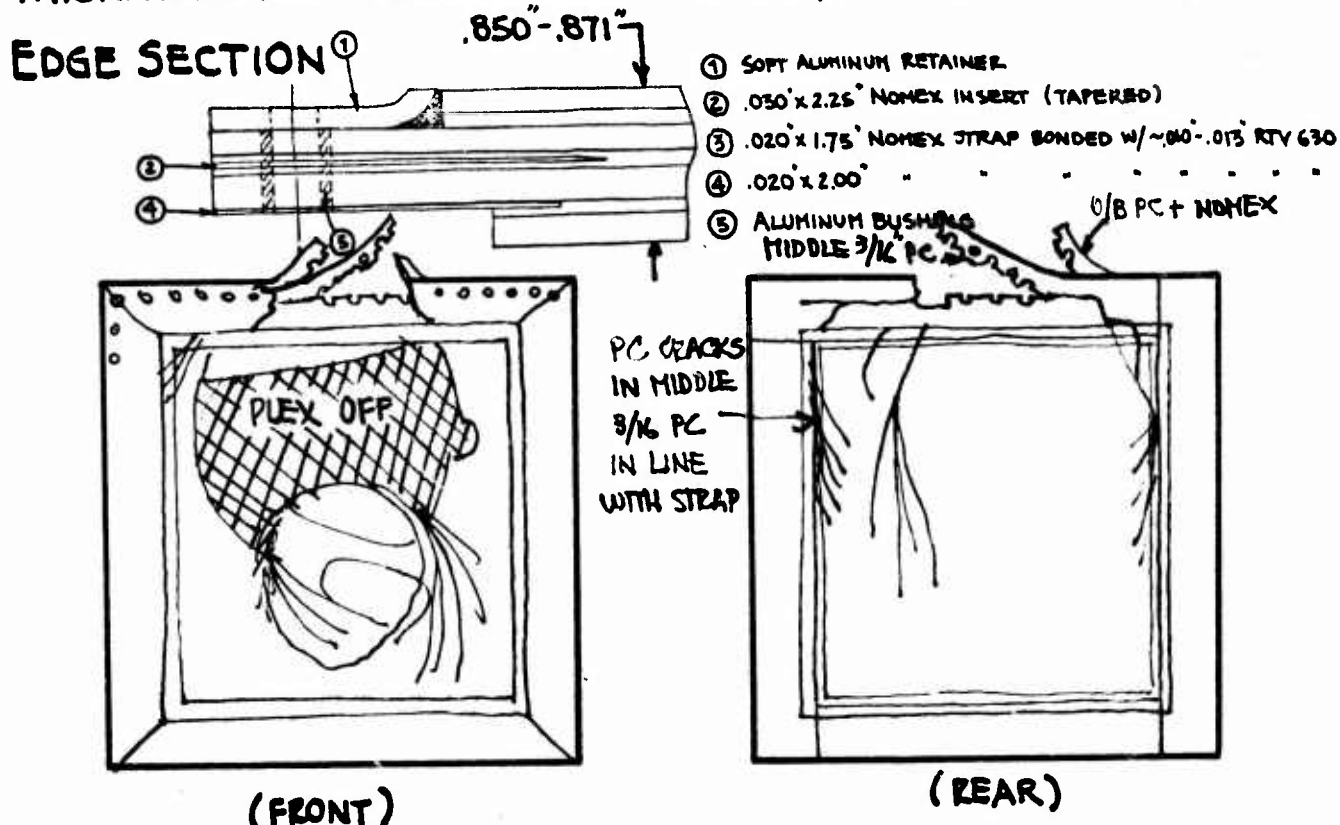
(45,353 FT-LB)

BIRD BOUNCED. NO POLYCARBONATE CRACKING ON BACK  
PLY. NO SHEARING OR CRACKING ON TOP EDGE. BEST  
PERFORMANCE OF ALL PANELS SHOT ??? APPROX. 30% OF  
OUTBOARD PLY BLOWN OFF. GOOD ADHESION ELSEWHERE.  
RESIDUAL VISIBILITY EXCELLENT.

SAMPLE CODE : 9030-17A

CONSTRUCTION : .125" AS-CAST ACRYLIC - .090" 11Z - .125" PC - .090" 11Z -  
.188" PC - .060" 11Z - .188" PC

THICKNESS : .866" AREAL DENSITY : 5.38 LB./FT<sup>2</sup> PANEL WT. : 24 LB.



RESULTS ON 5 - 7 - 73 @ 66°F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-19 SPEED : INTENDED : 850 FPS  
(1) PRELIM. : 901 " BIRD WT. : 4.11 LB  
FINAL : 901 " K.E. : 51,693 FT-LBS  
" 533 KT.

REMARKS :

BIRD PENETRATED. TOP EDGE SHEARED 18". RETAINER PEELED BACK & REMOVED OVER 8" ON TOP EDGE. 1/8" PC PLY SHEARED IN LINE WITH BOLT HOLES AROUND PENETRATION. COHESIVE FAILURE OF INSERT IN PENETRATION AREA. 3/16" PC PLY FAILED GENERALLY IN LINE WITH FRAME AT TOP. FLOATING PC OK. SIDE PC CRACKS IN LINE WITH STRAPS, NOT INSERT OR FLOATING PLY.

NOMEX-630-PC ADHESION BETTER THAN INTERLAMINAR, IN PENETRATION AREA.

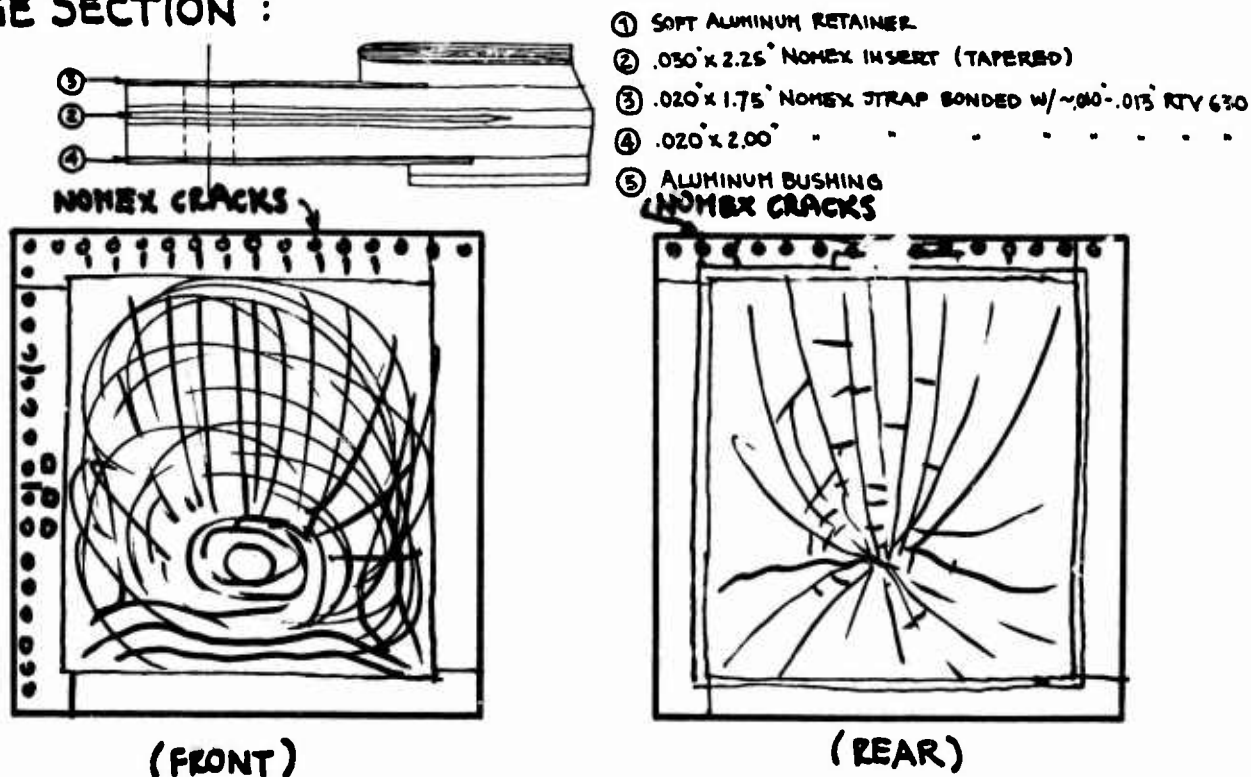
NO CRACKS VISIBLE THRU .090" & .060" INTERLAYERS.

**SAMPLE CODE : 9030-19A**

CONSTRUCTION: .110" HERCULITE II - .120" IIZ - .125" PC - .090" IIZ - .188" PC.  
.090" IIZ - .050" AS-CAST ACRYLIC

THICKNESS: .783" AREAL DENSITY: 5.57 LB./FT<sup>2</sup> PANEL WT.: 24.0 LB.

**EDGE SECTION :**



RESULTS ON 5 - 7 - 73 @ 68°F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-20 SPEED: INTENDED 850 FPS BIRD WT. : 1826 Gms (4.12 #)  
(No.2) PRELIM 870 FPS  
REMARKS : FINAL 870 " K.E. : 47,226 FT-LBS  
" 515 KT

ONE OR TWO OF TISSUE THRU BOLT HOLES AND AFTER BOLT FAILURE WHICH ALLOWED EDGE TO DEFLECT DOWNWARD. SIXTEEN BOLTS GONE FROM TOP EDGE. CENTRAL  $7\frac{1}{2}$ " OF  $3/16$ " PC PERMANENTLY DEFORMED INWARD, ONLY TWO BOLT HOLES AT END OF DEFORMATION CRACKED ALL OTHERS OK.  $1/8$ " PC INTACT BUT DEFORMED IN CENTER OF TOP EDGE. NO PC CRACKS. PLEX CRACKED BUT NO SPALL AT ALL.

ENTIRE PANEL BULGED TOWARD O/B FACE.

SOME TENSILE CRACKS IN TOP EDGE NOMEX BUT NONE INTO PC.

EDGE PC PLIES SEPARATED FOR 13" ALONG TOP DUE TO INTERLAMINAR SPLITTING OF INSERT.





CONSTRUCTION: .125" AS-CAST ACRYLIC - .090" IIZ - .125" PC - .090" IIZ - .188" PC - .060" IIZ - .188" PC

# EDGE SECTION ①



- ① SOFT ALUMINUM RETAINER
- ② .030" x 2.25" NOMEK INSERT (TAPERED)
- ③ .020" x 1.75" NOMEK STRAP BONDED W/ ~90-.015 RTV 630
- ④ .020" x 2.00" " " " " " " " "
- ⑤ ALUMINUM BUSHING (NEAR 1/4" DIA. x 3/4" L)

SHEAR IN MIDDLE  $\frac{3}{16}$  PC.

CRACKS  
IN 1/B  
3/16" PC

(FRONT)

(REAR)

RESULTS ON 5-7-73 @ 70°F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-22 SPEED: INTENDED : 850 FPS BIRD WT. : 1815 gm (4.0 LB)  
(NO.4) PRELIM : 901 FPS  
FINAL : 881 FPS K.E. : 48,042 FT-LBS  
REMARKS : " : 521 KT

REMARKS :

BIRD TISSUE THRU BOLT HOLES AND 4" SHEAR IN MID 3/16" PC PLY.  
NINE OF 21 BOLTS GONE ON TOP EDGE. WITHOUT RETAINER NO SHEARING  
OF EDGE PLIES, BUT, WITH BOLTS GONE, MIDDLE PC PLY WAS BENT  
SEVERELY OVER FRAME WITH 4" CRACK IN LINE WITH FLOATING PLY.  
INSERT GENERALLY HELD. FLOATING PLY CRACKED AS SHOWN.

BOLTS FAILING AT 1ST OR 2ND THREAD IN LINE WITH BOTTOM OF PANEL. IT IS APPARENT THAT THIS SHOT AND WT-20 WERE TESTING BOLTS MORE THAN PANELS ALONE.

SAMPLE CODE : 9030-20A

CONSTRUCTION: .110" HERCULITE<sup>®</sup> II - .120" 11Z - .125" PC - .090" 11Z -  
.188" PC - .090" 11Z - .060" AS-CAST ACRYLIC

THICKNESS: .783" AREAL DENSITY: 5.57 LB./FT<sup>2</sup> PANEL WT.: 24.1 LB.

**EDGE SECTION :**

**DGE SECTION :**

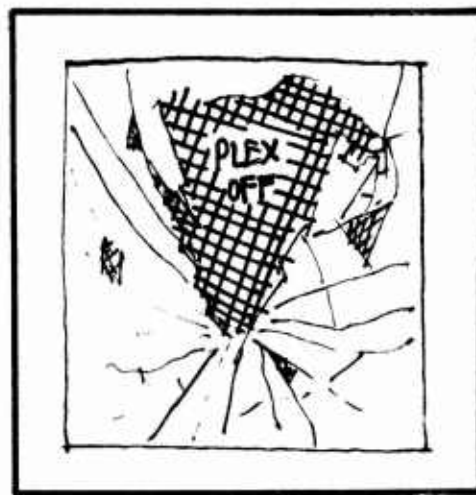
$.469' - .484'$

$.770' - .800'$

- ① SOFT ALUMINUM RETAINER
- ② .030" x 2.25" NOMEX INSERT (TAPEDED)
- ③ .020" x 1.75" NOMEX STRAP BONDED W/ ~90% .015 RTV 630
- ④ .020" x 2.00" " " " " " " " "
- ⑤ ALUMINUM BUSHING



(FRONT)



( REAR )

RESULTS ON 5-7-73 @ 68 °F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-23  
(NO.5)

**SPEED:** INTENDED 850 FPS  
PRELIM 866 FPS  
FINAL 854 FPS  
" : 505 KT

BIRD WT. : 1805gm (3.98 LB)  
K.E. : 44,888 FT-LBS

REMARKS :

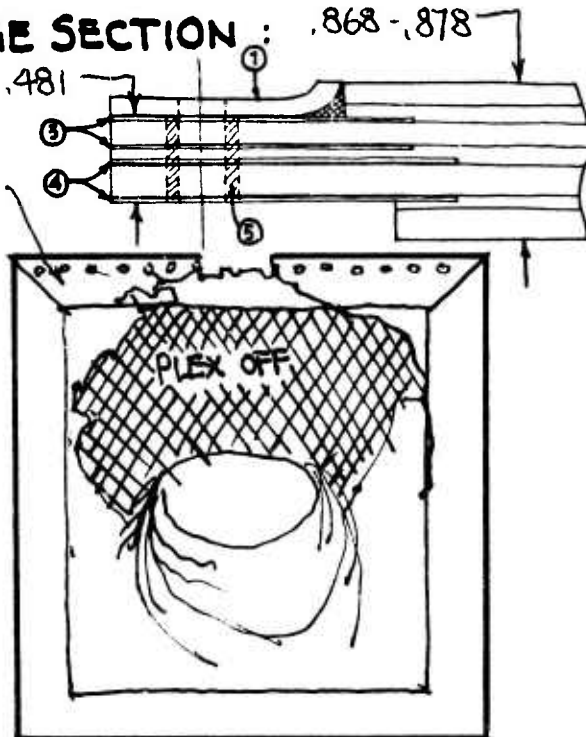
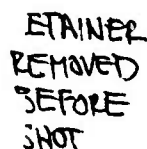
BIRD DID NOT PENETRATE. NO SERIOUS DAMAGE TO PANEL. NO PC CRACKS. SIX BOLTS REMOVED ALONG TOP EDGE BUT NO TISSUE THRU HOLES. BOLTS FAILED, AS BEFORE, AT SHANK-THREAD TRANSITION. 50% OF ACRYLIC OFF INBOARD AS SPALL. POSSIBLE THAT ACRYLIC PREPARATION NOT COMPLETE (NO CEMENT)

PERMANENT BULGE OF  $\sim .5"$  TOWARD INBOARD. LIKE 19A  
EXCEPT FOR DIRECTION.

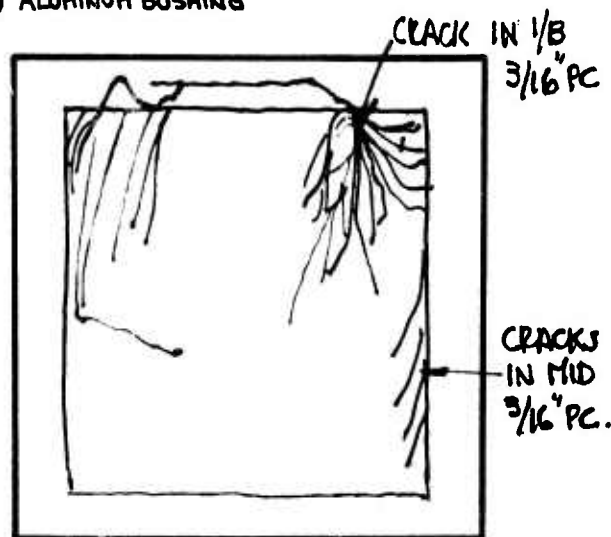
CONSTRUCTION: .125" AS-CAST ACRYLIC - .090" IIZ - .125" PC - .090" IIZ -  
.188" PC - .060" IIZ - .188" PC

EDGE SECTION: .868-.878

- ① SOFT ALUMINUM RETAINER
- ② .030" x 2.25" NOMEK INSERT (TAPERED)
- ③ .020" x 1.75" NOMEK JTRAP BONDED W/ ~.000"-.013" RTV 630
- ④ .020" x 2.00" " " " " " " " "
- ⑤ ALUMINUM BUSHING



(FRONT)



(REAR)

SHOT NO.: WT-24 SPEED  
NO. 6

INTENDED : 850 FPS

PRELIM 880

FINAL: 349. "

BIRD WT. : 1835gm; 4.05 LB

K.E. : 45,273 FT-LBS

REMARKS: AEDC BOLTS (SAE GRADE 5) ON TOP EDGE & RETAINER REMOVED.

BIRD PENETRATED. ENTIRE TOP EDGE SHEARED. CENTRAL IMPACT PORTION OF TOP EDGE AND PORTIONS OF TOP HALF OF SIDES SHEARED IN LINE WITH FRAME. FAILURE WORSE THAN 18A (WT-21) WHICH HAD A RETAINER ON TOP EDGE.

ONLY 1 CENTRAL BOLT REMOVED ON TOP EDGE.

STRAPS TORN ON EDGE

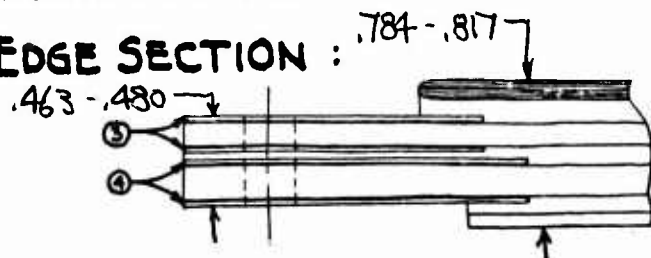


SAMPLE CODE : 9030-20B

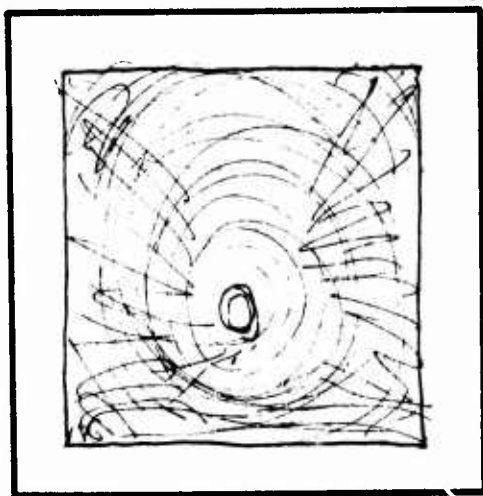
CONSTRUCTION : .110" HERCULITE II - .120" IIZ - .125" PC - .090" IIZ -  
.188" PC - .090" IIZ - .060" AS-CAST ACRYLIC

THICKNESS : .783" AREAL DENSITY : 5.57 LB./FT<sup>2</sup> PANEL WT. : 24.3 LB.

EDGE SECTION :

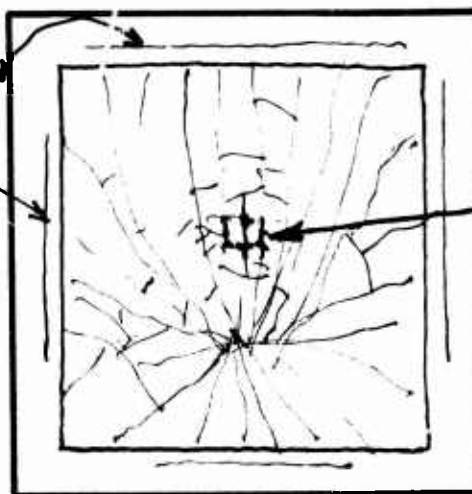


- ① SOFT ALUMINUM RETAINER
- ② .030" x 2.25" NOMEX INSERT (TAPERED)
- ③ .020" x 1.75" NOMEX STRAP BONDED W/ ~.010" RTV 630
- ④ .020" x 2.00" " " " " " " " " " " " "
- ⑤ ALUMINUM BUSHING



(FRONT)

IMPRESSION  
FROM  
BENDING  
OVER  
FRAME



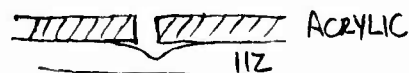
(REAR)

RESULTS ON 5-8-73 @ 77°F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-26 SPEED : INTENDED 850 FPS BIRD WT. : 1812 gm ; 4.0 LB.  
NO. 8 PRELIM 859 K.E. : 45.959 FT-LBS  
REMARKS : FINAL 862 " : 510 KT.

BIRD DID NOT PENETRATE. NO EDGE DAMAGE EXCEPT CRACKS IN OUTBOARD NOMEX DUE TO MAX STRESS FROM BENDING OVER FRAME. 3" INTERLAMINAR SEPARATION OF O/B-FACING STRAP ON 1/B PC PLY VISIBLE AT CENTER OF TOP EDGE.

NO ACRYLIC SPALL. 1"-1 1/2" RESIDUAL BULGE. IN MAXIMUM BULGE AREA PLEX CRACKS OPENED SLIGHTLY AND THERE APPEARS TO BE SOME ELONGATION OF IIZ UNDER PLEX CRACKS WITH ACCOMPANYING MINOR DELAMINATION AS SHOWN. →





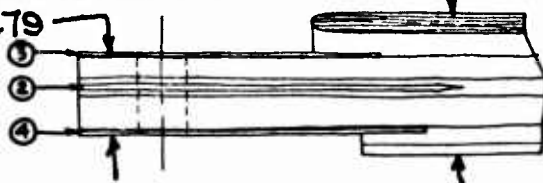
SAMPLE CODE : 9030-19B

CONSTRUCTION : .110" HERCULITE II - .120" IIZ - .125" PC - .090" IIZ -  
.188" PC - .090" IIZ - .060" AS-CAST ACRYLIC

THICKNESS : .783" AREAL DENSITY : 5.57 LB./FT<sup>2</sup> PANEL WT. : 24.1 LB.

EDGE SECTION : .798-.811

.466-.479



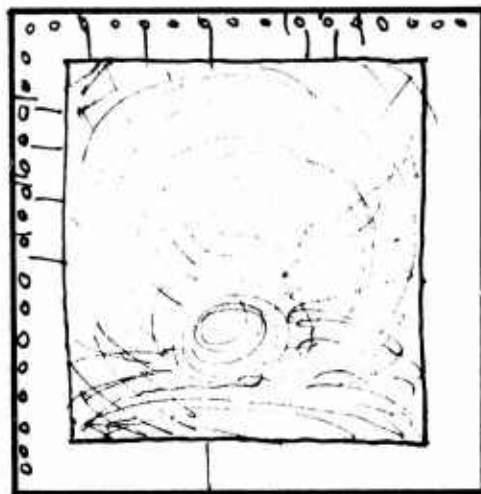
① SOFT ALUMINUM RETAINER

② .030" x 2.25" NOMEX INSERT (TAPERED)

③ .020" x 1.75" NOMEX STRIP BONDED W/ ~.00-.015 RTV 630

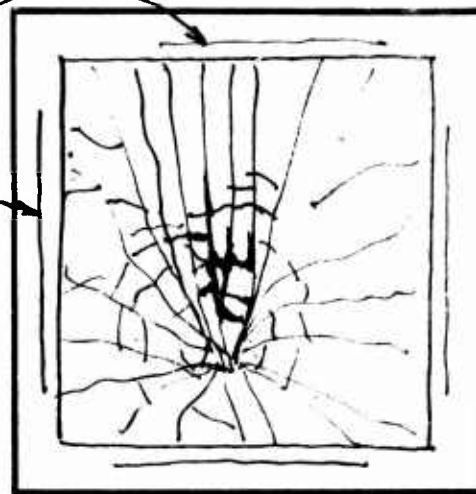
④ .020" x 2.00" " " " " " "

⑤ ALUMINUM BUSHING



(FRONT)

IMPRESSION  
FROM  
BENDING  
OVER  
FRAME



(REAR)

RESULTS ON 5 - 8 - 73 @ 78 °F AND 23° INSTALLATION ANGLE

SHOT NO. : WT-27 SPEED : INTENDED : 850 FPS BIRD WT. : 1875 gm; 4.13 LB.  
(NO.9) PRELIM : 872 FPS

503 KT - FINAL : 853 FPS K.E. : 46,629 FT-LBS

REMARKS : AEDC STOCK 1/4-20 BOLTS ALL AROUND.

BIRD DID NOT PENETRATE. SIX BOLTS OFF TOP EDGE. NO DAMAGE TO EDGE ANYWHERE EXCEPT NOMEX CRACKS AT BOLT HOLES AS SHOWN. NO PC CRACKS OR DAMAGE.

PLEX CRACKED AS USUAL, BUT NO SPALL WHATSOEVER. APPROXIMATE 1" RESIDUAL BULGE WITH SLIGHT IIZ NECKING & VERY MINOR DELAM AT CRACKS IN MAXIMUM BULGE AREA.

PRACTICALLY IDENTICAL TO 20-B (WT-26).



CONSTRUCTION: .125" AS-CAST ACRYLIC - .090" IIZ - .125" PC - .090" IIZ - .188" PC - .060" IIZ - .188" PC

# EDGE SECTION ①



(REAR)

SHOT NO.: WT-28 SPEED: INTENDED: 850 FPS  
(NO. 10) 48% KT PRELIM: 848 FPS  
FIN: 821 FPS

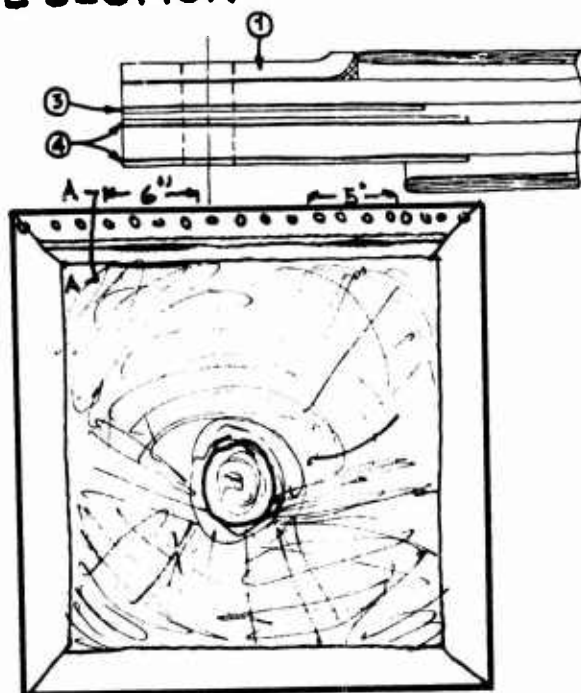
BIRD WT. : 1830 gm : 4.04 LB.  
K.E. : 42,150 FT-LBS

REMARKS : AEDC BOLTS (SOFT) USED.

BIRD PENETRATED. TOP EDGE SHEARED. TWO BOLTS OFF. FAILURE LIKE 18B (WT-24). EXTENDED  $\frac{1}{8}"$  &  $\frac{3}{16}"$  PC SHEARED IN LINE WITH FRAME. FLOATING  $\frac{3}{16}"$  PC NOT DAMAGED. BOTH  $\frac{1}{8}"$  & MID  $\frac{3}{16}"$  PILES CRACKED ALONG SIDES. SOME CRACKS APPEAR TO START AT BOLT HOLES. SIDE EDGE ATTACHMENT CRACKS GENERALLY IN LINE WITH FRAME.

SAMPLE CODE : 9030-21A  
CONSTRUCTION : .085" HERCULITE<sup>®</sup> II - .090" 11Z - .125" PC - .090" 11Z -  
.188" PC - .120" 11Z - .085" HERCULITE<sup>®</sup> II

**EDGE SECTION :**



(FRONT)

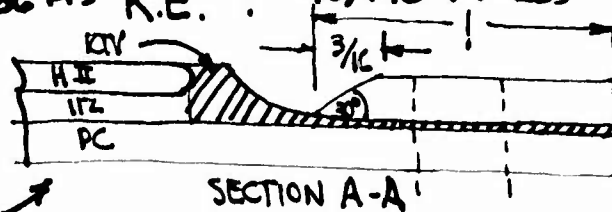
- ① SOFT ALUMINUM RETAINER
  - ② .030" x 2.25" NOMEX INSERT (TAPERED)
  - ③ .020" x 1.75" NOMEX JTRAP BONDED W/ ~90% .013 RTV 630
  - ④ .020" x 2.00" " " " " " " " "
  - ⑤ ALUMINUM BUSHING
- NOMEX CRACKED 7



(REAR)

SHOT NO.: WT-29 (NO. 11) INTENDED: 850 FPS SPEED: PRELIM: 869 FPS BIRD WT.: 1814 gm; 4.00 LB. 507 KT = FINAL: 856 FPS K.E.: 45,470 FT-LBS

BIRD DID NOT PENETRATE. PORTION  
OF TOP EDGE RETAINER REMOVED  
LEAVING MODIFIED 1" RETAINER SHOWN



NO RETAINER PEELING AND ONLY SLIGHT SEPARATION FROM RTV IN 2 PLACES. 8 BOLTS OFF ALONG TOP EDGE (SHEARED @ 1<sup>ST</sup> THREAD)

SPALL. INBOARD SPALL PERFORATED FOIL OVER FORM PLACED VERTICALLY BEHIND PANEL & HORIZONTALLY BELOW (40") PANEL. PARTICLES STUCK IN BOTH W/P'S. LARGEST PARTICLE: .060" x .188" x .750".

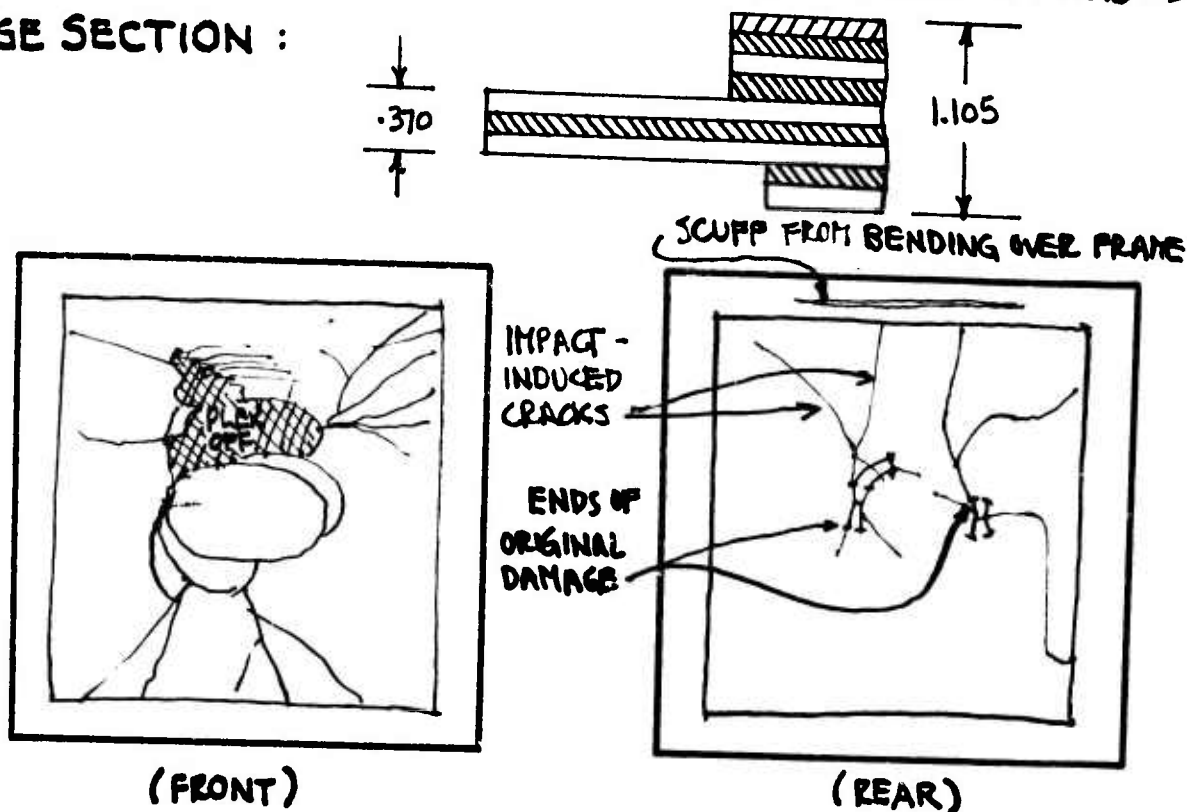
BOTH W/PS. LARGEST PARTICLE: .060 x .100 x .150.  
BOTTOM STRAP CRACKED ALONG TOP EDGE IN LINE WITH FRAME. UNDER STRAP, PC INDENTED BY FRAME BUT NOMEX CRACK NOT INTO PC. 165

SAMPLE CODE : 9030 - 16A

CONSTRUCTION : .125" As Cast ACRYLIC - .120" 112 - .125" PC - .120" 112  
- .125" PC - .120" 112 - .125" PC - .120" 112 - .125" PC

THICKNESS: 1.105" AREAL DENSITY: 6.89 LB./FT<sup>2</sup> PANEL WT.: 28.5 LB.

EDGE SECTION :



RESULTS ON 5 -9 -73 @ 61 °F AND 23° INSTALLATION ANGLE

SHOT NO.: WT-30 SPEED: INTENDED - 850 FPS  
(NO. 12) PRELIM. - 868 "

BIRD WT.: 1850 gm; 4.08 LB  
KE: 44,920 FT-LBS

REMARKS : INBD. PC CUT WITH CHISEL BY D.C. CHAPIN TO SIMULATE GUNSIGHT IMPRINT.

BIRD DID NOT PENETRATE. ALTHOUGH 5 BIRDS WERE REMOVED FROM TOP EDGE, THERE WAS NO SHEARING OR STRUCTURAL DAMAGE.

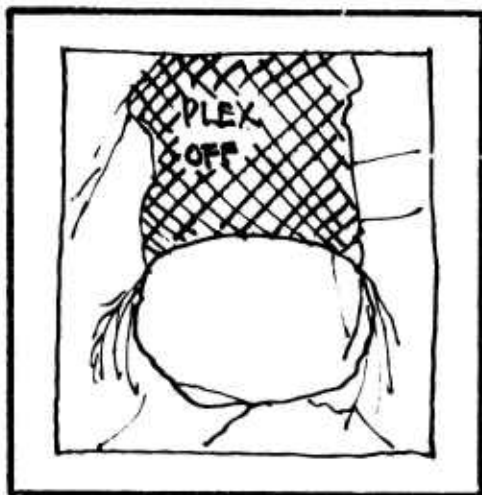
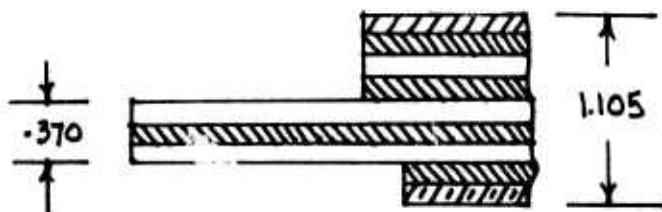
ADDITIONAL CRACKING OF INBOARD PC PLY DID OCCUR DURING IMPACT AS SHOWN IN SKETCH. CRACKS WHICH DEVELOPED DID STOP AT 112 SURFACE WITH VERY SLIGHT LOCAL DELAM.

SAMPLE CODE : 9030-15A

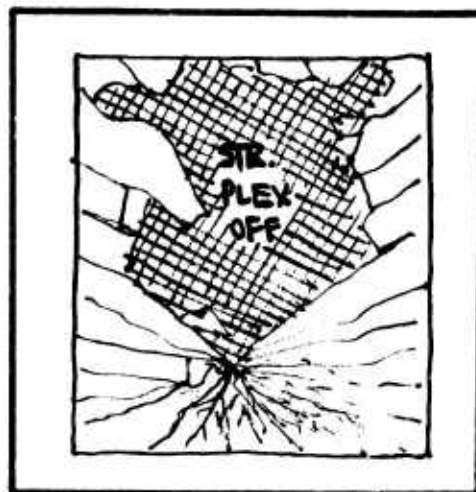
CONSTRUCTION : .125" AS CAST ACRYLIC - .120" 112 - .125" PC - .120" 112  
.125" PC - .120" 112 - .125" PC - .120" 112 - .125" STRETCHED  
ACRYLIC.

THICKNESS: 1.105" AREAL DENSITY: 6.88 LB./FT<sup>2</sup> PANEL WT.: 27.8 LB.

EDGE SECTION :



(FRONT)



(REAR)

RESULTS ON 5 -9 -73 @ 65 °F AND 23 ° INSTALLATION ANGLE

SHOT NO.: WT-31 SPEED: INTEND 925 FPS  
(NO.13) PRELIM 800 " BIRD WT.: 1787 gm; 3.94 LB.  
FINAL: 888 FPS = 52 KT. KE: 48,213 FT-LBS

REMARKS : AEDC SOFT BOLTS TOP EDGE .

BIRD DID NOT PENETRATE . NO SHEARING OR STRUCTURAL DAMAGE .  
CONSIDERABLE STRETCHED ACRYLIC SPALL . LARGE SHARP PIECES .  
APPROXIMATELY 50% OF S/A OFF .

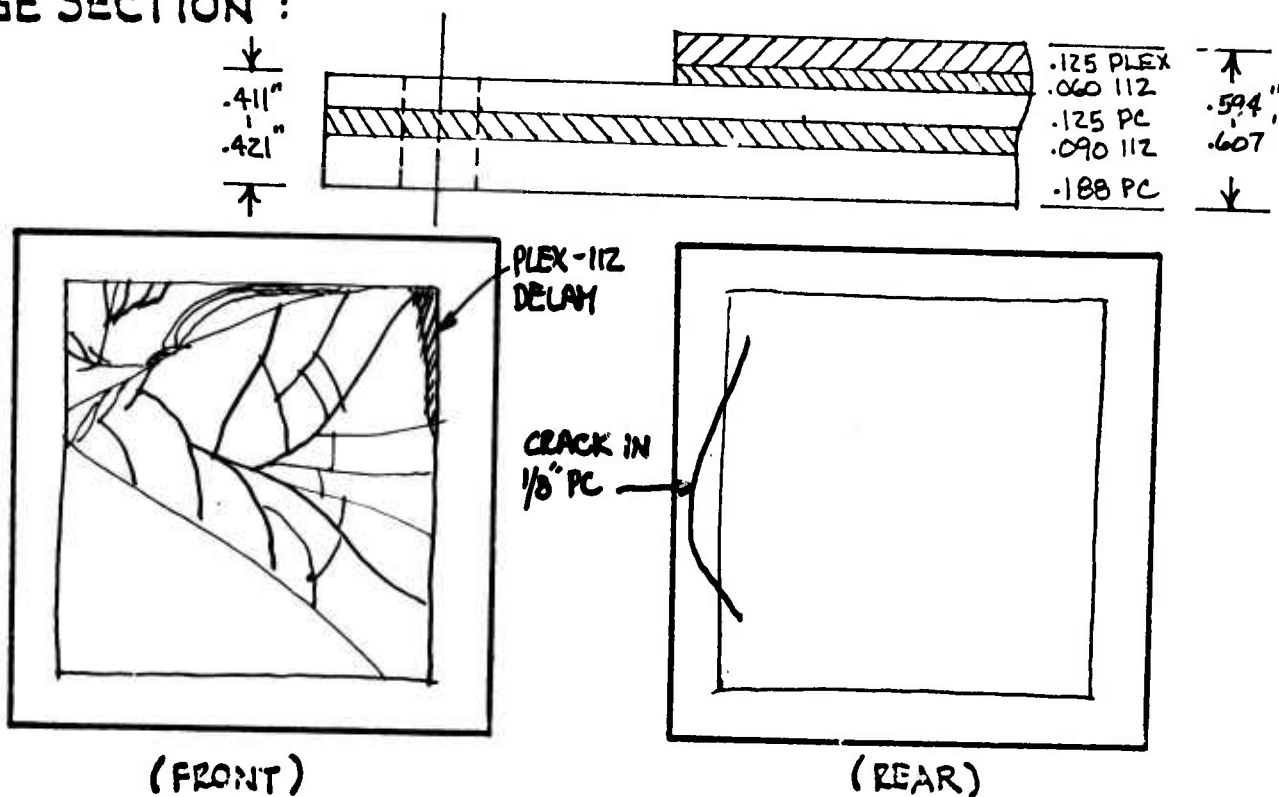
SIX BOLTS REMOVED FROM TOP EDGE BUT NO EFFECT ON  
PERFORMANCE OF PANEL .

SAMPLE CODE : 9031-1A

CONSTRUCTION : .125" AS-CAST ACRYLIC - .060" 11Z - .125" PC - .090" 11Z -  
.188" PC

THICKNESS : .588" AREAL DENSITY : 3.66 LB./FT<sup>2</sup> PANEL WT. : 16 LB. 10<sup>08</sup>

EDGE SECTION :



RESULTS ON 5 - 9 - 73 @ 74 °F AND 13.2° INSTALLATION ANGLE

SHOT NO. : WT-32 SPEED : PRELIM 819 FPS.  
(NO. 14) FINAL : 819 FPS  
: 485 KTS

BIRD WT. : 1899 gm = 4.18 LB.

K.E. : 43,559 FT-LBS

REMARKS : PPG BOLTS ON TOP EDGE

BIRD DID NOT PENETRATE. IMPACT OF PKG. JUST AT BOTTOM EDGE  
ALTHOUGH LOAD NOT SUFFICIENT TO FORCE TISSUE UNDER EXTENDED  
SECTION. NO BOLTS REMOVED & NO BOLT HOLE DAMAGE.

NEGLIGIBLE ACRYLIC REMOVED FROM IMPACT FACE. ONE  
CRACK IN 1/8" PC AS SHOWN. NO RESIDUAL BULGE.

GOOD RESIDUAL VISIBILITY.

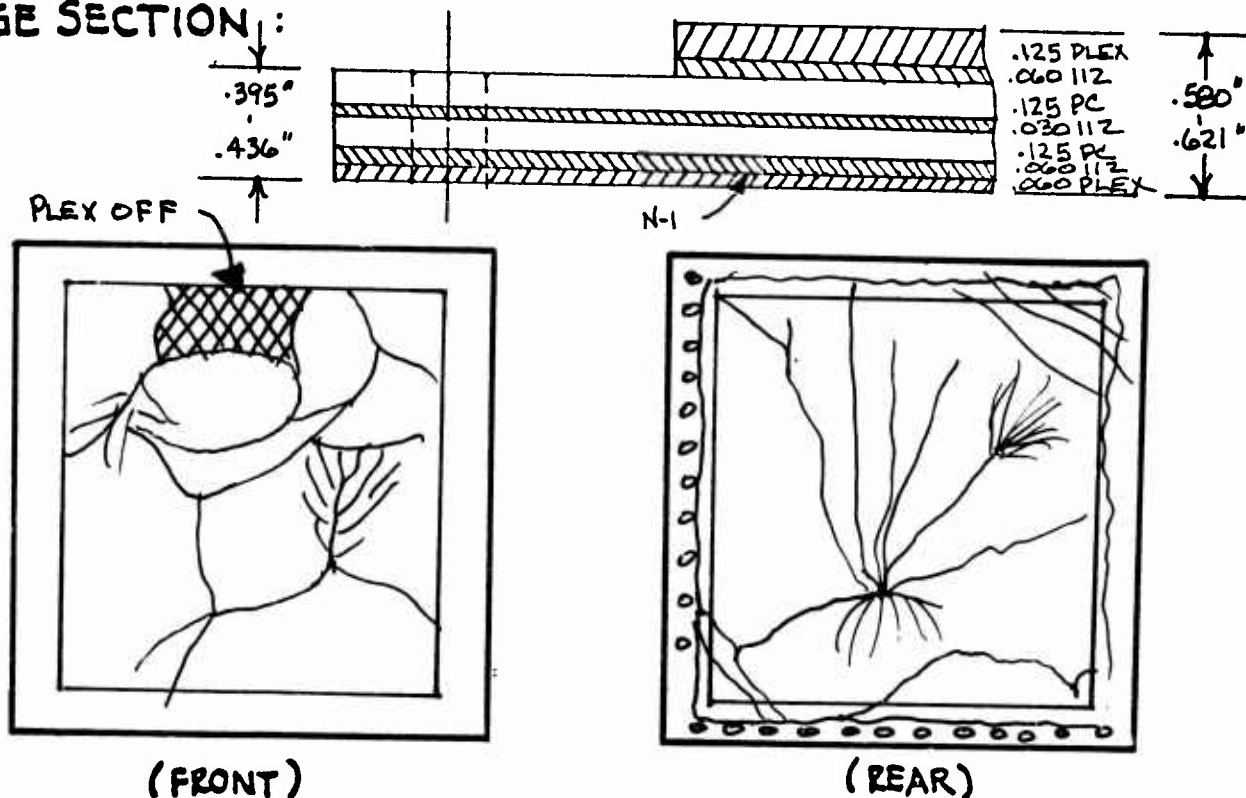


SAMPLE CODE : 9031-2A

CONSTRUCTION : .125" AS CAST ACRYLIC - .060" 112 - .125" PC -  
.~~.030~~" 112 - .~~.030~~" PC - .060" 112 - .030" AS CAST ACRYLIC  
.030" .125"

THICKNESS : .585" AREAL DENSITY : 3.64 LB./FT<sup>2</sup> PANEL WT. : 16.6 LB.

EDGE SECTION :



RESULTS ON 5-9-73 @ 74°F AND 13.2° INSTALLATION ANGLE

SHOT NO. : WT-33 SPEED : INTENDED :  
PRELIM : 877 FPS  
FINAL : 807 FPS  
56 500 KTS.

BIRD WT. : 1787 GMS

K.E. : 44,869 FT-LBS

REMARKS : SOFT AEDE BOLTS

BIRD DID NOT PENETRATE. NO SERIOUS STRUCTURAL DAMAGE. BOTH ACRYLIC RACING BUES FAILED HOWEVER NO SPALL WHATSOEVER FROM INBOARD PLY. I/B ACRYLIC CRACKED WHERE BEINT OVER FRAME. THIN I/B ACRYLIC PLY SHOULD BE FLOATING W/ STRAP OR SPACER PREVENTING INTERIOR ENCROACHMENT SINCE SOME CRACKS FORMED DURING MOUNTING.

FOUR BOLTS OFF BUT NO EFFECT.

IMPACT POINT JUST AT BOTTOM EDGE.

RESIDUAL VISIBILITY POORER THAN 1-A (WT-32) NO RESIDUAL BULGE.

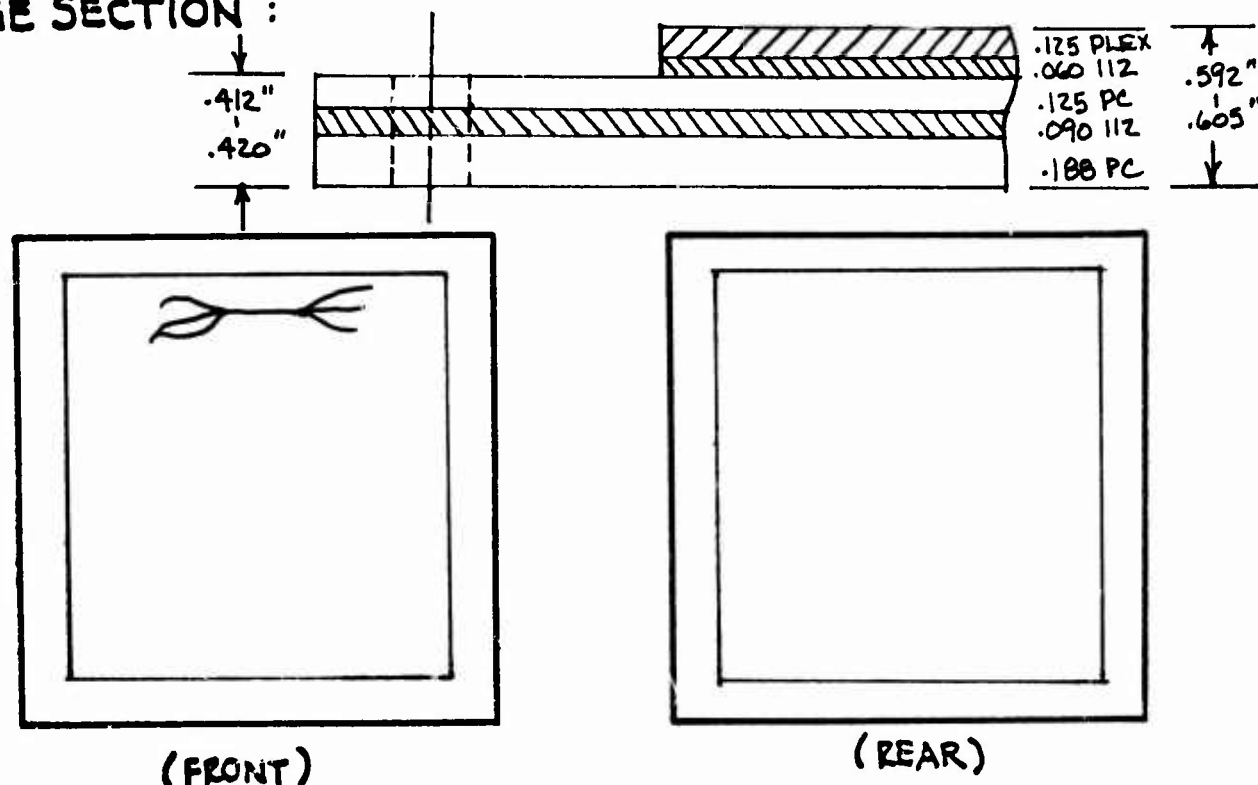


SAMPLE CODE : 9031-1B

CONSTRUCTION : .125" AS CAST ACRYLIC - .060" 11Z - .125" PC - .090" 11Z - .188" PC.

THICKNESS : .588" AREAL DENSITY : 3.66 LB./FT<sup>2</sup> PANEL WT. : 16.5 LB.

EDGE SECTION :



RESULTS ON 5-9-73 @ 75 °F AND 13.2 ° INSTALLATION ANGLE

SHOT NO. : WT-34 SPEED : INTENDED : 950 FPS BIRD WT. : 1800 GMS  
PRELIM : 874 FPS  
FINAL : 869 FPS K.E. : 46,373 FT.-LBS  
: 514 KTS

REMARKS :

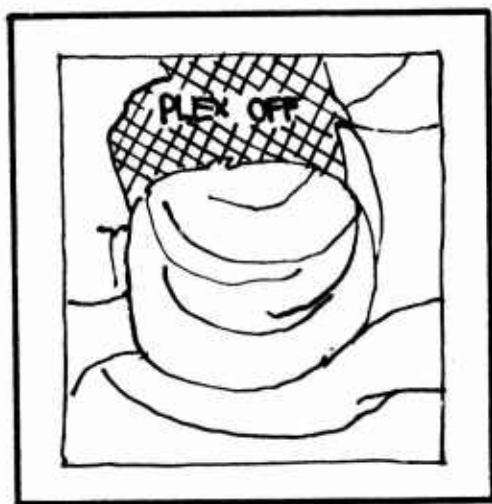
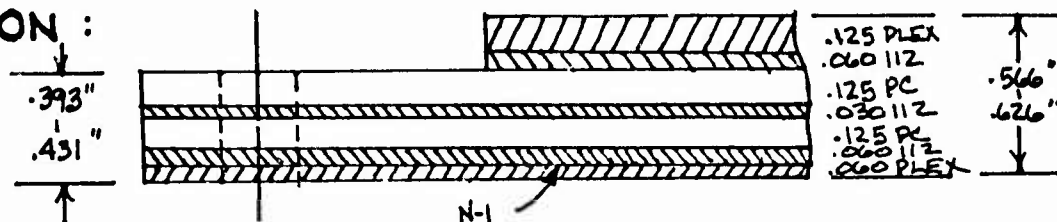
BIRD DID NOT PENETRATE. ESSENTIALLY NO STRUCTURAL DAMAGE TO PANEL. NO DAMAGE TO IMPACT SURFACE OR INBOARD PC PLY. SECOND PLY OF LAMINATE DAMAGED AS INDICATED. EXCELLENT RESIDUAL VISIBILITY. NO BOLTS BLOWN OUT BY IMPACT.

SAMPLE CODE : 9031-2B

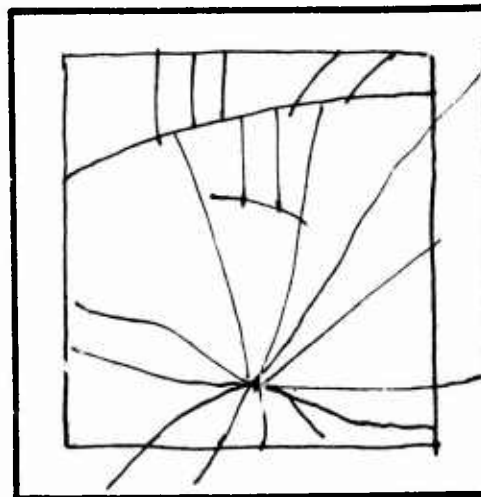
CONSTRUCTION : .125" AS CAST ACRYLIC - .060" 112 - .125" PC - .030" 112 -  
.125" PC - .060" 112 - .060" AS CAST ACRYLIC

THICKNESS : .585" AREAL DENSITY : 3.64 LB./FT<sup>2</sup> PANEL WT. : 16 LB. 8<sup>oz</sup>

EDGE SECTION :



(FRONT)



(REAR)

RESULTS ON 5 - 9 - 73 @ 72°F AND 13.2° INSTALLATION ANGLE

SHOT NO. : WT-35 SPEED : INTEND : 950 FPS  
PRELIM : 917 FPS. BIRD WT. : 1842 gm.  
532 KTS FINAL : 898 FPS K.E. : 50,837 FT-LBS

REMARKS : SOFT AEDC BOLT USED.

BIRD DID NOT PENETRATE. NO BOLTS REMOVED. INBOARD ACRYLIC  
CRACKED SEVERELY BUT NO SPALL.

NO FILM COVERAGE DUE TO PREMATURE FIRING RESULTING FROM  
DIAPHRAM FAILURE.

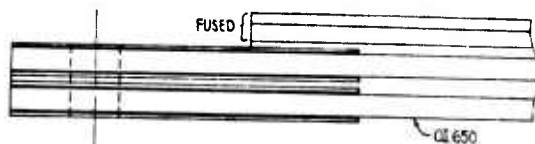
RESIDUAL VISIBILITY WORST OF FOUR CANOPY PANELS. SIGHT  
PERMANENT BULGING.

SAMPLE CODE : 9031-3A

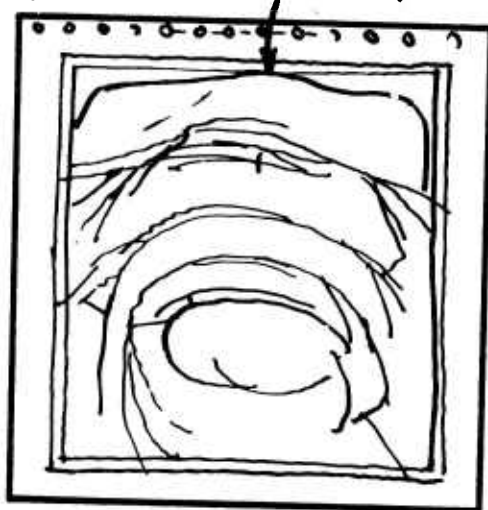
CONSTRUCTION : .060" AS-CAST ACRYLIC + .093" PC (FUSED) - .060" I12 -  
.125" PC - .090" I12 - .125" PC (OI 650)

THICKNESS : .553" AREAL DENSITY : 3.46 LB./FT<sup>2</sup> PANEL WT. : 16 1/4 LB.

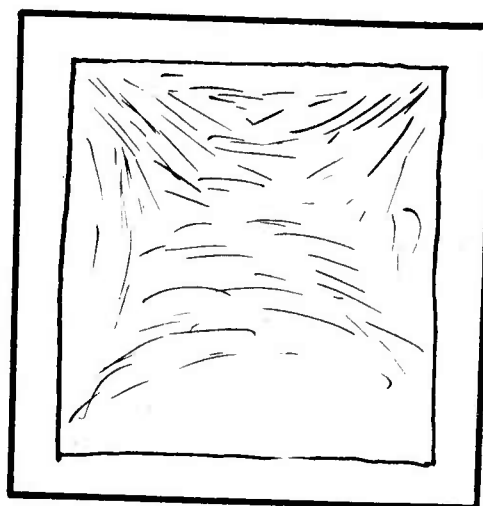
EDGE SECTION :



CRACK IN O/B 1/8" PC



(FRONT)



(REAR)

RESULTS ON 7-9-73 @ 83 °F AND 13.2 ° INSTALLATION ANGLE

SHOT NO. : WT-36 SPEED : INTENDED : 850 FPS  
PRELIM : 859 " BIRD WT. : 3.92 LB  
ACTUAL : 840 FPS K.E. : 42,875 FT-LB  
" = 497 KT

REMARKS :

BIRD DID NOT PENETRATE. OUTBOARD FUSED PLY CRACKED AS A SINGLE PLY IN MOST PLACES. MINOR NOMEX CRACKING AT TOP EDGE CENTER. CRACK (AS SHOWN) IN OUTBOARD .125" PC PLY STARTING AT STRAP EDGE IN CENTER.

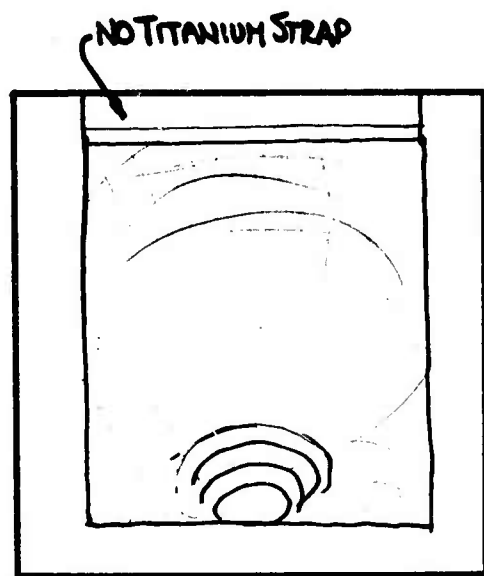
OI 650 COATING CRAZED DURING IMPACT AS A USUAL, BUT THERE WAS NO ATTENDANT DAMAGE TO THE INBOARD .125" PC PLY.

SAMPLE CODE : 9031-4A

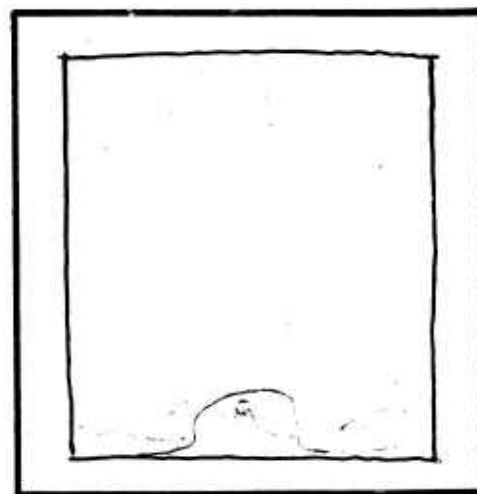
CONSTRUCTION : .085" HERCULITE II - .060" 112 - .188" PC - .060" 112 -  
.085" HERCULITE II

THICKNESS : .478" AREAL DENSITY : 4.04 LB./FT<sup>2</sup> PANEL WT. : 19 1/4 LB.

EDGE SECTION :



(FRONT)



(REAR)

RESULTS ON 7-10-73 @ 82 °F AND 13.2 ° INSTALLATION ANGLE

SHOT NO. : WT-37 SPEED : INTENDED - 850 FPS BIRD WT. : 4.04 LB  
PRELIM -  
ACTUAL - 888 FPS K.E. : 49,481 FT-LB  
" = 526 KT

REMARKS :

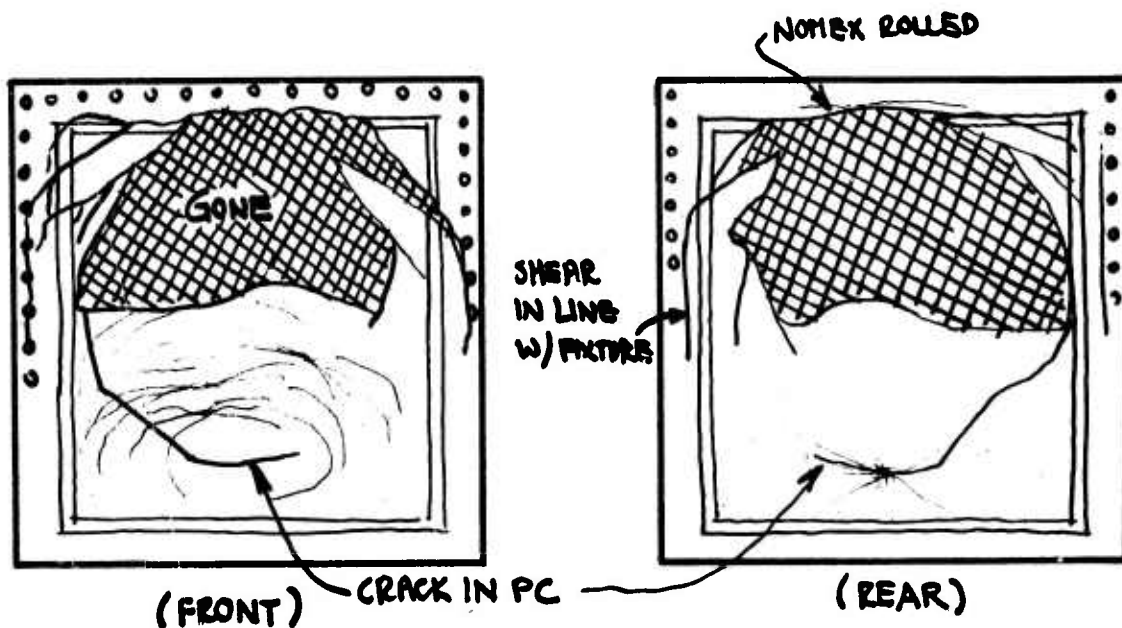
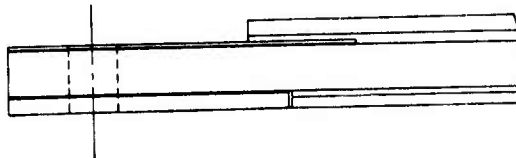
BIRD DID NOT PENETRATE, NO STRUCTURAL DAMAGE TO EDGES ATTACHMENTS. PANEL HAS ~ 1/2" RESIDUAL BULGE TOWARD 1/3 AND OVERALL WARP ~ 3/4". SPALL APPEARS TO HAVE BEEN COMPARABLE TO W/S SHOTS. NO RESIDUAL VISIBILITY. IT IS IMPOSSIBLE TO DETERMINE THE CONDITION OF THE PC PLY, BUT SINCE THERE WAS NO PENETRATION, IT IS ASSUMED TO BE OK.

SAMPLE CODE : 9031-5A

CONSTRUCTION : .090" CR-39<sup>①</sup> - .060" IIZ - .250" PC - .030" IIZ - .060"  
AS-CAST ACRYLIC

THICKNESS : .490" AREAL DENSITY : 3.11 LB./FT<sup>2</sup> PANEL WT. : 14 1/4 LB.

EDGE SECTION :



RESULTS ON 7-10-73 @ 84 °F AND 13.2° INSTALLATION ANGLE

SHOT NO. : WT-38 SPEED INTENDED : 850 FPS BIRD WT. : 4.04 LB  
PRELIM : 890 "  
ACTUAL : 863 " K.E. : 46,700 FT-LB  
" = 511 KT

REMARKS :

BIRD PENETRATED. BRITTLE TYPE FAILURE WITH TOP HALF OF PANEL BLOWN OUT IN ONE MAJOR PIECE. EDGE SHEARING IN LINE WITH FIXTURE. TOP EDGE SHEARED OUT IN LINE WITH .080" NOMEX STRAP. CRACK IN PC IN LINE WITH PLEX CRACK AT IMPACT POINT, BUT NOT EXACTLY COINCIDENT (I.E. CRACK DID NOT PROPAGATE THRU .090" IIZ).

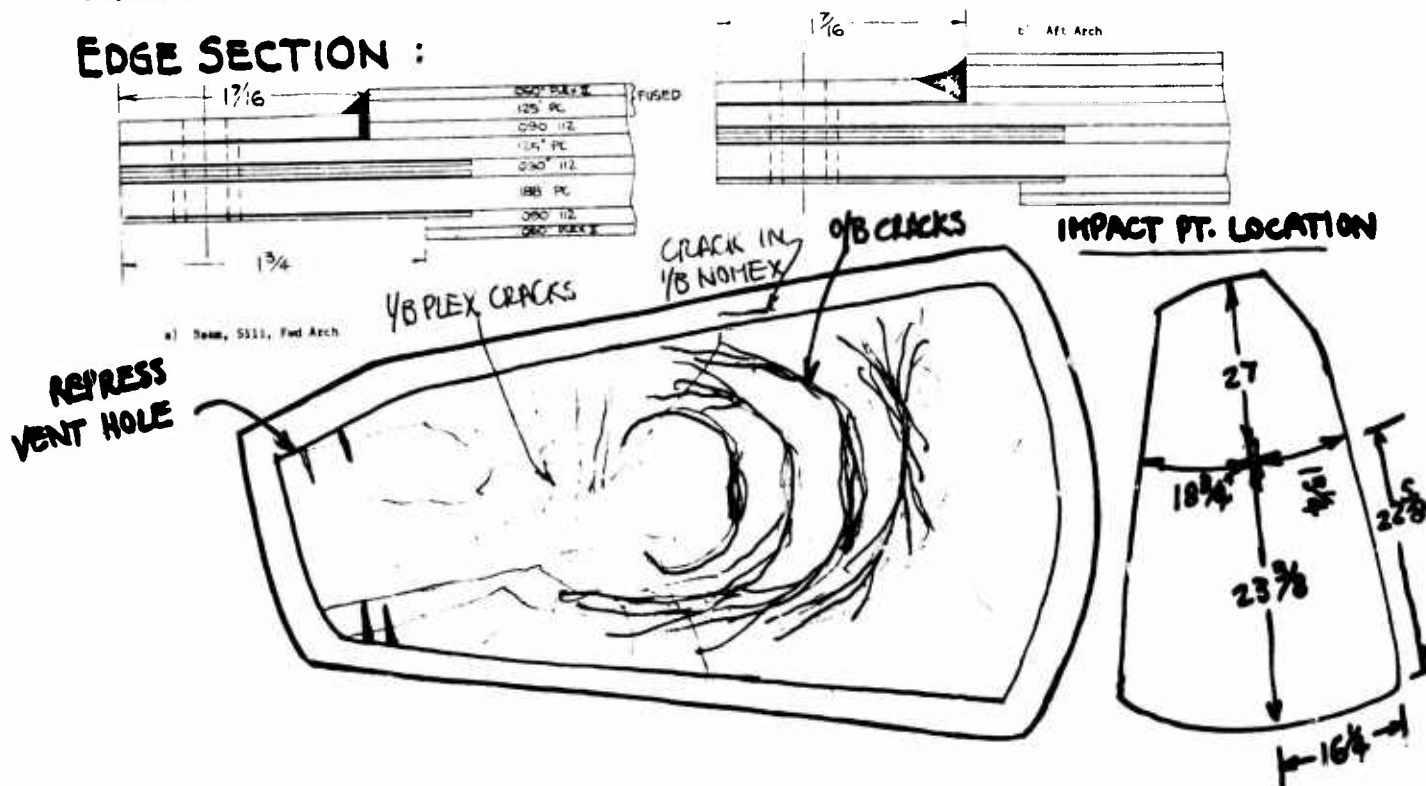
GOOD ADHESION TO PLEX & CR-39. CR-39 FRACTURE PATTERN MORE COMPLETE THAN SEEN WITH ACRYLIC.

SAMPLE CODE : 9030-25

CONSTRUCTION : (SEE EDGE SECTION)

THICKNESS : .828" AREAL DENSITY : 5.16 LB./FT<sup>2</sup> PANEL WT. : 54 $\frac{3}{4}$  LB.

EDGE SECTION :



RESULTS ON 7-11-73 @ ~82 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-30 SPEED : INTENDED - 850 FPS PRELIM - 870 " BIRD WT. : 1747 GM = 3.8 #  
516 KT = FINAL  $\pm$  872 " K.E. : 45,359 FT-LB

REMARKS : NEW FRAME (#2) AND SPS TITANIUM BOLTS USED.

BIRD DID NOT PENETRATE. NO APPARENT DAMAGE TO PC PLIES. BOTH FACING PLIES CRACKED AS SHOWN ABOVE. NO ACRYLIC SPALL FROM INBOARD DURING DEFLECTION. CRACK IN INBOARD NOHMX AT BEAM AS SHOWN. REMOVAL OF SECTION OF STRAP SHOWS THAT CRACK IS IN REINFORCEMENT, NOT PC. SLIGHT NOHMX TENSILE WHITENING AT BOLT HOLES NEAR CRACK.

REPRESS DOES NOT APPEAR TO HAVE HAD ANY EFFECT. NO DAMAGE TO RETAINER. ALL BOLTS AND BUSHINGS OK.

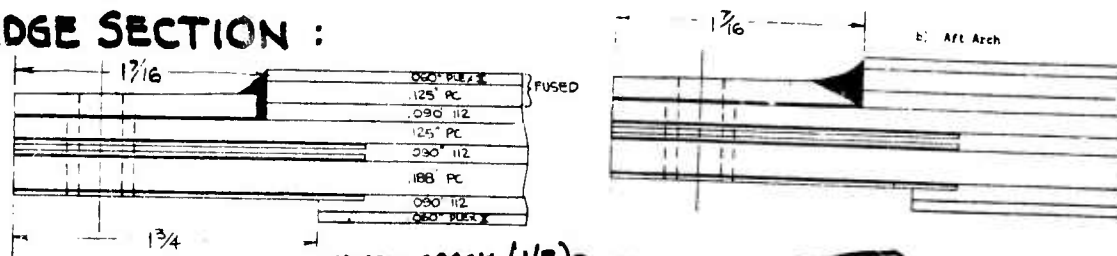


SAMPLE CODE : 9030-26

CONSTRUCTION : (SEE SKETCH OF EDGE SECTION)

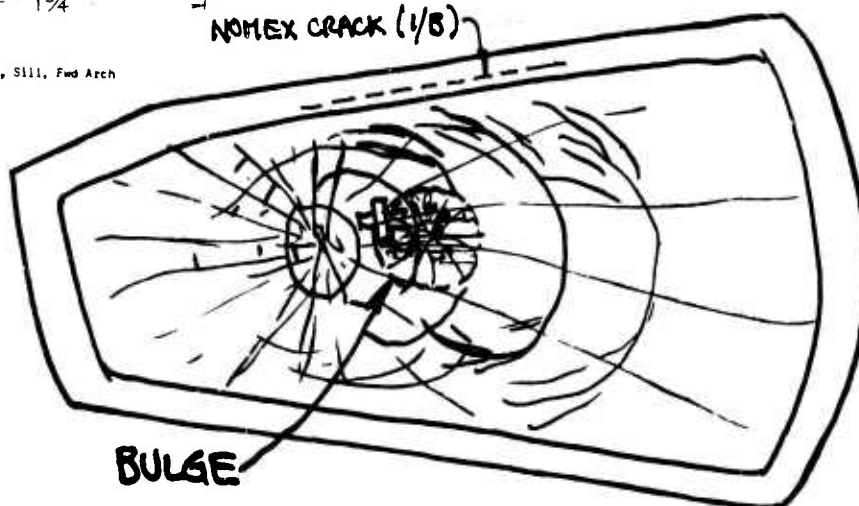
THICKNESS : .828" AREAL DENSITY : 5.16 LB./FT<sup>2</sup> PANEL WT. : 54 3/4 LB.

EDGE SECTION :



a) Beam, Still, Fwd Arch

SAME IMPACT POINT  
AS WT-39.



RESULTS ON 7 - 11 - 73 @ ~84 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-40 SPEED : INTENDED : 1200 FPS  
PRELIM : 1175 FPS BIRD WT. : 1745 gm = 3.83 LB.  
727 KT = FINAL : 1225 FPS K.E. : 96.636 FT-LB

REMARKS : NEW FRAME AND SPS TITANIUM BOLTS USED.

BIRD DID NOT PENETRATE. RESIDUAL BULGE (3" DEEP, 7" DIAMETER) LOCATED 4" BEHIND TARGET "X". ACRYLIC SPALL OFF 5"x4" AREA AT MAXIMUM BULGE (90% OFF) NEITHER 1/8" OR 3/16" PC CRACKED, EVEN IN EXTREME BULGE.

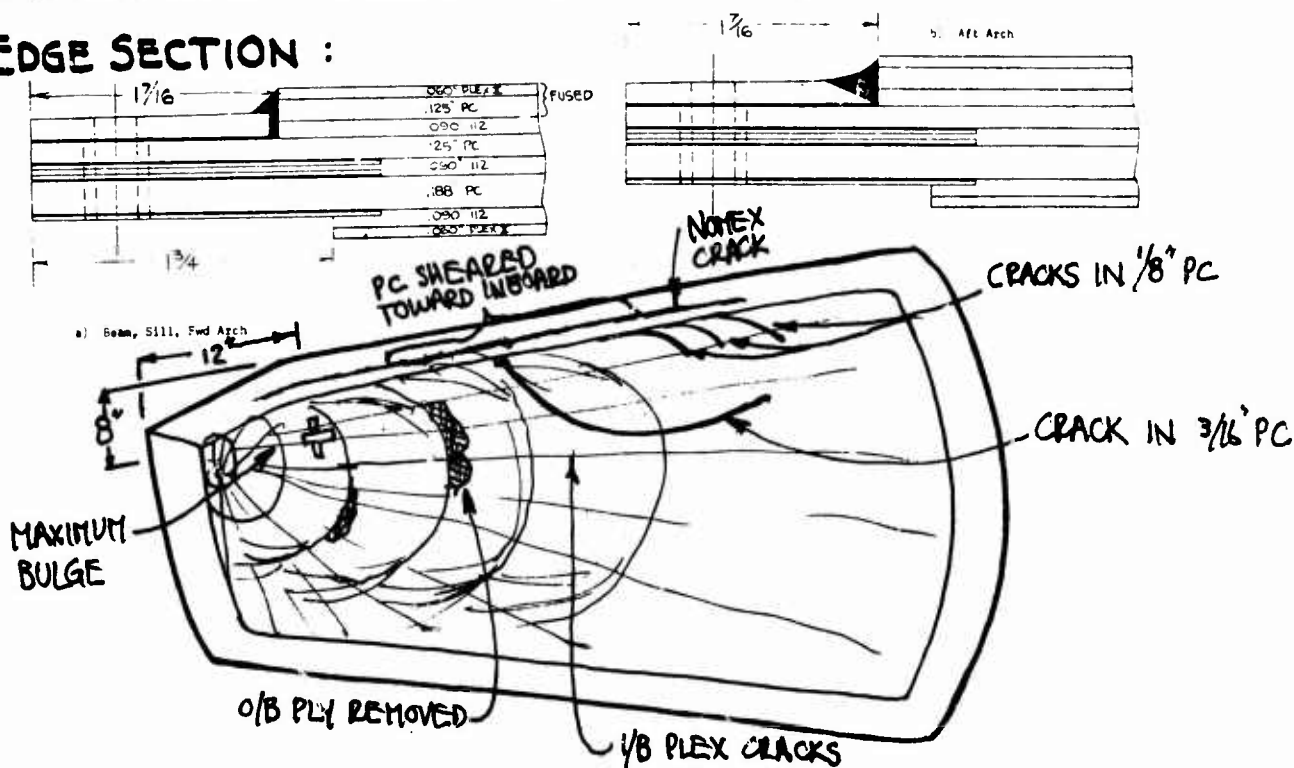
SABOT BROKE UP IN BARREL WITH PIECES PRECEDING BIRD. MOVIES SHOW BIRD IN ONE PIECE.

BOLTS & RETAINER OK. RTV/630 ADHESION OK THROUGHOUT.

CRACK (26" LONG) IN INBOARD BEAM EDGE REINFORCEMENT IN LINE WITH BENDING OVER FRAME. REMOVAL OF STRAP SECTION SHOWS THAT THE CRACK IS ONLY IN THE NOMEX (WITH 1 PLY STILL OK) AND NO DAMAGE TO THE PC.

CONSTRUCTION: (SEE EDGE SECTION)

**EDGE SECTION :**



SHOT NO.: WT-41 SPEED: INTENDED - 1200 FPS BIRD WT. : 4.13 LB  
FINAL = 1189 FPS K.E. : 90,618 FT-LB.  
REMARKS : No. 2 FRAME, SPS BOLTS " = 704 KTS

BIRD DID NOT PENETRATE. LARGE RESIDUAL BULGE WITH ACRYLIC SPALLED IN MAX. BULGE AREA. CRACK IN BEAM EDGE ATTACHMENT AND PC WITH CRACKS FROM EDGE SHEAR LINE INTO VISION AREA IN BOTH  $\frac{1}{8}"$  &  $\frac{3}{16}"$ . OUTWARD PLY PULLED AWAY FROM RETAINER ALONG FORWARD HALF OF BEAM. APPROXIMATELY  $\frac{1}{4}"$  OUTWARD PERMANENT WARP IN FWD. HALF OF BEAM EDGE. CLOSE TO LIMIT.

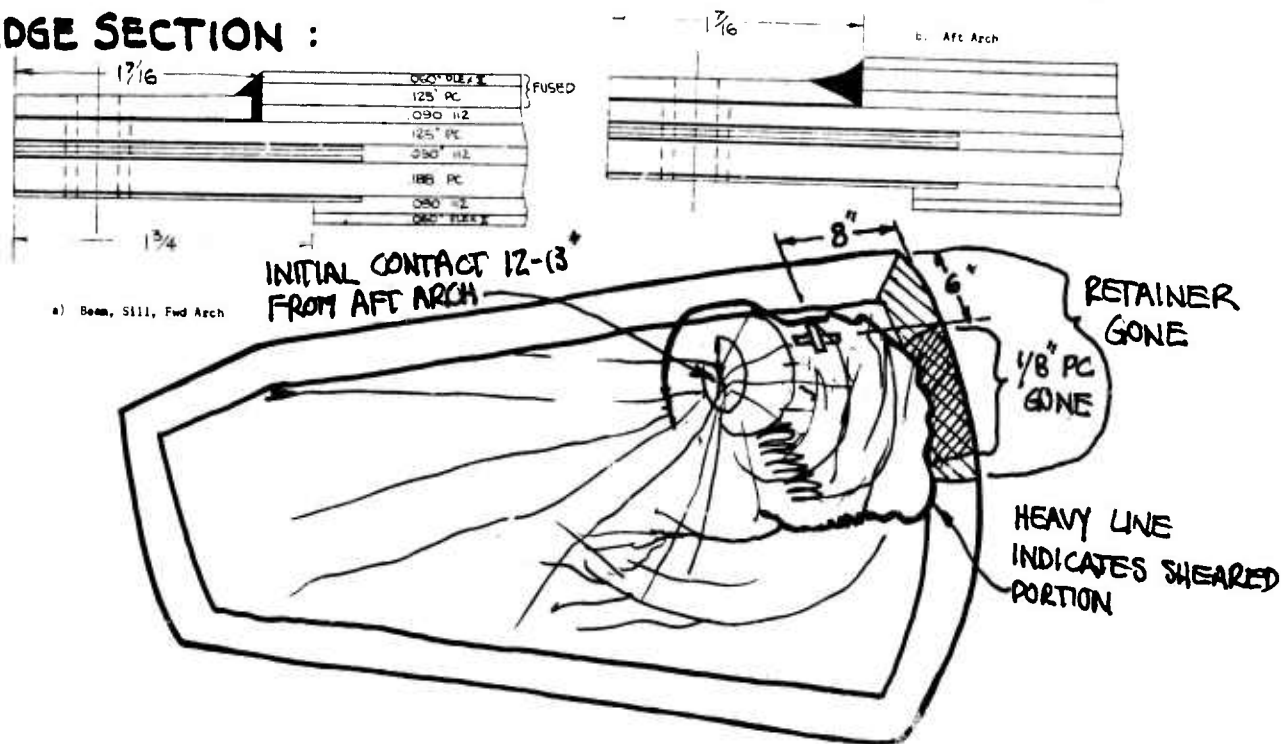
RETAINER OK EXCEPT LOOSE FOR 12" ALONG BEAM STARTING AT CORNER WITH FORWARD ARCH.

SAMPLE CODE : 9030-23

CONSTRUCTION : (SEE EDGE SECTION)

THICKNESS : .828" AREAL DENSITY : 5.16 LB./FT<sup>2</sup> PANEL WT. : 54 3/4 LB.

EDGE SECTION :



RESULTS ON 7 -12 -73 @ ~85 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-42 SPEED : INTENDED : 1200 FPS BIRD WT. : 1870 gm = 4.12 LB.  
FINAL : 1168 FPS  
" : 692 KT K.E. : 87,322 FT-LB.

REMARKS : FRAME No. 2 ; SPS BOLTS.

BIRD PENETRATED. CORNER OF AFT ARCH AND BEAM SHEARED AND OPENED AS SHOWN. SECTION OF RETAINER BLOWN OFF, BUT NOT PEELED, INDICATING NO TUNNELING. ELEVEN BOLTS OFF; FIVE BOLTS STILL IN RETAINER. RETAINER BOLTS BENT BUT INTACT WITH FAILURE BY PULLING OUT OF NUTS.

SHEAR LINES IN PENETRATED CORNER VARY IN LOCATION FROM PLY TO PLY. EXACT MODE OF FAILURE CANNOT BE DETERMINED. SOME PLEX SPALL FROM BULGE/FLAP. IN STRIPPED EDGE SECTION, POOREST RTV/630 ADHESION WAS TO THE PC. APT 18" OF BEAM EDGE WARPED OUTWARD ~ 3/8".

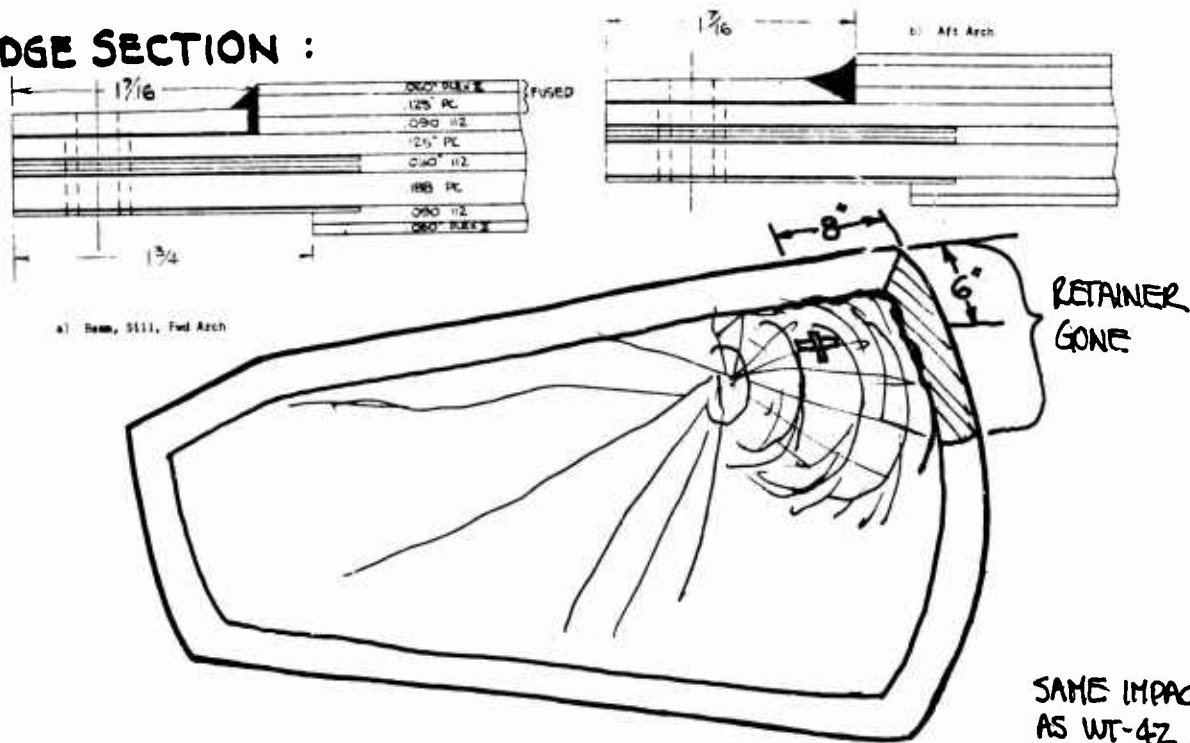
LITTLE DAMAGE TO REMAINING 3/4 OF PANEL.

SAMPLE CODE : 9030-24

CONSTRUCTION : .060" PLEX II / .125" PC (FUSED) - .090" IIZ - .125" PC -  
.090" IIZ - .188" PC - .090" IIZ - .060" PLEX II

THICKNESS : .828" AREAL DENSITY : 5.16 LB./FT<sup>2</sup> PANEL WT. : 54 3/4 LB.

EDGE SECTION :



RESULTS ON 7 -13-73 @ ~80 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-43 SPEED : INTENDED : 850 FPS BIRD WT. : 1728 gm = 3.93 LB.  
FINAL = 857 " K.E. : 45,021 FT-LB  
" = 509 KT

REMARKS : FRAME No.2 ; SPS Bolts

BIRD PENETRATED. FAILURE SIMILAR TO 9030-23 (WT-42) ALTHOUGH LESS SEVERE. SECTION OF THE AFT ARCH RETAINER REMOVED AND BOLTS PULLED OUT OF THE NUTS. IMPACT SLIGHTLY CLOSER TO THE BEAM THAN 9030-23. AFT PORTION OF BEAM EDGE DEFLECTED O/B ~ 3/8".

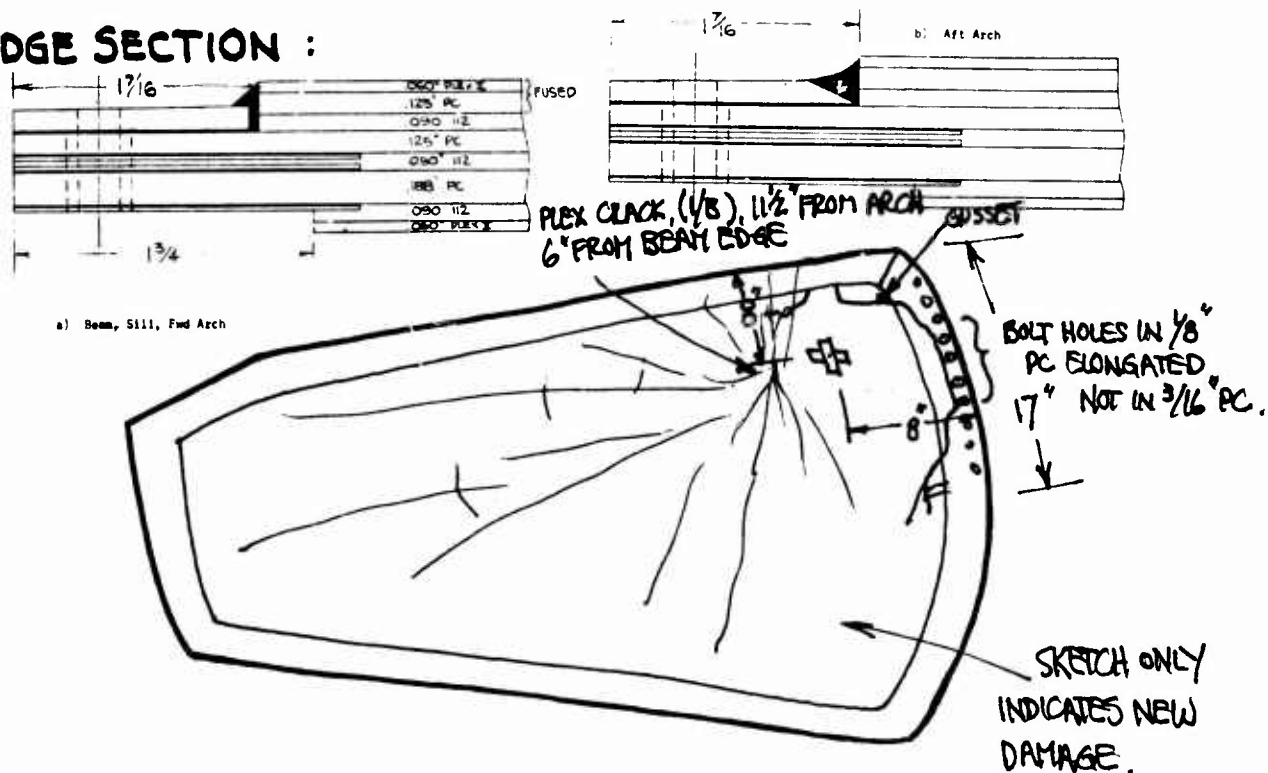
SHEAR FLAP AND DAMAGE TO REMAINDER OF WINDSHIELD LESS THAN 9030-23. CLOSE TO LIMIT. WOULD PROBABLY PASS WITH LESS RIGID FRAME.

SAMPLE CODE : 9030-25 (2<sup>ND</sup> IMPACT)

CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .828" AREAL DENSITY : 5.16 LB./FT<sup>2</sup> PANEL WT. : 54<sup>3</sup>/<sub>4</sub> LB.

EDGE SECTION :



RESULTS ON 7-24-73 @ ~85 °F AND 22 ° INSTALLATION ANGLE

SHOT NO.: WT-44 SPEED: INTENDED - 850 FPS BIRD WT. : 4.06 LB.

FINAL = 849 FPS

K.E. : 45,442 FT-LB

REMARKS : SHOT IN MODULE, USING STEEL A/C-TYPE BOLTS

MODULE (FROM FM SERIES) HAD STRENGTHENED AFT 1/4 H ARCH.

BIRD PENETRATED, TISSUE THRU CORNER LIKE ~~WT-43~~ WT-43, ALTHOUGH LESS SEVERE. TISSUE SPATTER (~10% OF BIRD) ON CENTRAL PORTION OF AFT BULKHEAD. ARCH IS LESS RIGID THAN FRAME BUT STILL LITTLE DEFLECTION AND PRACTICALLY NO ROTATION IN GUSSETED AREAS.

FAILURE DUE TO SHEARING OF 3/16" PC PLY IN LINE WITH EDGE OF SUPPORT AND SUBSEQUENT TENSILE FAILURE OF 1/8" PLY OF PC. SHEARING IS REMINISCENT OF EARLY FLAT PANEL FAILURES PRIOR TO FRAME GRINDING. BOLT HOLE DEFORMATION (OR LACK OF IT) SHOWS THAT 3/16" PC IS DOING NO WORK BEFORE SHEARING.

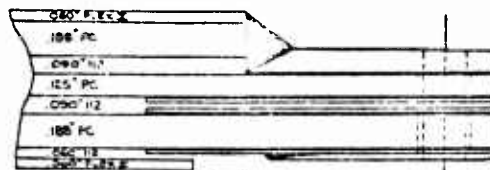


SAMPLE CODE : 9030-31

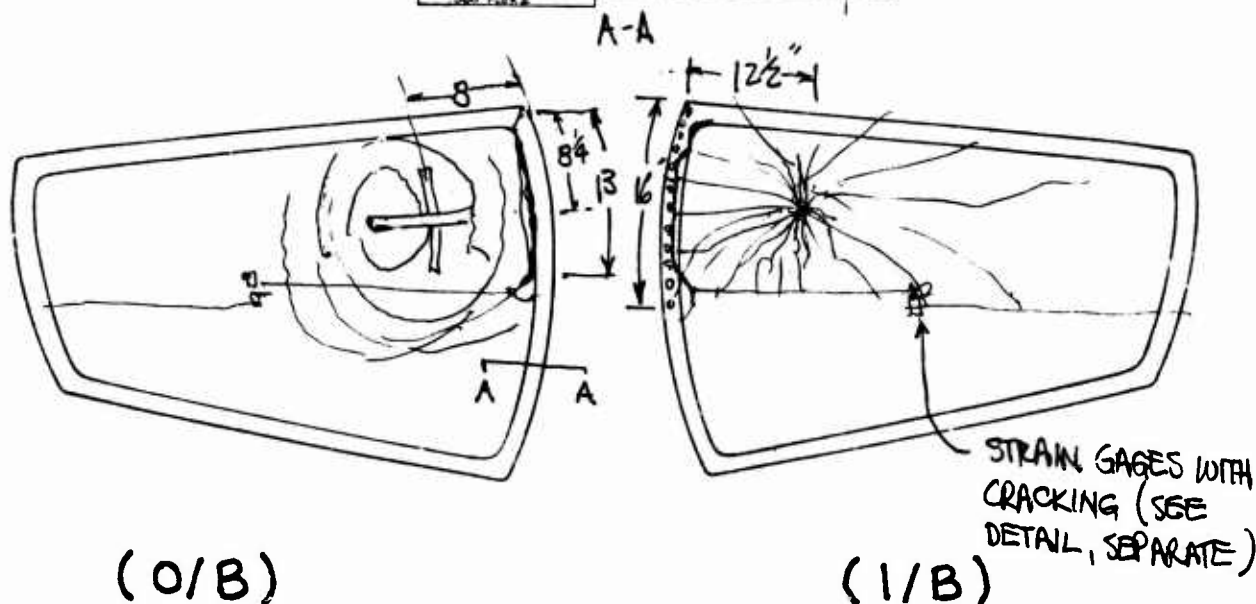
CONSTRUCTION : .060" PLEX II / .188" PC - .090" IIZ - .125" PC - .090" IIZ -  
.188" PC - .060" IIZ - .060" PLEX II

THICKNESS : .861" AREAL DENSITY : 5.36<sup>2</sup> LB./FT<sup>2</sup> PANEL WT. : 55. LB. 29

EDGE SECTION :



L.T. = 68.8 - 69.5%  
HAZE = 1.0 - 1.3%



RESULTS ON 8-27-73 @ ~ <sup>85</sup> °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-47 SPEED : INTEND : 880 FPS. BIRD WT. : 1760 gm  
FINAL : 891 FPS  
= 527.5 KT K.E. : 47,789 FT-LB

REMARKS : BIRD PENETRATED

CORNER, AFT OF IMPACT POINT "SHEARED", PERMITTING TISSUE TO PENETRATE. BOTH PC PLIES FAILED ALONG 13" LINE COINCIDENT WITH END OF SUPPORT LEDGE. HOWEVER, PC DID NOT SHEAR. NO CRACK AS RESULT OF Ti STRIP WHICH ROTATED AND YIELDED ALONG ARCH. PC PUSHED PAST Ti STRIP. NEGLIGIBLE RESIDUAL ROTATION OR DEFLECTION OF ARCH WITH McAIR'S INTERIM MODIFICATION.

FAILURE LESS SEVERE THAN WT-44, BUT TISSUE PENETRATION COMPARABLE. <sup>CRACKING</sup> CRACKS FROM TAPE HOLDING STRAIN GAGE WIRES DID NOT AFFECT RESULTS.

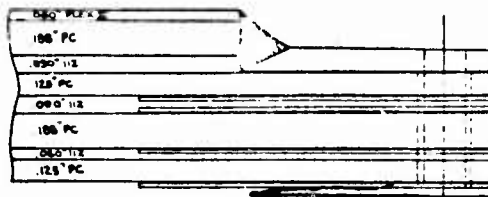


SAMPLE CODE : 9030-33

CONSTRUCTION : (SEE EDGE SECTION)

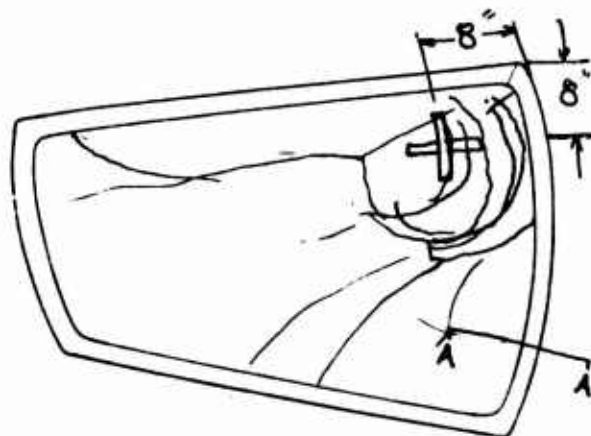
THICKNESS : .926" AREAL DENSITY : 5.77 LB./FT<sup>2</sup> PANEL WT. : 61.5 LB.

EDGE SECTION :  
(A-A)



L.T. = 48-65.6%

HARE = 0.6-1.3%



(O/B)



(I/B)

RESULTS ON 8-28-73 @ 85-90°F AND 22° INSTALLATION ANGLE

SHOT NO. : WT-48 SPEED : INTENDED : 850 FPS. BIRD WT. : 1815 gm = 4.00 LB  
PRELIM = 873 FPS  
FINAL = 878 FPS = 520 KT. K.E. : 47.855 FT-LB.

REMARKS :

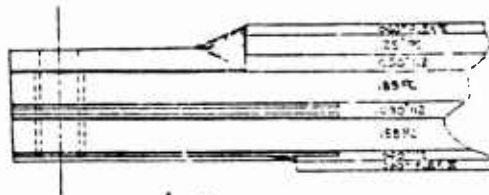
BIRD DID NOT PENETRATE, OUTBOARD PLY CRACKED BUT NO OBSERVABLE FRACTURING OF STRUCTURAL PC PLYS. TITANIUM STRIP BENT OVER LEDGE DURING DEFLECTION BUT NO SHEARING. NOMEX CRACKED UNDER STRIP, IN LINE WITH END OF LEDGE. DEFORMATION OF PC UNDER NOMEX CRACK BUT NO FRACTURE. NUMEROUS "STRESS CRACK" CRACKS IN INBOARD NOMEX IN AREA OF MAX. DEFLECTION.

SAMPLE CODE : 9030-3Z

CONSTRUCTION : .060" PLEX II / .125" PC - .090" IIZ - .188" PC - .090" IIZ - .188"  
PC - .060" IIZ - .060" PLEX II

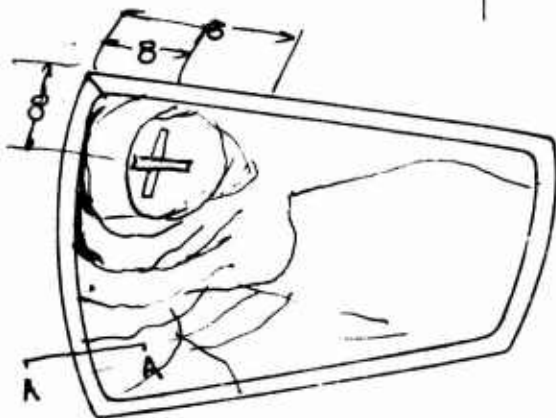
THICKNESS: .81" AREAL DENSITY: 5.362 LB./FT<sup>2</sup> PANEL WT.: 56 LB.

EDGE SECTION :

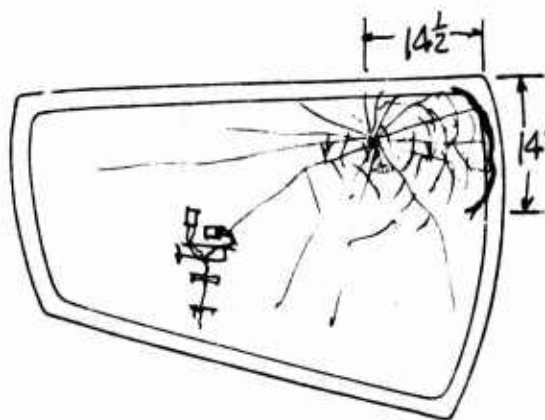


L.T. =

HAZE = 0.7-1.1%



(O/B)



(I/B)

RESULTS ON 8-29-73 @ ~90 °F AND 22 ° INSTALLATION ANGLE

SHOT NO.: WT-49 SPEED: INTENDED = 850 FPS BIRD WT.: 1883 gm = 4.15 LB.  
FINAL ~~850~~ = 870 FPS  
FINAL = 515 KT K.E. : 48,747 FT-LB

REMARKS : BIRD PENETRATED.

ARCH CORNER, AFT OF IMPACT POINT, "SHEARED" AND PERMITTED TISSUE TO PENETRATE. PC PILES FAILED GENERALLY COINCIDENT WITH ARCH SUPPORT LEDGE END, ALTHOUGH FAILURE OF THE I/B WAS NOT A CLEAN SHEAR AS WITH WT-44. FAILURE WAS PRACTICALLY IDENTICAL TO WT-47 (9030-31) WITH ESSENTIALLY THE SAME PC FAILURE PATTERN IN BOTH. THE PC PUSHED PAST THE STAINLESS STEEL STRIP WHICH WAS YIELDED IN BENDING OVER THE ARCH PLUS ELONGATED LONGITUDINALLY, BUT NOT SHEARED. THE FWD. EDGE OF AFT RETAINER WAS PUSHED DOWN

IN THIS SHOT THERE WAS GREATER RESIDUAL ROTATION OF THE ARCH WITH THE MCAIR INTERIM FIX.

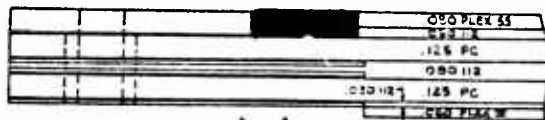
GENERALLY, THERE IS LITTLE IMPROVEMENT IN PERFORMANCE IN THIS 3/16-3/16 EDGE THAN WITH THE 1/8-3/16 OF 9030-31.

SAMPLE CODE : 9031-34

CONSTRUCTION : .080" PLEX 55 - .060" IIZ - .125" PC - .090" IIZ - .125" PC -  
.030" IIZ - .060" PLEX II

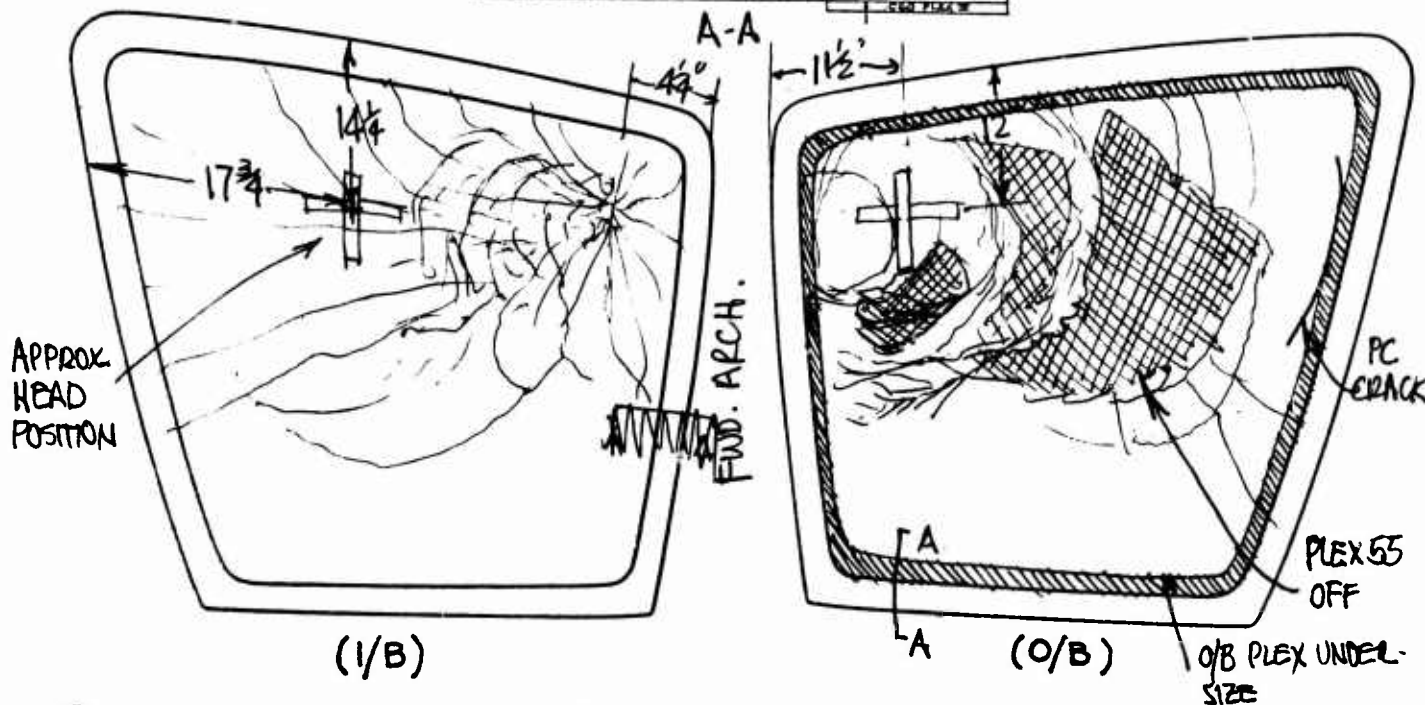
THICKNESS : .510" AREAL DENSITY : 3.545 LB./FT<sup>2</sup> PANEL WT. : 35.5 LB.

EDGE SECTION :



L.T. = 75.2-76.9%

HAZE = 0.8-1.1%



RESULTS ON 8-30-73 @ ~85°F AND ° INSTALLATION ANGLE

SHOT NO.: WT-51 SPEED: INTENDED = 850 FPS  
PRELIM = 875 FPS BIRD WT. : 1870 gm = 4.13 LB  
FINAL = 860 FPS = 509 KT KE : 47,304 FT-LB

REMARKS : CSK. BOLT FWD ARCH ; PRG HATCH . \*  
BIRD DID NOT PENETRATE . NO VISIBLE PC DAMAGE . OUTBOARD PLY OF  
PLEX 55 CRACKED WITH MUCH MORE REMOVED THAN EXPERIENCED WITH PLEX II .  
NO PLEX II SPALL FROM I/B SURFACE & NO CRACKS INTO .030" IIZ .

GOOD RESIDUAL VISIBILITY . NO PERMANENT BULGE OR DEFLECTION .

\* NOT TRUE . CRACK IN OUTBOARD PC PLY VISIBLE AT REAR ARCH AS  
SHOW IN SKETCH ABOVE .

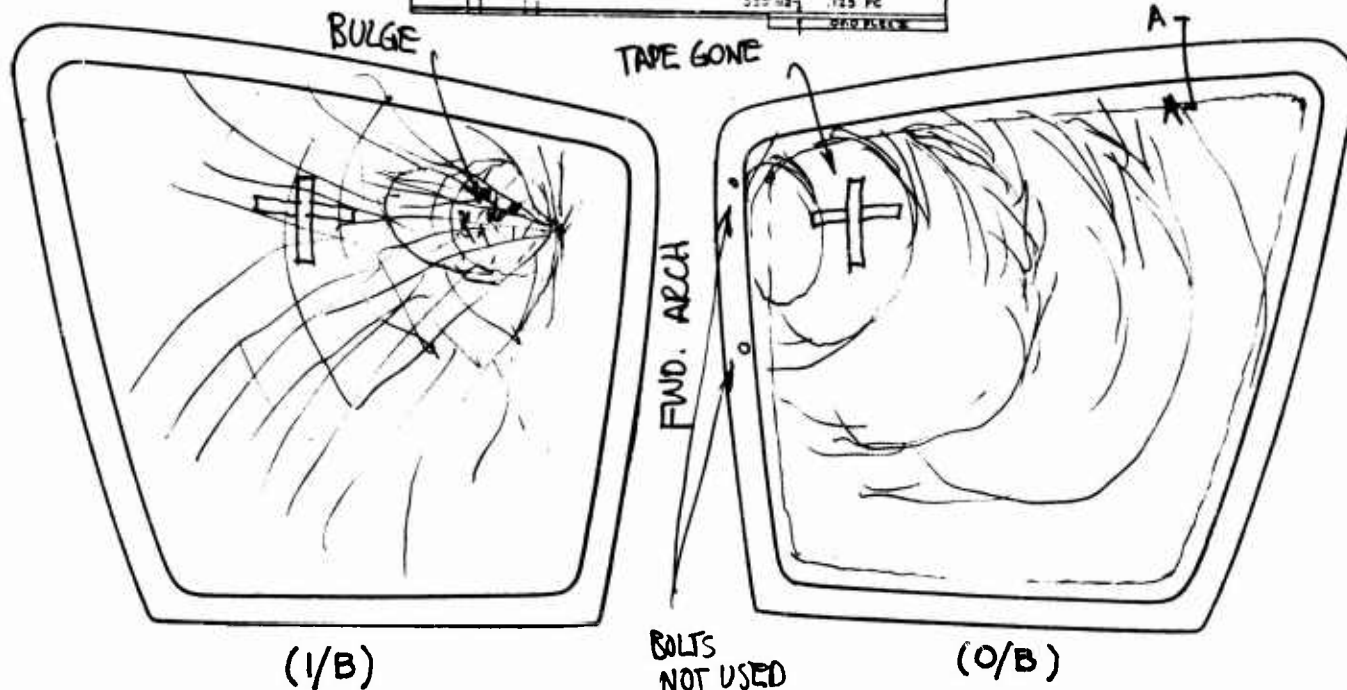
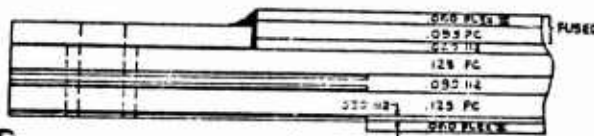
SAMPLE CODE : 9031-35

CONSTRUCTION : .060" PLEX II / .093" PC - .060" IIZ - .125" PC - .090" IIZ -  
.125" PC - .030" IIZ - .060" PLEX II

THICKNESS : " AREAL DENSITY :  $4.00 \text{ LB./FT}^2$  PANEL WT. : 39.25 LB.

EDGE SECTION :

(A-A)



RESULTS ON 8-31-73 @  $\sim 75^\circ \text{F}$  AND  $^\circ$  INSTALLATION ANGLE

SHOT NO. : WT-52 SPEED : INTENDED = 1150 FPS BIRD WT. : 1890 gm = 4.16 LB,  
PRELIM = 1170  
FINAL = 1156 FPS K.E. = 86,384 FT-LB  
" = 684 KT = MACH 1.04

REMARKS :

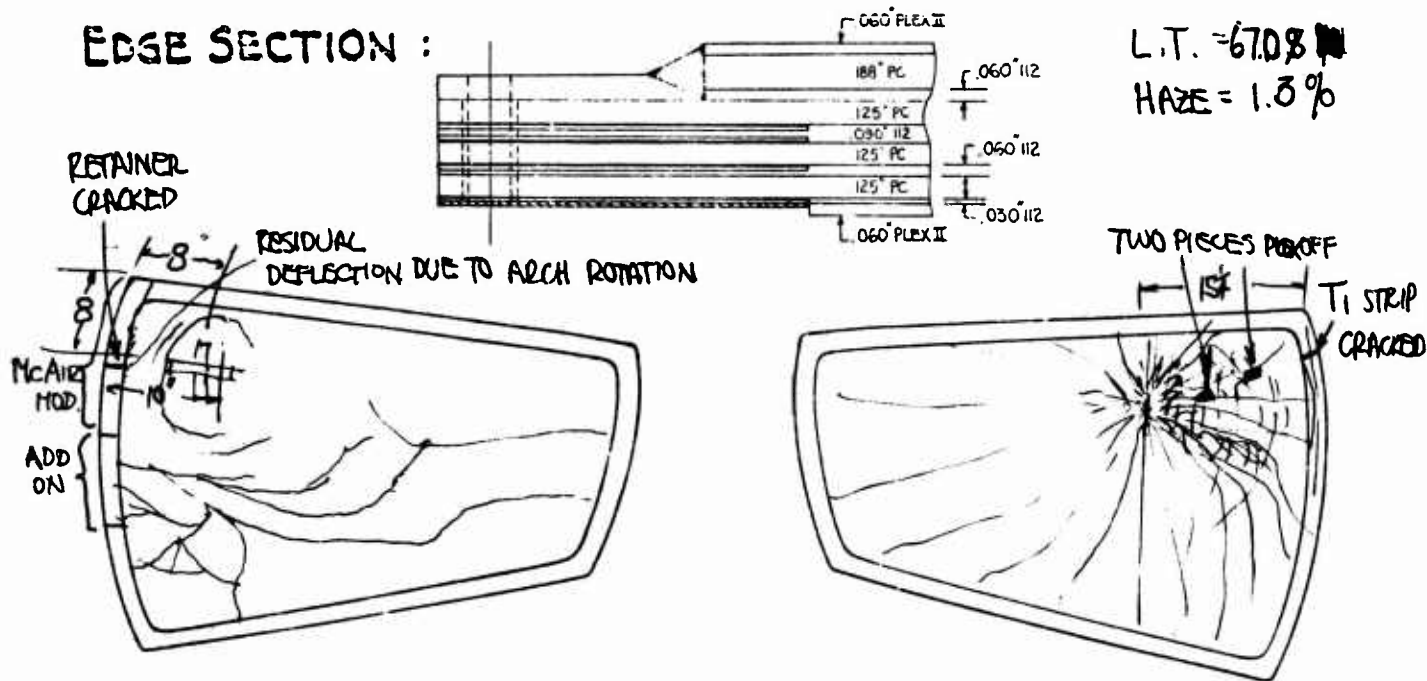
BIRD DID NOT PENETRATE, SAME IMPACT PT AT WT-52. AEDC HATCH.  
LARGE RESIDUAL BULGE CENTERED  $\sim 4"$  BEHIND IMPACT TARGET. SOME PLEX  
BLOWN OFF IN BULGED AREA LIKE HIGH SPEED WINDSHIELD SHOTS. LOTS OF  
DAMAGE TO FACING PLEX RESULTS IN POOR RESIDUAL VISIBILITY. NO CRACKS  
INTO .030" IIZ.

SAMPLE CODE : 9030-37

CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .923" AREAL DENSITY : 5.75 LB./FT<sup>2</sup> PANEL WT : 61 LB.

EDGE SECTION :



(O/B)

(I/B)

RESULTS ON 9-26-73 @ 85 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-53 SPEED : INTENDED : 800 FPS  
PRELIM : 805 "  
FINAL : 871 FPS = 516 KT BIRD WT. : 1852 gm = 4.08 LB  
K.E. : 48,055 FT/LB

REMARKS : ARCH MOD. NOT MILLED, CORNER HI-LOKS REMOVED, 1/4" ANGLE SECTION (STEEL) ADDED AT END OF MCAIR MOD.

BIRD DID NOT PENETRATE. NO APPARENT DAMAGE TO PC STRUCTURAL PLIES. TYPICAL FRACTURES OF O/B AND I/B FACES. RESIDUAL DEFLECTION IN IMPACT AREA, MAXIMUM AT RETAINER/PLEX INTERFACE. " RETAINER ROTATION.

TWO PIECES PLEX SPALL AS SHOWN. CONSIDERABLE PC DEFORMATION OVER ARCH FLANGE BUT NO FAILURE (GOOD ADHESION OF I/B RTV 630 TO PC) MORE PC DEFORMATION OVER ARCH FLANGE EDGE THAN 9030-36 (WT-54). LESS "STRESS-COAT" CRACKING OF I/B NOMEX THAN WT-54 OR WT-48. MAXIMAL RTV 630 ADHESION TO RETAINER.

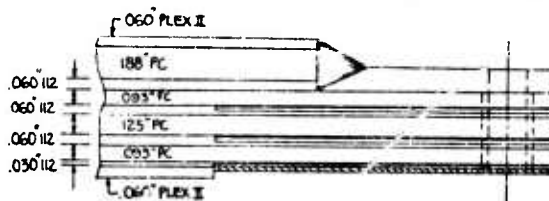


SAMPLE CODE: 9030-36

CONSTRUCTION: SEE EDGE SECTION

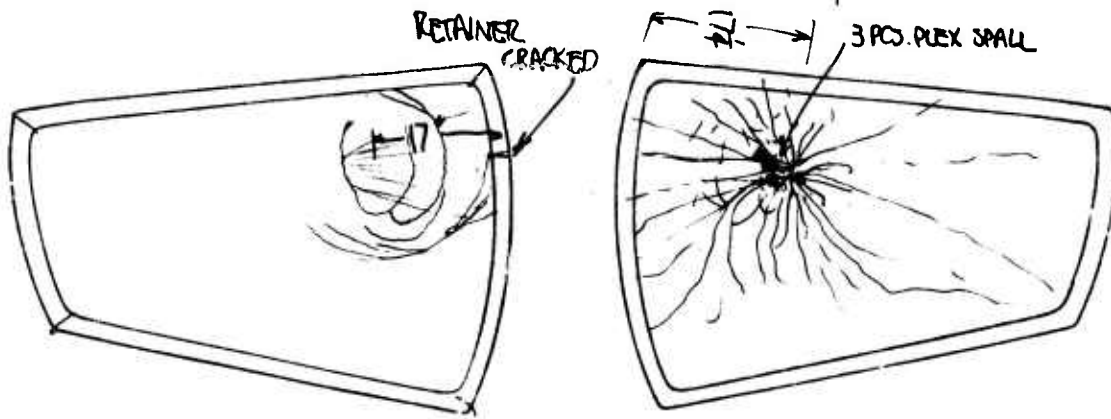
THICKNESS: .829" AREAL DENSITY: 5.16 LB./FT<sup>2</sup> PANEL WT.: 54.7 LB.

EDGE SECTION :



L.T. = 72%

HAZE = 1%



(0/8)

(1/B)

RESULTS ON 9-27-73 @ 80 °F AND 22 ° INSTALLATION ANGLE

SHOT NO.: WT-54 SPEED: INTENDED: 850 FPS.  
ACTUAL: 882 FPS BIRD WT.: 1840 gm = 4.05 LB.  
" = 521 KT KE: 18.775

REMARKS: MILLED ARCH REINFORCEMENT; HI-LOKS IN PLACE.

BIRD DID NOT PENETRATE. NO APPARENT PC DAMAGE. MORE DEFORMATION OF TI SUPPORT STRIP THAN WT-53. REMOVAL OF SUPPORT STRIP SHOWS PC SHEAR DISPLACEMENT COINCIDENT WITH ARCH FLANGE BUT NO PC FRACTURE UNDER NOMEX CRACKS. "STRESS COAT" CRACK PATTERN (LIKE WT-48) IN NOMEX IN IMPACT AREA. RETAINER ROTATED & CRACKED AS SHOWN. POOR ADHESION OF 1/8 NOMEX. CONSIDERABLE STRUCTURAL DAMAGE TO MODEL. ARCH FLANGE CRACKED.

CONSIDERABLE STRUCTURAL DAMAGE TO MODULE. ARCH FLATTENED & ROTATED IN IMPACT AREA, WITH CRACK IN FLANGE. REINFORCEMENT YIELDED IN IMPACT AREA. ARCH-SILL FILLET BROKEN. ARCH COMPLETELY LOOSE AT SILL END. NOT SUITABLE FOR ANOTHER O15 SHOT.

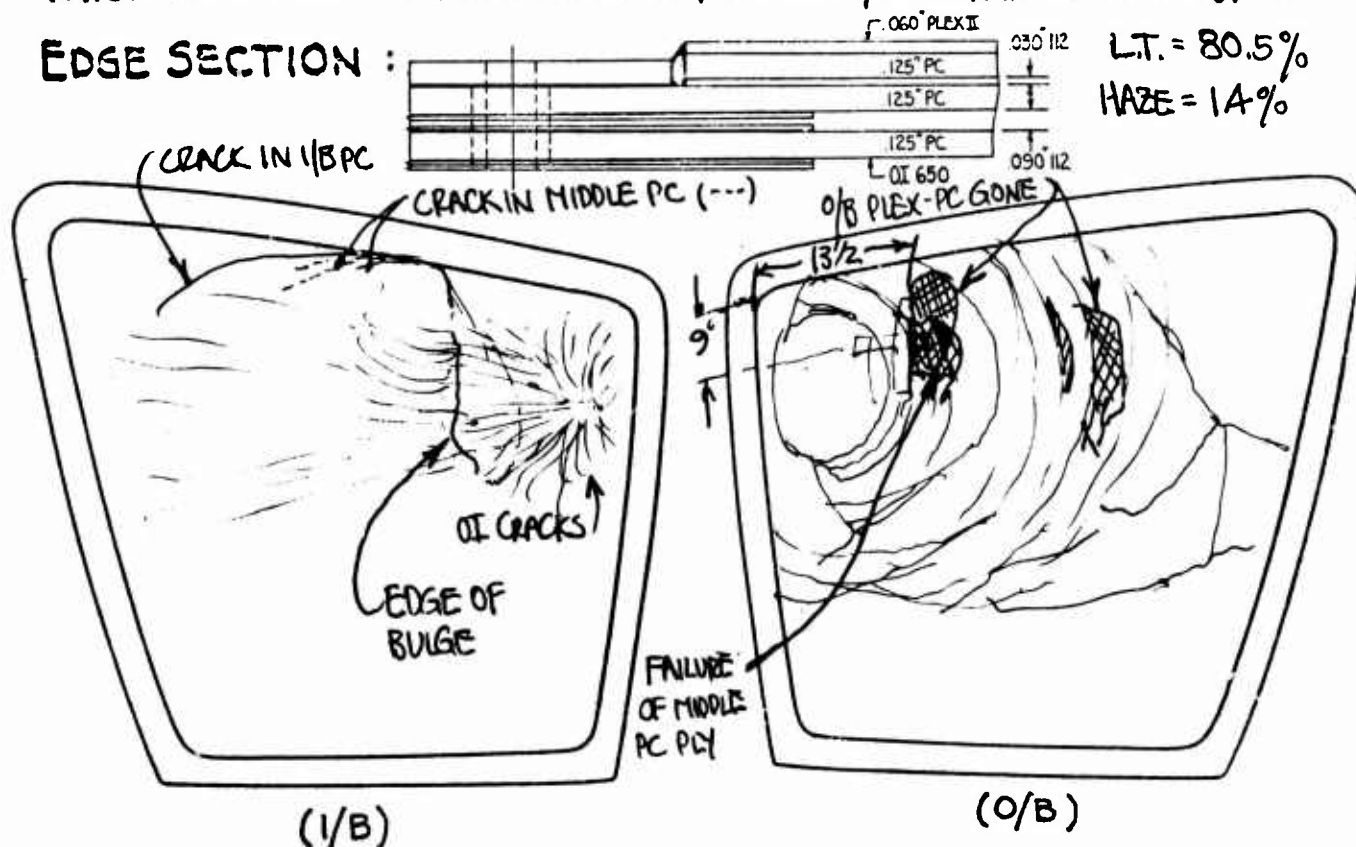


SAMPLE CODE : 9031-41

CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .555" AREAL DENSITY : 3.46 LB./FT<sup>2</sup> PANEL WT. : 36.6 LB.

EDGE SECTION :



RESULTS ON 10-10-73 @ 80 °F AND ° INSTALLATION ANGLE

SHOT NO. : WT-55 SPEED : INTENDED = 850 FPS.  
PRELIM. = 861 FPS  
FINAL = 866 FPS = 513 KT

BIRD WT. : 4.10 LB = 1861 gm  
K.E. : 47,735 FT LB

REMARKS : PRG HATCH (2<sup>nd</sup> TEST).

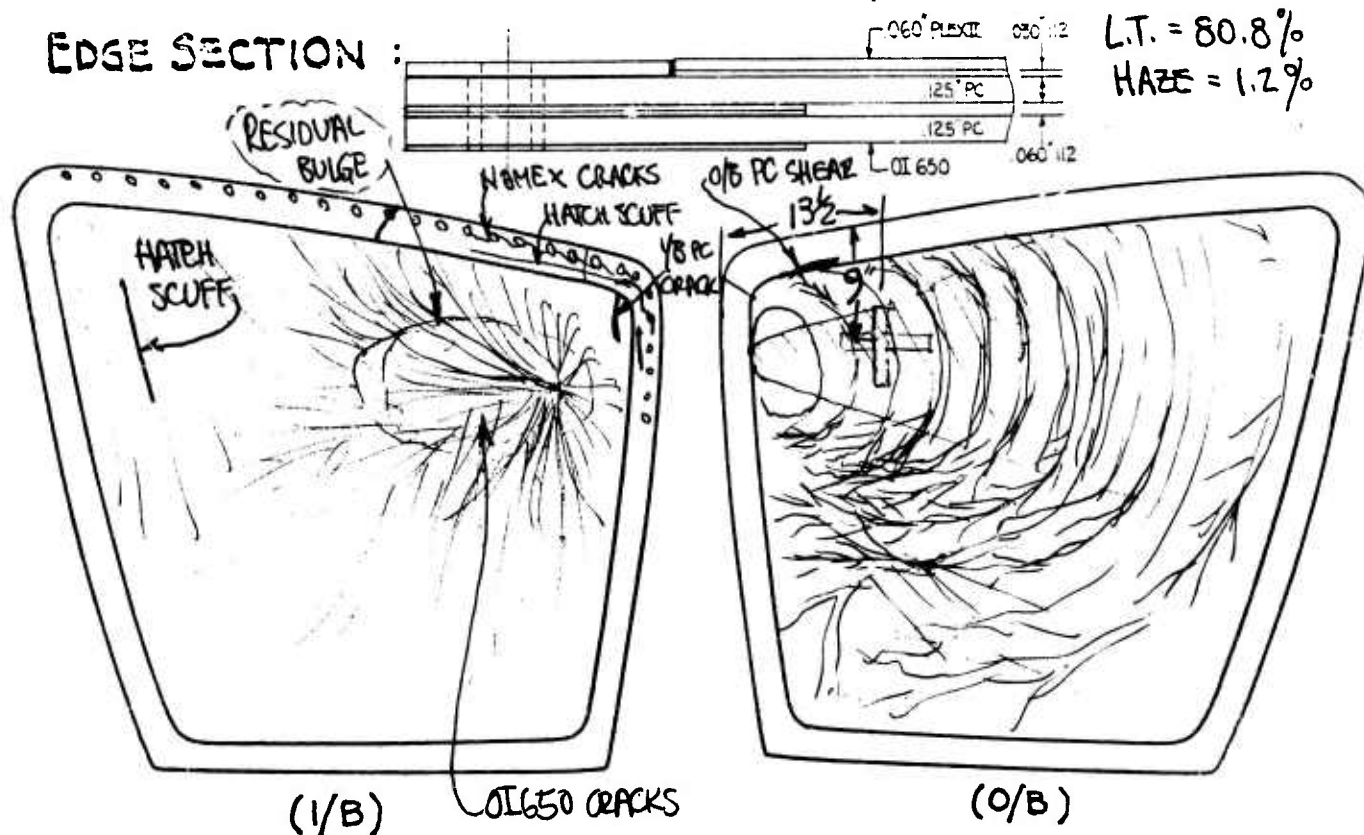
BIRD DID NOT PENETRATE. CONSIDERABLE DAMAGE IN THE IMPACT AREA. THE FUSED FACING PLY IS GONE IN SEVERAL PLACES AND THE MIDDLE PC PLY IS CRACKED AND PENETRATED. THERE IS A SHARP, IRREGULAR BULGE IN LINE WITH THE DAMAGED AREA. THE 1/8 PC PLY'S OI650 COATING HAS MANY SMALL CRACKS RELATED TO THE IMPACT STRAIN BUT THIS HAS NOT CAUSED ANY FAILURE OF THE PC. BOTH PC STRUCTURAL PLYS DO HAVE CRACKS ORIGINATING AT THE BEAM EDGE CLOSE TO THE MAXIMUM BULGE.

SAMPLE CODE : 9031-40

CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .400" AREAL DENSITY : 2.49 LB./FT<sup>2</sup> PANEL WT. : 25.8 LB.

EDGE SECTION :



RESULTS ON 10-10-73 @ ~83 °F AND ° INSTALLATION ANGLE

SHOT NO. : WT-56 SPEED : INTENDED = 850 FPS  
FINAL = 844 FPS  
= 500 KT. BIRD WT. : 1826 gm = 4.03 LB.  
K.E. : 44,488 FT-LB.

REMARKS : UNSHOT AEDC HATCH (APPARENTLY NOT LATCHED DURING TEST)

BIRD DID NOT PENETRATE. RESIDUAL BULGE APPROXIMATELY 1/2" MAXIMUM.  
OUTBOARD PLY HAS MANY UNIFORMLY-SPACED CRACKS WITH NO SIGNIFICANT  
AMOUNT MISSING. INBOARD PC SHOWS OT 650 CRACKING BUT NO PC-FRACTURE  
ASSOCIATED WITH IT.

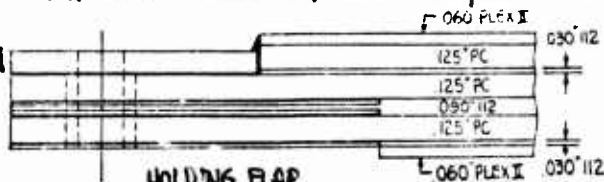
BOTH PC STRUCTURAL PLYS HAVE SUSTAINED SOME DAMAGE AS SHOWN IN  
THE SKETCHES ABOVE. THE INBOARD NOMEX STRAP ALSO CONTAINS CRACKING AS  
SHOWN.

SAMPLE CODE : 9031-4Z

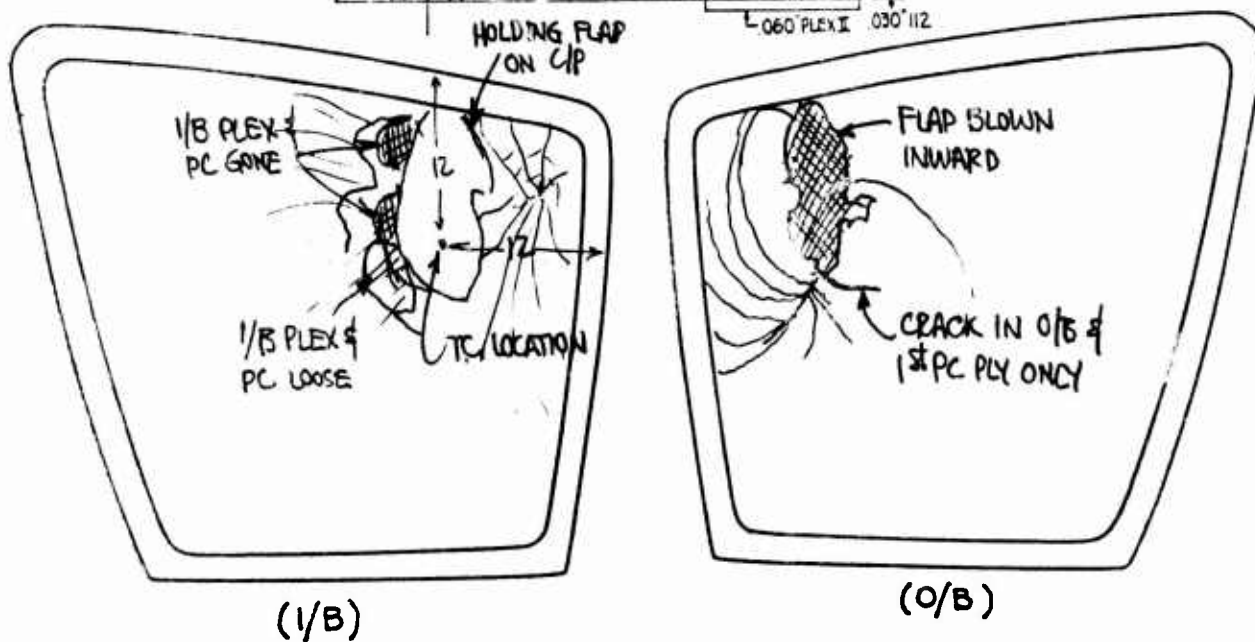
CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .645" AREAL DENSITY : 4.03 LB./FT<sup>2</sup> PANEL WT. : 39.4 LB.

EDGE SECTION



L.T. = 79.0 %  
HARE = 1.6 %



RESULTS ON 10 - 16 - 73 @ \* °F AND MODULE<sup>9</sup> INSTALLATION ANGLE

SHOT NO. : WT-57 SPEED : INTENDED : 850 FPS BIRD WT. : 1746 gm  
FINAL : 872 FPS

REMARKS :

\* O/B AMBIENT = -28°F  
O/B SURFACE = -2°F  
O/B INTERLAYER = -59°F?  
MIDDLE I/L = -5°F  
I/B SURFACE = +44°F  
I/B AMBIENT = +77°F

NOTE ! CHECK OF RECORDER  
CALIBRATION REVEALED A +11°F  
ERROR. ACTUAL AMBIENTS AND  
SURFACE TEMPS ARE AT LEAST 11°F LESS.

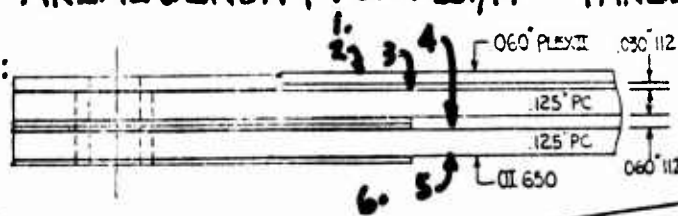
MOUNTED IN PPG-FURNISHED HATCH (3<sup>rd</sup> TEST ON HATCH)

BIRD PENETRATED. FOOTBALL-SHAPED, 4 1/2" x 12" FLAP  
BLOWN INWARD. FAILURE IS IN LINE WITH AND ORIGINATES  
FROM CRACKS IN THE O/B PLY. ONLY LOW ENERGY. CRACKS  
AT THE EDGE OF THE FLAP WERE STOPPED BY THE CENTER  
INTERLAYER AT -5°F.

THE SHAPE AND TYPE OF PENETRATION IS  
ALMOST IDENTICAL TO THAT OCCURRED DURING PPG'S  
IN-HOUSE PROGRAM WHEN A WINDSHIELD WAS  
PENETRATED AFTER +2°F SOAK.

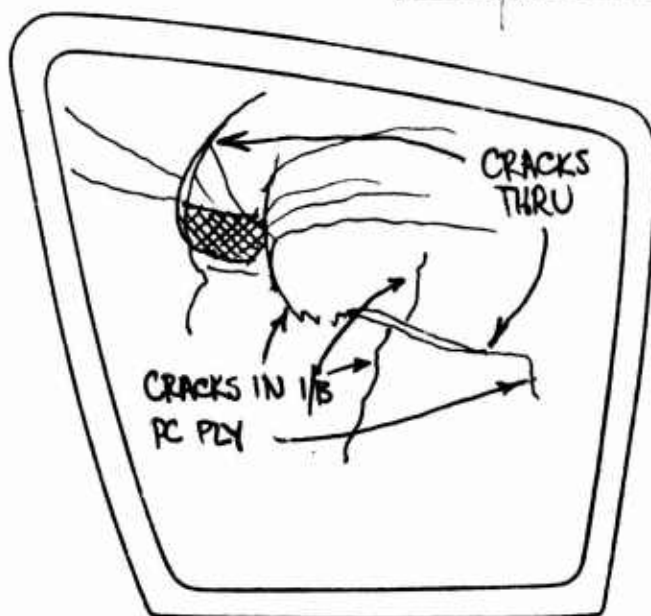
CONSTRUCTION: SEE EDGE SECTION

EDGE SECTION :

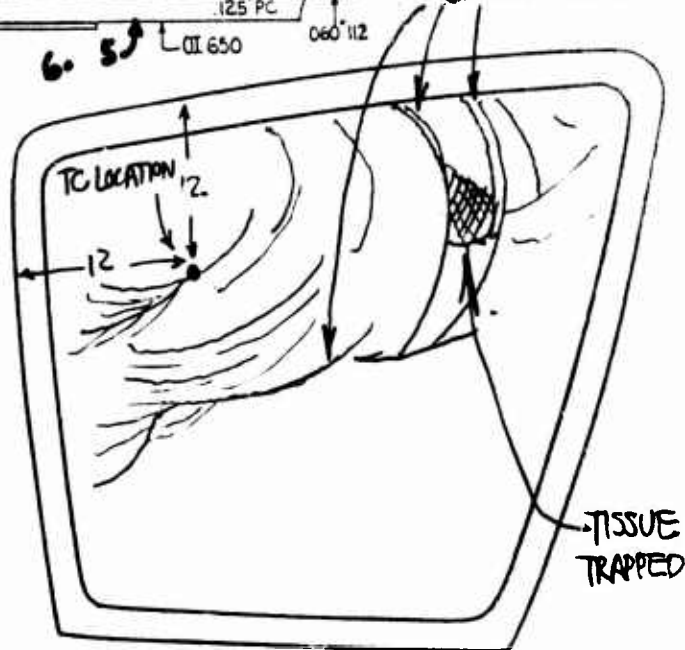


WACC = 1.3%

CRACKS THRU



(1/B)



(O/B)

RESULTS ON 10-16-73 @ \* ° F AND MODULE<sup>1</sup> INSTALLATION ANGLE

SHOT NO.: WT-58 SPEED: INTENDED: 850 FPS BIRD WT.: 1895 gm  
FINAL: 879 FPS  
" = 570 KT. KINETIC ENERGY: 1

REMARKS :

1. \* O/B AMBIENT =  $-31^{\circ}\text{F}$
2. O/B SURFACE =  $+10^{\circ}\text{F}$
3. O/B 1/L =  $+9^{\circ}\text{F}$
4. 1/B 1/L =  $+22.6^{\circ}\text{F}$
5. 1/B SURFACE =  $+43^{\circ}\text{F}$
6. 1/B AMBIENT =  $+76^{\circ}\text{F}$

NOTE: 1/L TEMPS FROM L&N  
POTENTIOMETER

OTHERS READ FROM  
RECORDER CHART.

BIRD PENETRATED"

BAD SHOT. BIRD PKG. HIT TEMPERATURE ENCLOSURE CURTAIN FRAME PRIOR TO HITTING CANOPY. NO PLUGS OR FLAPS WERE BLOWN OUT BUT TWO CRACKS COMPLETELY THRU THE LAMINATE ALLOWED SOME TISSUE THROUGH DURING DEFLECTION. THESE CRACKS ORIGINATE FROM THE O/B SURFACE.

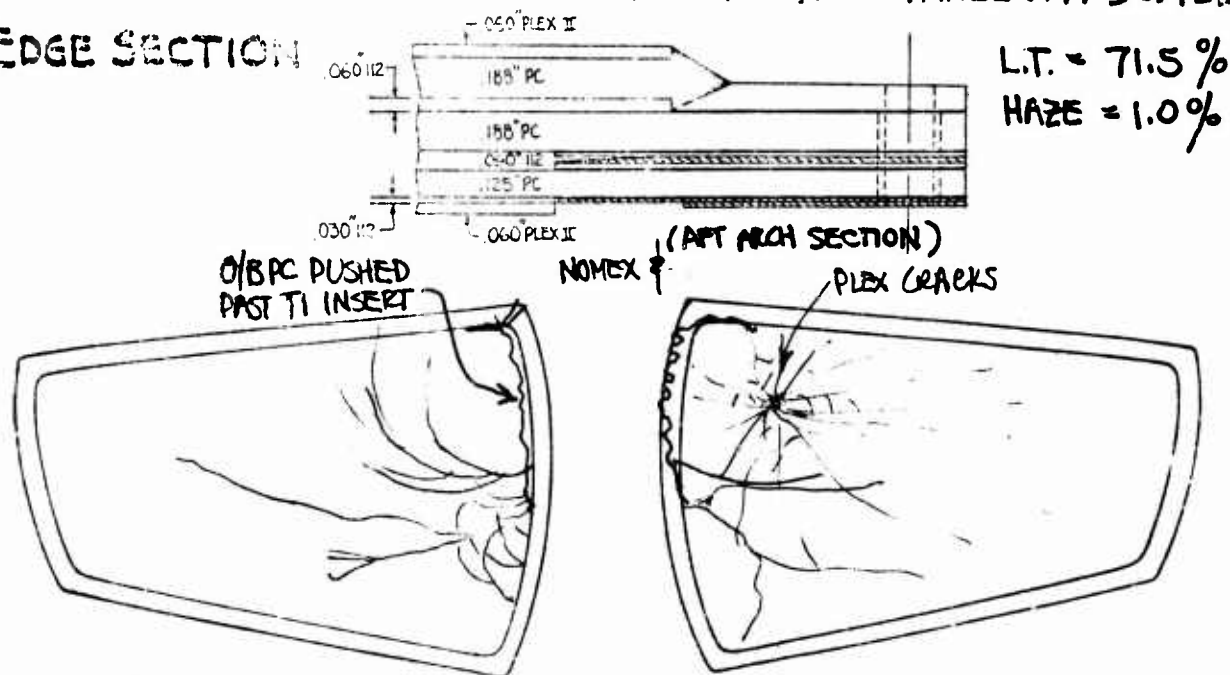
SOME PC EMBRITTLEMENT FROM THE 230°F OIL/50 CURE IS INDICATED BY FRACTURING OF THE 1/8 PC PLY. THESE CRACKS ARE INDEPENDENT OF CRACKS PROPAGATING FROM FRONT PILES.

SAMPLE CODE : 9030-38

CONSTRUCTION : SEE EDGE SECTION

THICKNESS : .801" AREAL DENSITY : 4.99 LB./FT<sup>2</sup> PANEL WT. : 53.4 LB.

EDGE SECTION



(O/B)

(I/B)

RESULTS ON 10 -25-73 @ ~80 °F AND 22 ° INSTALLATION ANGLE

SHOT NO. : WT-59 SPEED : PRELIM. : 833 FPS BIRD WT. : 4.06 LB = 1840 gm  
FINAL : 772 FPS  
= 458 KT K.E. : 37,507 FT LB

REMARKS : BIRD PENETRATED. NEW MILLED INTERIM ARCH REINFORCEMENT (NEW ARCH) (NO HI-LOKS)  
CORNER FLAP BLOWN IN AS WITH PREVIOUS TESTS ON W/S WITH TWO PC STRUCTURAL PLYS (e.g. WT-47, -49). DAMAGE ACTUALLY GREATER THAN OTHERS IN SPITE OF PLY REVERSAL, TITANIUM SUPPORTS AND LOWER BIRD SPEED. ARCH ALSO SUSTAINED MOST DAMAGE OF ALL 1973 MODULE SHOTS. THERE IS A 14" CRACK IN THE MOUNTING FLANGE AND THE FLANGE AND REINFORCEMENT ARE ROTATED 90° AGAINST VERTICAL FLANGE DIRECTLY BEHIND IMPACT AREA.

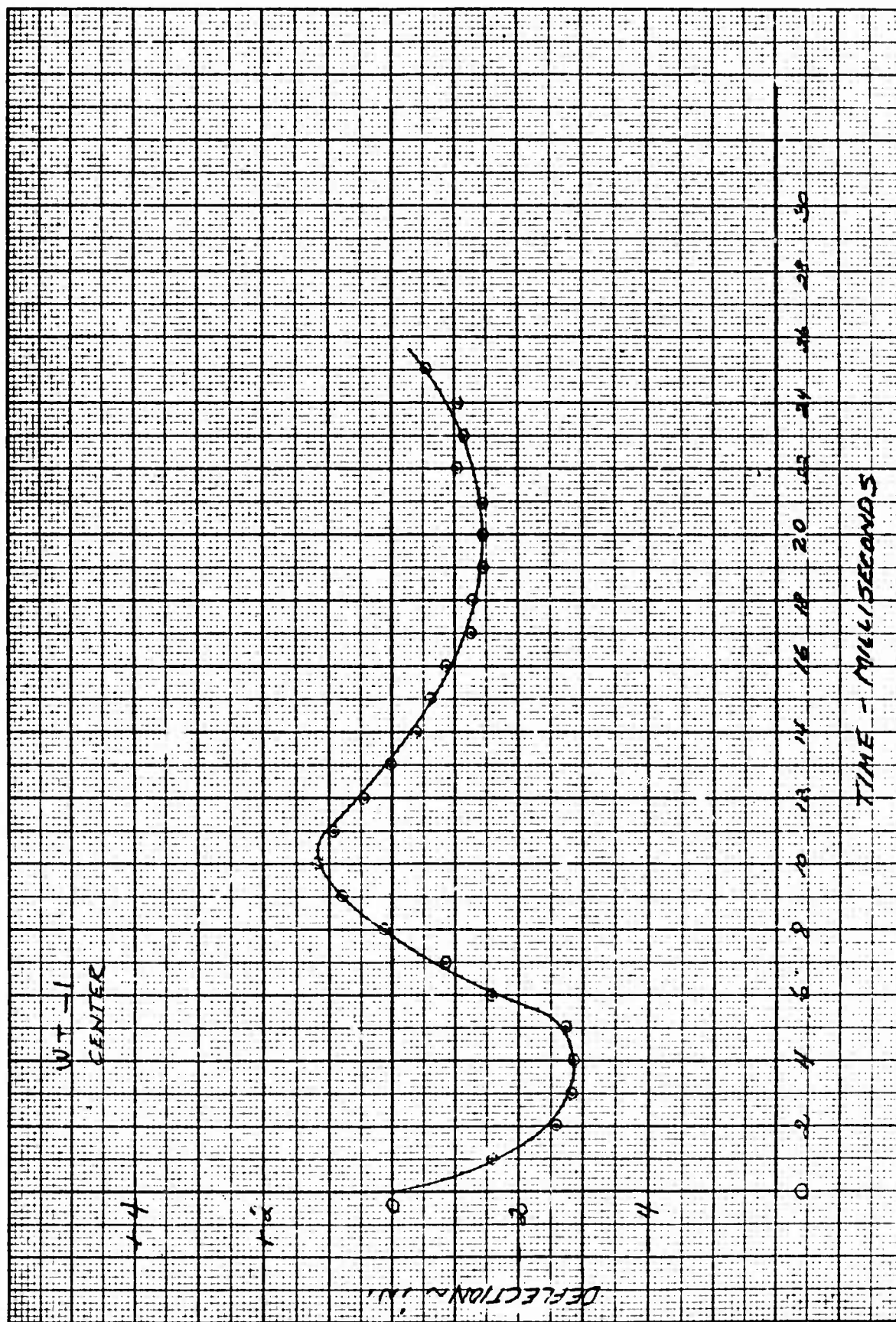
DISTINCT ORIGINS ARE DIFFICULT TO LOCATE. THE EXTENDED EDGE AND MOUNTING SUPPORT WERE OVERPOWERED BY THE IMPACT.

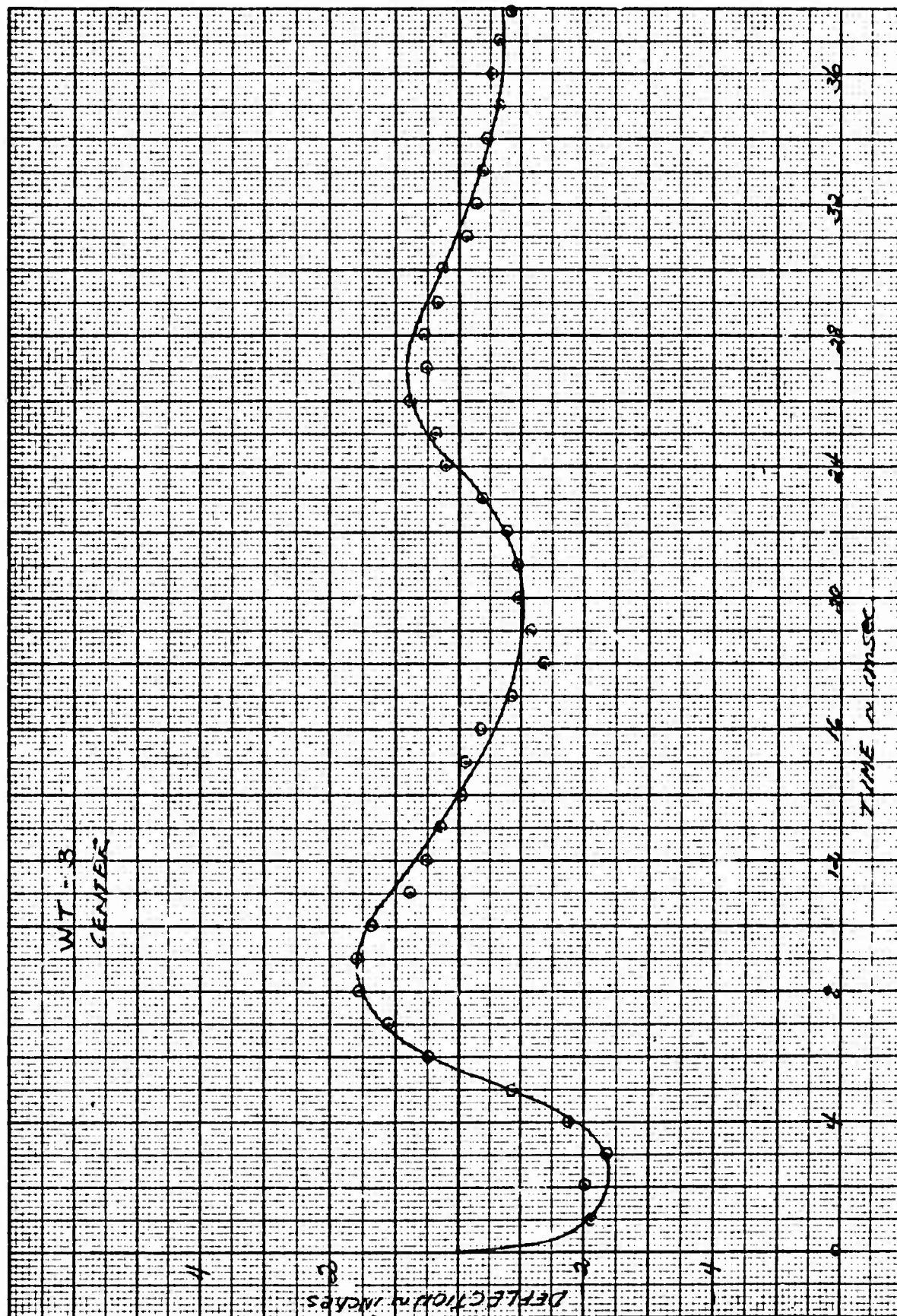


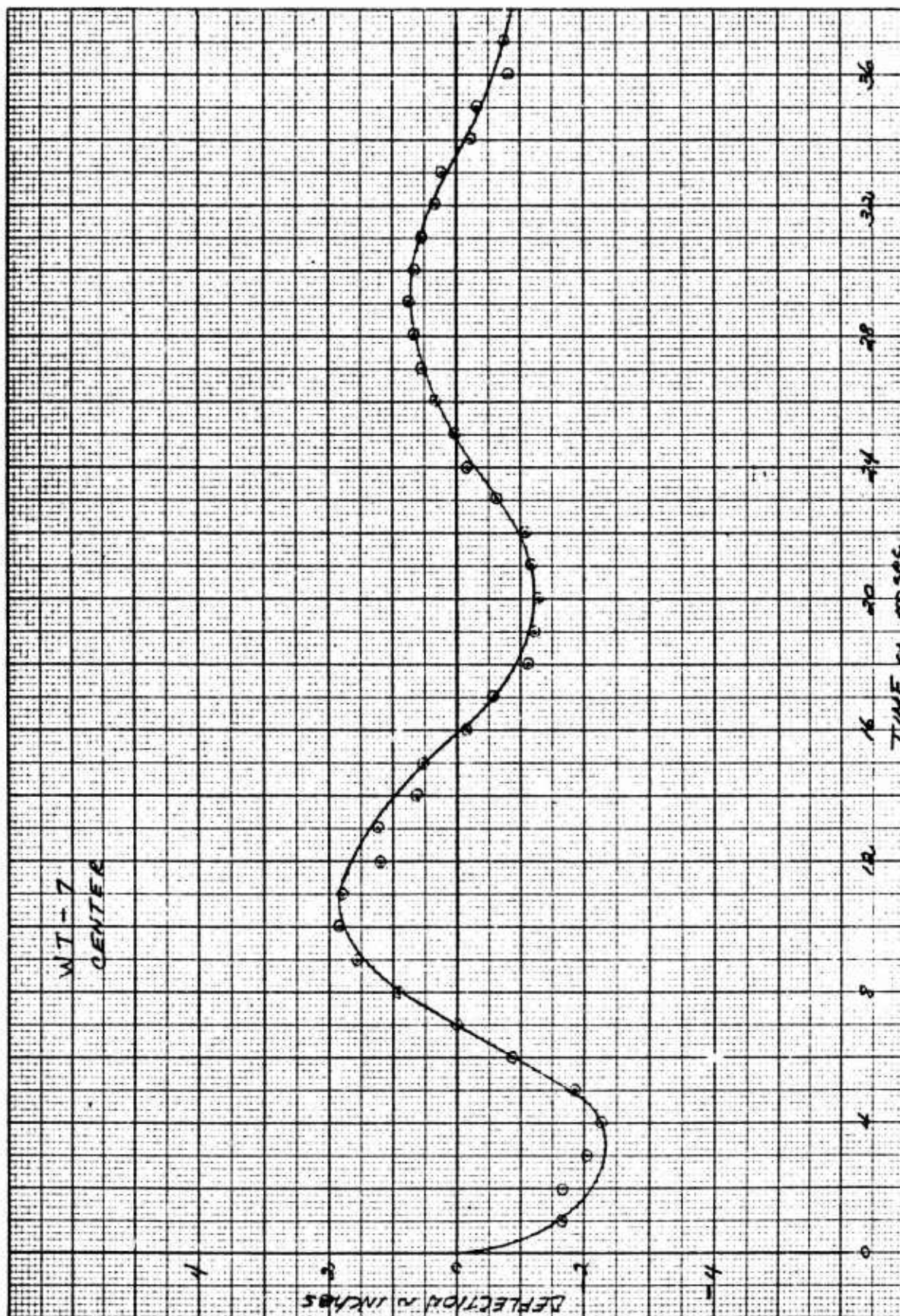
## APPENDIX 2

The following appendix contains deflection data for those shots WT-1 through WT-38 in Task I where readings were possible. The information was generated by Arnold Engineering Development Center and is included at the request of Captain D. C. Chapin.



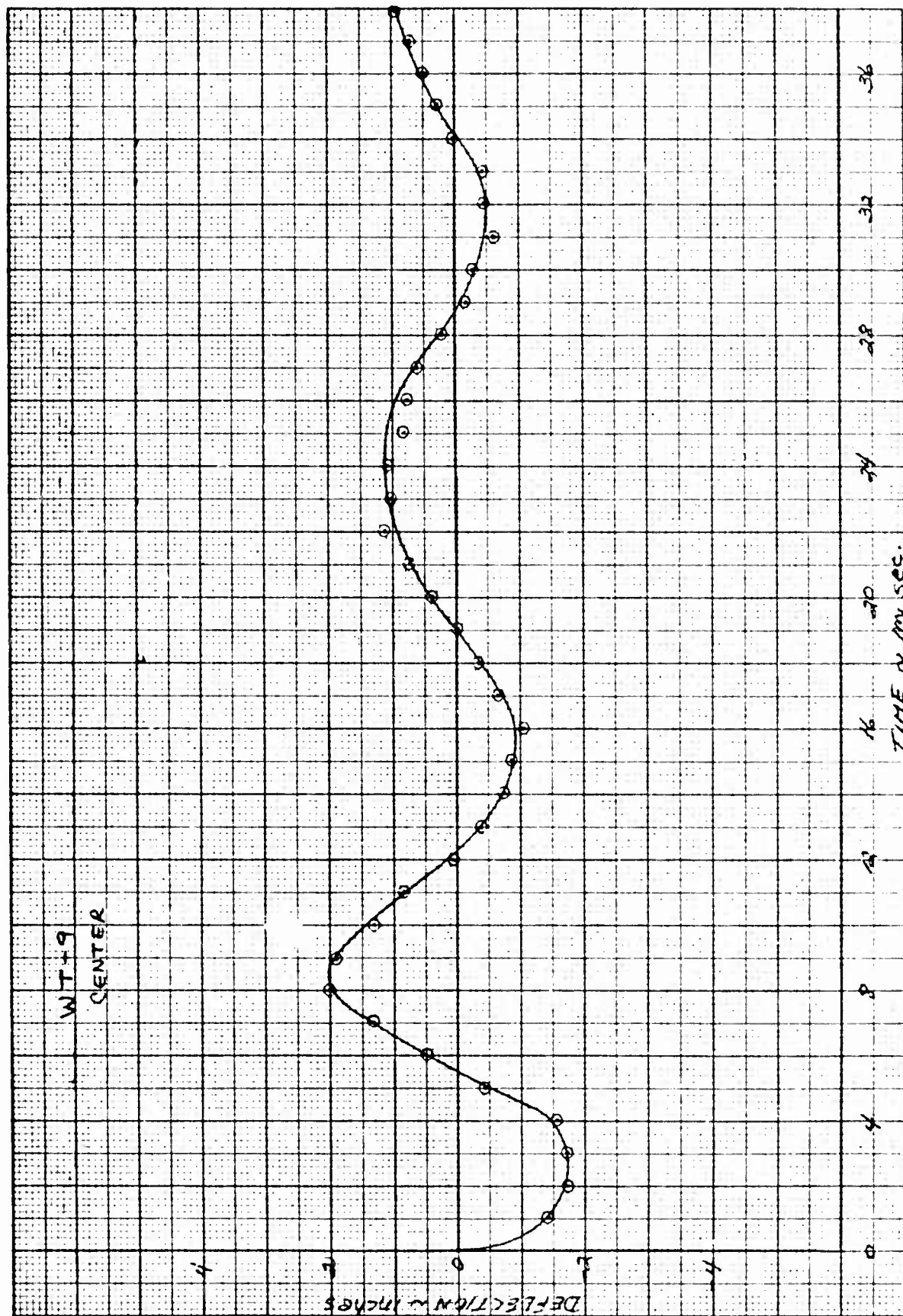


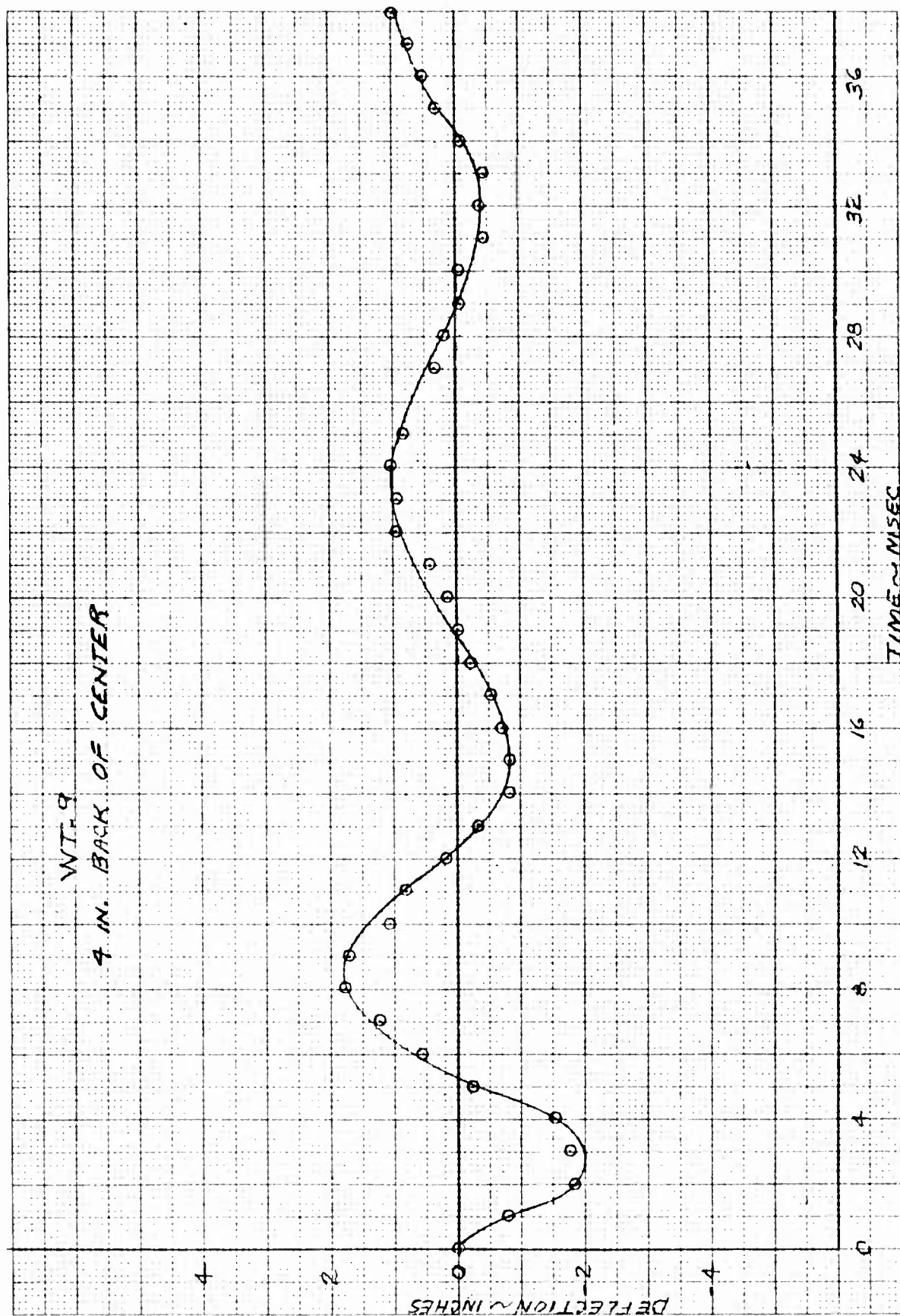




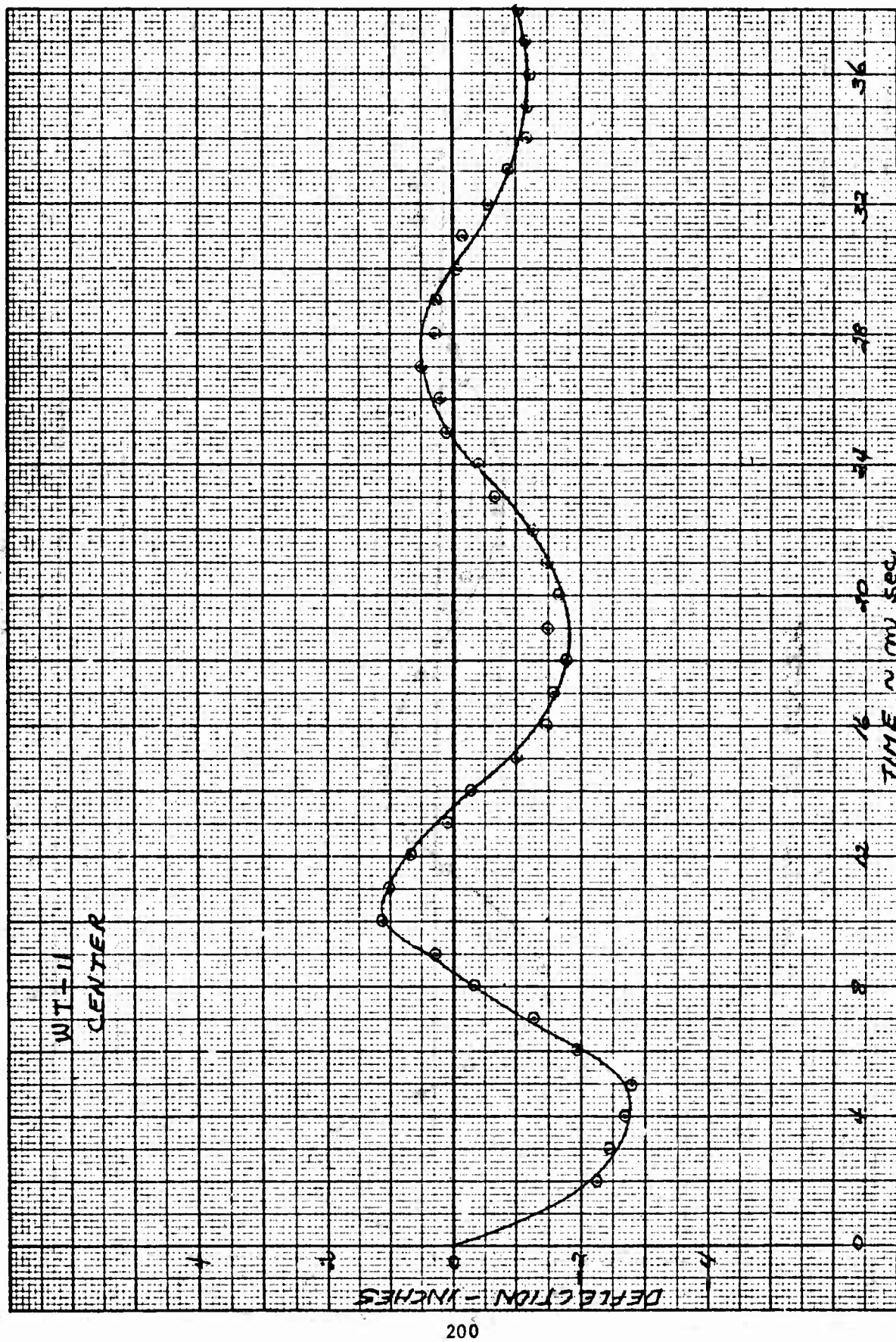


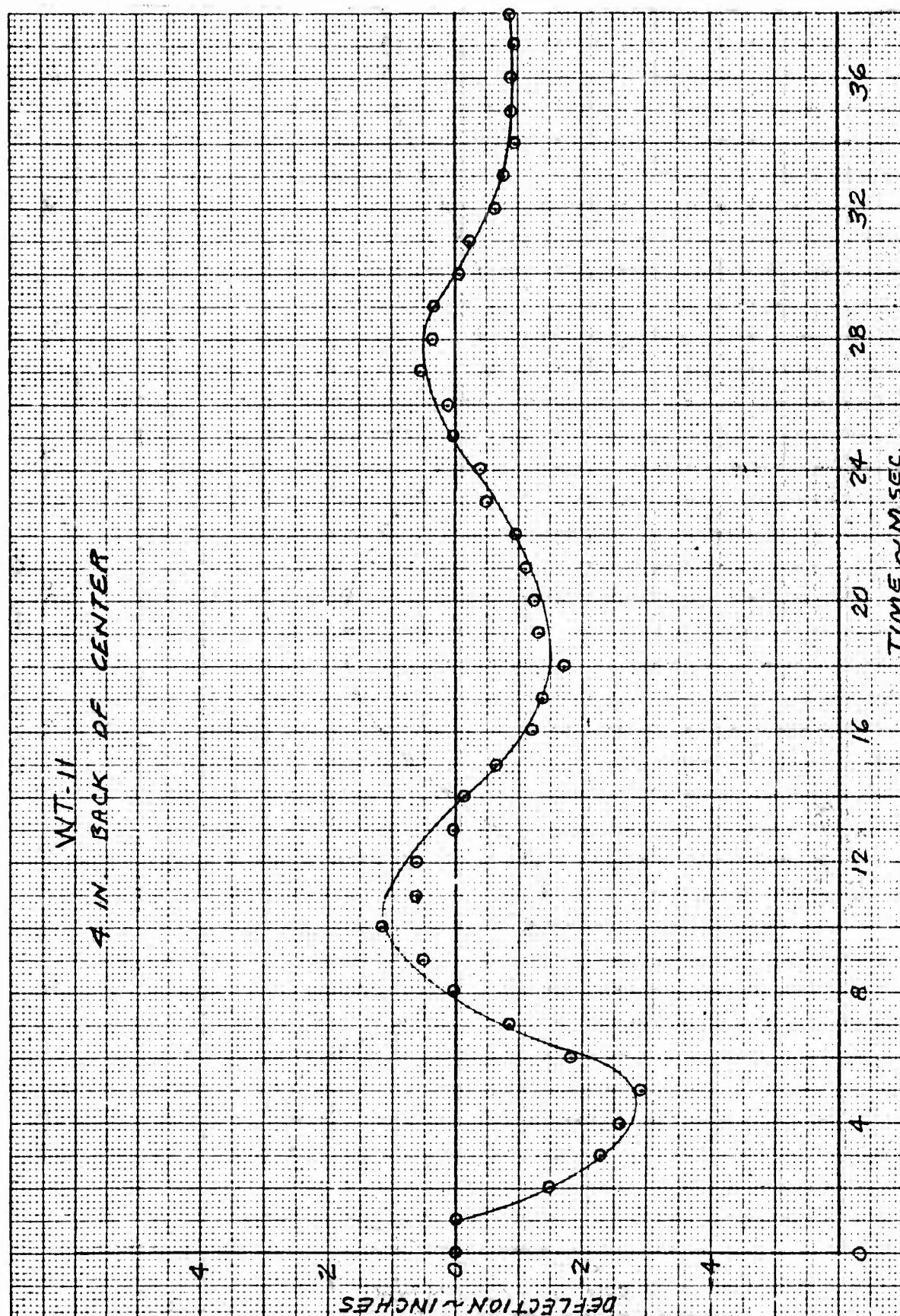


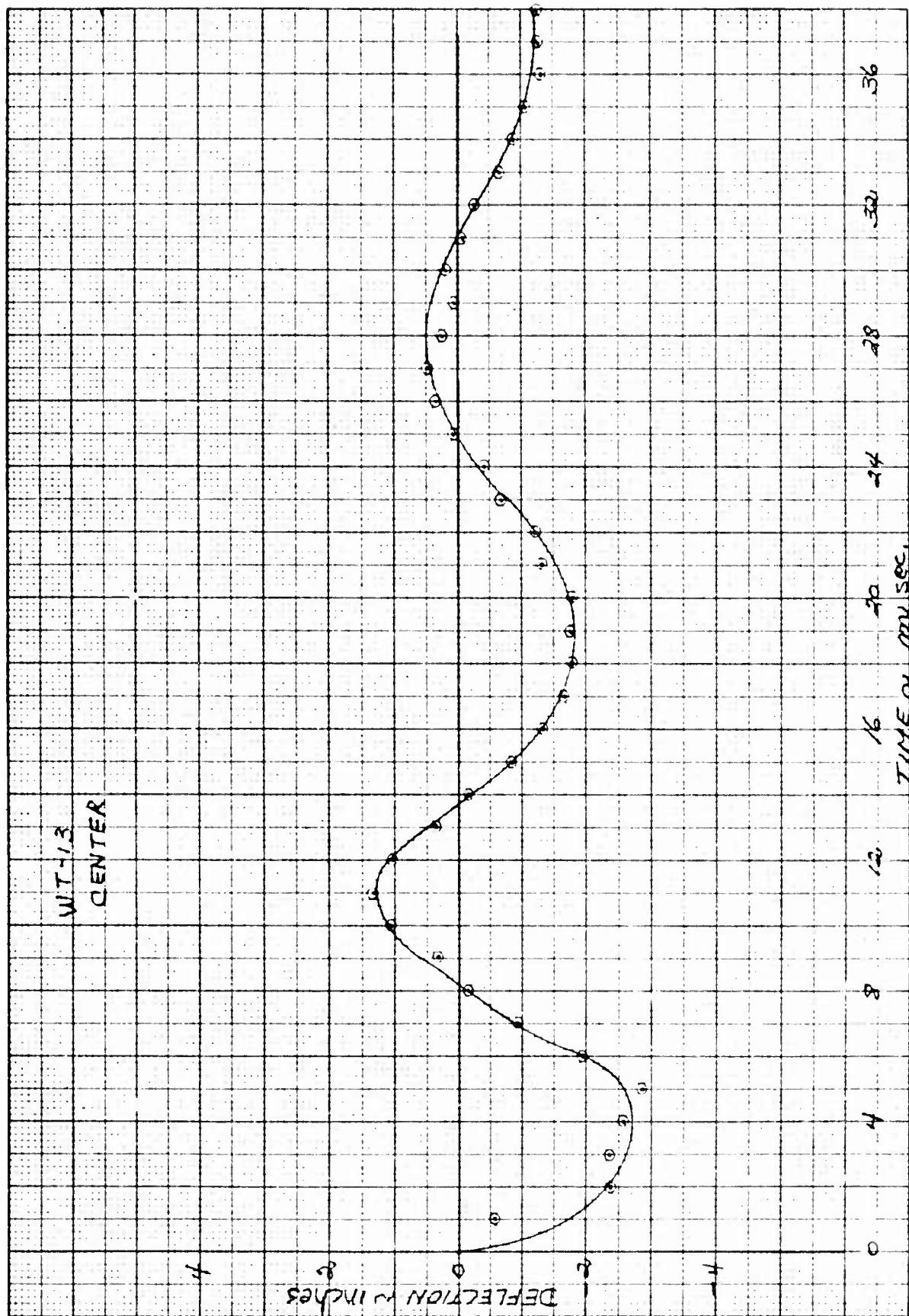




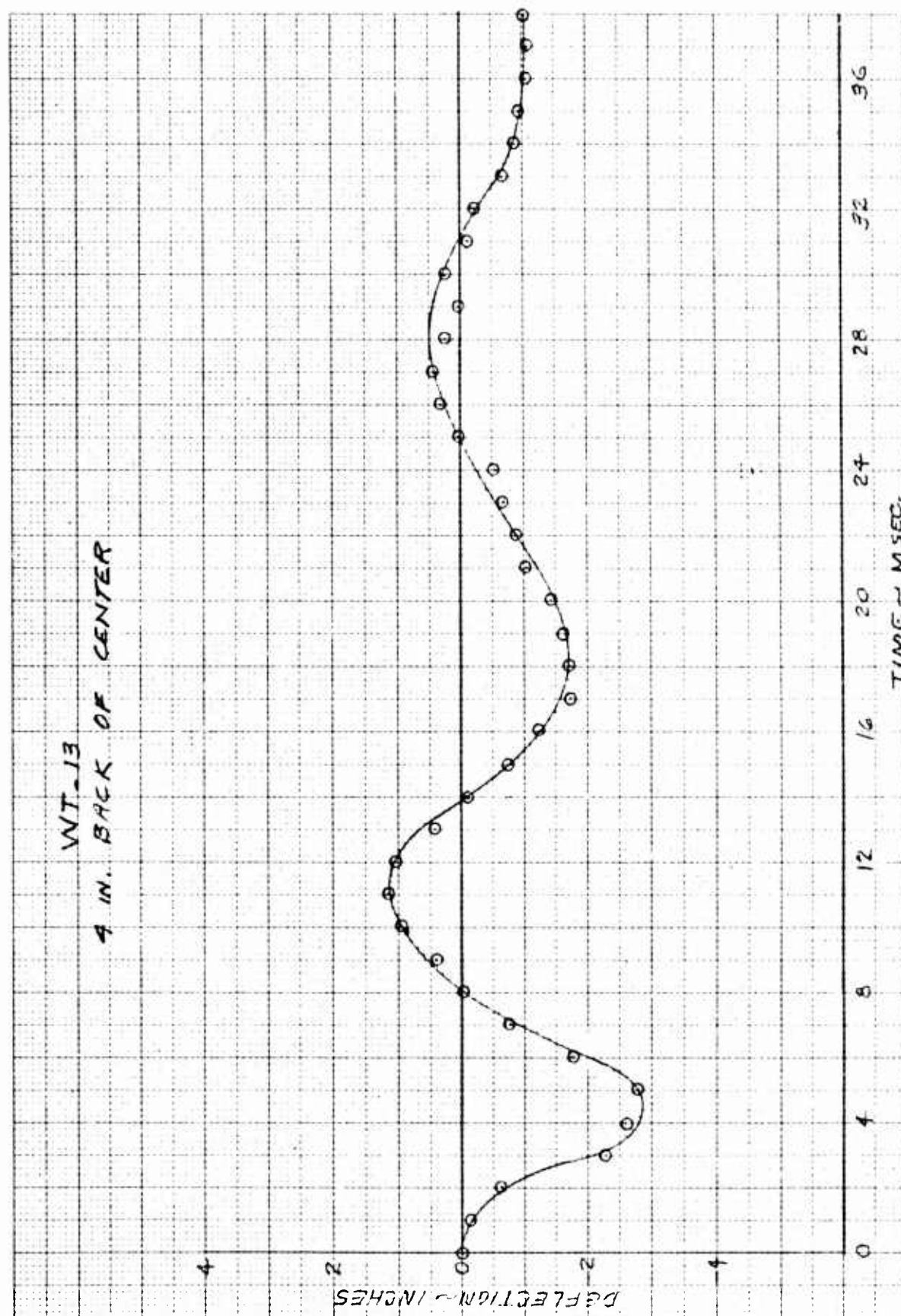


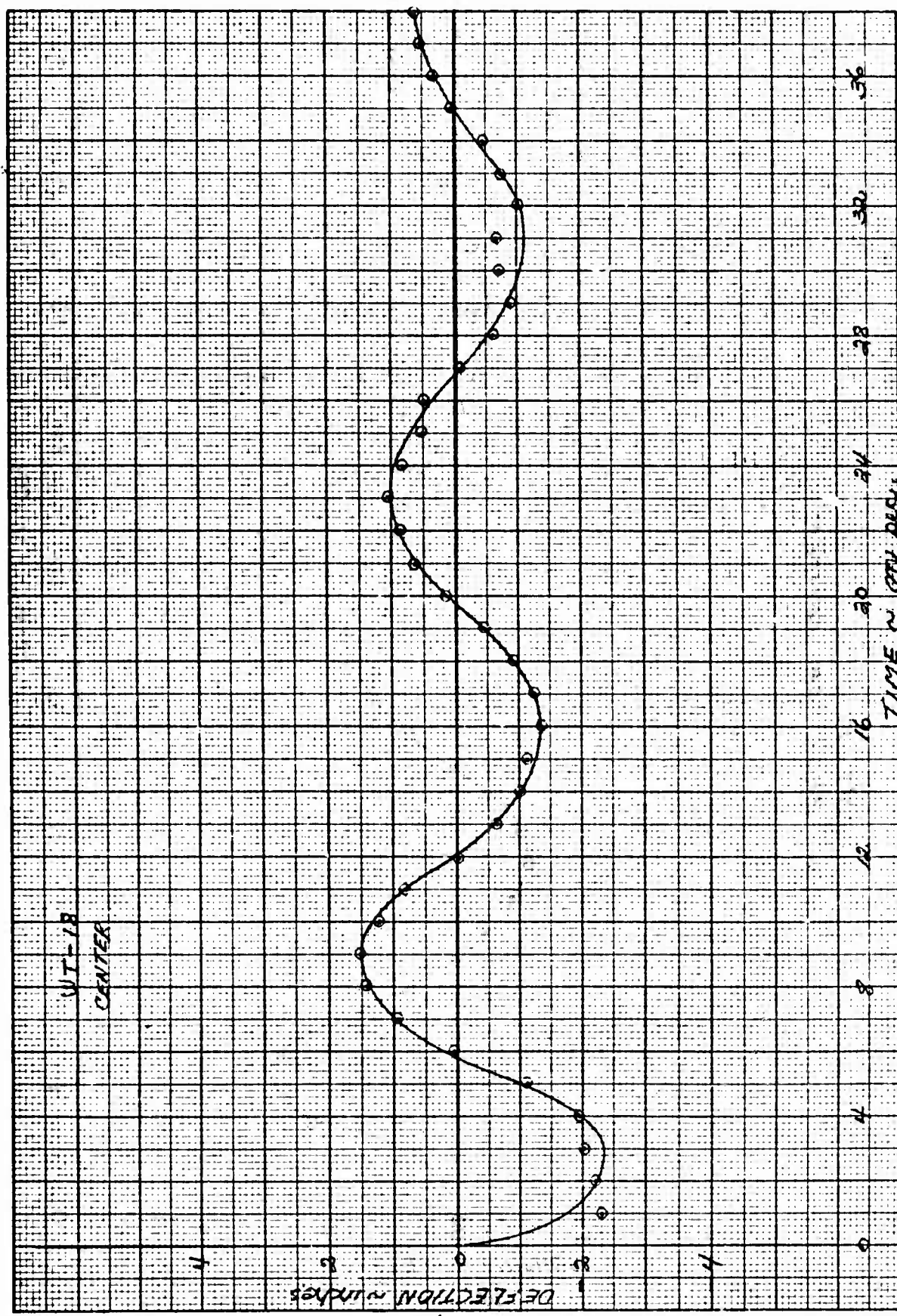


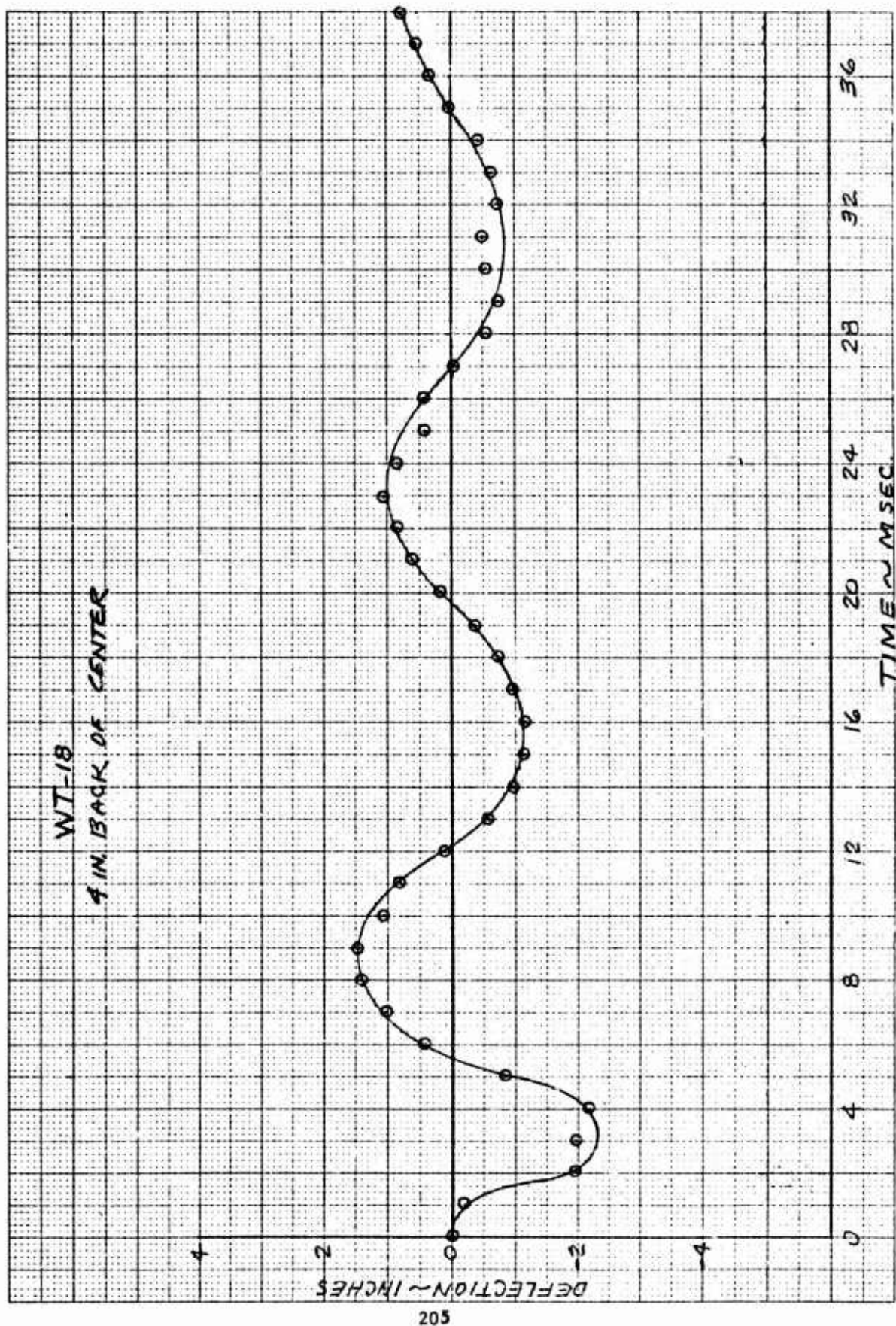




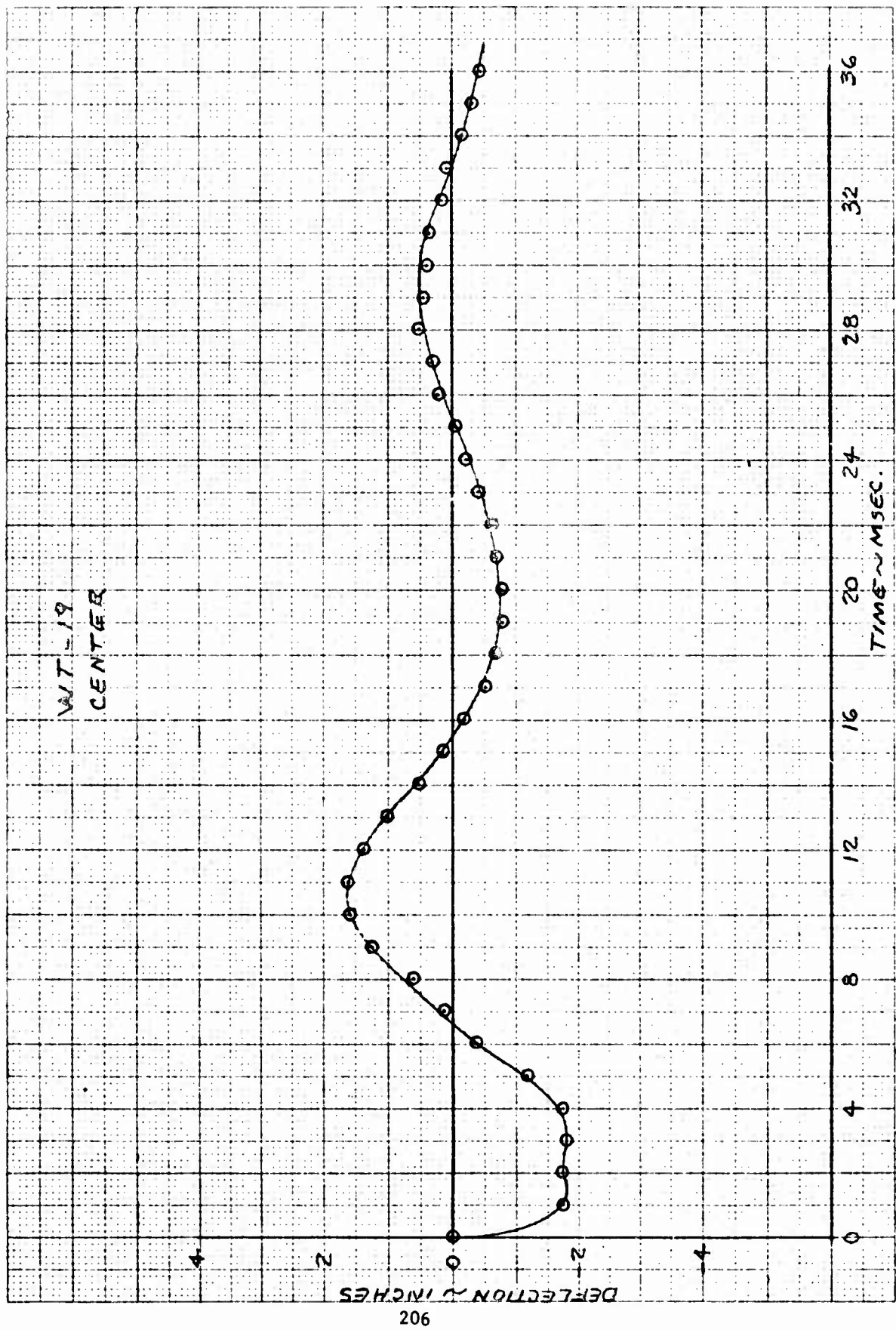


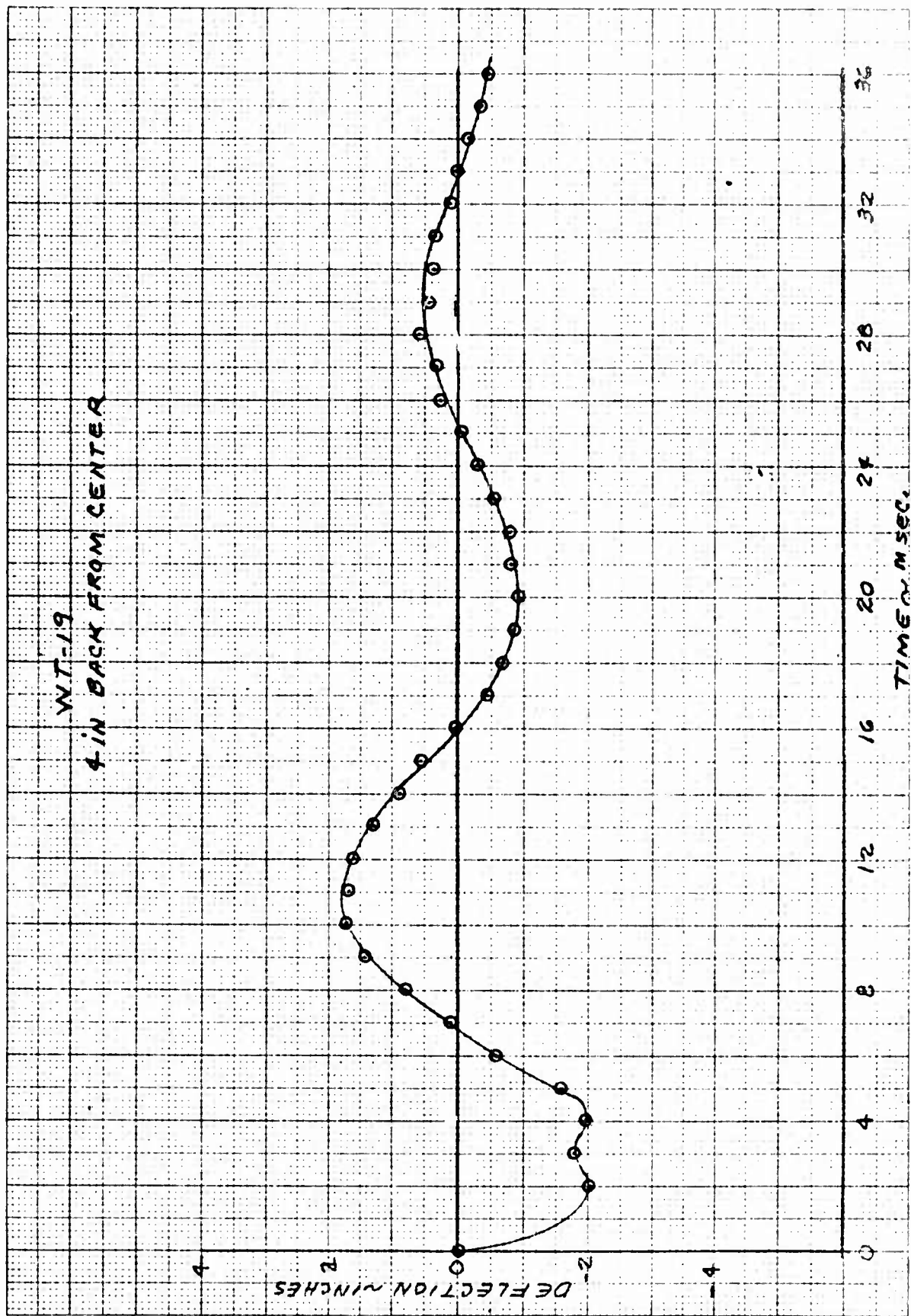


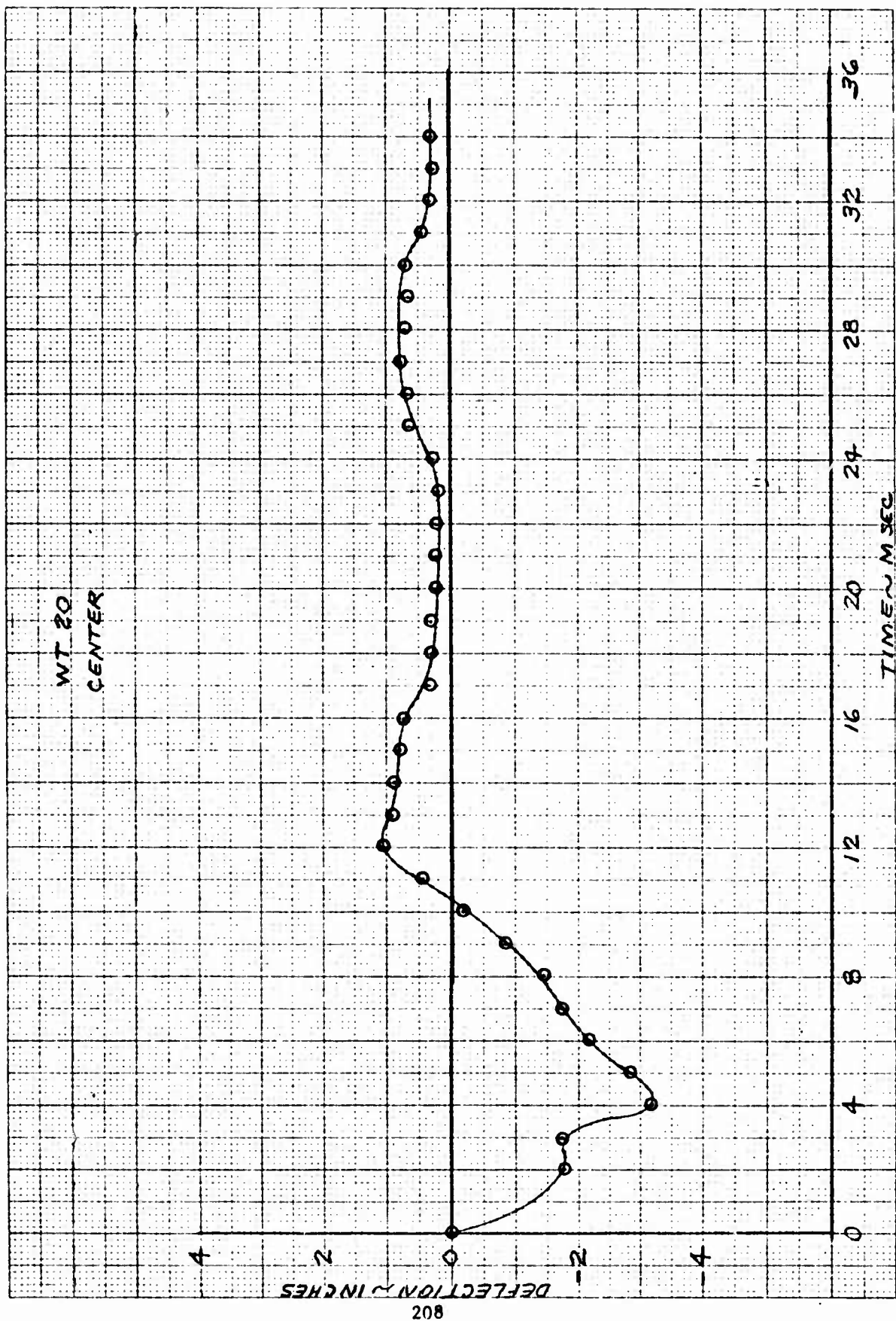


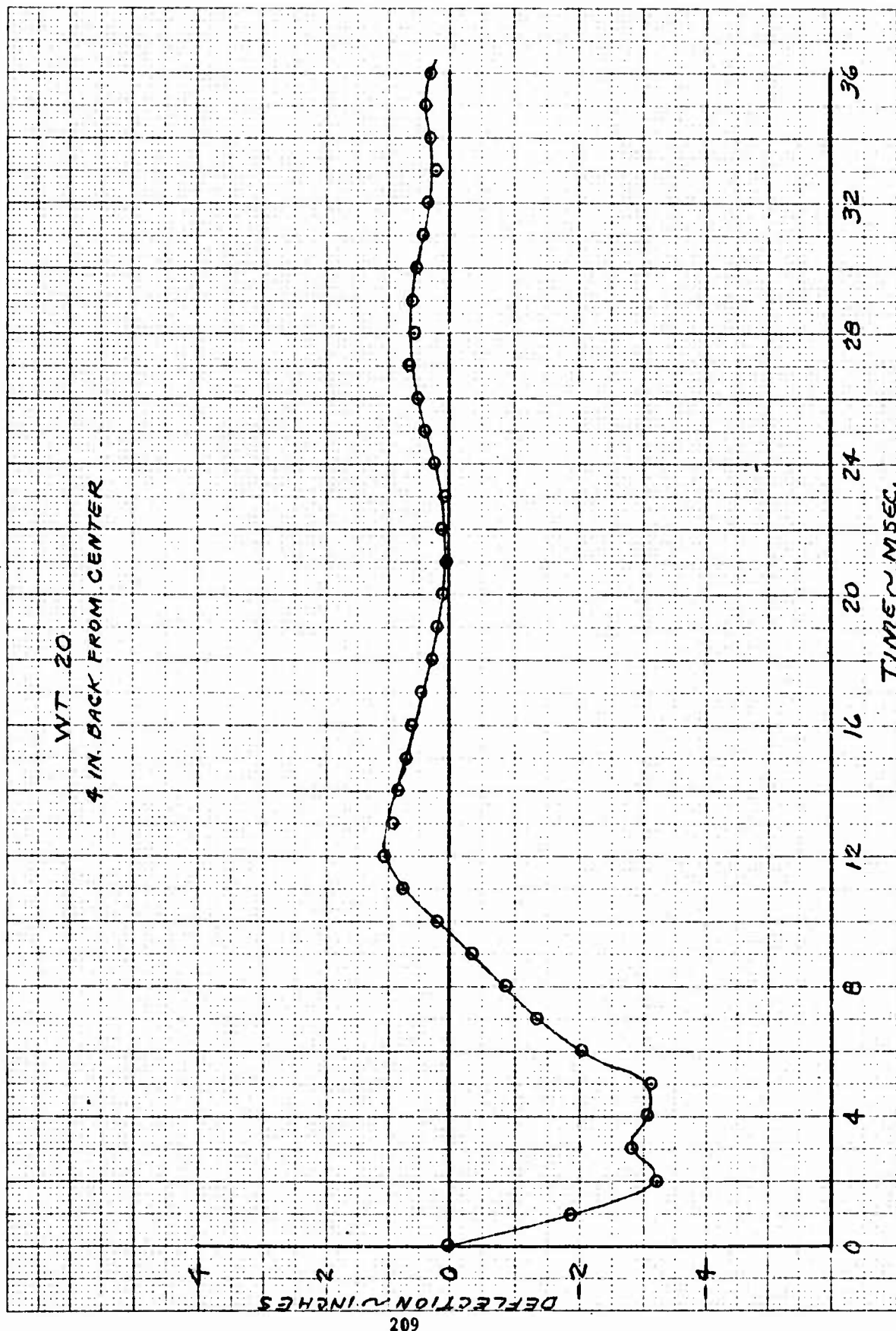




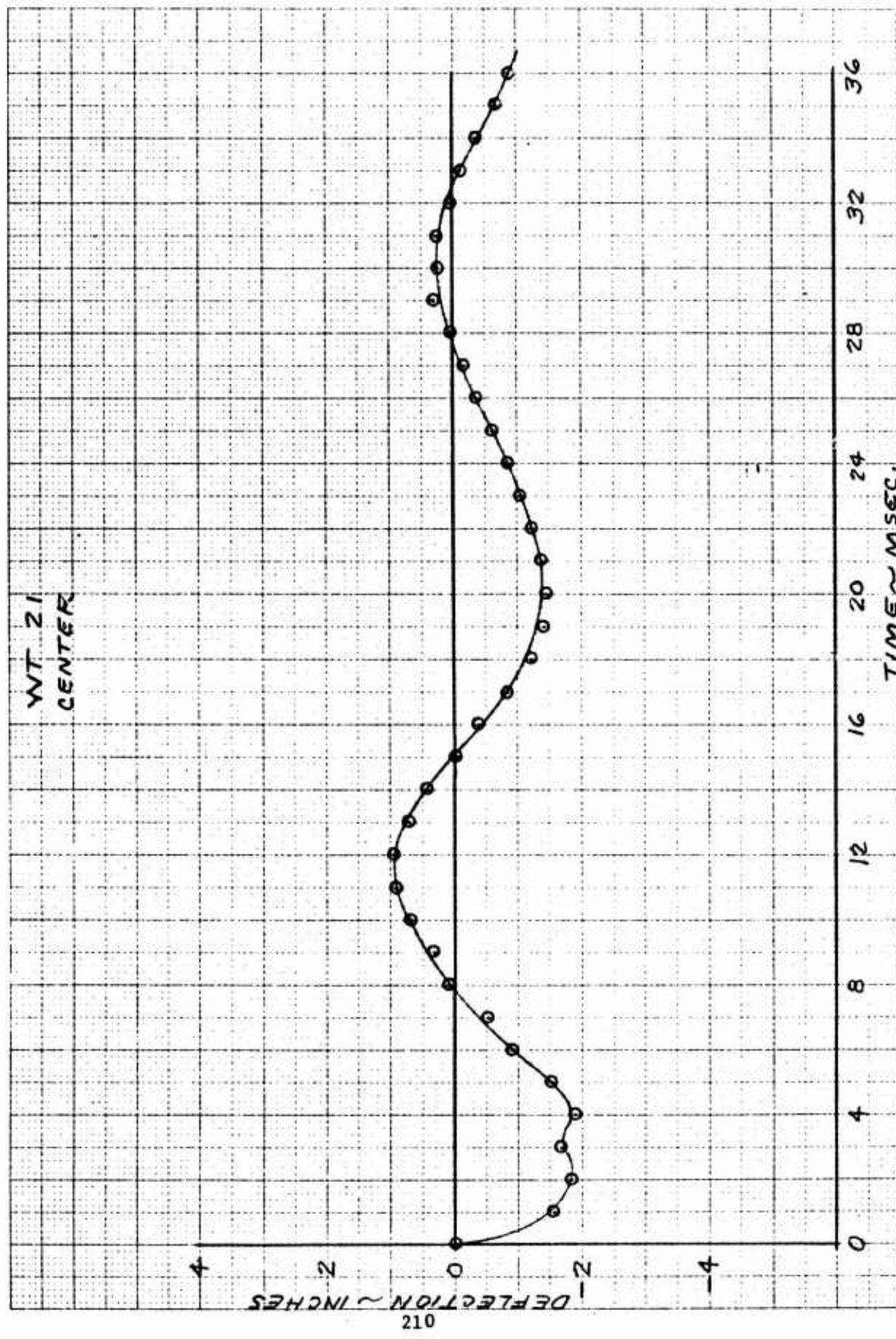


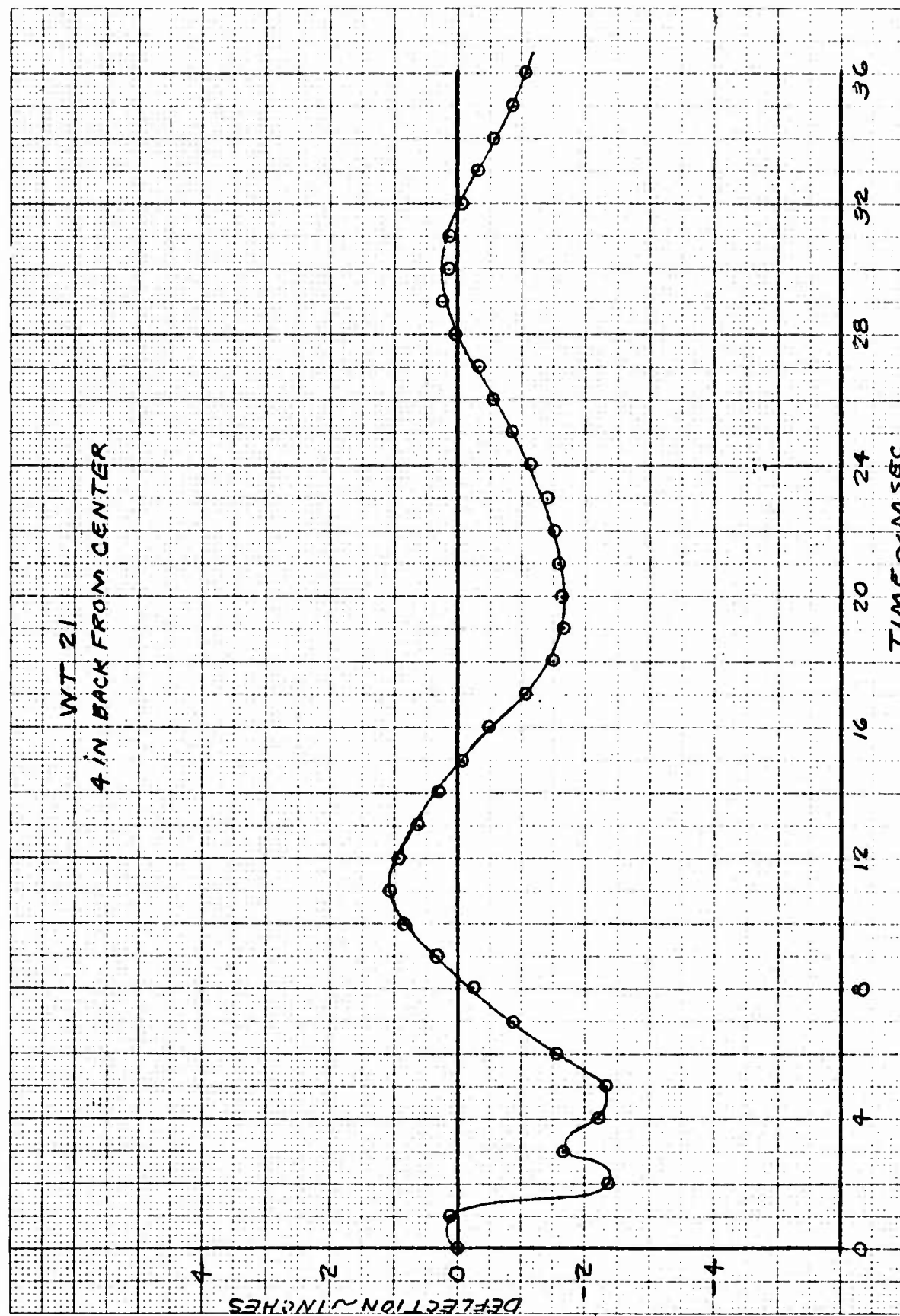




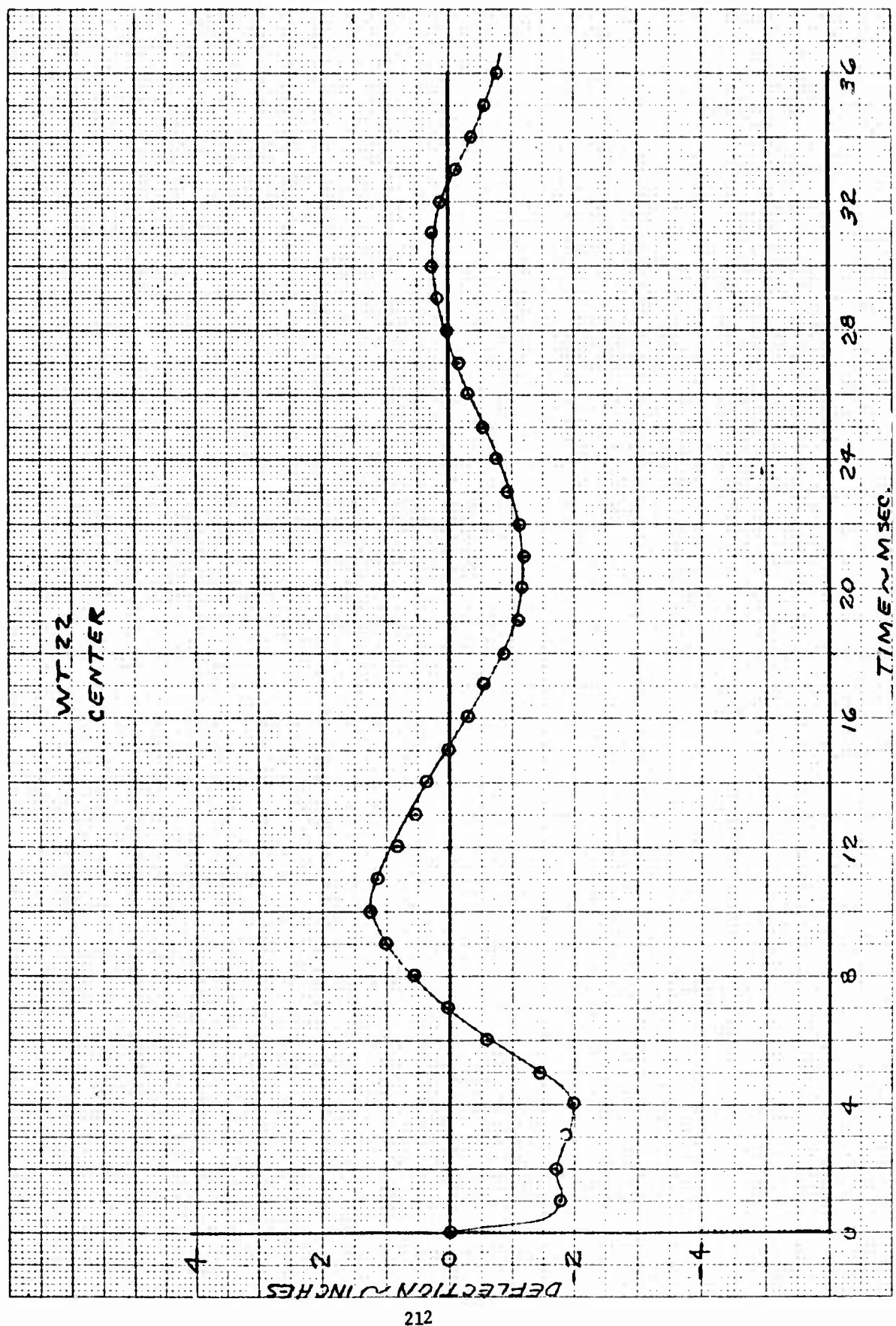


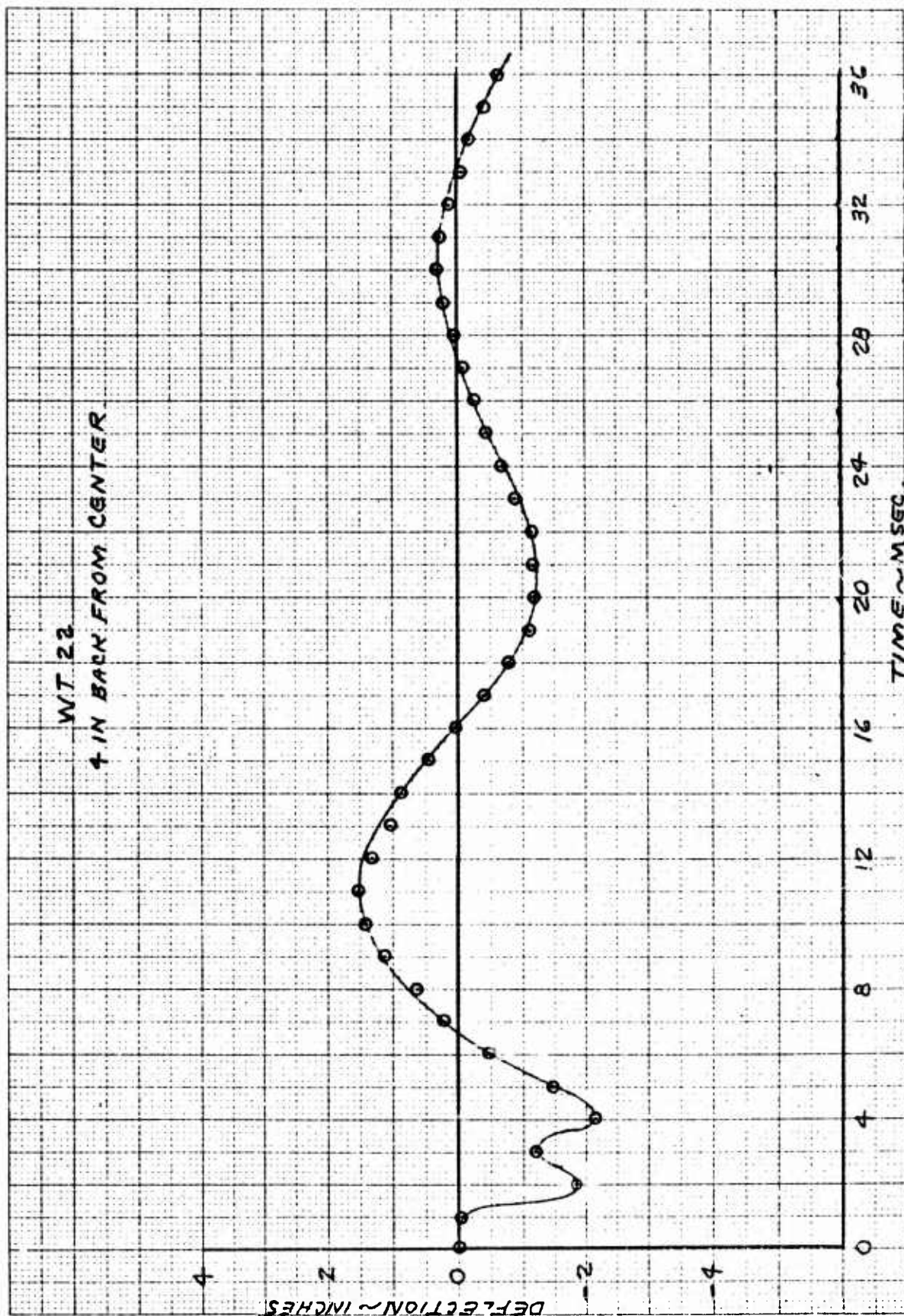


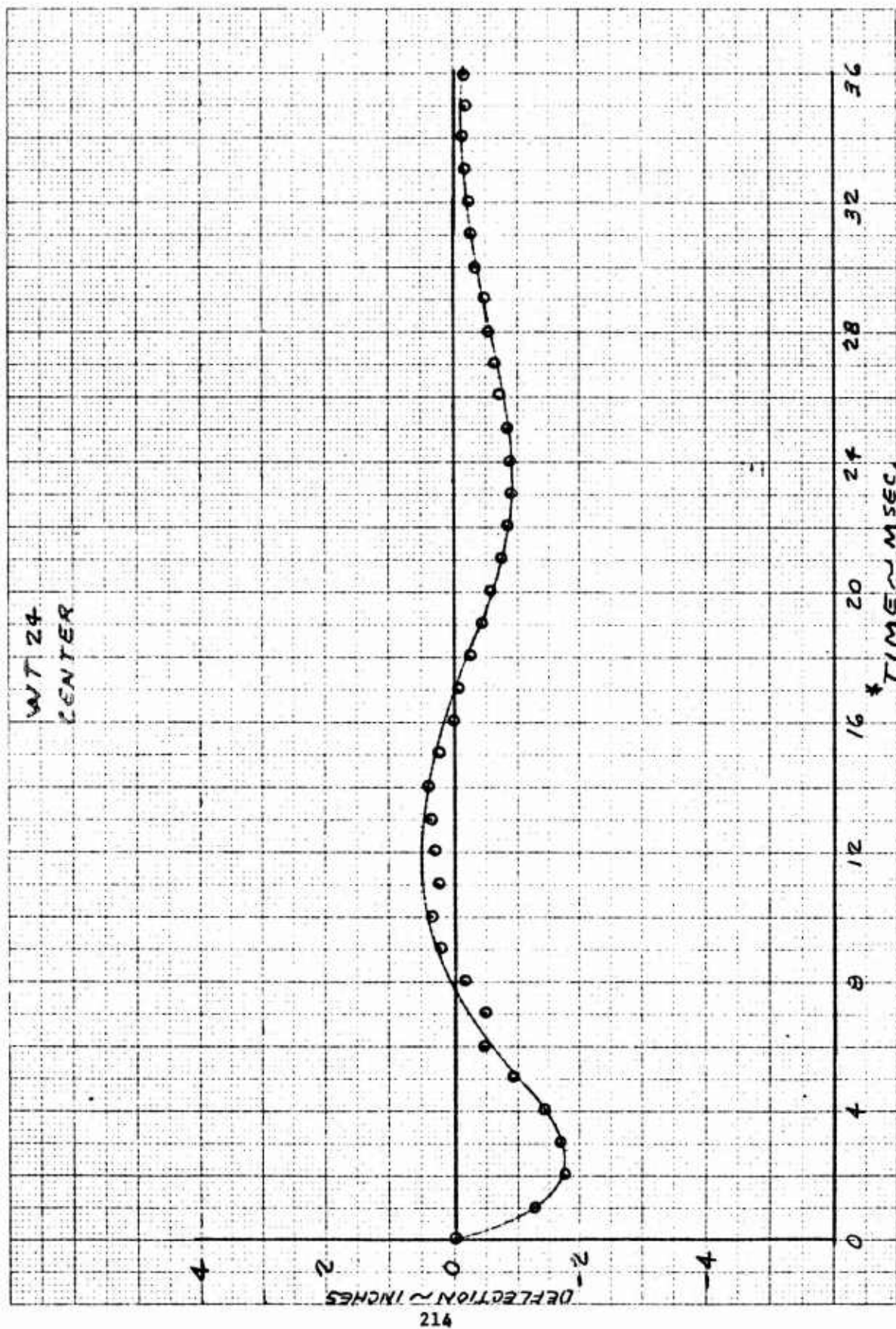






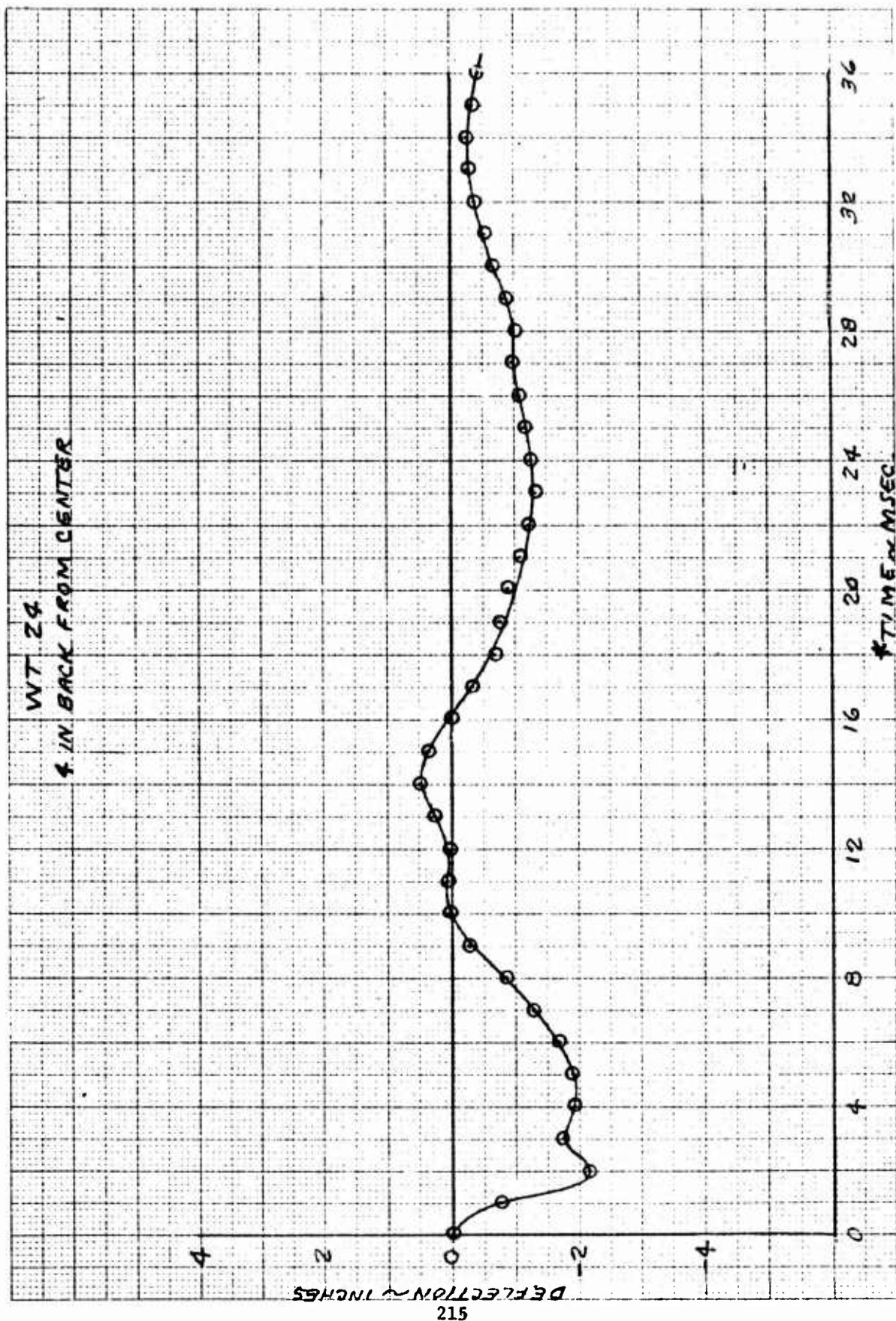




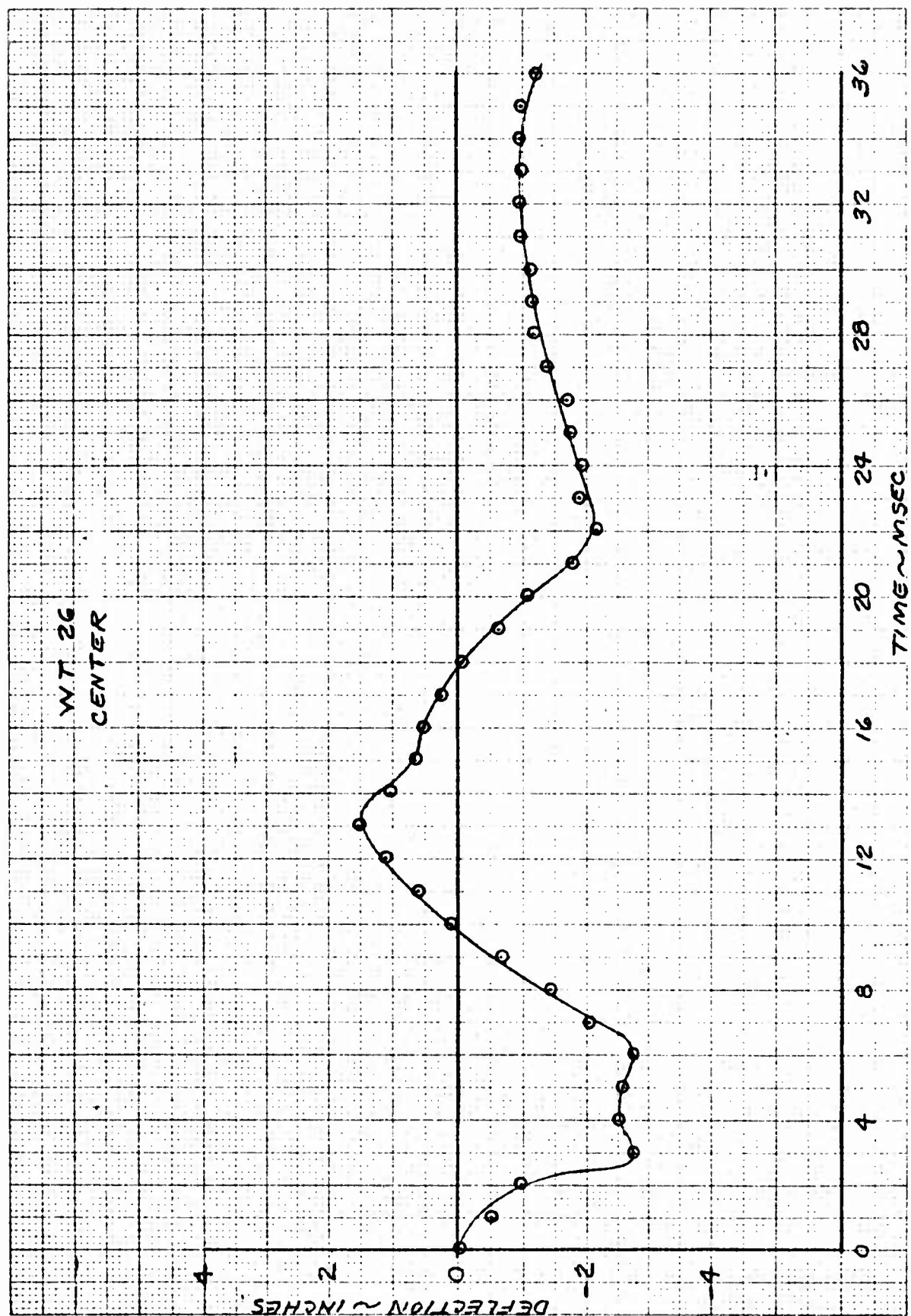


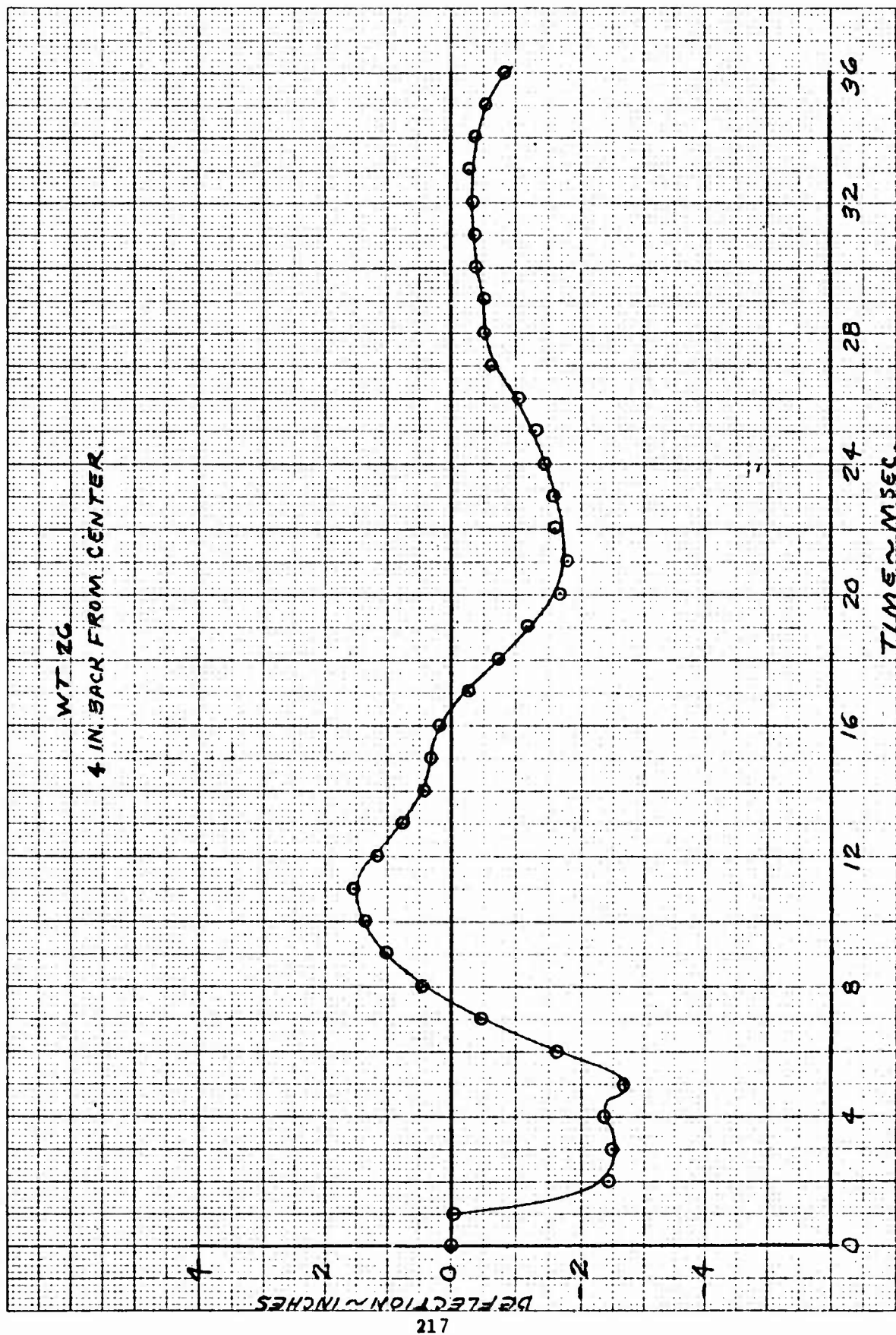
\* no spring lights (and only 5A is on for one max.)



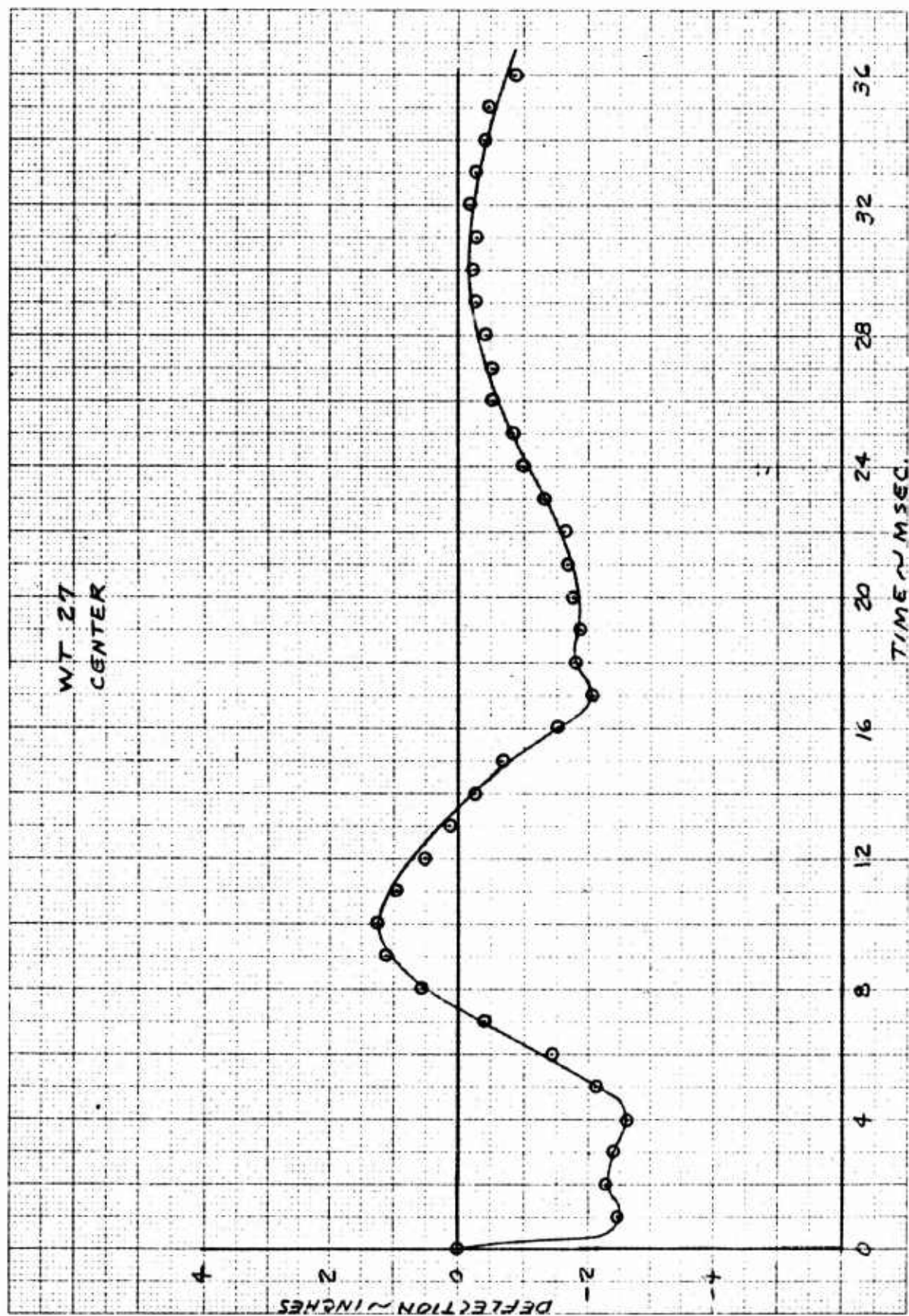


\* No timing lights (read every 5th frame for 1 msec)

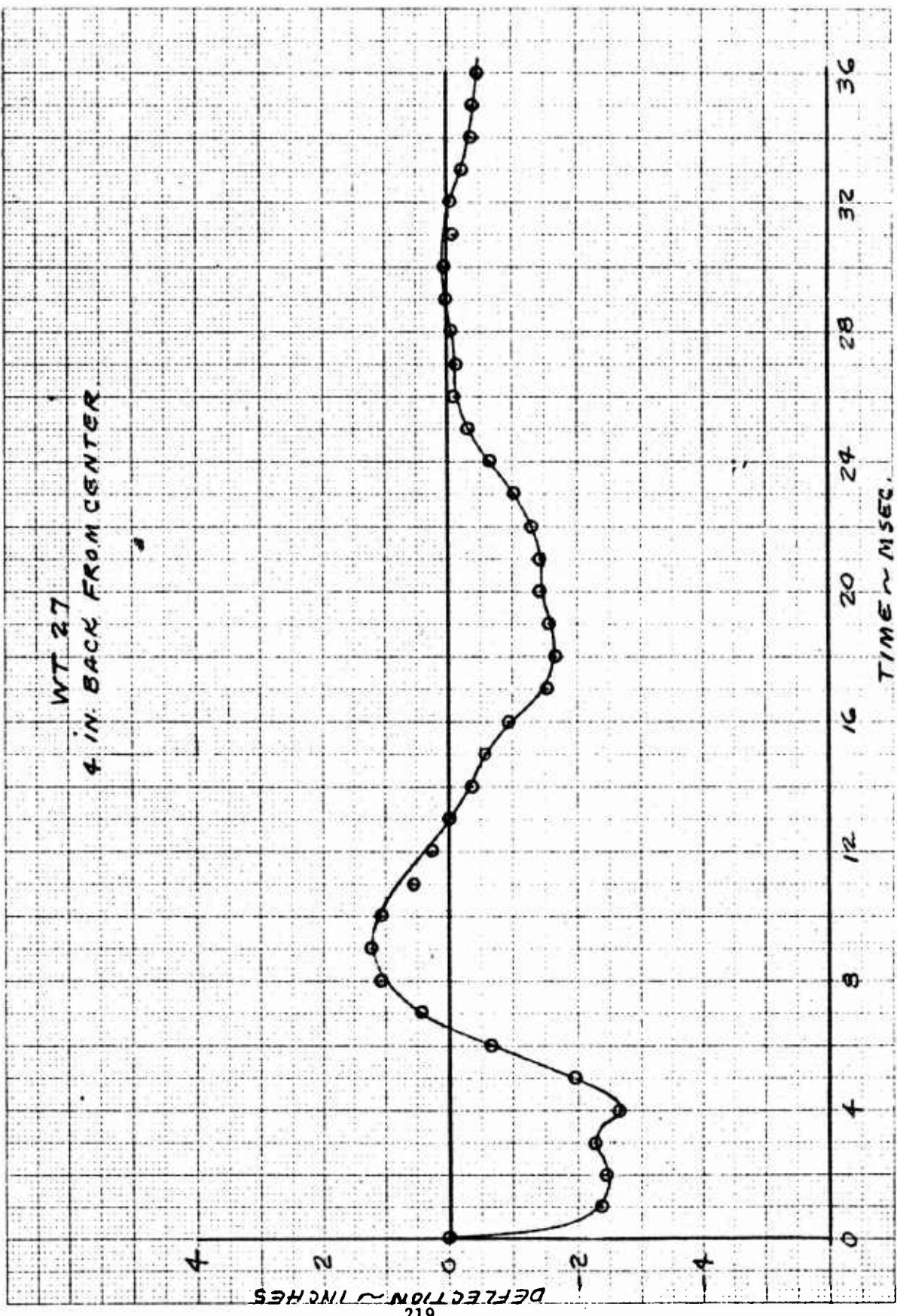


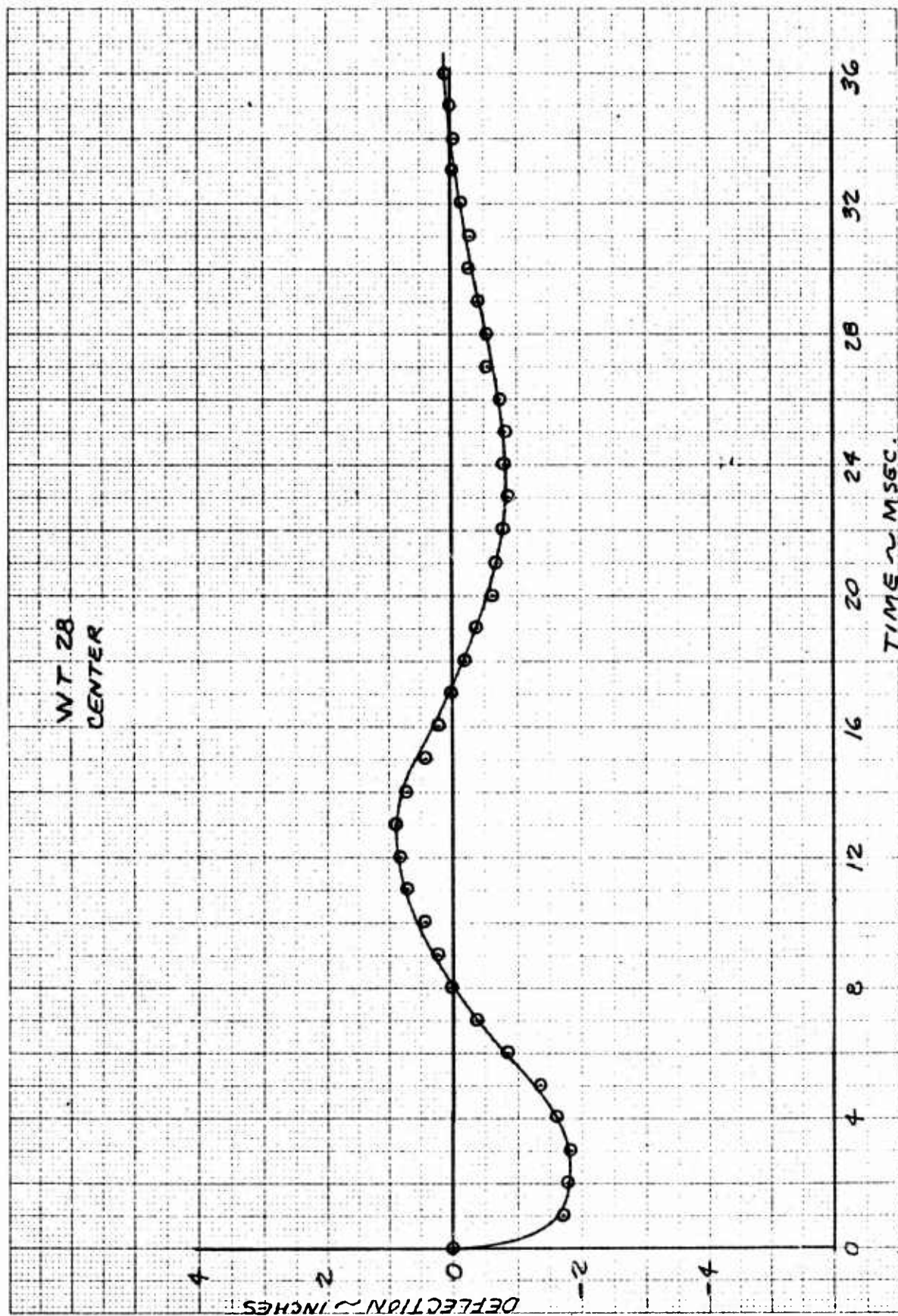




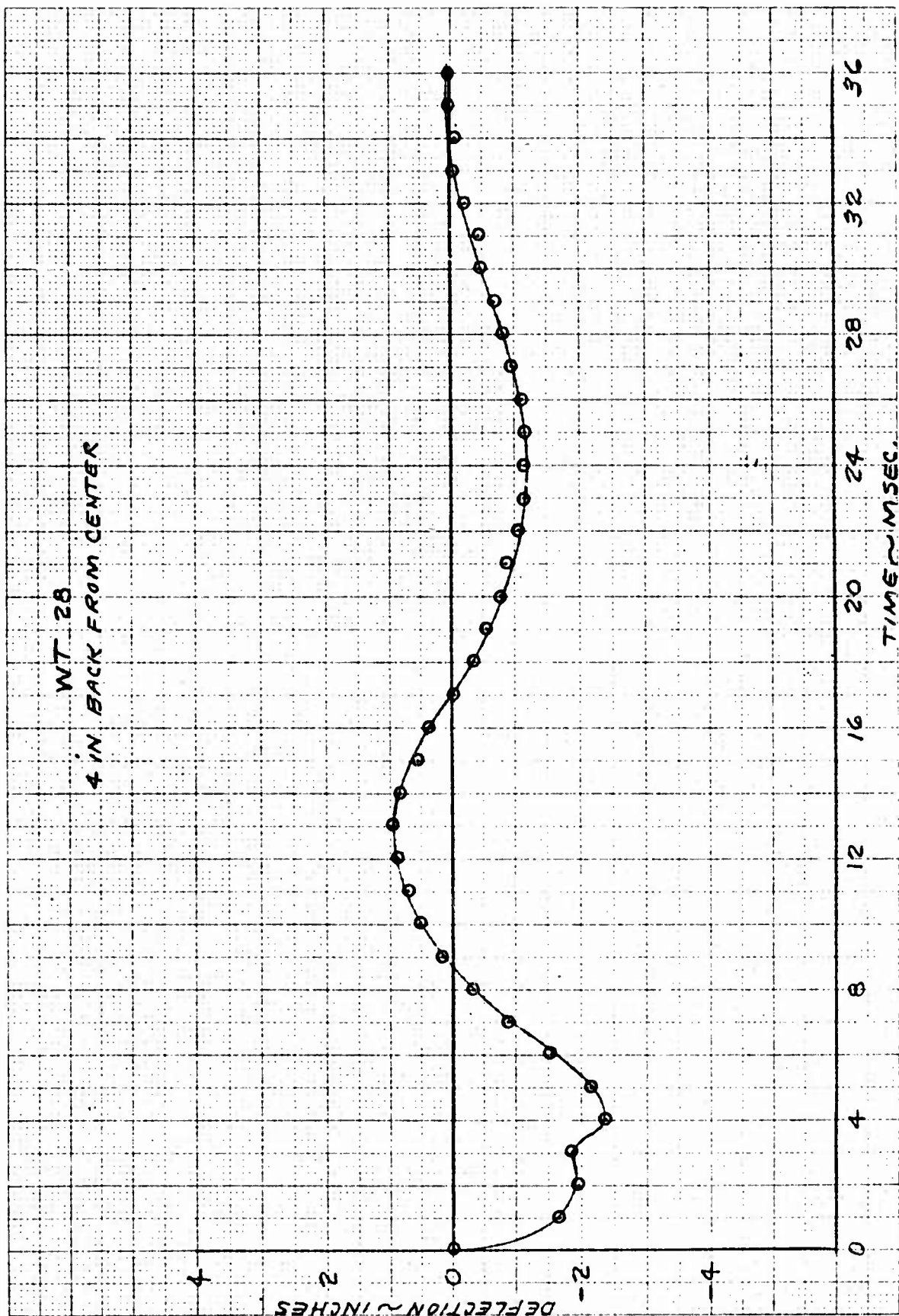


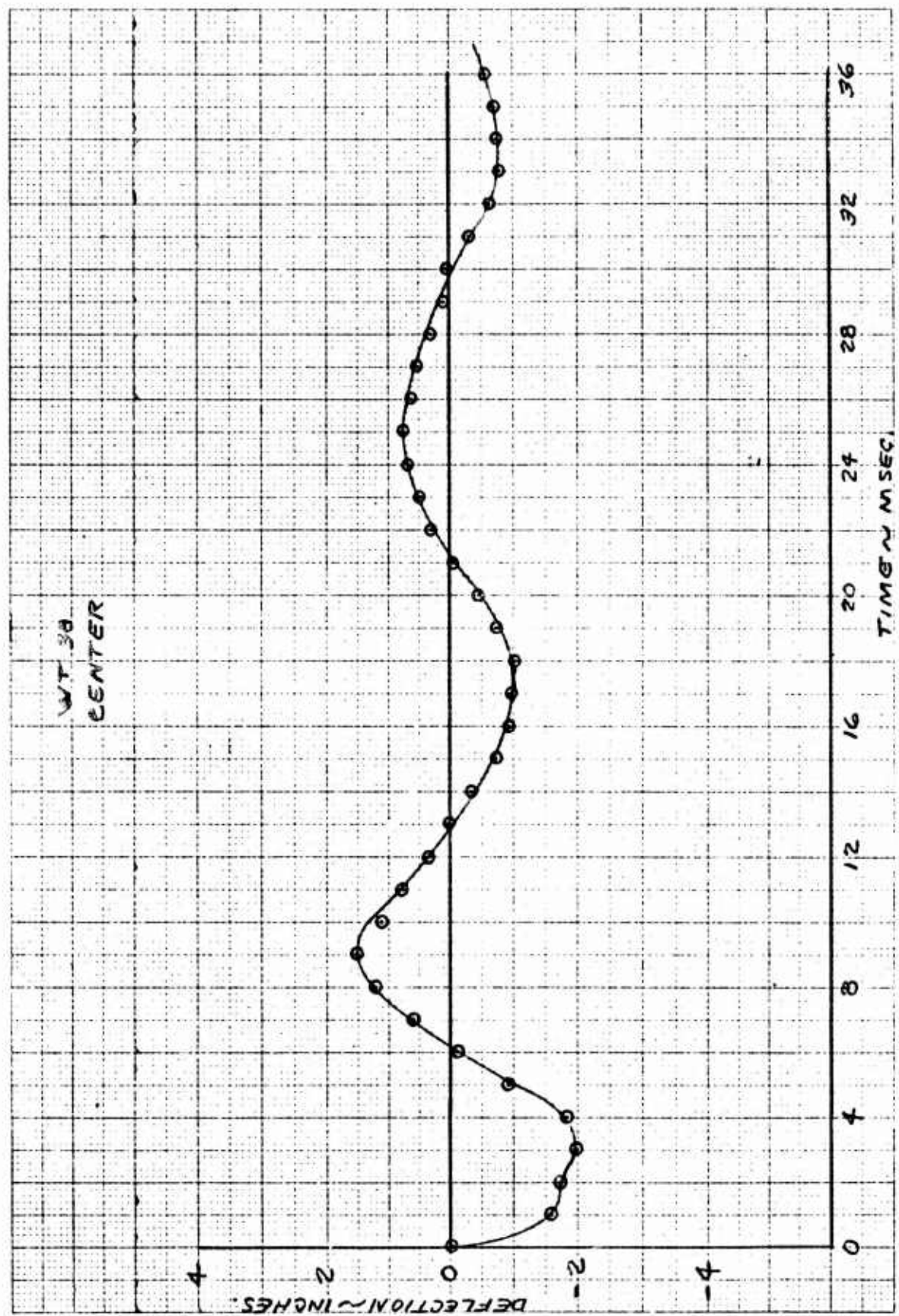
WT 27  
4 IN. BACK FROM CENTER



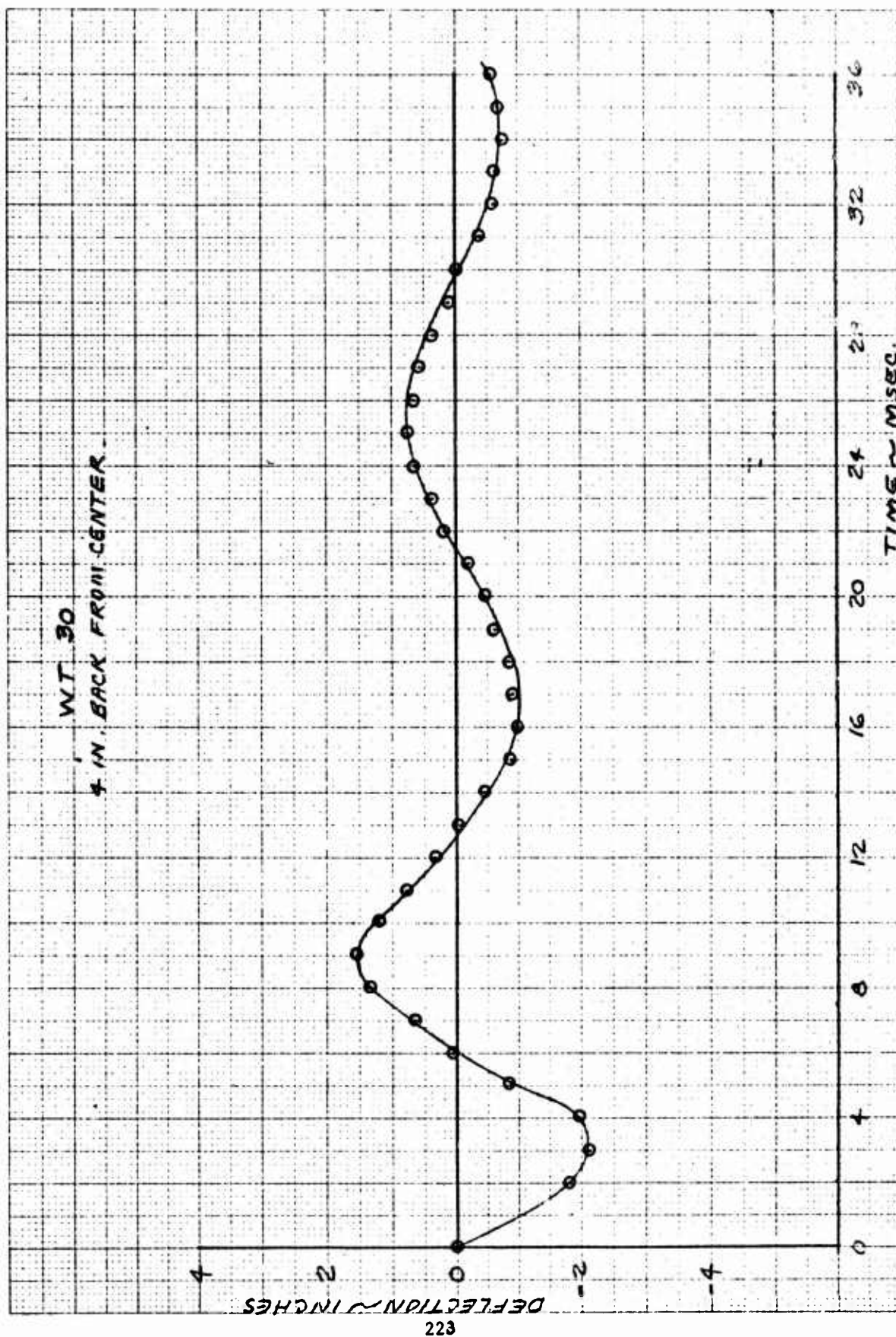


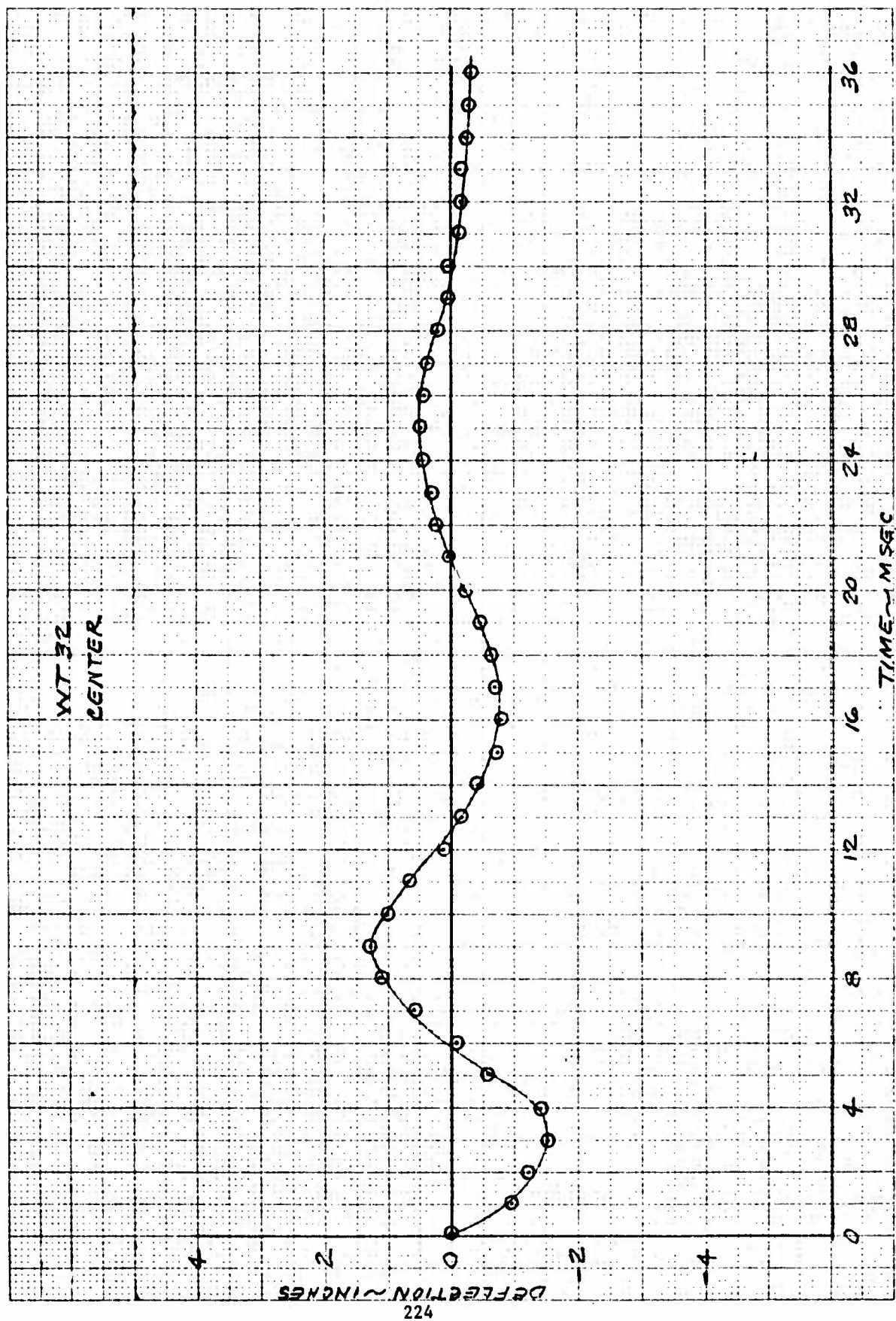


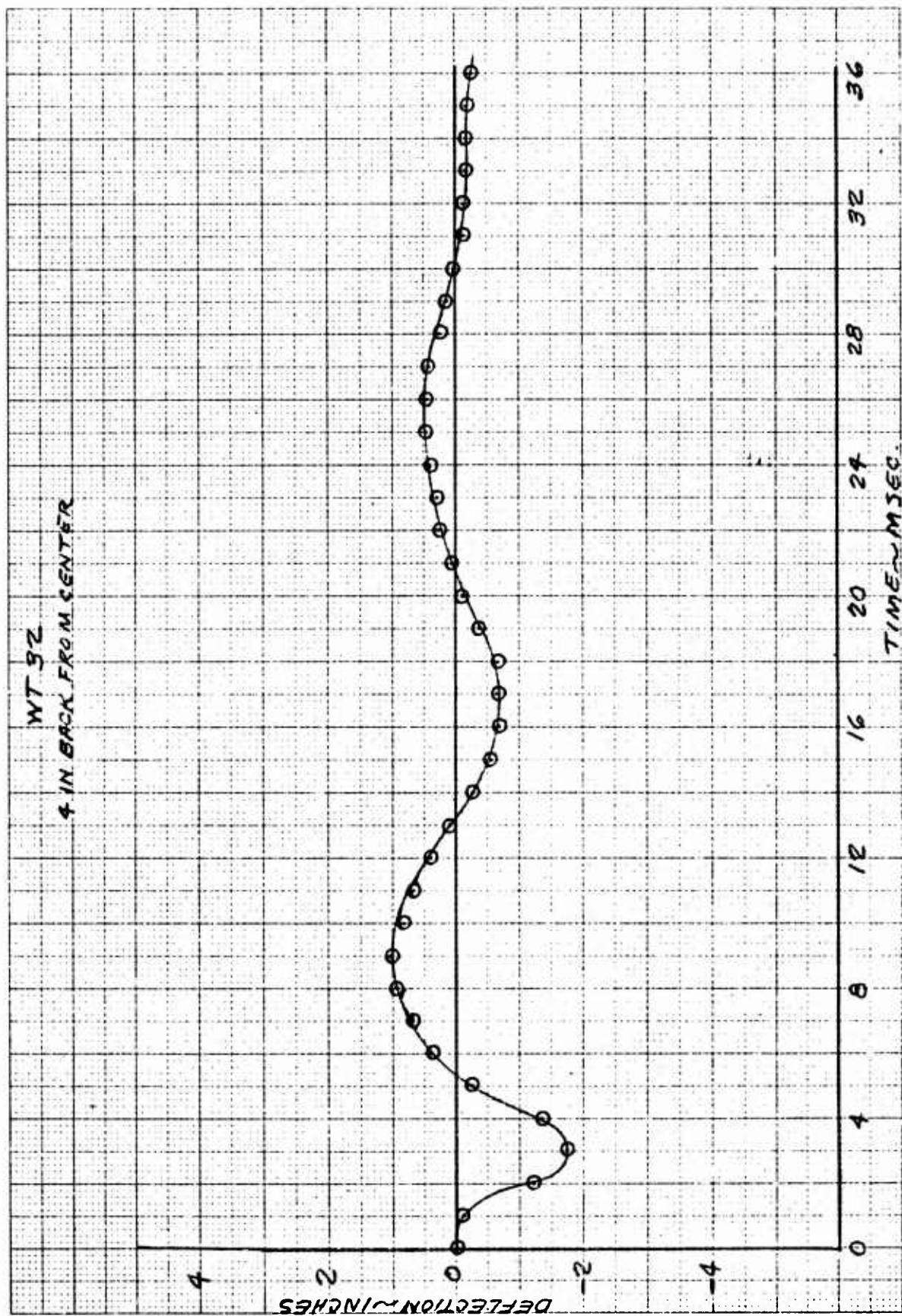




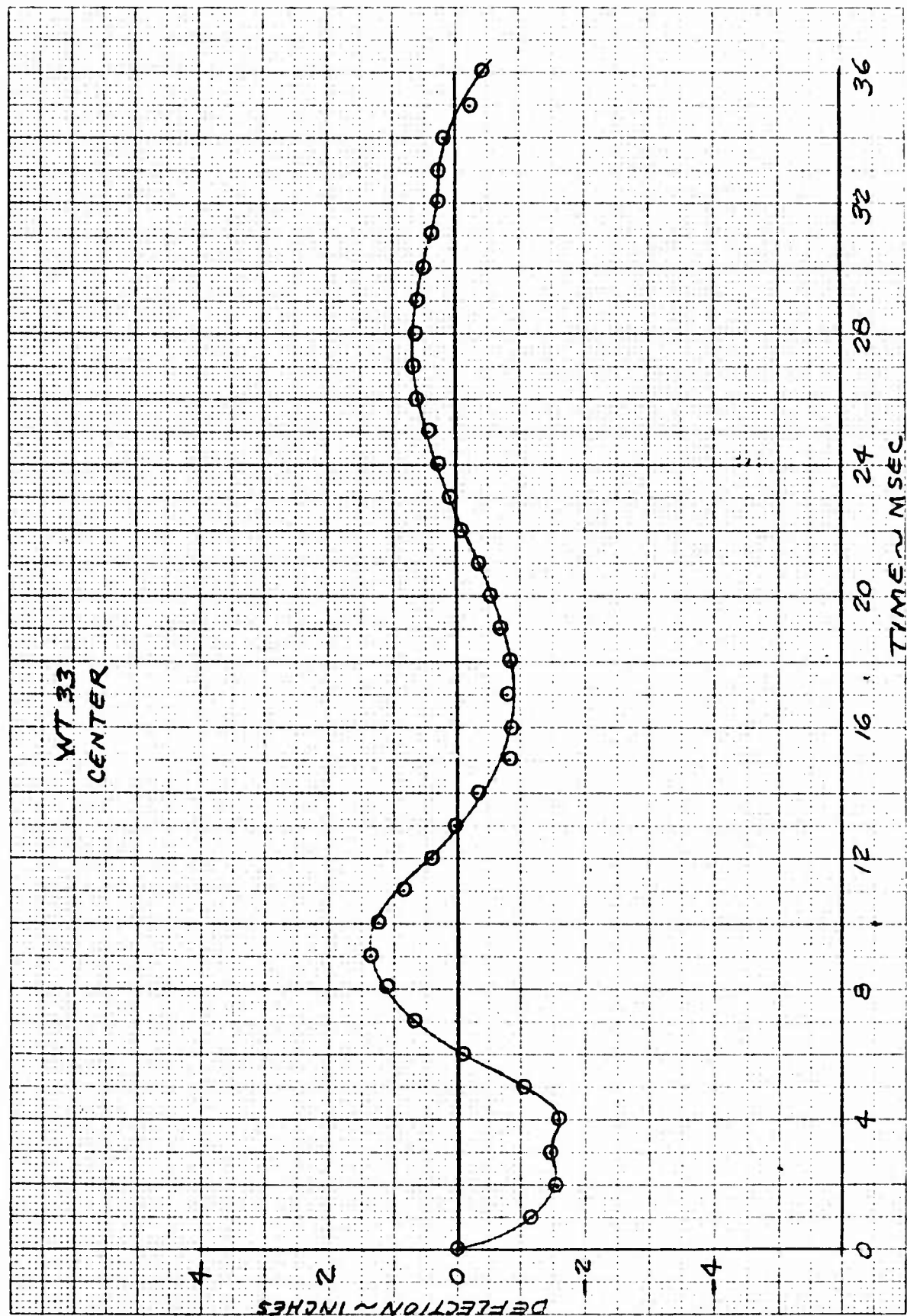


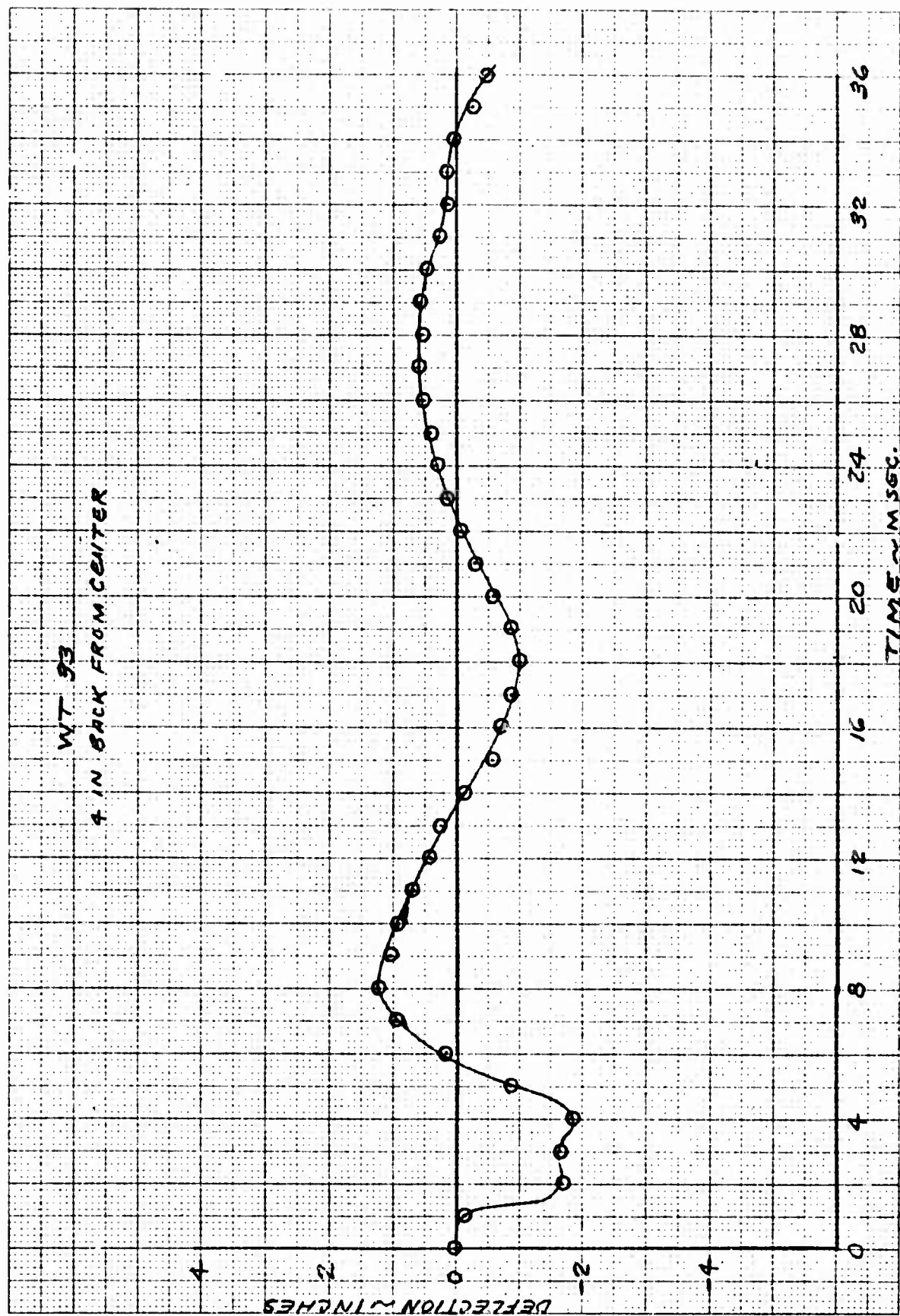




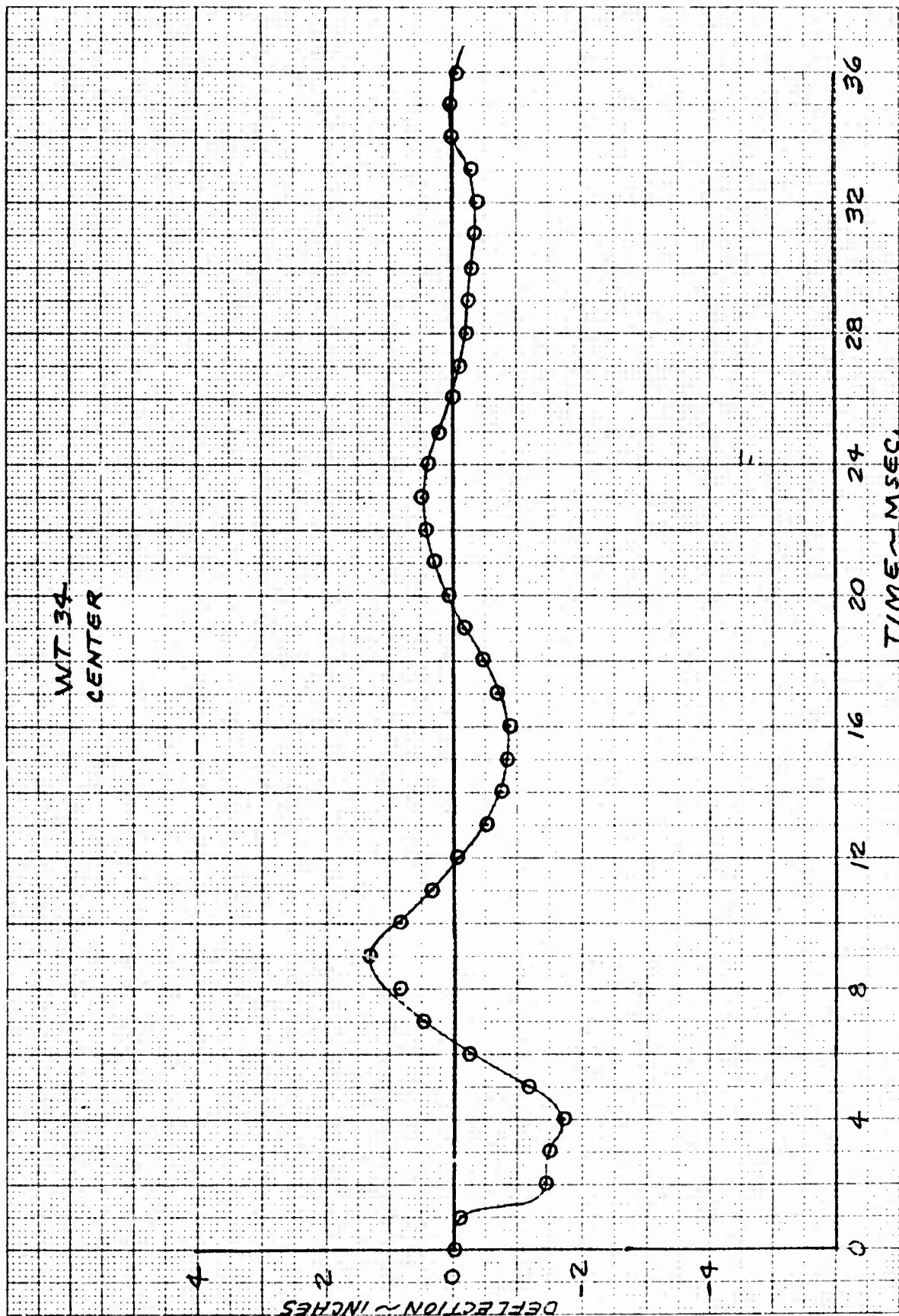


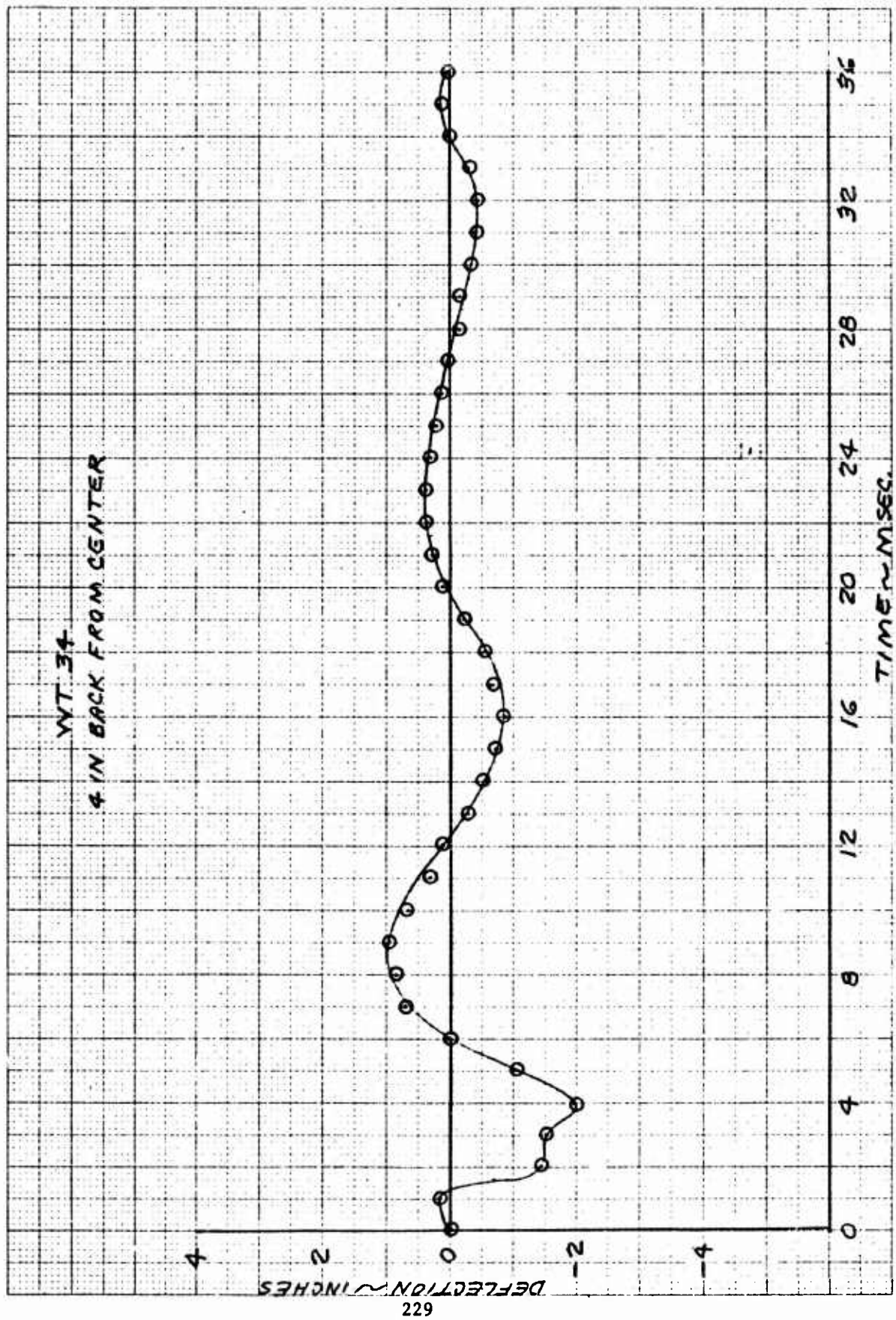




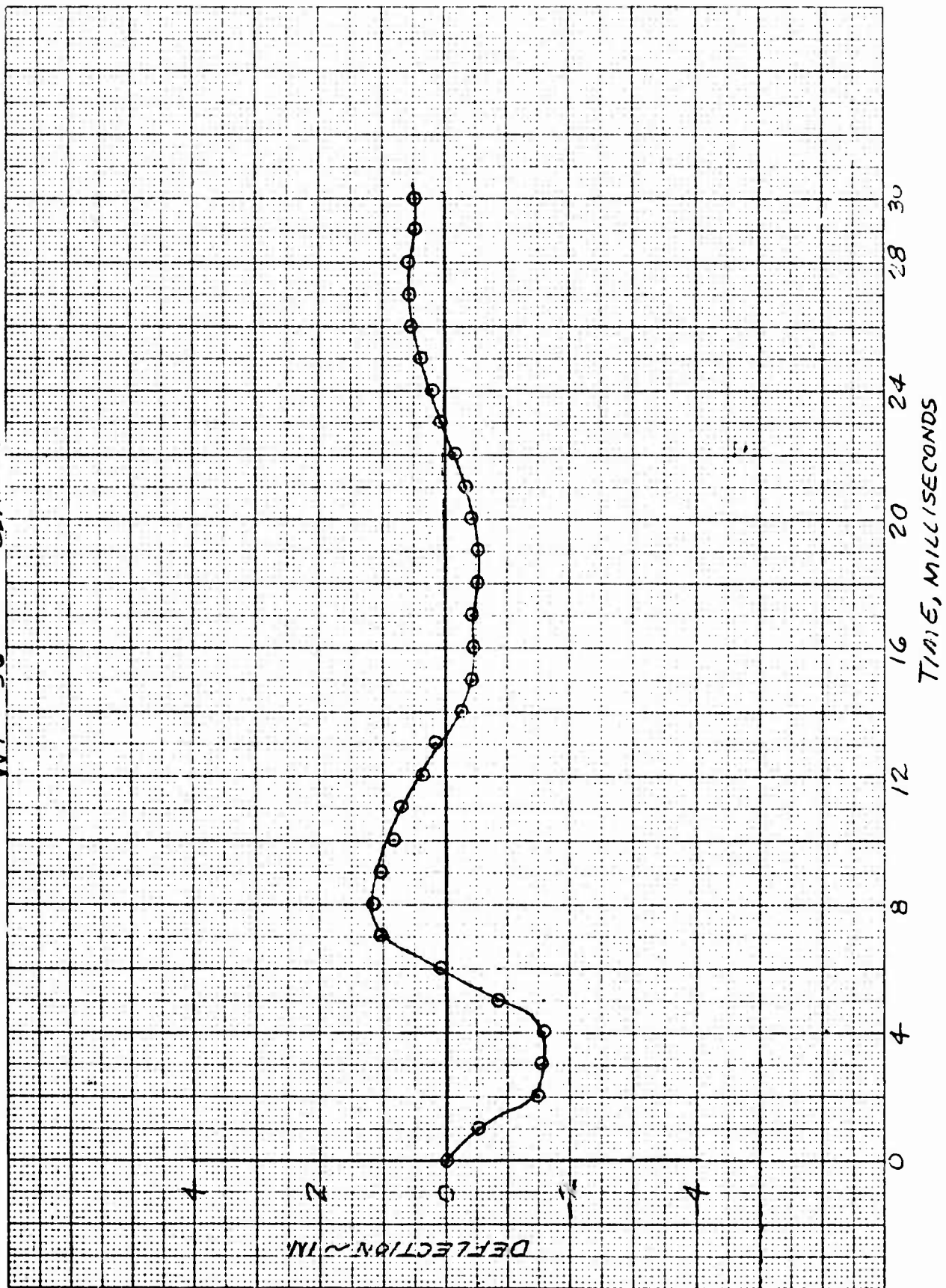






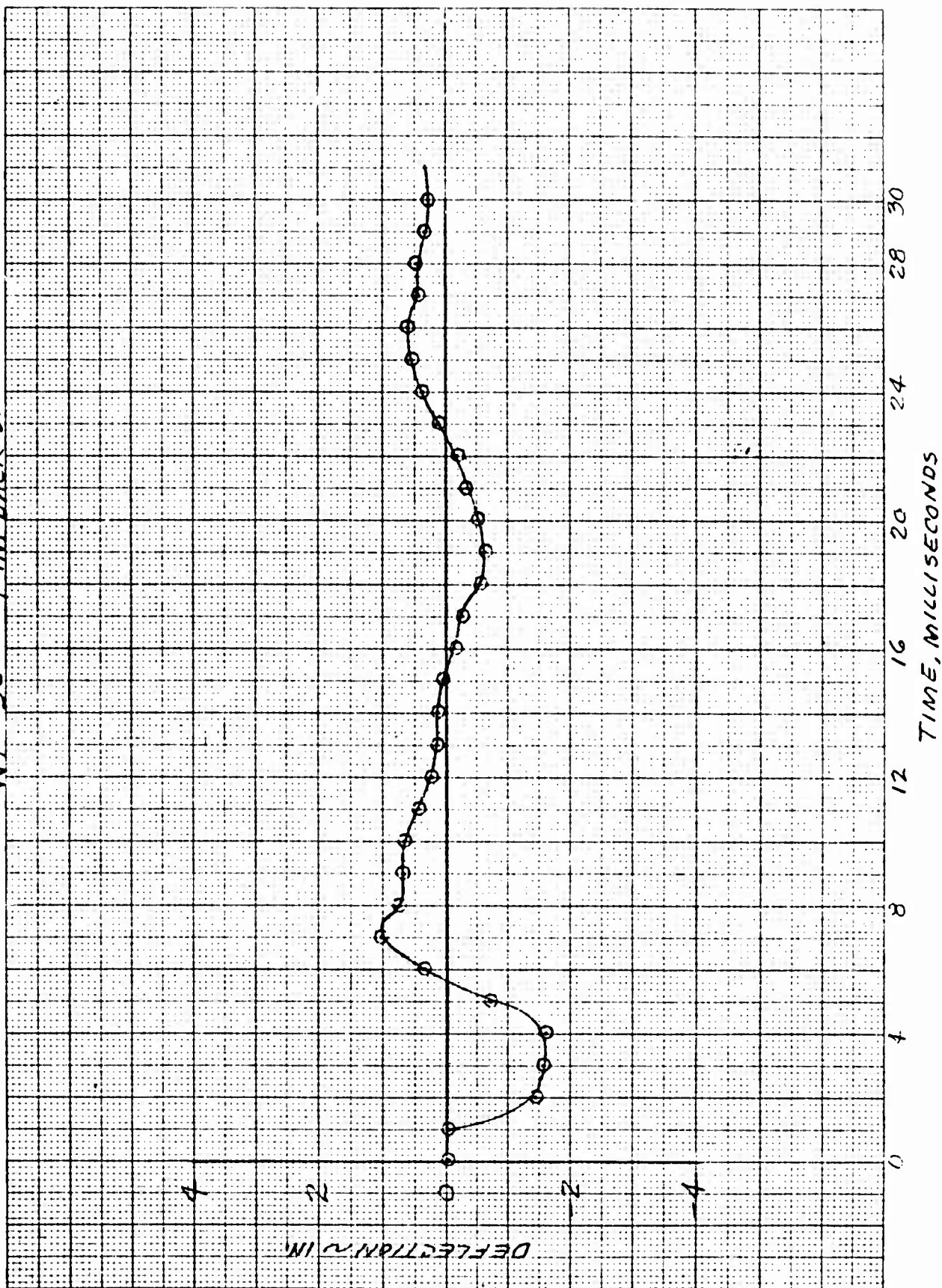


WT - 36 CENTER

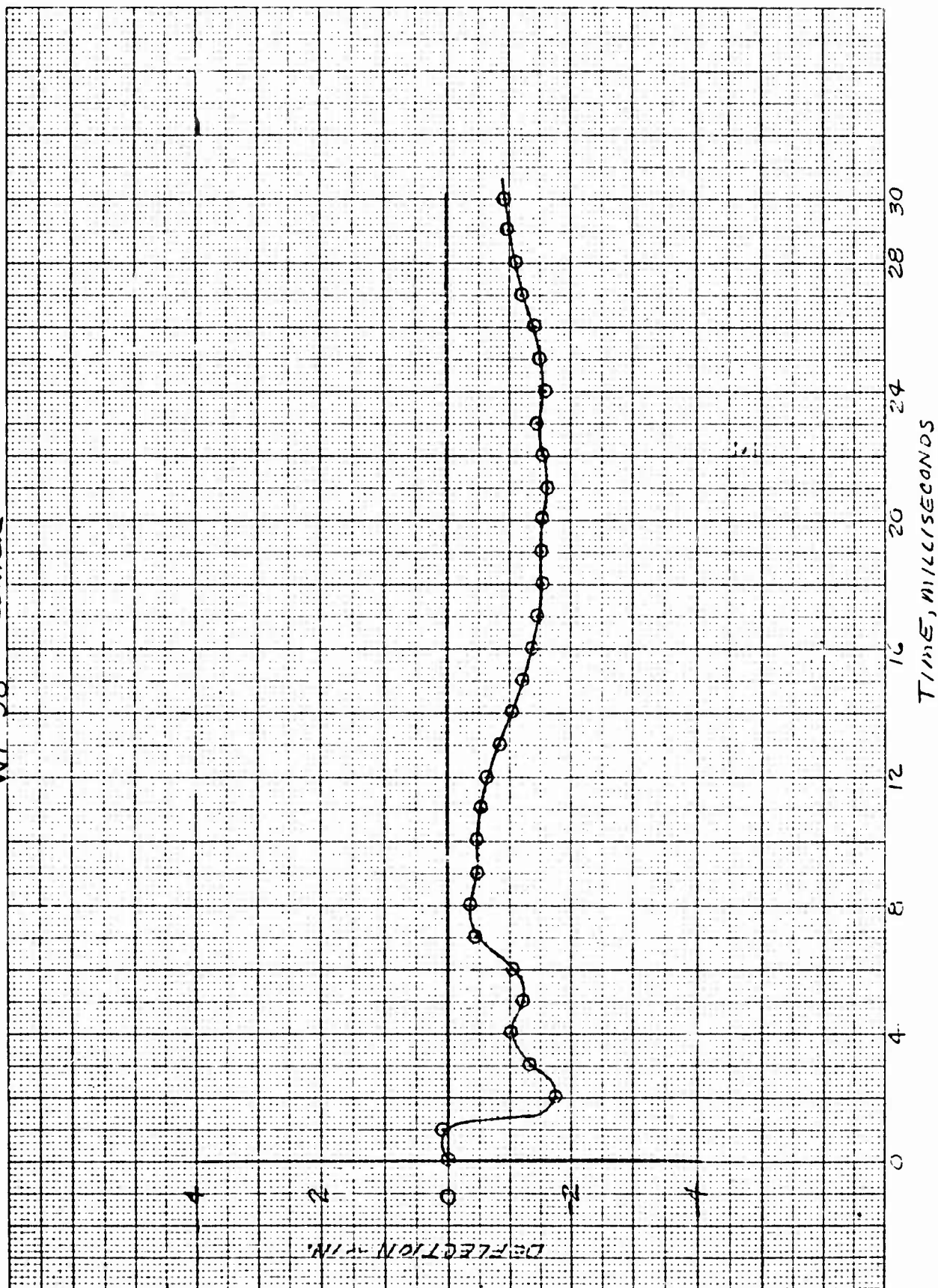




WT-36 4 IN. BACK OF CENTER

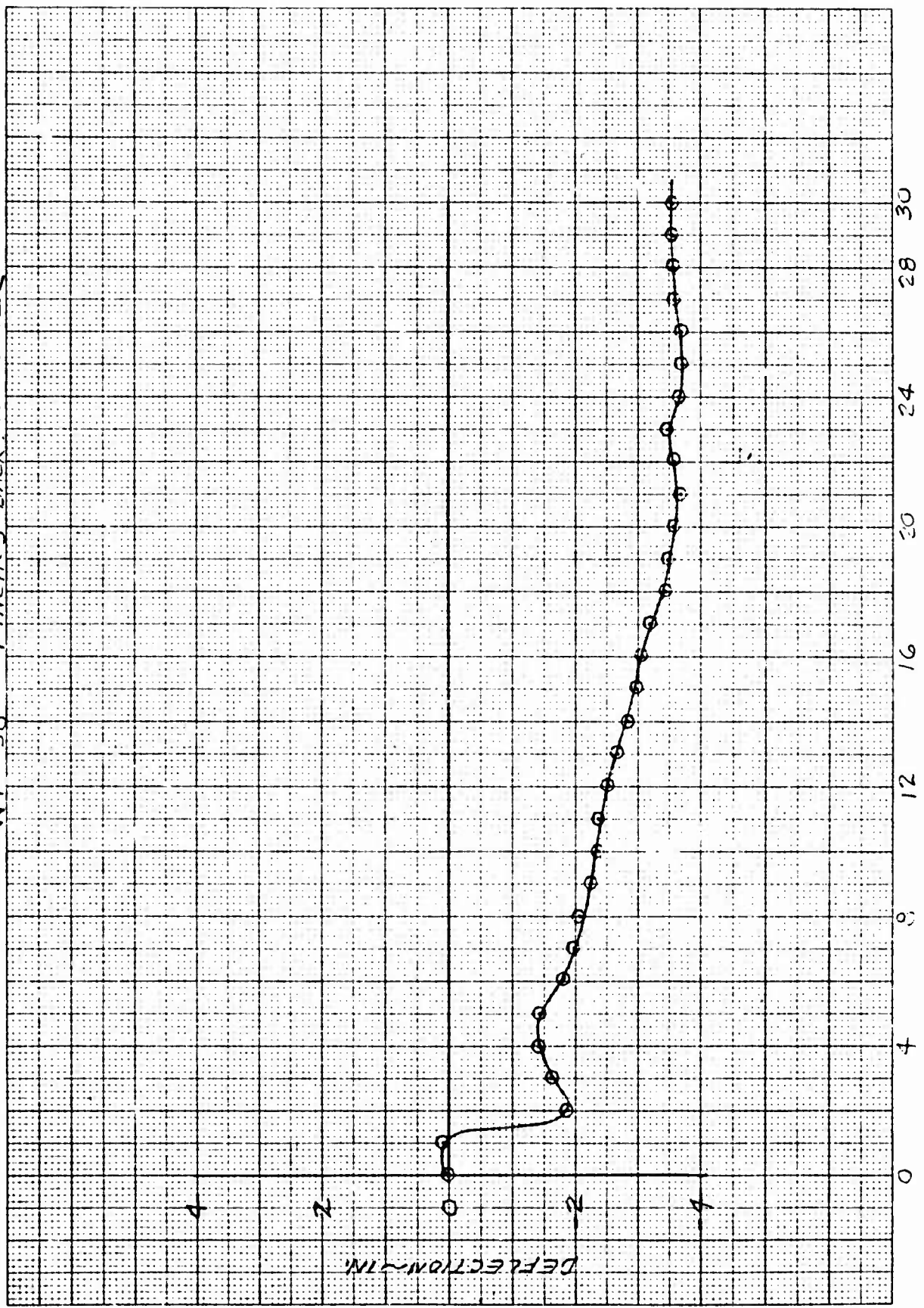


WT-38 CENTER





WT - 38 4 INCHES BACK OF CENTER



### APPENDIX 3

Three bird impact tests were conducted during Task II which received WT numbers but were accomplished by the Air Force to supplement the efforts of PPG INDUSTRIES under Contract F33615-73-C-3099. All three were conducted on windshields produced by PPG in November 1972 and were similar to those tested in the FM Series<sup>12</sup> of module impacts.

The Table summarizes the shots and a sketch of the panel from WT-45 and -46 follows.

TABLE XXIV - AIR FORCE-SPONSORED BIRD IMPACTS

| <u>Test No.</u> | <u>Mounting Conditions</u>  | <u>Impact Results</u> | <u>Remarks</u>                                                                            |
|-----------------|-----------------------------|-----------------------|-------------------------------------------------------------------------------------------|
| WT-45           | #2 Test Frame               | OK @ 497 KT           | LCOS caused no failure of I/B ply. Combining glass destroyed.                             |
| WT-46           | #2 Test Frame               | Failed @ 708 KT       | Same panel as WT-45. Compare with WT-41 impact in forward beam corner. Fracture as shown. |
| WT-50           | Module with Interim Fitting | Failed @ 529 KT       | Comparison with FM-2 shows effect of arch reinforcement.                                  |

---

<sup>12</sup>E. J. Sanders, "Investigation of the Effects of Bird Impacts on the F-111 Crew Module," LTR-AEDC-VKF-ASA-1-73, March 1973.

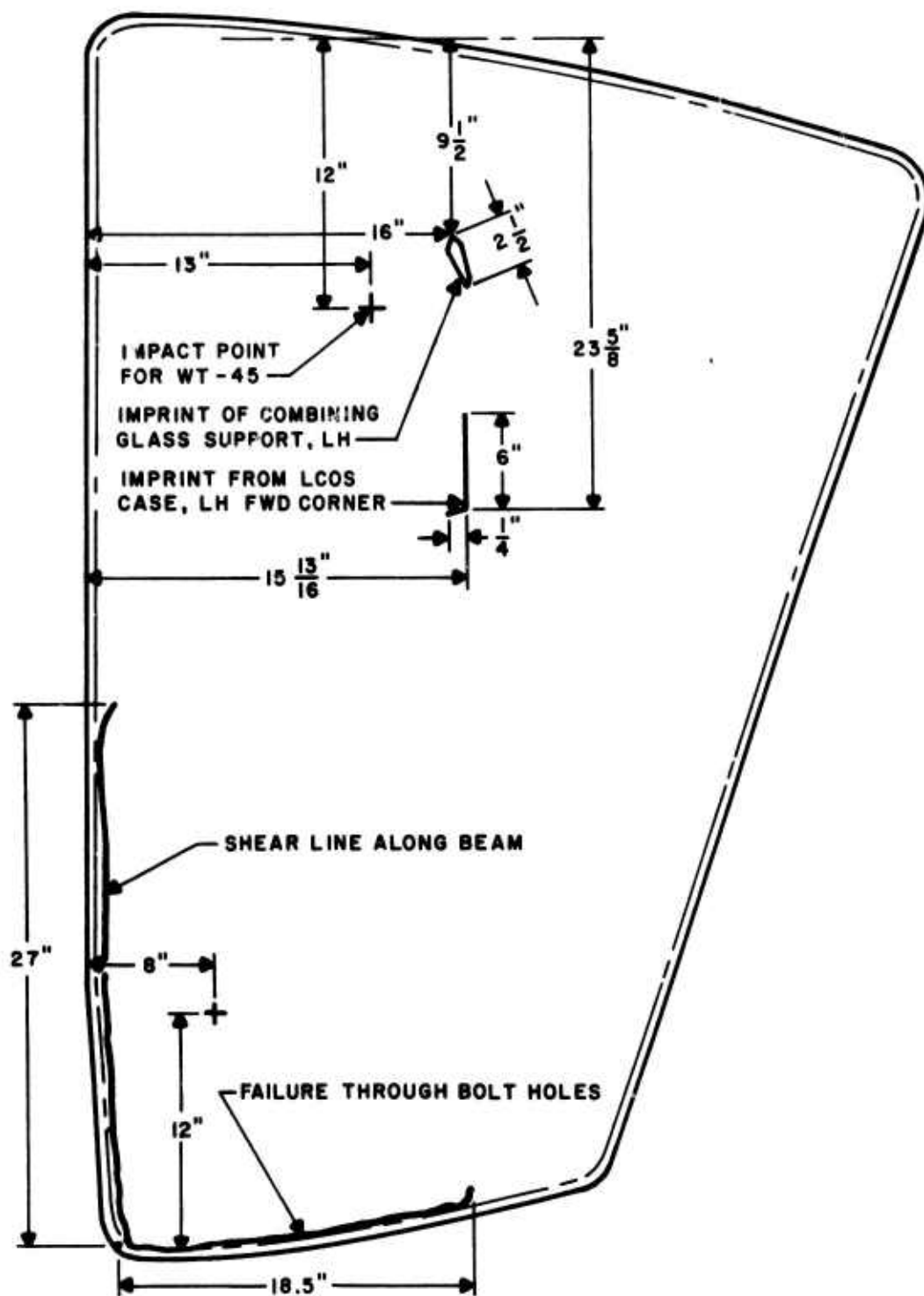


FIGURE 53. IMPACT RESULTS FOR WT 45 & 46.