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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AAMRL-TR-88-058	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Armstrong Aerospace Medical Research Laboratory, AFSC, HSD 6b. OFFICE SYMBOL (If applicable) AAMRL/HEF	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Wright-Patterson AFB OH 45433-6573	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62202F; PROJECT NO. 7184; TASK NO 18; WORK UNIT ACCESSION NO. 02

11. TITLE (Include Security Classification)

Specifications and Measurement Procedures for Aircraft Transparencies (U)

12. PERSONAL AUTHOR(S)

LaPuma, Peter T., 1Lt, USAF; Bridenbaugh, John C.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Dec 87 TO Jun 88	1988 September	57

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
01	03	
14	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Windscreens; Haze; Angular Deviation; Luminance Transmissivity; Aircraft Transparencies; Optical Specifications; Optical Distortion; (KT)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report is a summary of the specification requirements for optical quality for several military aircraft transparencies. It is intended to provide the design engineer with an easy reference to a majority of the accumulated historical information concerning optical quality. Keywords: aircraft canopies; optical quality;

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Peter T. LaPuma, 1Lt, USAF	22b. TELEPHONE (Include Area Code) 513-255-8871 22c. OFFICE SYMBOL AAMRL/HEF

DD Form 1473, JUN 86 Previous editions are obsolete.

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SUMMARY

This report is prepared in an effort to combine and condense information on the optical parameters used to describe the quality of an aircraft transparency. The first portion of this report defines and clarifies these parameters so that the reader may gain a further understanding of their meaning. The parameters that will be addressed in this report include:

Angular Deviation

Optical Distortion

Luminous Transmittance

Haze

Major and Minor Optical Defects

Miscellaneous Effects

Acceptable limits have been derived over time for the parameters listed above so that the optical quality of an aircraft transparency may be better defined. This report will also include a condensed version of these acceptable limits for 13 different aircraft transparencies currently in the defense inventory. There is also a chart of miscellaneous physical data which describes the transparency for 11 of the 13 aircraft.

PREFACE

This report was prepared under Work Unit 71841802 by personnel of the Crew Systems Effectiveness Branch of the Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio 45433-6573. Acknowledgement is given to Laura L. Mulford and Martha A. Hausmann for their assistance in preparing this report. Also, acknowledgement is given to Dr H. Lee Task for his invaluable technical assistance.

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LIST OF FIGURES

INTRODUCTION

This report is intended to serve as a reference for understanding the major optical effects encountered in specifying aircraft transparencies. It will provide the reader with useful information for establishing specifications for an aircraft windscreen by reviewing and comparing the broad range of current designs, optical requirements, and test methods. It also serves as a quick reference to the optical requirements of modern aircraft transparencies.

The report is divided into the following categories.

1. A discussion of the cause and effect of various optical phenomena related to aircraft transparencies.

2. An abbreviated listing of optical requirements taken from 13 military windscreen specifications.

3. Windscreen configurations, dimensions, and material make-up.

BACKGROUND

Aircraft windscreens must be constructed of thick materials and shaped into extreme geometries, due to aerodynamic design considerations and birdstrike protection requirements. These extreme configurations introduce various optical effects that alter the pilot's view through the transparencies. The degree of degraded visual performance caused by these optical effects is important to determine and control since they can adversely impact mission accomplishment and safety.

In reviewing the history of windscreen specifications and measurement, it is easy to see that optical quality has been difficult to define and measure. The level of acceptability has also been difficult to establish and quantify. To date, many efforts have been made to define optical parameters that can be tested in order to increase pilot performance and these efforts have met with some degree of success. A methodology has evolved that takes into account past mistakes and includes a significant amount of newly acquired knowledge including maintenance practices in the field.

OPTICAL PROBLEMS WITH WINDSCREENS

For tactical reasons, modern day, high performance aircraft are required to fly high speed, low altitude missions. The high speed capability requires that the windscreen design offer reduced aerodynamic drag by presenting minimum angle resistance to the airstream. The low altitude capability requires a windscreen that is relatively thick in order to reduce the potential damage from bird impact. Consequently, windscreen design involves a trade-off between reduced aerodynamic drag, birdstrike protection, and visibility.

The resulting compromise is usually a thick, curved, multi-layered plastic surface intersecting the pilot's line of sight at a shallow angle. The geometry of such an optical element results in significant optical problems due to the refraction of light incident upon the angled surfaces. Additionally, flaws introduced in the manufacturing process and from service wear and abuse contribute to the visual problems the pilot experiences.

OPTICAL EFFECTS

Over time, various windscreen optical parameters have been identified and defined. They can be summarized categorically as follows:

Angular Deviation
Optical Distortion
Luminous Transmittance
Haze
Major and Minor Optical Defects
Miscellaneous Effects

The following pages will elaborate upon the optical phenomena associated with each of the parameters outlined above. In addition to their cause and effect, the discussion will include measurement techniques and miscellaneous suggestions.

Angular Deviation

Definition: The angular displacement of a light ray from its original path as it passes through a transparent material, expressed as an angular measurement (degree, minutes of arc, milliradians).

Angular deviation is an optical effect that causes objects seen through a transparency to appear displaced from their true location. In passing through each transparent surface of the windscreen, light rays are bent (refracted) and thereby may deviate in angle from their original path as they reach the eye. The effect is the same as in looking at a goldfish in a clear pond. The image of the fish does not appear where the fish is located due to the deviation caused by the water. The amount of deviation is a function of the index of refraction of the transparent material and the angle between the observer's line of sight and the transparent surfaces.

To fully understand angular deviation, it is important to recognize a distinction between angular deviation and another phenomenon called lateral displacement. In order to illustrate, Figure 1 depicts a light ray refracted by a transparency section that has parallel surfaces. The path of the ray is not changed in angle with these parallel surfaces, because the refraction angles are equal and opposite. This image shift is known as lateral displacement, as opposed to angular deviation. The shift in location of an image due to lateral displacement is constant with distance so the amount of error (d) is very small. (Lateral displacement is under the category entitled MISCELLANEOUS EFFECTS, but is described here for purposes of clarity). In Figure 2, the surfaces are not parallel. The unequal refraction angles result in a net angular change (alpha) in the path of the ray. This is angular deviation. The shift in location of an image due to angular deviation can become very significant with an increase in distance. Angular deviation can be caused by changes in thickness or curvature across a transparency. As windscreen designs become thicker and more severely angled, angular deviation begins to contribute significantly to inaccurate target aiming.

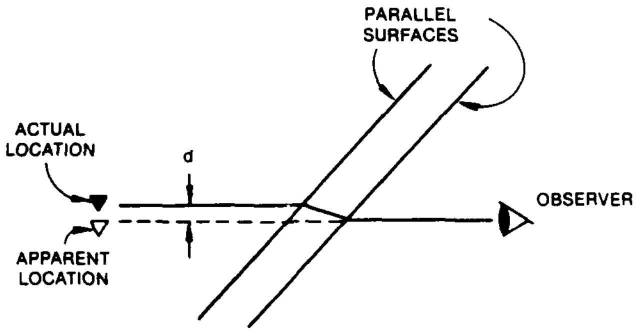


Figure 1. Lateral Displacement

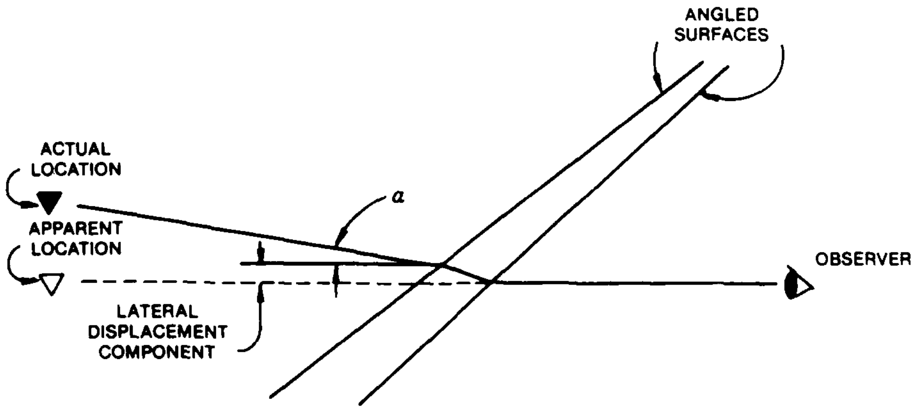


Figure 2. Angular Displacement (d)

Test Method: There have been several techniques devised to measure angular deviation. Virtually all of them measure the change in location of a point (image) when the windscreen is set into place and then removed. A number of measurements may be required to verify that a given windscreen is optically suitable because the angle between the pilot's line of sight and the transparent surface will vary across the windscreen. Details of this test procedure are given in ASTM 801-83.

The area of greatest concern is usually the gunsight area. Although angular deviation errors are not usually large in this area, their effects can be devastating. The slightest angular deviation here can translate directly into sighting errors unless accurately compensated for. For this reason, methods to measure angular deviation in this critical zone should be carefully chosen for aircraft that will have a Head-Up Display (HUD). Error data must reflect pure angular components and not be contaminated by lateral displacement errors.

Recalling earlier discussion, lateral displacement errors are insignificant at great distances. However, in a laboratory environment, test distances are necessarily abbreviated and lateral displacement errors could be the cause of a significant portion of the total image shift. Only test set-ups that employ some means to measure image shift at optical infinity will yield pure angular deviation error data. Accurately compiled error information can then be compensated for in the aircraft's weapon delivery computer or by optical means. An excellent reference that discusses methods to measure angular deviation, including ones that give pure error data, is AMRL-TR-82-43.

Optical Distortion

Definition: The rate of change of angular deviation resulting from an irregularity in a transparent part. This may be expressed as the angular bending of the light ray per unit of length of the part (i.e., milliradians per centimeter). It may also be expressed as the slope of the angle of localized grid line bending (i.e., 1 in 5).

Optical distortion can be thought of as the continuous change of angular deviation across a transparency. The effect of viewing through all points of the windscreen at the same time does more than cause the image of an object to be misplaced. If the effects of refraction across a windscreen are varied, objects can be magnified, minified, lengthened, foreshortened, misshaped, widened, narrowed, etc. The image one sees in a Funhouse mirror is an appropriate, but extreme, example of these effects.

Optical distortion is caused by a wide variety of things - changes in thickness, changes in curvature, changes in shape, heat induced stress, physical stress, etc. In general, anything that changes the refractive properties across a transparency will introduce distortion. In Figure 3, variations in thickness and curvature result in a continuous change in angular deviation (Distortion) as viewing angle is changed.

In addition to affecting the apparent size and shape of stationary objects, optical distortion can also cause moving objects to appear to vary in shape and motion in an irregular way as they are seen passing through different viewing areas of the windscreen. The net effect is a hindrance to the pilot and an additional burden for one already under a heavy workload.

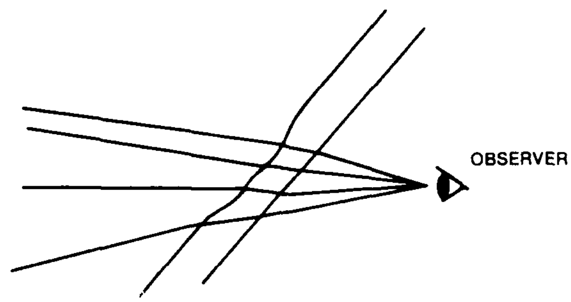


Figure 3. Distortion (Effects exaggerated)

Test Method: The method most often employed to assess the degree of optical distortion in a transparency utilizes a photographic procedure. A camera is placed at the pilot's eye position and a photograph is taken through the windscreen of a large, lighted gridboard. The horizontal and vertical elements of the grid are evenly and accurately spaced. A second exposure is then made on the same film frame with the windscreen removed. The distortion characteristics of the transparency become evident upon examining the shifted grid line spacing. Test set-up procedures, fixture sizes, spacing, and test distances are quite similar, if not the same, for most aircraft systems. The degree of distortion in a given area of the windscreen is indicated by the rate at which a grid line is bent. (Termed "Grid Line Slope" which is the x to y ratio of position change.) Details of this test procedure are given in ASTM 733-81.

Luminous Transmittance

Definition: The ratio of the intensity of light emerging from a transparency to the intensity of light incident upon it.

In simple terms, luminous transmittance relates to the amount of light that "gets through" a given transparency. That which does not get through is absorbed within the transparent material or reflected from any surfaces where a change in index of refraction occurs. A reduction in luminous transmittance is equivalent to turning down the lights, a clear disadvantage in situations where ambient light levels and/or image contrast levels are low.

Testing Method: Luminous Transmittance is measured using a photometer and a calibrated light source. The amount of light transmitted is given as a percentage of the total emitted from the source. Details of this test procedure are given in ASTM D1003.

Haze

Definition: Spatial attribute of smokiness or dustiness that interferes with clear vision. The ratio of diffuse to total transmittance of a beam of light.

As light enters or passes through a transparency, some of the light may be scattered or diffused, and may appear as haze or fog in the transparency. Haze is generally defined in terms of light scattered and, therefore, lost in passage through the transparency. In fact, the scattered light creates a veiling luminance that reduces the contrast of objects viewed through the windscreen. The most predominant cause of haze is tiny surface scratches that usually come about as a result of the cleaning process. The haze effect is increased as the angle of incidence is increased.

Test Method: A rather sophisticated test set-up is required to accurately measure haze in the laboratory. A collimated light source is used in conjunction with a device to determine the amount of scattered light. A haze figure is then calculated and expressed as a percentage. Details of this test procedure are given in ASTM D1003 and in ASTM 943-85.

Major and Minor Optical Defects

Optical defects, in general, are undesirable imperfections that occur through some combination of materials used and/or by some manufacturing procedures employed. Specifications usually impose limitations on their severity, the area they may obscure, and how objectionable they can be, in terms of visual impact. Separate rules are applied depending upon whether they are considered major or minor defects. There are many distinct defects and equally many self-descriptive terms that refer to them.

A sampling of some major terms are: deep scratches, bullseye, gouges, gross distortion, orange peel, chips, cracks, crazing, spalls, etc. (any defect which may significantly impair visibility through the windscreen).

Minor terms include: light scratches, embedded particles, inclusions, bubbles, blemishes, seeds, surface dimples, pimples, etc. (imperfections).

Acceptance criterion is usually based upon visual inspection since testing with instrumentation can be impossible or meaningless.

Miscellaneous Effects

Miscellaneous effects are undesirable optical phenomena that are, for the most part, unavoidable; however, since their visual consequences are tolerable, specifications do not presently place limits on them. Some examples are: lateral displacement, multiple images, birefringence, reflections, etc.

Lateral displacement has been described. Birefringence, also known as rainbowing, is a polarization effect. In sunlight, it may appear from within the cockpit as an apparently random dispersion of light into its component colors. The effects are not serious. Multiple images and reflections are depicted in Figures 4 and 5, which are relatively self-explanatory.

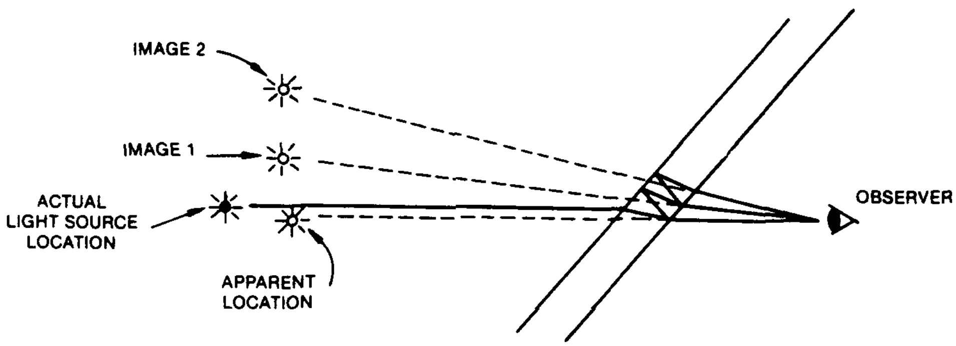


Figure 4. Multiple Images

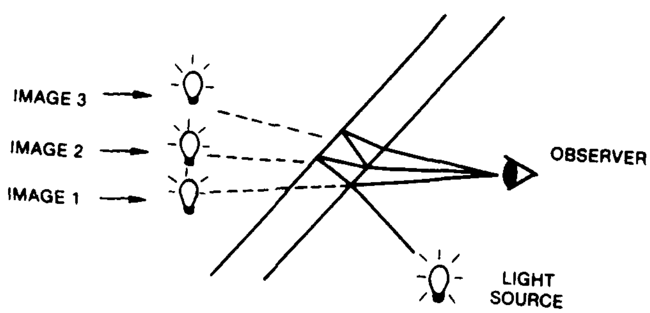


Figure 5. Internal Reflections

INDEX FOR QUICK REFERENCE TABLES

The table below is an index of page numbers for the following Optical Specifications and Physical Data for 13 primary aircraft in the current Defensive Inventory.

* The Physical Data for this aircraft include a newer configuration followed by the older configuration

\+ No Physical Data available

A-7 Optical Parameters

ANGULAR DEVIATION

Elevation .... (+) or (-) 2 mrad (6.88 min of arc)
Azimuth .... (+) or (-) 3 mrad (10.32 min of arc)

Between azimuth
viewing angles of ...... (+) or (-) 2 mrad (6.88 min of arc)
(+) or (-) 2 degrees

Deviation is measured from the following 2 positions:
1) design eye position
2) 1 inch up and 3 inches forward of the design eye position

OPTICAL DISTORTION

Maximum of 1 in 10 Grid Line Slope also when visually inspected. There shall be no immediate blurring, divergence, convergence or jumping of grid lines. Local distortion is allowable if it does not distract from aircrew performance.

LUMINOUS TRANSMITTANCE ... Minimum of 79 %

HAZE ... Maximum of 3.5 %

OPTICAL DEFECTS

Scratches ...... maximum of F-428-3 in critical optical area
...... maximum of F-428-4 in outer optical area
...... maximum of F-428-6 in 0.5 inch wide optics waived area

Orange Peel .... visual inspection judged to cause impairment

MINOR OPTICAL DEFECTS

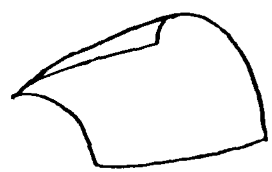
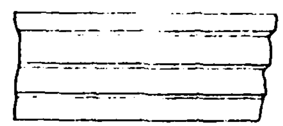
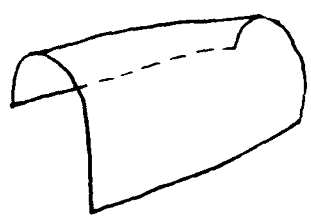
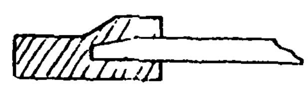
Critical Optical Area .. maximum of 0.035 in. in dia. provided they are not grouped in a manner causing impairment

Outer Optical Area ..... maximum of 0.09 in. in dia. provided they are not grouped in a manner causing impairment

Non-visual and Optical Waived Areas ... visible defects within the 0.5 inch wide optics-waived area (area adjacent to mounting surface) shall be permitted regardless of size, provided it is structurally intact.

AIRCRAFT: A-7D/K **TYPE:** ATTACK (CLOSE AIR SUPPORT)

MANUFACTURER: LTV

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
*WINDSHIELD			.125 ACRYLIC (CAST) .03 URETHANE .25 POLYCARBONATE .03 URETHANE .25 POLYCARBONATE .03 URETHANE .125 ACRYLIC (CAST)
CANOPY SWEDLOW			1875 STRETCHED ACRYLIC 25 NYLON EDGE

SLOPE (DEGREES)	
WEIGHT (LB)	
DAYLIGHT AREA (IN.^{2})	2598
CABIN PRESSURE (PSI)	
MAX. CRUISE (KNOTS)	
BIRD PROOF SPEED (KNOTS)	480
RAIN REMOVAL (TYPE)	
HEATING	

MISC. DATA:

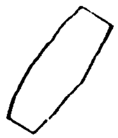
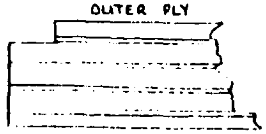
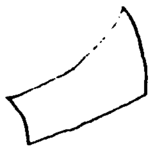
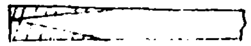
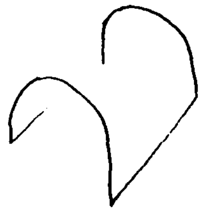
NEWER ONE PIECE WINDSHIELD WITH COMPOSITE AFT ARCH

* PROPOSED DESIGN

Figure 6. A-7D/K windscreen physical properties.

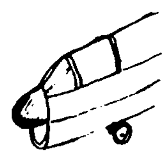
AIRCRAFT: A-7D **TYPE:** ATTACK (CLOSE AIR SUPPORT)

MANUFACTURER: LTV

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
CENTER WINDSHIELD PPG			.25 SEMI TEMPER .04 PVB .25 SEMI TEMPER .02 PVB .25 FULL TEMPER .02 PVB .75 FULL TEMPER .02 PVB .25 FULL TEMPER
SIDE WINDSHIELD SWEDLOW			.25 STRETCHED ACRYLIC .32 NYLON EDGE
CANOPY GLASS SWEDLOW			.1875 STRETCHED ACRYLIC .25 NYLON EDGE

			SLOPE (DEGREES)
35	10 ea	48.2	WEIGHT (LB)
2598	716	346	DAYLIGHT AREA (IN.^{2})
			CABIN PRESSURE (PSI)
			MAX. CRUISE (KNOTS)
	[illegible]		BIRD PROOF SPEED (KNOTS)
			RAIN REMOVAL (TYPE)
			HEATING

MISC. DATA:



⟨OLD VERSION⟩

Figure 7. A-7D windscreen physical properties.

A-10 Optical Parameters

ANGULAR DEVIATION

Quarter Panels ... Maximum of 6 min. of arc in all 4 zones

Center Panel ... Critical Vision Area - Maximum of 3 minutes of arc
Scanning Area - Maximum of 31.5 seconds of arc

OPTICAL DISTORTION

Quarter Panels ... Zone 1 - maximum of 1 grid per 10 grid run
Zone 2 - maximum of 1 grid per 8 grid run
Zone 3 - maximum of 1 grid per 4 grid run
Zone 4 - maximum of 1 grid per 2 grid run

Center Panel ... Critical Vision Area - Max. of 1 grid in 15
Scanning Area - Max. of 1 grid in 10

LUMINOUS TRANSMITTANCE

Quarter Panels ... Minimum of 83% measured perpendicular to the surface
Center Panel ... Minimum of 65% at a 52 degree angle of incidence

HAZE

Unavailable

OPTICAL DEFECTS

Any defect greater than the maximum diameter for minor optical defects and any chips or cracks that would cause structural problems

MINOR OPTICAL DEFECTS

Bubbles - Minor defect if between 0.062 and 0.15 inches

Lint - Minor defect if between 0.062 and 0.15 inches

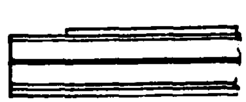
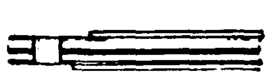
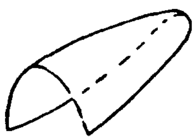
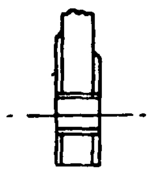
Pits - Minor defect if between 0.062 and 0.25 inches

Bullseye - Minor defect if between 0.062 and 0.25 inches

Foreign Objects - Minor defect if between 0.062 and 0.125 inches

AIRCRAFT: A-10A TYPE: ATTACK (CLOSE AIR SUPPORT)

MANUFACTURER: FAIRCHILD REPUBLIC CO.

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD CTR. PANEL PPG TRIPLEX	 FLAT	 OUTBD	GLASS LAMINATE (SODA LIME) .187 SEMI-TEMPER .080 PVB INTERLAYER .375 FULL TEMPER .040 PVB INTERLAYER .375 FULL TEMPER .080 PVB INTERLAYER .125 LIGHT TEMPER
SIDE PANEL PPG GOODYEAR	 COMPOUND CURVED	 OUTBD	PLASTIC LAMINATE .080 CAST ACRYLIC .030 POLYURE. INTER. .156 POLYCARBONATE .030 POLYURE. INTER. .156 POLYCARBONATE .030 POLYURE. INTER. .080 CAST ACRYLIC RUBBER BUSHED ALUM. SPACER
CANOPY SWEDLOW	 COMPOUND CURVED	 OUTBD →	MONOLITHIC ACRYLIC .06 NYLON FABRIC .25 STR ACRYLIC .06 NYLON FABRIC ALUM. SPACER

Windshield	Side panel	Canopy	
	38° @ ℄ ACFT		SLOPE (DEGREES)
46.4	38.2 /SHIP SET	63	WEIGHT (LB)
2312	231 in^2/PANEL	110	DAYLIGHT AREA ($IN.^2$)
	2.5		CABIN PRESSURE(PSI)
	350		MAX. CRUISE (KNOTS)
-	300	300	BIRD PROOF SPEED (KNOTS)
-	-	JET AIR	RAIN REMOVAL (TYPE)
WINDSHIELD - CONDUCTIVE COAT. SIDE PANEL - HOT AIR (DEFOG) CANOPY - HOT AIR (DEFOG)			HEATING

MISC. DATA: DESIGN DRIVERS:
BIRD & BULLET IMPACT FOR W/S CTR PANEL.
BIRD IMPACT FOR W/S SIDE PANEL.

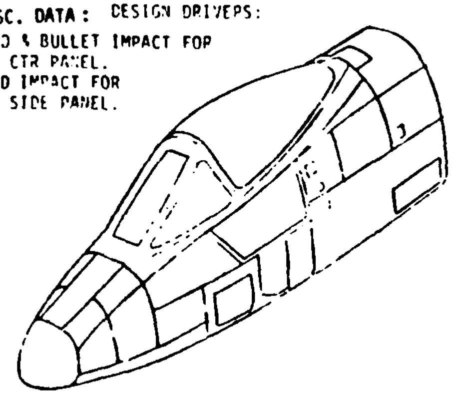


Figure 8. A-10A windscreen physical properties.

AV-8 Optical Parameters

ANGULAR DEVIATION

Windshield Only
Critical Vision Area ... maximum deviation of 1 minute of arc
Remaining Areas ... maximum deviation of 3.5 minutes of arc

OPTICAL DISTORTION

Windshield ... maximum allowable Grid Line Growth of 0.02 grid and there shall be no distortion which causes the observer to focus on the windscreen

Canopy ... maximum of 1.5 grids or a maximum of 2 grids is acceptable IF it is gradual (min. of 12 grid)

LUMINOUS TRANSMITTANCE ... Minimum of 89 %

HAZE ... AV-8/GR Mk.5/TAV-8 Windshield ... Maximum of 2 %
TAV-8 Blast Shield .... Maximum of 3 %

OPTICAL DEFECTS

Any optical defect which causes vision impairment shall be cause for rejection.

EXCEPTIONS:

Within 1 inch of any edging, adhesive burns or localized distortion at edge attachment joints or localized distortion resulting from rework of scratches or dings shall be disregarded unless it is objectionable to the inspector.

AV-8/GR Mk.5 ... Localized distortion within a 2 inch in diameter circle located on B.L. 0.000 and 17.25 inches from forward edge is acceptable

TAV-8 Forward Canopy ... Localized distortion within a 2 inch in diameter circle centered 18 inches, left or right, true along outer mold line from B.L. 0.000 and 24 inches from forward edge is acceptable

TAV-8 Aft Canopy ... Localized distortion within a 2 inch in diameter circle centered at the following locations (+) or (-) 1 inch is acceptable

- -- 3 inches, left or right, true along outer mold line from 1.5 inches to the right of B.L. 0.000 and 4 inches from the forward edge measured at B.L. 0.000
- -- On 1.5 inches to the right of B.L. 0.000 and 26.5 inches from the forward edge measured at B.L. 0.000
- -- On 1.5 inches to the right of B.L. 0.000 and 35.5 inches from the forward edge measured at B.L. 0.000

B1-B Optical Parameters

ANGULAR DEVIATION

Zone 1 .... Maximum of 7 minutes of arc
Zone 2 .... Maximum of 10 minutes of arc
Zone 3 & 4 ... Not Applicable

OPTICAL DISTORTION

Zone 1 ... Maximum Grid Line Slope of 1 in 9
Zone 2 ... Maximum Grid Line Slope of 1 in 6
Zone 3 ... Maximum Grid Line Slope of 1 in 3
Zone 4 ... Not Applicable

LUMINOUS TRANSMITTANCE ... Minimum of 53 %

HAZE ... Maximum of 5 %

OPTICAL DEFECTS

Scratches

- ASTM F-428 Scratch Standards will be used to determine category
- Scratch Length refers to each individual scratch
- Scratches on the inner "heated" surface of the glass ply are acceptable if they are approximately parallel to current flow
- Faint hairline scratches are not accountable as optical defects

Scratch Category	Allowable Length in inches #4	#5	#6	#7
Zone 1	1.0	0.5	0.125	0
Zone 2	3.0	2.0	1.0	0
Zone 3	5.0	3.0	1.5	1.0
Zone 4	No scratches more severe than #7 No scratches greater than #6 shall extend to the edge of the glass			

MINOR OPTICAL DEFECTS

- Minor defects include: scratches, embedded particles, smears, pits, etc.
  Zone 1 ... Maximum number of 3 defects when visually inspected
  Zone 2 ... Maximum number of 5 defects when visually inspected
  Zone 3 ... Maximum number of 5 defects when visually inspected

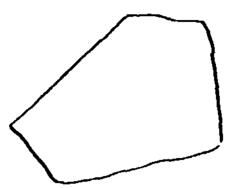
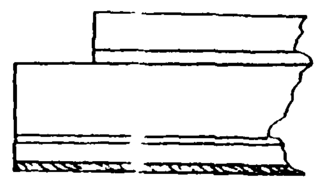
- The area of a defect shall not exceed 1/64 square inches, defects less than 0.05 in. in dia. are acceptable provided they are not grouped in a manner causing impairment

- Cuts 0.005 inches in depth or greater shall be cause for rejection

- No more than 2 defects shall occur in a circular area 12 inches in dia.

AIRCRAFT: B-1B **TYPE:** BOMBER

MANUFACTURER: ROCKWELL

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD			.12 TEMPERED GLASS .235 SILICONE INTERLAYER .87 POLYCARBONATE .120 SILICONE INTERLAYER .15 POLYCARBONATE PROTECTIVE COATING

SLOPE (DEGREES)	
WEIGHT (LB)	
DAYLIGHT AREA (IN.^{2})	
CABIN PRESSURE(PSI)	
MAX. CRUISE (KNOTS)	
BIRD PROOF SPEED (KNOTS)	550
RAIN REMOVAL (TYPE)	
HEATING	

MISC. DATA:

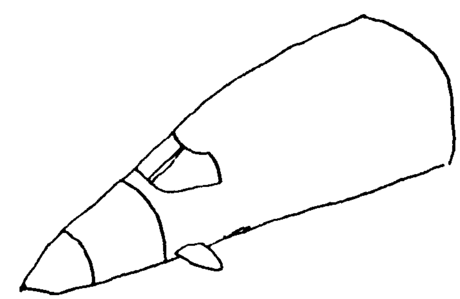


Figure 9. B-1B windscreen physical properties.

F-5E Windshield Optical Parameters

ANGULAR DEVIATION

Flight Area - maximum of 1.4 grids determined from pilot's eye position

Gunsight Area - maximum of 1 grid determined from pilot's eye position

OPTICAL DISTORTION

Flight Area and Gunsight Area - any apparent grid line shall not exceed 1/2 in any 2 x 2 square (4 grids)
And shall not exceed a gradual change of 1.2 inches in 12 inches of run

LUMINOUS TRANSMITTANCE

In Accordance With MIL-P-25690A

HAZE

Maximum of 3% for unweathered monolithic acrylic (IAW MIL-P-25690A)

MINOR OPTICAL DEFECTS

Flight Area - Maximum of 1 minor defect per 1 foot squared circular area (template radius is 6.77 inches)
No Major defects are permitted

Gunsight Area - No Major or Minor defects shall be permitted

- Minor defects are considered to be embedded particles, bubbles, dimples, etc. that do not exceed a 0.125 inches in diameter, or scratches that do not exceed 0.005 inches in depth

- Major defects are chips, cracks, spalls, gouges, and scratches deeper than 0.005 inch and more than 0.05 inch in length or other defects clustered to produce sustained visual distraction

F-5E and F-5A Crew Enclosures Optical Parameters

ANGULAR DEVIATION

Windshield ... Supercritical Area - maximum of 0.3 grid
Critical Area - maximum of 0.4 grid

Canopy ... Critical Area - maximum of 0.5 grid

OPTICAL DISTORTION

Windshield ... Supercritical Area - Maximum apparent grid line slope of 1/5 in any 2 x 2 square (4 grids) and Maximum of 0.4 inch in 6 inches of run

Critical Area - Maximum of 0.5 grid in 6 grids of run

Canopy ... Critical Area - Maximum apparent grid line slope of 1/3 in any 2 x 2 square (4 grids) and Maximum of 0.5 inch in 4 inches of run

LUMINOUS TRANSMITTANCE - In Accordance With MIL-P-25690A

HAZE - Maximum of 3% for unweathered monolithic acrylic (IAW MIL-P-25690A)

MAJOR OPTICAL DEFECTS

Windshield ... Supercritical and Critical Areas - No major defects allowed
Noncritical Area - Acceptable provided no structural weakening

Canopy ... Critical Area - No major defects are allowed
Semi-Critical Area - Major defects are not allowed
Noncritical Area - Acceptable provided no structural weakening

MINOR OPTICAL DEFECTS

Windshield ... Supercritical Area - No defects are allowed
Critical Area - Maximum of 1 minor defect per 1 foot squared of circular area (template radius is 6.77 inches)
Noncritical Area - Acceptable provided no structural weakening

Canopy ... Critical Area - Maximum of 2 minor defects provided that 2 or more defects cannot be encompassed in 1 foot squared of circular area
Semi-Critical Area - Maximum of 1 minor defect provided that 2 or more defects cannot be encompassed in 1 foot squared of circular area
Noncritical Area - Acceptable provided no structural weakening

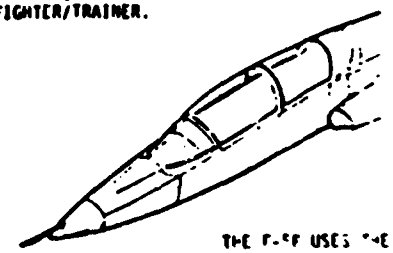
AIRCRAFT: F-5 TYPE: FIGHTER

MANUFACTURER: NORTHROP CORP.

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD SIERRACIN PPG	 CURVED CONICAL		.71 STR. ACRYLIC MIL-P-25690 FIBERGLASS EDGE
CANOPY PPG	 COMPOUND CURVED	END  SIDE 	.25 STR ACRYLIC MIL-P-25690

24° ? ℄		SLOPE (DEGREES)
31	42	WEIGHT (LB)
1200	680	DAYLIGHT AREA (IN.^{2})
5 PSI		CABIN PRESSURE
Mach 1.6		MAX. CRUISE (KNOTS)
≈120	≈260	BIRD PROOF SPEED (KNOTS)
NONE		RAIN REMOVAL (TYPE)
HOT AIR DEFOG		HEATING

MISC. DATA: F-5E IS SINGLE PLACE, SHOWN HERE IS F-5F, THE TWO-PLACE FIGHTER/TRAINER.



THE F-5F USES THE SAME TRANSPARENT PARTS SHOWN FOR THE T-38.

Figure 10. F-5 windscreen physical properties.

F-14A Tomcat Optical Parameters

ANGULAR DEVIATION

Unavailable

OPTICAL DISTORTION

Zone 1 ... maximum of 1 grid per 12 grid run
Zone 2 ... maximum of 1 grid per 8 grid run

LUMINOUS TRANSMITTANCE

Unavailable

HAZE

Unavailable

OPTICAL DEFECTS

Rejectable Blemishes

Crazing is not permissible and crazed panels shall be rejected
Zone 1 .... Scratches over 0.01 inch deep are rejectable
Zone 2 and 3 ... Scratches over 0.01 inch deep are subject to Material Review Board action

MINOR OPTICAL DEFECTS

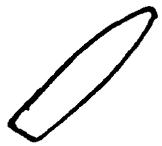
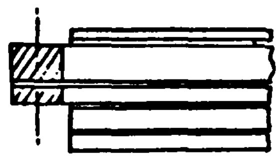
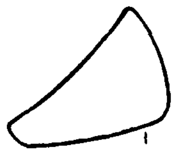
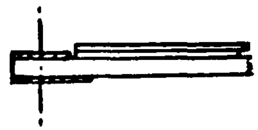
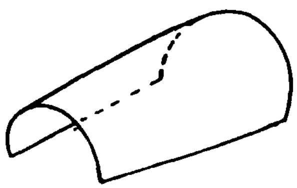
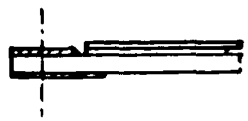
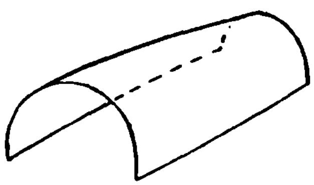
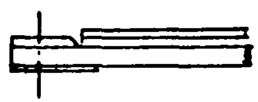
Minor defects are blemishes such as pinholes, pimples, cement marks, orange peel, hazing, and similar defects which do not impair transparency or reduce visibility and are not grouped in a manner that creates the effect of a major blemish.

Zone 1 ... maximum of 1 minor defect per 1 square foot of circular area
Zone 2 ... maximum of 2 minor defect per 1 square foot of circular area
Zone 3 ... minor defects in excess of 2 are not cause for rejection

NOTE: A cluster of no more that 3 blemishes within a 1 inch diameter circle can be considered one blemish. However, any such cluster in Zone 1 and 2 shall be at least 3 inches from another cluster or blemish within a 1 square foot circular area.

AIRCRAFT: F-14A TOMCAT **TYPE:** INTERCEPTOR/FIGHTER

MANUFACTURER: GRUMMAN AEROSPACE

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD PPG, IND			.187 SEMI-TEMP GLASS .06 PVB .50 FULL-TEMP GLASS .08 PVB .25 FULL-TEMP GLASS .06 PVB .50 ANNEALED GLASS .02 PVB .25 ANNEALED GLASS
SIDE QUARTER PANELS SWEDLOW			.125 CAST ACRYLIC .10 SILICONE CIP .300 STRETCHED ACRYLIC NYLON/EPOXY EDGE
FORWARD CANOPY SWEDLOW			.100 CAST ACRYLIC .100 SILICONE CIP .200 STRETCHED ACRYLIC
AFT CANOPY SWEDLOW			.100 CAST ACRYLIC .100 SILICONE CIP .200 STRETCHED ACRYLIC

30 @ ℄				SLOPE (DEGREES)
68	63.4	13.4	69	WEIGHT (LB)
4000	3750	500	432	DAYLIGHT AREA (IN.^{2})
5.8				CABIN PRESSURE (PSI)
MACH 2.4				MAX. CRUISE (KNOTS)
350				BIRD PROOF SPEED (KNOTS)
JET AIR BLAST				RAIN REMOVAL (TYPE)
HOT AIR BLAST				HEATING

MISC. DATA: TANDEM SEATS

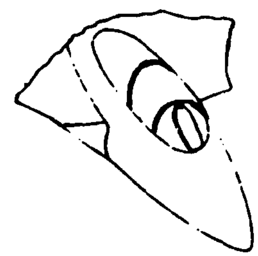


Figure 11. F-14A windscreen physical properties.

F-15 Optical Parameters

ANGULAR DEVIATION

Critical Optical Area ... maximum of 1.8 minutes of arc (0.52 mrad)

Remaining Areas (except 1 inch from the trimmed edge of windshields without edging) ... maximum of 3.5 minutes of arc (1.02 mrad)

OPTICAL DISTORTION

Critical Optical Area for WINDSHIELD - Maximum allowable grid line growth on the photograph is 0.02 inch. Also, the area will be visually inspected for any distortion which makes the observer focus on the windshield.

FORWARD and AFT CANOPIES (single and two place aircraft only) - Shall be visually examined for distortion and Grid Lines shall generally appear parallel and shall indicate any abrupt changes

FORWARD CANOPY Supplement (single place aircraft only) - A photograph method shall be used with the photo enlarged to 12 squares (grid board squares) per inch. A displacement of 1 1/2 grids is acceptable. A displacement of 1 1/2 to 2 grids is acceptable if the change is gradual (occurring over a minimum of 12 grids)

LUMINOUS TRANSMITTANCE

Minimum of 89 %

HAZE

Maximum of 2 %

OPTICAL DEFECTS

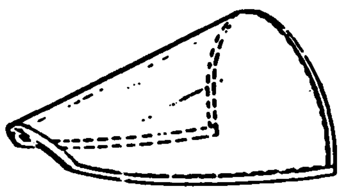
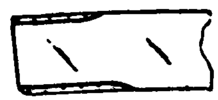
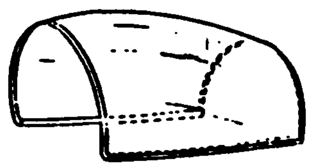
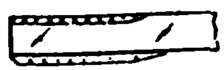
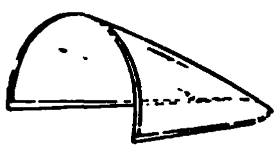
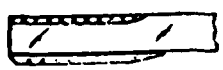
Any optical defect which causes vision impairment shall be cause for rejection.

EXCEPT: within 1 inch of any edging or any localized distortion caused by the reworking of scratches unless they are grouped together or are objectionable to the inspector

The transparency shall show no evidence of "orange peel" or "twinkling" which causes vision impairment

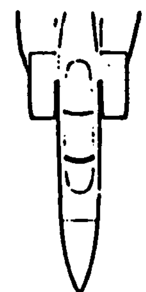
AIRCRAFT: F-15 TYPE: FIGHTER

MANUFACTURER: McDONNELL DOUGLAS

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD (SWEDLOW)	 CURVED CONICAL		.90 STRETCHED ACRYLIC FIBERGLASS EDGE * .94 STRETCHED ACRYLIC
FWD CANOPY (SWEDLOW)	 COMPOUND CURVE		.30 STRETCHED ACRYLIC FIBERGLASS EDGE
AFT CANOPY (SWEDLOW)	 COMPOUND CURVED		.30 STRETCHED ACRYLIC FIBERGLASS EDGE

28 @ ℄			SLOPE (DEGREES)
20	55	50	WEIGHT (LB)
1566	4300	1175	DAYLIGHT AREA (IN.^{2})
	5		CABIN PRESSURE(PSI)
	795 @ S.L.		* MAX. CRUISE (KNOTS)
	394 PLUS * 400 Kts		BIRD PROOF SPEED (KNOTS)
	HOT AIR		RAIN REMOVAL (TYPE)
	HOT AIR		HEATING

MISC. DATA:



* FOR THE E-MODEL IN PRODUCTION NOT BOLTED TO FRAME

Figure 12. F-15 windscreen physical properties.

F-16 A/B/C/D Optical Parameters

ANGULAR DEVIATION

The method used to correct for angular deviation in the F-16 is a unique approach to limiting visual error caused by the canopy. The aircraft's onboard computer is used to correct for the angular deviation in the windscreen. When the pilot positions the pipper on a target, the computer adjusts for the angular deviation error in order to accurately deliver the weapon to the true target. The methods and the correction formulas that are used are too lengthy to include here, but for further information, refer to AFAMRL-TR-82-8, "The Measurement of Angular Deviation and its Relation to Weapons Sighting Accuracy in F-16 Canopies".

Binocular Disparity limits are set for the azimuth of F-16 C/D only. The area to be measured is 6 degrees right and left of center in azimuth and from 2 degrees to 12 degrees down in elevation. Limits are:

- 42 values shall not exceed -4.0MR to +4.0MR
- 41 values shall not exceed -3.0MR to +2.5MR
- 42 values shall not exceed -2.5MR to +1.0MR

OPTICAL DISTORTION

Visual Survey ... there shall be no apparent bending, blurring, divergence, convergence, or jumping of grid lines

Photographically Measured

Zone 1 ... Maximum of 1 grid per 11 grid run (except 1 in 9 in a limited forward area of Zone 1)
Zone 2 ... Maximum of 1 grid per 9 grid run

LUMINOUS TRANSMITTANCE ... Solar Coated - Minimum of 65 %
Non Solar Coated - Minimum of 79 %

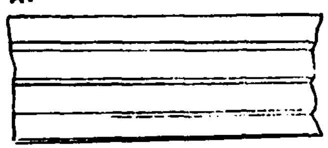
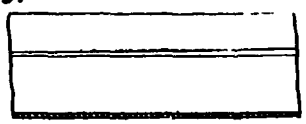
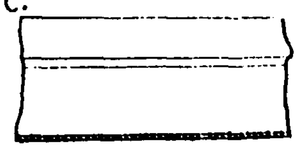
HAZE ... Maximum of 4 %

MINOR OPTICAL DEFECTS

There shall be no more than 20 minor optical defects per zone (greater than 0.035 inches in diameter) as seen by the design eye position.

AIRCRAFT: F-16 **TYPE:** FIGHTER

MANUFACTURER: GENERAL DYNAMICS

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
FOREWARD WINDSHIELD/ CANOPY			
GOODYEAR	see other data sheet for shape	A. 	.150 PLEX II ACRYLIC .030 POLYURETHANE .187 POLYCARBONATE .030 POLYURETHANE .187 POLYCARBONATE .030 POLYURETHANE .120 PLEX II ACRYLIC
TEXSTAR		B. 	.125 PLEX II ACRYLIC .06 POLYURETHANE .50 POLYCARBONATE COATING.
SIERRACIN		C. 	.175 PLEX II ACRYLIC .03 SILICON .50 POLYCARBONATE COATING

SLOPE (DEGREES)	
WEIGHT (LB)	
DAYLIGHT AREA (IN.^{2})	
CABIN PRESSURE(PSI)	
MAX. CRUISE (KNOTS)	
BIRD PROOF SPEED (KNOTS)	
RAIN REMOVAL (TYPE)	
HEATING	

MISC. DATA:

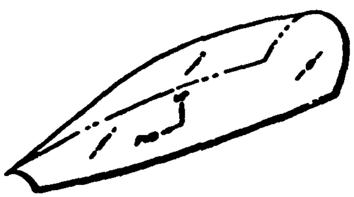
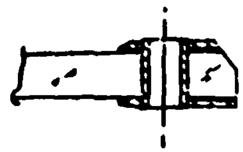
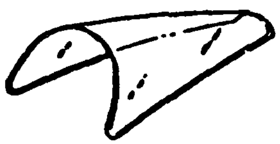
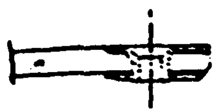
A. IN SERVICE BUT NOT IN PRODUCTION

B., C. THESE LAMINATED CANOPIES ARE IN PRODUCTION

Figure 13. F-16 windscreen physical properties.

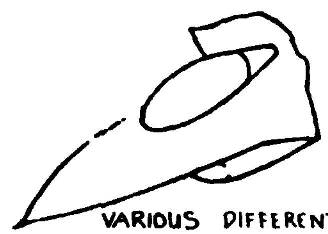
AIRCRAFT: F-16 TYPE: FIGHTER

MANUFACTURER: GENERAL DYNAMICS

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD/ CANOPY (TEXSTAR)			* .75 POLYCARBONATE
AFT CANOPY (TEXSTAR)			.25 POLYCARBONATE

SLOPE (DEGREES)	31 AC C_L
WEIGHT (LB)	12 137
DAYLIGHT AREA ($IN.^2$)	4200
CABIN PRESSURE(PSI)	5
MAX. CRUISE (KNOTS)	795 @ S.L.
BIRD PROOF SPEED (KNOTS)	350 PLUS
RAIN REMOVAL (TYPE)	GROUND APPLIED REPELLENT
HEATING	NONE

MISC. DATA: DESIGN DRIVEN BY VISION AND BIRD IMPACT.



VARIOUS DIFFERENT DESIGNS ARE CURRENTLY BEING EVALUATED. SEE NEXT DATA SHEET

*AN ACRYLIC - INTERLAYER - POLYCARBONATE LAMINATE IS BEING EVALUATED.

Figure 14. F-16 windscreen physical properties (continued).

F-18 Windshield Optical Parameters

ANGULAR DEVIATION

Critical and Center Optical Area ... maximum of 1 minute of arc
Outer Optical Area ... maximum of 2 minutes of arc
Remaining Vision Area ... maximum of 4 minutes of arc

OPTICAL DISTORTION

Optical Area ... Free of any distortion which causes the observer to focus on the windshield
Center Optical Area ... Maximum Grid Line Growth is 0.01 inches
Outer Optical Area ... Maximum Grid Line Growth is 0.02 inches

Canopy - visually inspected for grid lines that are generally parallel and indicate no abrupt slope changes

LUMINOUS TRANSMITTANCE ... Minimum of 89 %

HAZE ... Maximum of 2 %

OPTICAL DEFECTS

- There shall be no defects that cause the observer to be distracted or to focus on the defect

- There shall be no evidence of surface or internal "Orange Peel" or "Twinkling", which cause visual impairment

MINOR OPTICAL DEFECTS

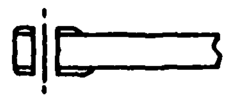
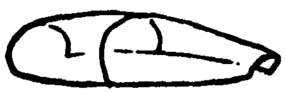
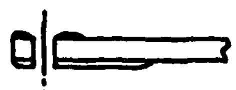
- If the diameter of defects exceeds 0.035 inches, it shall be cause for rejection, unless the defects do not cause vision impairment

- Defects less than 0.035 inches in dia. are acceptable, provided they are not grouped in a manner causing vision impairment

- Any defects (regardless of size) that cause visual impairment shall be cause for rejection

- Defects within 1 inch of any edging shall be disregarded unless they effect structural integrity

AIRCRAFT: F/A-18L TYPE: FIGHTER
(IDENTICAL TO F/A-18A OR TF-18A)
MANUFACTURER: NORTHROP/MCAIR

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD SWEDLOW	 CURVED CONICAL		.05 FIBERGLASS EDGE .60 STRETCHED ACRYLIC .04 FIBERGLASS EDGE
CANOPY (SINGLE PLACE) SWEDLOW	 COMPOUND CURVED		.05 FIBERGLASS EDGE .25 STRETCHED ACRYLIC .08 FIBERGLASS EDGE
CANOPY (TWO PLACE) SWEDLOW	 COMPOUND CURVED TWO PIECES		.05 FIBERGLASS EDGE *.25 STRETCHED ACRYLIC .08 FIBERGLASS EDGE *.35 FOR FORWARD PIECE

24° @ A/C C_L			SLOPE (DEGREES)
106	49	47	WEIGHT (LB)
7300	3380	1500	DAYLIGHT AREA (IN.^{2})
5.5 PSI			CABIN PRESSURE
M2.0			MAX. CRUISE (KNOTS)
4 LB BIRD @ 360 KNOTS			BIRD PROOF SPEED (KNOTS)
JET AIR BLAST			RAIN REMOVAL (TYPE)
JET AIR BLAST			HEATING

MISC. DATA:

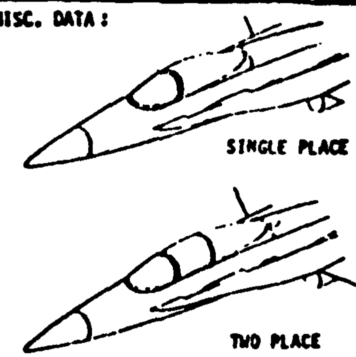


Figure 15. F/A-18L windscreen physical properties.

F-111 Optical Parameters

ANGULAR DEVIATION

Due to inadequacy in the previous deviation standards, the following revised standards were developed based on data collected from operational F-111 windscreens in May of 1982. The present revision requires that the avionics area be measured every 2 degrees and the non-avionics area be measured every 4 degrees. The reason the following error limits are set up in a statistical fashion is to fit the deviation error to a smooth curve across the windscreen, as well as to assign maximum limits for the allowable errors. This revision is subject to change as more data becomes available, but the theory should remain the same.

Avionics Area:	Maximum Allowed Value	
	Azimuth Error	Elevation Error
Absolute Value of the Mean	3.0 mrad	2.0 mrad
Standard Deviation	1.5	2.0
Absolute Maximum Value	7.0	5.0
Absolute Mean + Standard Deviation	4.0	3.0

Non-Avionics Area:	Maximum Allowed Value	
	Azimuth Error	Elevation Error
Absolute Value of the Mean	3.0 mrad	2.5 mrad
Standard Deviation	3.5	2.5
Absolute Maximum Value	9.0	6.0
Absolute Mean + Standard Deviation	3.0	5.0

OPTICAL DISTORTION

Windshield .. Unavailable

Canopies .... maximum of 1:10 in Zone 1
maximum of 1:6 in Zone 2

LUMINOUS TRANSMITTANCE

Windshield and Canopy
With Radar Reflective Coating - Minimum of 65 %
Without Radar Reflective Coating - Minimum of 84 %

HAZE

Windshield and Canopy
With Radar Reflective Coating - Maximum of 4 %
Without Radar Reflective Coating - Maximum of 3 %

OPTICAL DEFECTS

Scratches - 0.02 inch width, 0.01 inch depth or 3 inches in length

Lint or Hair - 3 inches in length

Smears or rubs - 5/8 inch wide or 1 1/2 inch length

Translucent Inclusions - 0.125 square inch area

Opaque Inclusions - 0.07 square inch area

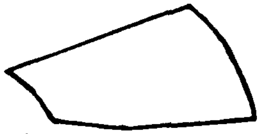
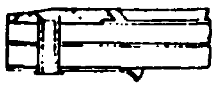
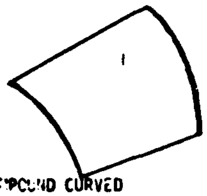
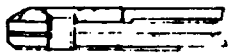
The total number of translucent inclusions between (0.35 - 0.125) or opaque inclusions between (0.35 -0.07) shall not exceed 12 per panel

Delaminated Areas

Outboard Acrylic Edge - max. of 1/8 inch around entire periphery
Inboard Acrylic Edge - max. of 1/4 inch around entire periphery

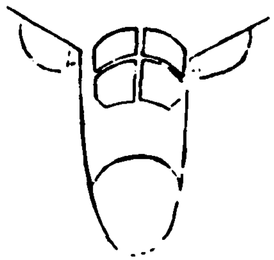
AIRCRAFT: F-111/FB-111 TYPE: FIGHTER/BOMBER

MANUFACTURER: GENERAL DYNAMICS

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD (ADBIRT) SIERRACIN PPG SWEDLOW	 CURVED CONICAL		AL RETAINER .125 STR ACRYLIC .060 INTERLAYER .250 POLYCARBONATE .030 INTERLAYER .250 POLYCARBONATE SST STRAP
CANOPY (ADBIRT) SIERRACIN PPG SWEDLOW	 COMPOUND CURVED		AL RETAINER .125 STR ACRYLIC .060 INTERLAYER .125 POLYCARBONATE .030 INTERLAYER .125 POLYCARBONATE .020 NOMEX RETAINER

22° @ A/C ℄		SLOPE (DEGREES)
30	48	WEIGHT (LB)
1722	1767	DAYLIGHT AREA (IN.^{2})
9.2		CABIN PRESSURE
M2.5+		MAX. CRUISE (KNOTS)
500		BIRD PROOF SPEED (KNOTS)
JET AIR BLAST		RAIN REMOVAL (TYPE)
JET AIR BLAST		HEATING

MISC. DATA: DESIGN DRIVEN BY WEIGHT AND BIRD IMPACT.



NOTES: ADBIRT IS SECOND ITERATION OF F-111 TRANSPARENCY DESIGN. ORIGINAL WAS 2-PLY OF .12 GLASS, FIRST ITERATION (BIRT) IS HEAVY PLASTIC MULTIPLE CONSTRUCTION WITH A .25" THICK ACRYLIC OUTER PLY AND THREE .125 POLYCARBONATE PLIES.

Figure 16. F-111/FB-111 windscreen physical properties.

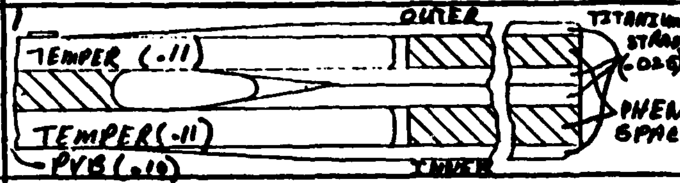
TRANSPARENCY WUC DRAWING NO.	MANUF. PART No.	BOLT-TYPE	CROSS-SECTION	AREA (IN²)	WEIGHT (lbs.)	TORQUE (lbs.-IN)
Front Windshield 16AAC/D 17-17683	PPG 17-17683	TITANIUM ALLOY		1714	39	20
Canopy Hatch 16ABD/E CK03200	PPG 17-17684	TITANIUM ALLOY	SEE DETAIL I SAME	1631	35	20

Figure 17. F/FB-111A/D/E/F windscreen physical properties (older configuration).

T-37 and A-37 Optical Parameters

ANGULAR DEVIATION

Unavailable

OPTICAL DISTORTION

Distortion Limits in Critical and Semicritical Areas

Separation Measurements (From Actual Photograph)	Max. Total Length of Split Lines
0 - 0.0115 inches	Unlimited
0.0115 - 0.02 inches	75 inches
0.02 - 0.03 inches	20 inches
0.03 - 0.04 inches	7 inches

LUMINOUS TRANSMITTANCE

Unavailable

HAZE

Any turbidity within the sheet or on the surface is allowable in the semicritical and not in the critical zone, provided it does not encompass more than one square inch, does not affect grid line definition, and does not affect overall quality of the part.

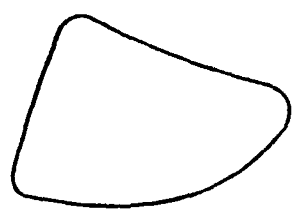
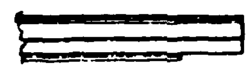
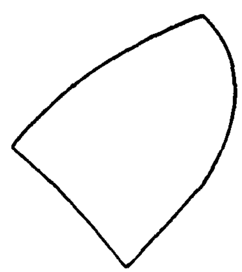
OPTICAL DEFECTS

Hairline Scratches - (not perceptible by fingernail test) - shall be less than 3 inches and not grouped together causing a fogged area

Fine cracks (crazing), fogged areas, loss of definition or blurred lines, or any condition that will be distracting to the pilot shall be cause for rejection.

AIRCRAFT: T-37B / A-37B TYPE: TRAINER / ATTACK

MANUFACTURER: CESSNA AIRCRAFT

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
	 COMPOUND CONTOUR		.08 CAST ACRYLIC .03 INTERLAYER .19 POLYCARBONATE .03 INTERLAYER .19 POLYCARBONATE .03 INTERLAYER .08 POLYCARBONATE
	 COMPOUND CONTOUR		.250 STR ACRYLIC

SLOPE (DEGREES)	39 @ ℄ OF AC	
WEIGHT (LB)	11.2	23
DAYLIGHT AREA (IN.^{2})	1038	893
CABIN PRESSURE(PSI)	NONE	
MAX. CRUISE (KNOTS)	T = 313	A = 440
BIRD PROOF SPEED (KNOTS)		250
RAIN REMOVAL (TYPE)	NONE	
HEATING	ANTI-ICE: NONE DEFOG : HOT AIR	

MISC. DATA:

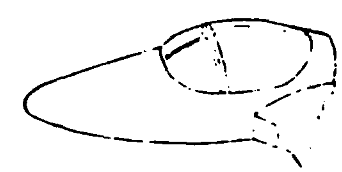


Figure 18. T/A-37B windscreen physical properties.

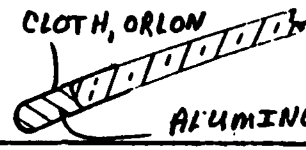
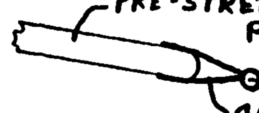
TRANSPARENCY WUC DRAWING NO.	MANUF. PART No.	BOLT-TYPE	CROSS-SECTION	AREA (IN^2)	WEIGHT (lbs.)	TORQUE (lbs.-IN)
Windshield 111A/B 4011707	Goodyear 4011707	Low-Alloy Steel		893	NA	—
Canopy Glass 1112B 4011708	Goodyear 4011708	Low-Alloy Steel		1038	NA	—

Figure 19. T-37 windscreen physical properties (older configuration).

T-38 Optical Parameters

Student's Windshield (critical area)

ANGULAR DEVIATION

Determined from student's eye position ... maximum of 0.4 grid
Determined from instructor's eye position ... maximum of 0.7 grid
Except 6 inches wide across the forward edge ... maximum of 1 grid

OPTICAL DISTORTION

Determined from student's eye position ... maximum slope of 1/12
Determined from instructor's eye position ... maximum slope of 1/8

Student's Canopy (critical area)

ANGULAR DEVIATION

Determined from the instructor's eye position, deviation shall not exceed 1 grid forward, or 3 grids aft, of a line located 10 inches aft of the student's eye position

OPTICAL DISTORTION

Determined from instructor's eye position ... maximum slope of 1/8
EXCEPT: A slope of 1/5 is allowed, provided the total cumulative distorted area does not exceed 100 grids with no individual distortion area over 25 grids.

Instructor's Canopy (critical area)

ANGULAR DEVIATION

Rotate canopy's longitudinal centerline 60 degrees to the right and then rotate to the left of a perpendicular to the grid board ... from the instructor's eye the deviation shall not exceed 1 grid vertically and 0.8 grid horizontally

Raise canopy's longitudinal centerline 32 degrees from the horizontal and perpendicular to the grid board ... from instructor's eye the deviation shall not exceed 0.5 grid vertically and 0.8 grid horizontally within 50 grids to the right or left of the centerline

OPTICAL DISTORTION

From instructor's eye position ... maximum slope of 1/8

Instructor's Windshield (critical area)

ANGULAR DEVIATION

Determined from instructor's eye position ... maximum of 0.4 grid

OPTICAL DISTORTION

Determined from instructor's eye position ... maximum slope of 1/12

LUMINOUS TRANSMITTANCE

Minimum of 80% when measured normal to the surface

HAZE

Maximum of 3%

MINOR DEFECT

Embedded particles, seeds, bubbles, dimples, bumps that can be covered by a circle 0.25 inch in diameter or scratches up to 0.005 inches in depth. Also, minor defects are those which do not impair vision or are clustered to give the effect of a major defect.

MAJOR DEFECT

Cracks, chips, spalls, gouges or scratches in excess of 0.005 inch deep and 0.05 inch in length. Also, other defects clustered to produce a foggy area, cause distortion, or sustained visual distraction

ALLOWABLE DEFECTS FOR BOTH WINDSHIELDS AND CANOPIES

All Critical Areas (and Semi-critical Area for Instructors Canopy)

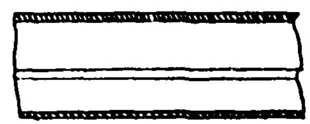
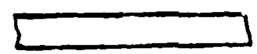
- No major defects allowed. Maximum of 1 minor defect per 1 square foot (6.77 inch radius) circular area

All Noncritical Areas

- Distortion and minor defects are acceptable, provided they do not weaken the structure or appear unsightly

AIRCRAFT: T-38 **TYPE:** TRAINER

MANUFACTURER: NORTHROP CORP

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
WINDSHIELD PPG			PPG 5300 OUTER LINER .375 POLYCARBONATE .06 PPG 112 INTERLAYER .187 POLYCARBONATE PPG 8500 COATING
INSTRUCTORS WINDSHIELD SWEDLOW	SEE OLD CONFIGURATION FOR SHAPE		.50 POLYCARBONATE
CANOPY SWEDLOW	SEE OLD T-38 CONFIGURATION		

SLOPE (DEGREES)	
WEIGHT (LB)	
DAYLIGHT AREA (IN.^{2})	
CABIN PRESSURE (PSI)	
MAX. CRUISE (KNOTS)	
BIRD PROOF SPEED (KNOTS)	≈250 400
RAIN REMOVAL (TYPE)	
HEATING	

MISC. DATA:

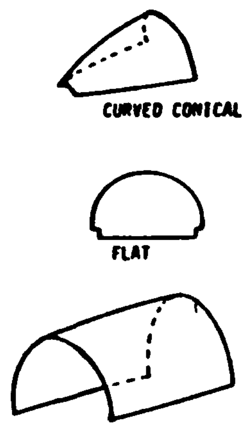
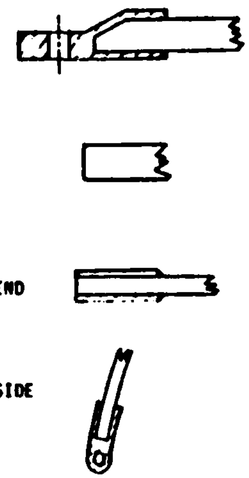
NEWER LAMINATED WINDSHIELD

USES SAME CANOPIES AS THE OLDER VERSION

Figure 20. T-38 windscreen physical properties.

AIRCRAFT: T-38 TYPE: TRAINER

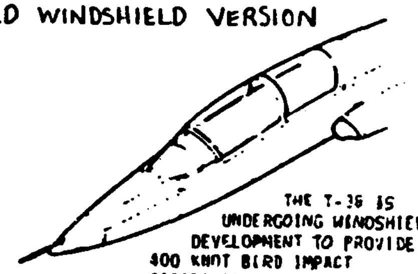
MANUFACTURER: NORTHROP CORP.

TRANSPARENCY AND SUPPLIER	SHAPE	CROSS SECTION AND EDGE	MATERIALS
FORWARD (STUDENT) WINDSHIELD SIERRACIN PPG, IND.	 CURVED CONICAL		.60 STRETCHED ACRYLIC MIL-P-25690 FIBERGLASS EDGE ATTACH
AFT (INSTRUCTOR'S) WINDSHIELD SWEDLOW	FLAT		.40 STR. ACRYLIC MIL-P-25690
FORWARD CANOPY SWEDLOW	COMPOUND CURVED	END SIDE	.25 STRETCHED ACRYLIC MIL-P-25690 FIBERGLASS EDGE ATTACH
AFT CANOPY SWEDLOW	SIMILAR TO FORWARD CANOPY		.40 STRETCHED ACRYLIC MIL-P-25690

	Forward windshield	Aft windshield	Forward canopy	Aft canopy
SLOPE (DEGREES)	27°			
WEIGHT (LB)	41	33	5.8	34
DAYLIGHT AREA (IN.^{2})	1120	1490	280	550
CABIN PRESSURE	5 PSI			
MAX. CRUISE (KNOTS)	MACH 1.2			
BIRD PROOF SPEED (KNOTS)	120	120	≈80	220
RAIN REMOVAL (TYPE)	NONE			
HEATING	HOT AIR DEFOG			

MISC. DATA:

OLD WINDSHIELD VERSION



THE T-38 IS UNDERGOING WINDSHIELD DEVELOPMENT TO PROVIDE A 400 KNOT BIRD IMPACT CAPABILITY AND RETAIN THE THROUGH-THE-CANOPY (TTC) EJECTION CAPABILITY.

Figure 21. T-38 windscreen physical properties (older configuration).

The tables that follow are intended to show comparisons between the aforementioned aircraft. The three different Optical Parameters that will be addressed are:

Optical Parameter	Page Number
Maximum Allowable Haze	45
Minimum Allowable Luminous Transmittance	46
Maximum Allowable Distortion	47

The values for these charts were taken directly from the Specifications for each aircraft and then arranged in tabular form for clarity when comparing.

MAXIMUM ALLOWABLE HAZE CHART

AIRCRAFT	Haze Parameter
A-7	3.5 %
A-10	**
AV-8	
AV-8/GR Mk.5/TAV-8	2 %
TAV-8 Blast Shield	3 %
B1-B	5 %
F-5E Windshield	3 %
F-5E & F-5A Crew Enclosures	3 %
F-14A	**
F-15	2 %
F-16 A/B/C/D	4 %
F-18	2 %
F-111	
With radar reflective coating	4 %
Without radar reflective coating	3 %
T-37 & A-37	**
T-38	3 %

** Unavailable

MINIMUM ALLOWABLE LUMINOUS TRANSMITTANCE CHART

AIRCRAFT	Luminous Transmittance Parameter
A-7	79 % from pilot eye position
A-10	
Quarter Panels	83 % at normal
Center Panels	65 % at 52 degree incidence
AV-8	89 % normal to moldline
B1-B	53 % at normal
F-5E Windshield	IAW MIL-P-25690A
F-5E & F-5A Crew Enclosures	IAW MIL-P-25690A
F-14A	**
F-15	89 % normal to moldline
F-16 A/B/C/D	
Solar Coated	65 % at normal
Non-Solar Coated	79 % at normal
F-18	89 % normal to moldline
F-111	
With radar reflective coating	65 % at normal
Without radar reflective coating	84 % at normal
T-37 & A-37	**
T-38	80 % at normal

** Unavailable

MAXIMUM ALLOWABLE OPTICAL DISTORTION CHART

AIRCRAFT	OPTICAL DISTORTION
A-7	1:10
A-10	Quarter Panels - Zone 1 - 1:10 Zone 2 - 1:8 Zone 3 - 1:4 Zone 4 - 1:2 Center Panel - Critical Vision Area - 1:15 Scanning Area - 1:10
AV-8	Windshield - Max grid line growth of 0.02 Canopy - 1.5 grids per 12 grid run If gradual, 2 grids in 12 is acceptable
B1-B	Zone 1 - 1:9 Zone 2 - 1:6 Zone 3 - 1:3
F-5E Windscreen	Max. grid slope shall not exceed 1/2 in any 2 x 2 square and Max. of 1.2 in 12 grids of run
F-5E & F-5A Crew Enclosures	WINDSHIELD - Supercritical Area - Max. grid line slope of 1/5 in any 2 x 2 square and Maximum of 0.4 in 6 grids of run Critical Area - Max. of 0.5 in 6 grids of run CANOPY - Max. grid line slope of 1/3 in any 2 x 2 square and Max. of 0.5 in 4 grids of run
F-14A	Zone 1 - 1:12 Zone 2 - 1:8
F-15	Max. grid line growth of 0.02
F-16 A/B/C/D	Zone 1 - 1:11 (except 1:9 in small forward area) Zone 2 - 1:9
F-18	Center Optical Area - Max. grid line growth of 0.01 Outer Optical Area - Max. grid line growth of 0.02
F-111	Windscreen - Unavailable Canopy - Zone 1 - 1:10 Zone 2 - 1:6

OPTICAL DISTORTION CHART (Continued)

T-37 & A-37

Limits in Critical and Semicritical Area

Separation Measurement	Max. Total Length of Split Lines
0 - 0.0115	Unlimited
0.0115 - 0.02	75 inches
0.02 - 0.03	20 inches
0.03 - 0.04	7 inches

T-38 ... STUDENT WINDSHIELD - Student eye position - 1:12
Instructors eye position - 1:8

STUDENT CANOPY - 1:8 from instructors eye position (except 1:5 is allowed provided the total distorted area is accumulatively less than 100 grids with no individual distorted area over 25 grids

INSTRUCTOR WINDSHIELD - Instructors eye position - 1:12

INSTRUCTOR CANOPY - Instructors eye position - 1:8

CONCLUSION

This report reflects state of the art information that will obviously become outdated as technology continues to evolve. Revised editions of this Technical Report will be submitted whenever significant new information has accumulated. Hopefully, by reviewing the currently measured optical parameters in this report, the reader may now have a broader knowledge with which to apply the development of aircraft windscreens.

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MIL-W-81752 (AS) : Windshield Systems, Fixed Wing Aircraft - General Specification

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