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AN ILLUSTRATED GUIDE OF OPTICAL CHARACTERISTICS OF AIRCRAFT TRANSPARENCIES (U)

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ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

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TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Armstrong Aerospace Medical Research Laboratory

Item 18 (Keywords) continued:

Multiple Imaging
Reflections
Defect
Optical
Distortion
Transparency
Aircraft
Delamination
Diffraction
Acrylic
Rainbowing
Crazing
Characteristic
Polycarbonate

Preface

This report was prepared under work unit 7184-18-02 by members of Crew Systems Effectiveness Branch, Human Engineering Division, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Funding was provided by the Wright Research and Development Center's Aircrew Protection Branch (WRDC/FIVR). The authors express their appreciation to Mr. Malcolm Kelley of FIVR for his careful review of the draft report.

This is the second of a series of three technical reports relating to aircraft transparencies. The first report, AAMRL-TR-88-058, entitled *Specifications and Measurement Procedures for Aircraft Transparencies*, was published in September of 1988. The third report, *Optical Terms and Definitions of Aircraft Transparencies*, has not yet been published. The inside front cover of this report contains instructions for obtaining copies of these reports.

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Introduction

1.1 Purpose

The purpose of this report is to describe, and wherever possible illustrate, the optical characteristics common to aircraft transparencies. It may be used as a guide by aircrews, maintenance personnel, and others working with transparencies to accurately identify these characteristics.

It is important that windscreens which are removed from aircraft for optical deficiency are correctly labeled as to the nature of the deficiency and/or cause for removal. This information is used by Air Force laboratories to relate the severity of optical characteristics to aircrew acceptability. The results of these studies help the Air Force set realistic and relevant optical specifications for transparencies.

1.2 Background

The manufacturing of aircraft transparencies is not an exact process. Transparency manufacturers must control a number of variables in the production of a single transparency. One variable is the material from which transparencies are made. A sheet of polycarbonate, for example, might behave slightly differently than another sheet in the forming process, although both sheets are from the same supplier, and perhaps even from the same batch. Another variable is the process of finish polishing, which may be performed by an automated machine or in some cases by a skilled technician with a trained eye. These and other variables result in uncertainty in the optical quality of the final product.

Quality control of transparencies plays an important role in assuring that this variability in optical characteristics does not have a negative effect on the end user of the product, the pilot. This is not easy because optical parameters are difficult to quantify in parameters which relate to visual performance. Furthermore, there is seldom a clear distinction between acceptable and unacceptable values for these parameters.

1.3 Scope

This document describes and illustrates some of the more common optical characteristics which may impact aircrew visual performance. It is not comprehensive in that it does not include characteristics other than of an optical nature. It also does not include obvious optical characteristics like large scratches and gouges from maintenance tools. These large scratches are a leading reason for transparency removals. Most of the information contained in this document will apply to aircraft transparencies in general; however, the intended application of this work involves primarily modern military aircraft.

1.4 Nomenclature

The aircraft transparency industry, like other specialized fields, has a unique vocabulary. Thus it is important to define some of the terms which are used to describe transparencies. Transparencies are typically categorized by three primary characteristics: location on the aircraft, structure of composition, and type of material.

Location: Transparencies categorized by location on the aircraft are known as windscreens, canopies, windows, or other specialized names. However, there are numerous aircraft designs, and not all windscreens will fit neatly into one of these categories.

A windscreen, also called a windshield, is a transparency located in the forward section of the cockpit and provides the primary area of vision for pilots. It is usually a single windscreen, or in a pair (left and right). The forward transparency on most general aviation, military, and commercial aircraft is called a windscreen.

A canopy is a transparency which provides vision mainly to the overhead and side areas. A canopy system commonly consists of a single canopy (F-15), two canopies in tandem (F-4, T-38), or two canopy hatches side by side (F-111). In many military and in some general aviation aircraft, there is only one transparency which covers the entire cockpit and provides vision to the forward as well as the side and overhead areas. In this case the entire transparency is referred to as the canopy. An example of this is the F-16.

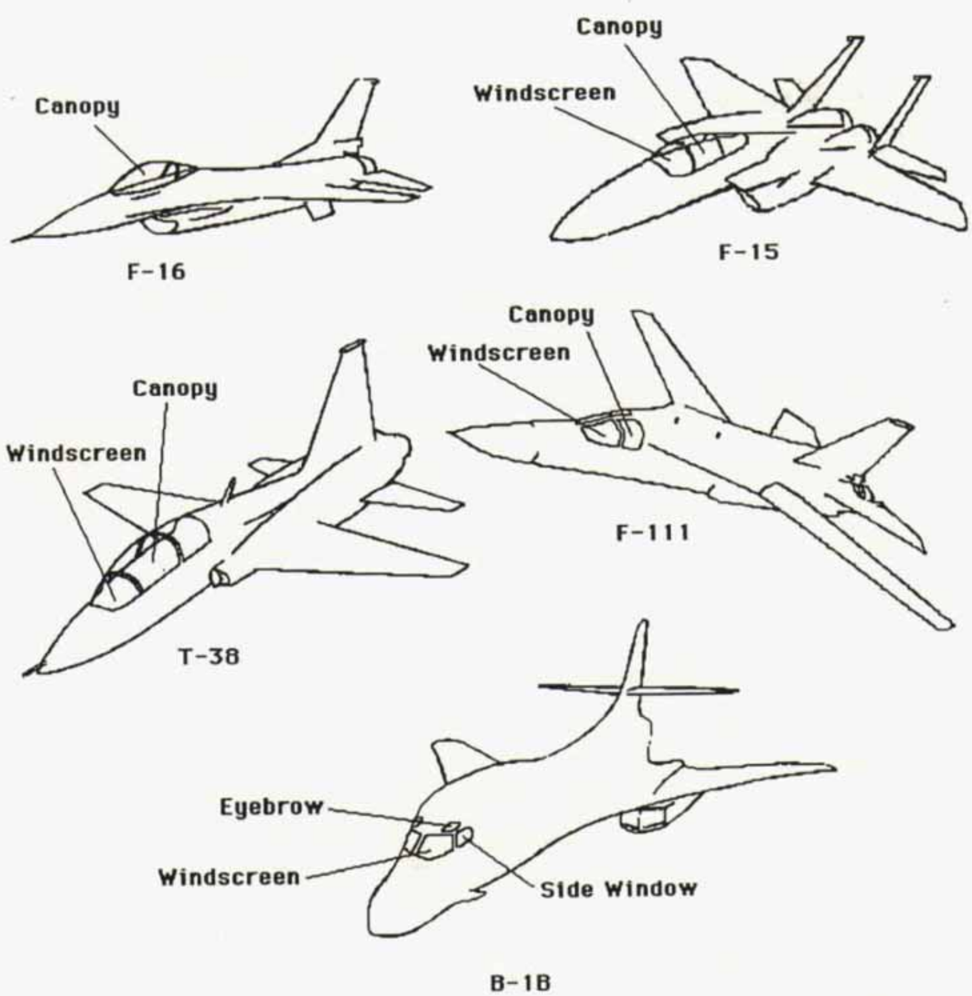

Figure 1.1: Some examples of aircraft transparencies.

A window is a transparency which provides vision mainly to the side areas. It is often smaller in size and can appear almost anywhere on the aircraft. Commercial passenger jets have many side windows, and most light general aviation aircraft have windows on the side door or fuselage.

Some other types of transparencies are the skylight and the eyebrow. Skylights are small overhead windows, often tinted, located above the pilot. The eyebrow is a small window found in pairs on some larger aircraft just aft of windscreen. The eyebrow windows provide limited vision to the forward overhead area. Figure 1.1 shows some examples of aircraft transparencies.

Composition: A transparency identified by structure of composition is known as either a monolithic or a laminate. A monolithic transparency is one which is constructed of a single ply of material. A laminate is a transparency which is constructed of two or more plies of material bonded together with another material known as an interlayer.

The plies of a laminated transparency may be of the same or different materials, and each ply has a specific name. The ply which provides primary strength of the transparency is known as the structural, main, or core ply, and is usually polycarbonate for smaller and faster aircraft (fighters) and glass for larger and slower aircraft (cargo aircraft). The ply exposed to the outer surface is commonly called the outer ply. It may be composed of glass, acrylic, or polycarbonate, and frequently has one or more coatings applied to it. The ply exposed to the inner surface is called the inner ply or spall shield. It is usually acrylic or polycarbonate, and may also have a coating applied to it (usually a hardcoat). Materials used to bond plies of a laminated transparency together are called interlayers; common interlayer materials are silicone and polyurethane. The interlayer is somewhat flexible to allow for thermal expansion of the plies while maintaining the bond between the plies.

Materials: Transparencies may also be identified by the type of material from which they are constructed. The most common materials are glass (includes various glass types), acrylic (cast and stretched), and polycarbonate. Laminates can be identified by a name such as a "polycarbonate/acrylic laminate". Materials are often identified by trade names within the transparency industry.

Glass is a very hard material and stands up well to abrasion, which makes it suitable for the outer surface of a windscreen, where many fine particles constantly impact the transparency during flight. The main disadvantages of glass are its weight and its inability to withstand significant impacts.

Polycarbonate is a relatively flexible material. It is used for its light weight, strength and ability to withstand impacts. Its primary disadvantage is that its surface is relatively soft, so it is easily abraded and scratched.

Acrylic has qualities between those of glass and polycarbonate. Its surface hardness is greater than polycarbonate, making it more abrasion resistant, but less than that of glass. Its strength is greater than that of glass, but less than polycarbonate.

Descriptive names for transparencies can also be combined to be more specific. One might refer to a "monolithic stretched acrylic cabin window," or a "polycarbonate/glass laminate windscreen." These are just two of many possibilities.

Optical Characteristics

2.1 Format

This chapter contains a list of optical characteristics common to aircraft transparencies. The definitions and explanations that follow will be for terms as they apply and are related to aircraft transparencies. Some terms may have more general meanings or be defined differently in other fields. The format used for each characteristic is:

- *Name of characteristic:* (alternate names in parenthesis)
- *Explanation:* This section generally includes a brief definition; it may also include the reason for the characteristic or other significant information.
- *Inspection:* A brief statement of how to inspect an aircraft transparency for the particular characteristic.
- *Measurement:* A listing of the procedure used to measure (quantify) the characteristic, if a procedure exists. Many characteristics have no objective measurement procedure; only a subjective estimate of the severity is made. If a procedure has been established, it is often documented as an American Society for Testing and Materials (ASTM) Standard Method.
- *Visual effect:* A statement of the impact of the characteristic on aircrew visual performance.
- *Illustrations:* Since this document focuses on optical characteristics, a major part of it will be devoted to the photographs and illustrations.

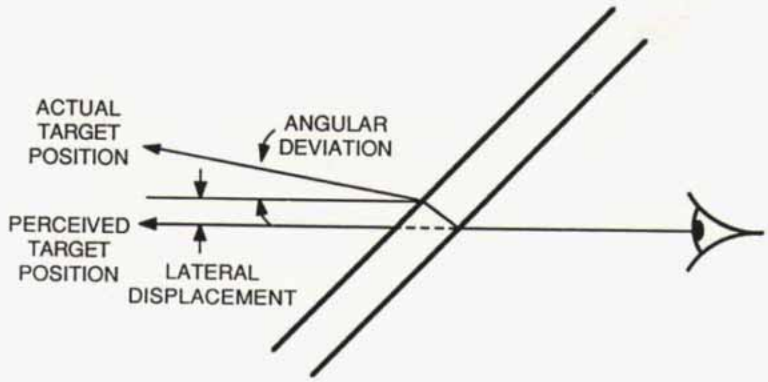

Figure 2.1: Angular Deviation.

2.2 Angular Deviation (prismatic deviation, deviation)

Explanation: Angular deviation is the angular change that occurs when a light ray passes through a transparency (see figure 2.1). The change is usually due to non-parallel surfaces in the transparency. The amount of angular deviation depends on the index of refraction of the material, the angle of incidence, and the shape of the material. (For a more detailed account refer to Hecht, 1975.)

It is especially important to characterize angular deviation in aircraft equipped with a head-up display (HUD). When the pilot places the HUD aiming reticle (pipper) on the target, he is aiming his weapon at the location where he visually perceives the target. If the transparency causes angular deviation, the target will actually be displaced from where the pilot sees it, similar to how an object under water appears in a different position from where it actually is.

Inspection: In general, angular deviation cannot be easily detected in the field by optical or visual means. Consistent bias effects in weapons aiming is an indication that uncompensated angular deviation may exist in the transparency. More often the derivative of angular deviation (rate of change of angular deviation) is noticed which manifests itself as distortion (see section on distortion).

Measurement: Measurement of angular deviation is performed with an angular deviation device (ASTM Standard Method F801) or a collimated light source and theodolite. These measurements are done in a laboratory with the windscreen removed from the aircraft. At present there are no methods of measuring angular deviation in the field.

Visual Effect: There is no obvious visual effect of angular deviation; the only effect is an indirect one due to weapons system inaccuracies caused by the angular deviation as discussed above.

2.3 Binocular Disparity

Explanation: Binocular disparity exists when the image seen with the left eye is different from the image seen by the right eye. A certain amount of disparity is natural, since the eyes are physically separated. However, excessive binocular disparity may be caused by the transparency or the interaction of the transparency with the HUD, leading to visual problems.

Binocular disparity is most often caused by the binocular deviation of the transparency. Binocular deviation is the difference in angular deviation measurements made from the left and right eye positions for a given view angle. Thus it is the angle that the eyes would have to converge or diverge to fixate on an object located at optical infinity. Binocular disparity can also occur when the HUD symbology appears at a different optical distance than the outside target does. This can cause either the HUD symbology or the target to appear widened or double.

Inspection: Binocular disparity is sometimes difficult to notice by visual inspection. It may be detected by alternately closing the left and right eyes and observing a shift in the position of an object.

Measurement: Binocular deviation can be measured by taking angular deviation measurements from the left and right eye position and subtracting the left eye result from the right eye result. This is done for both horizontal and vertical angular deviation directions. The horizontal data provides information on eye convergence or divergence and the vertical data provides information on eye dipvergence (one eye having to rotate upward or downward compared to the other eye in order to fuse the images). It may also be quantified by taking double exposure photographs through the transparency, with one exposure made with the camera in the left eye position and the other from the right eye position (without

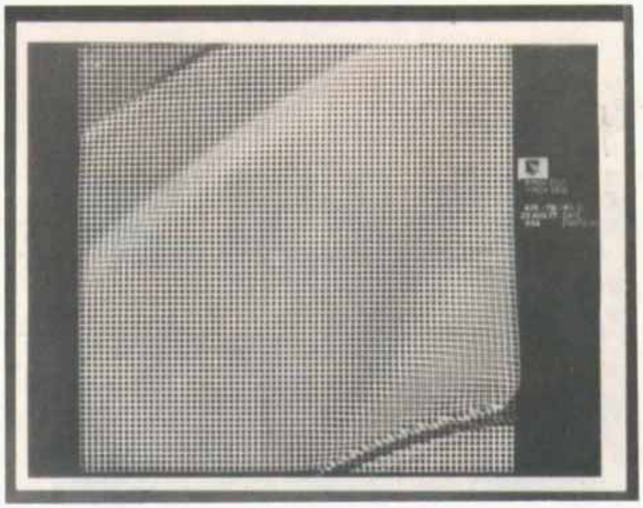

Figure 2.2: Double exposure photograph showing binocular deviation.

advancing the film). Separation of the grid lines indicates the presence of binocular deviation (see figure 2.2). This latter method, however, does not distinguish between lateral displacement effects and angular deviation effects. It is therefore only a good measure of binocular disparity for the specific grid board distance used to obtain the double exposure photographs.

Visual Effect: Binocular disparity may be manifested in several ways: eye strain, headache, fatigue, suppression of the image from one eye by the visual system, or doubling of vision. Sometimes these effects may occur only over a period of extended viewing. Tolerances for binocular disparity vary among individuals, so a certain amount of disparity may cause problems for one individual and not another.

2.4 Birefringence (rainbowing)

Explanation: The term birefringence means the material in question has two indices of refraction. Polycarbonate under stress becomes birefringent and thus exhibits two indices of refraction that align with the directions of the stress. These two indices of refraction cause polarized light to travel at different velocities through the material. The incoming linearly polarized light is converted to elliptically polarized light due to the birefringence. The degree of rotation of the electric field vector of the light further depends on the wavelength

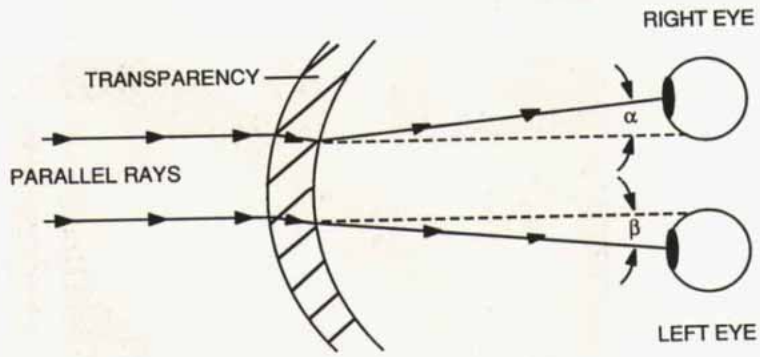

Figure 2.3: Binocular Deviation causing convergence of the eyes.

(color) of the light since the material also has a certain amount of chromatic dispersion. When the light exits the windscreen, the angle of exit acts like a partial analyzer (polarizer) which results in some wavelengths being attenuated more than others. Thus the exiting light exhibits a color effect depending on the degree of birefringence and the extent of the polarization. These color patterns, or rainbowing, can be relatively strong for clear blue sky days (blue sky can be about 80% polarized). The pattern of these colors on the windscreen remains constant as a result of built in residual stress in the windscreen (during the manufacturing process), but the actual colors making up the pattern will vary depending on the orientation of the windscreen with respect to the polarization vector of the exterior light.

Inspection: Birefringence is visible to the unaided eye when observing the transparency with a polarized light source, such as a clear blue sky. The birefringence pattern can be enhanced by observing it through a second polarizer, such as a pair of polarized sun glasses. (This is why USAF pilots are not allowed to fly with polarized sun glasses.)

Measurement: There is as yet no accepted method of measuring birefringence in terms of its effects on vision.

Visual Effect: Birefringence has been noted as a concern but has not been labeled as a problem. Anecdotal information gathered on F- 111 and B-1 windscreens indicates that the primary visual effect is one of annoyance or minor distraction.

Figure 2.4: Birefringence patterns of F-111 windscreens produced by two different manufacturing techniques.

Figure 2.5: Example of crazing.

2.5 Crazing

Explanation: Crazing is the occurrence of very small "micro cracks" in a transparency or coating. These cracks usually are localized and are oriented in the same direction. In bright light conditions and at certain sun geometries, the cracks will act like many tiny mirrors and reflect light into the pilot's line of sight (see figure 2.5). Crazing may be induced by chemicals, age, or other causes.

Inspection: Visual examination of the transparency under bright light conditions is a good way to observe crazing. However, the appearance of crazing is dependent upon the relative positions of the light source, transparency, and observer, so it may be difficult to observe if the geometry is not right.

Measurement: There is no quantitative method to measure crazing as of this writing. Extent of crazing is left to subjective judgement.

Visual Effect: Crazing can be almost invisible and have essentially no effect on vision until the sun angle is just right and the micro-cracks (acting like little mirrors) reflect the sunlight directly into the pilot's eyes. Under this reflection condition the visual effect is significant loss of contrast in the exterior world scene which can cause severe visual impairment during the time the reflection geometry is satisfied.

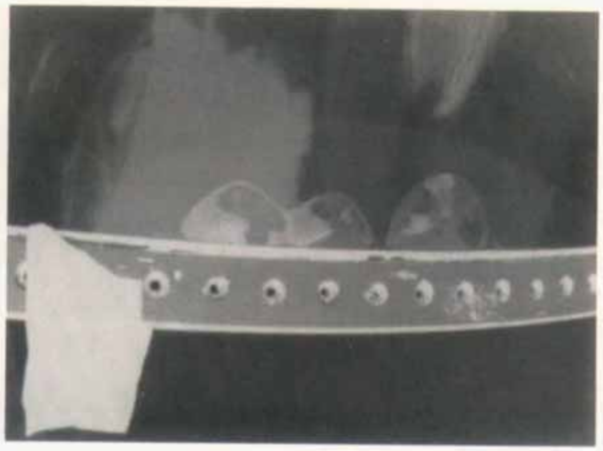

Figure 2.6: Delamination of an F-111 caused by overheating of the windscreen by the rain removal system.

2.6 Delamination

Explanation: Delamination is a separation of the layers of a laminated transparency which may be due to residual or induced stress in the transparency. There are several events that may enhance the occurrence of delamination, such as overheating the transparency, thermal cycling, and defective manufacturing.

Inspection: Delamination is detected by looking for bubble areas within the transparency; it often occurs near an edge.

Measurement: There is no specified method to measure delamination, although the width (distance from the edge of the windscreen) of the delamination area is commonly measured using a ruler.

Visual Effect: Delamination is easily noticed but is usually confined to the edges of a transparency (at least in its early stages). This reduces any effect on vision. The area that is delaminated has a lower transmissivity and higher reflectivity due to the extra air- plastic/glass interface that is created at the delamination. This also enhances the effect of multiple imaging.

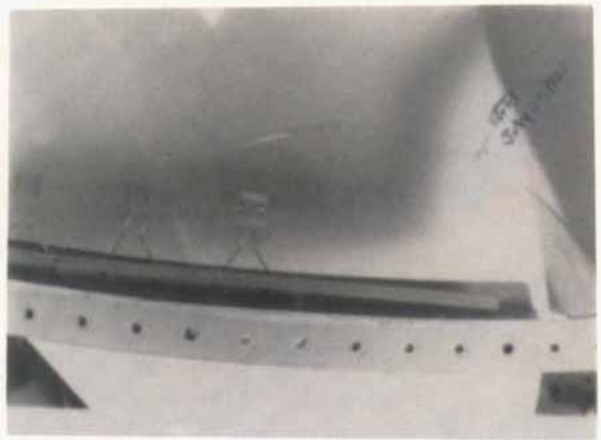

Figure 2.7: Delamination of a B-1B windscreen near the thermal sensors.

2.7 Diffraction (streaking, starburst patterns, bowtie effect, arcing)

Explanation: Diffraction is one of the three basic means by which light rays change their direction of travel (the other two are refraction and reflection). Diffraction is a rather complex subject, but the effect essentially occurs as a scattering of light from the edges of some obstacle. This scattering can occur from objects too small to see or from easily visible scratches on the surface of a transparency. Diffraction of light from very tiny objects (at the molecular level) is what gives rise to haze. This type of effect is evident in even new materials since it is a characteristic of the material itself (haze or halation is discussed in section 2.9). Diffraction also occurs from inclusions (meshes) and microscratches on the surface of the windscreen. Sometimes these scratches are not in random orientations but are in uniform directions, which give rise to an easily noticeable diffraction pattern. If the scratches are all in one direction or arch, the resulting diffraction pattern will appear as streaks emanating from point sources of light. These patterns are usually only evident at night when viewing point sources of light. This is because in the daytime the daylight scene washes out the pattern effects making them invisible to the naked eye.

Inspection: Diffraction is detected by looking through the transparency at a light source at night or in a dark environment.

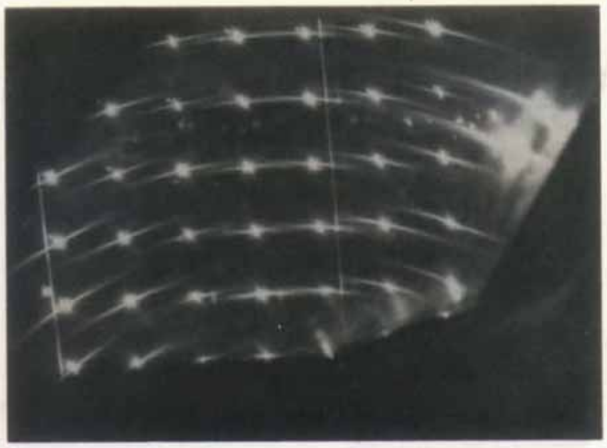

Figure 2.8: Diffraction patterns of the lights of a multiple imaging light array as viewed through a defective B-1B windscreen.

Measurement: There is no measurement for diffraction other than a subjective assessment.

Visual Effect: Diffraction patterns are usually only distracting; they are observed primarily at night.

2.8 Distortion

Explanation: Distortion is the rate of change of angular deviation across the transparency. It can be caused by non-parallelisms in the surfaces of a transparency or localized changes in the index of refraction of the transparent material. There are several types of distortion which have specific names within the transparency industry. Some of the more common types are listed here:

1. ***bullseye*** – caused by a localized depression or bulge in the transparency, creating a circular lens-like distortion; hence, the name "bullseye."
2. ***band distortion*** – distortion occurring in a narrow, elongated region across an area of the transparency.
3. ***edge distortion*** – distortion occurring at or near the edge of a transparency. Often the most severe distortion within the transparency will occur along an edge.
4. ***deletion line distortion*** – a thermally induced distortion occurring around the heater

Figure 2.9: Diffraction of a point light source through a canopy.

coating deletion line. A large temperature gradient between the heated and unheated portions of the windscreen may cause localized distortion in some transparencies where the index of refraction varies with temperature.

Inspection: Distortion is readily identified visually by viewing objects through the transparency and noting waviness in lines and changes in the shapes and relative sizes of objects, particularly near the edges of a transparency and in areas where the viewing angle is very acute.

Measurement: Currently three methods for measuring distortion are used within the transparency industry: grid line slope, displacement grade, and lens factor. The most widely used method is grid line slope (ASTM Standard Method F 733 or variations). Grid line slope measurements are made by taking a photograph of a grid board through the windscreen. The maximum slope of a horizontal grid line is the grid line slope value of the transparency.

Visual Effect: The visual effects of distortion depend upon the severity of distortion. Distortion may be distracting, give false motion cues by changing the perceived relative velocity of out-of-the-cockpit objects, or in some cases cause headache and nausea. Minor distortions, while aesthetically unappealing, have shown no significant degradation on the performance of visual tasks.

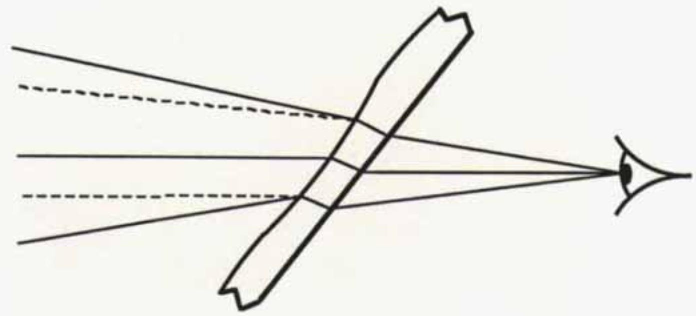

Figure 2.10: An illustration of how distortion occurs.

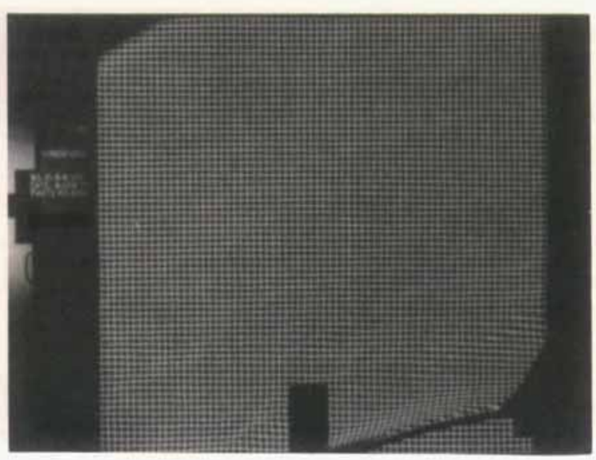

Figure 2.11: Distortion of a grid board as viewed through a transparency.

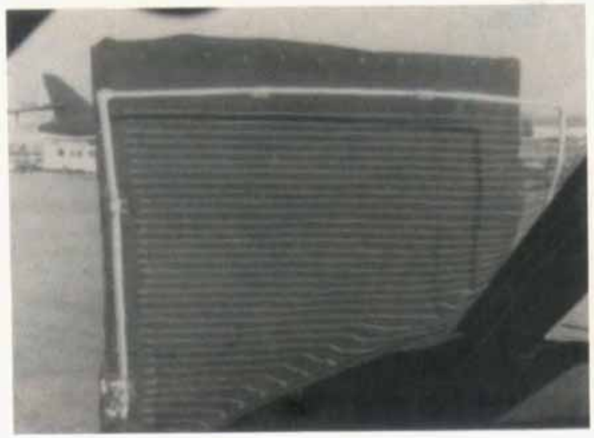

Figure 2.12: Distortion of a field-portable string board through a B-1B windscreen. Note the edge distortion.

Figure 2.13: Distortion of an aircraft when viewed through the heater coating deletion line of a B-1B windscreen.

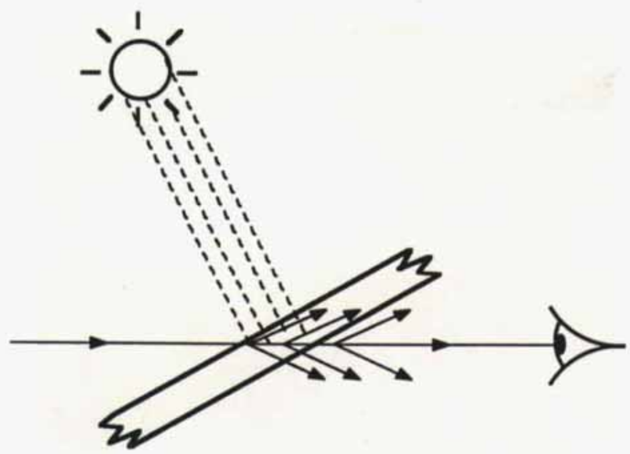

Figure 2.14: An illustration of how halation occurs.

2.9 Halation (haze, scatter, glare)

Explanation: Halation is the scattering of light by the windscreen into the line of sight of the pilot. It is caused by the diffraction of light by particles within the transparency or by fine scratches and/or dirt on the surface. It is most significant when flying towards the sun and may occlude significant portions of the field of view. (See figures 2.14 and 2.15.)

Inspection: Halation is observed by looking through the transparency with a bright light source (or the sun) shining on it. Any veiling glare or scattered light by the transparency that interferes with your view is known as halation, or haze. The amount of haze depends on the intensity and location of the light source and the view angle.

Measurement: Halation may be measured by ASTM Standard Method F 943 in the field and in the laboratory or by D 1003 in the laboratory only. Haze may be quantified as the haze index value (by ASTM F 943) or as percent haze (ASTM D 1003).

Visual Effect: Halation reduces the contrast of objects viewed through the transparency, which makes out-of-the-cockpit objects less visible and decreases the detection range of air-to-air targets.

2.10 Multiple Imaging (ghost images)

Explanation: Multiple imaging is observed only at night or in very dark ambient light

Figure 2.15: An example of halation.

conditions. It is the appearance of two or more images of a single object or light source. It is caused by light rays reflecting off the inner and outer surfaces of the transparency and back into the pilot's eye. Secondary images may vary in location and intensity with respect to the primary image. (See figures 2.16 - 2.19.)

Inspection: Multiple images are observed by looking through the transparency at night (or in a dark environment) at bright light sources. They appear as fainter images of the lights around the primary image.

Measurement: The angular displacement of the secondary images from the primary image may be measured following ASTM F 1165. The intensity ratio of the images may also be measured, although a formal procedure does not yet exist.

Visual Effect: In most cases multiple images are simply distracting. In extreme cases, they may give the pilot false motion cues, such as an inaccurate perception of approach velocity or rate of descent during nighttime landing.

2.11 Reflections (cockpit reflections)

Explanation: Reflections from transparency surfaces of cockpit objects (glare shield, flight suit, helmet, etc.) or instrument lights interfere with the aircrew's out-of-the cockpit vision. The reflections are most significant at night or in bright sunlight conditions.

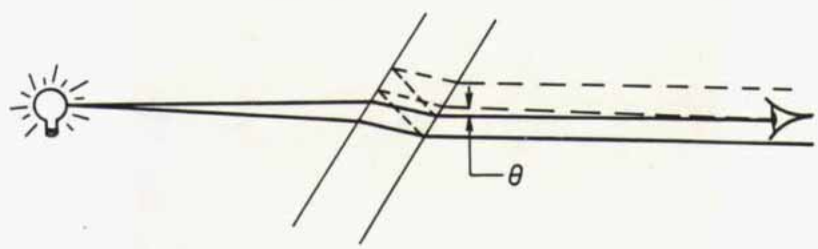

Figure 2.16: Illustration showing how multiple images are perceived.

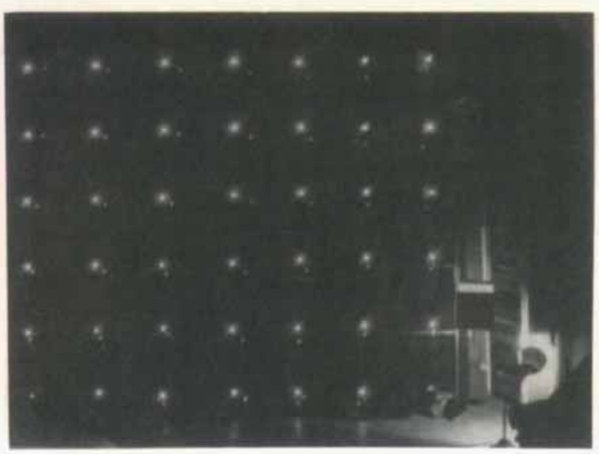

Figure 2.17: Multiple Imaging of a 7 X 7 light array.

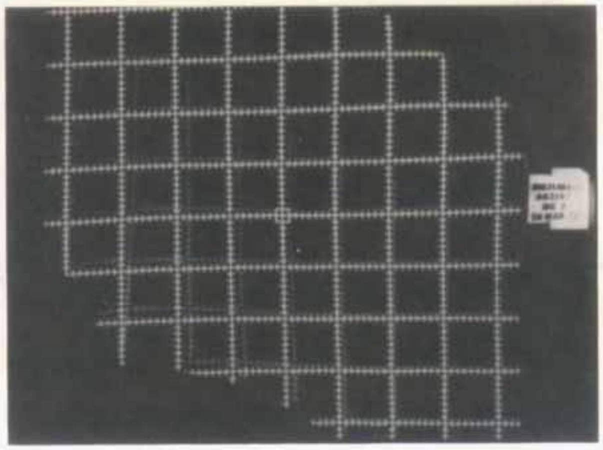

Figure 2.18: Multiple Imaging of a 6" grid board.

Figure 2.19: Multiple Imaging of lights through a B-1B transparency. (This transparency was later removed from the aircraft for objectionable multiple imaging.)

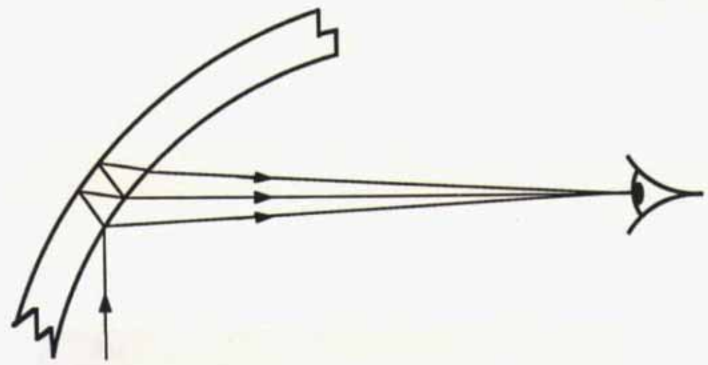

Figure 2.20: Illustration of how internal reflections occur.

Inspection: Reflections are easily observed visually under a variety of conditions.

Measurement: The reflectivity of a transparency may be measured photometrically. A new ASTM standard method is currently being published which details the measurement procedure.

Visual Effect: Reflections on the transparency reduce the contrast of out-of-the-cockpit objects and may even obscure these objects.

Figure 2.21: Reflections of the glare shield.

Comments

3.1 Notice to Aircrews and Maintenance personnel

By reading this technical report you may have learned of some optical defects of transparencies of which you previously were not aware. Now that you know about these characteristics, there may be a natural tendency to direct more of your attention to transparency optical quality, and perhaps be more critical of the transparencies which you are now flying. Undoubtably you will experience firsthand some, and perhaps many, of these characteristics;

This is not necessarily reason to have these transparencies removed from the aircraft.

Acceptable transparencies will exhibit many of these characteristics to some degree. It is only when these features become excessive that removal of the transparency is in order. This, of course, is a matter of judgement. It is probable that if you did not object to the transparency prior to reading this report, then the transparency is acceptable. Please use discretion when determining whether a transparency should be removed. If it is removed, however, carefully document the reasons for removal. Use this report as a guide so the reasons for removal are correctly and accurately identified.

3.2 General Comments

This report provides textual and pictorial information on the optical characteristics encountered in aircraft transparencies. There are measurement procedures available for quantifying most of these characteristics. However, the procedures for some of these, such as distortion, are still not satisfactory from the standpoint of being able to relate the measurement of distortion (grid line slope) to the subjective visual effect of the distortion. New procedures and methods of relating the values produced by these procedures of measurement are in development. There is still much work to be done to accurately characterize the optical effects of aircraft windscreens and their effects on visual performance.

Any questions concerning this report or current work in the area of characterizing the optical effects of aircraft windscreens should be directed to:

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Bibliography

[1] American Society for Testing and Materials. *Standard Test Method for Measuring Binocular Disparity in Transparent Parts.* Draft ASTM Standard Test Method (unpublished).

[2] American Society for Testing and Materials. *Standard Test Method for Measuring Optical Reflections from Transparent Materials.* Draft ASTM Standard Test Method (unpublished).

[3] American Society for Testing and Materials. *Standard Test Method for Measuring the Transmissivity of Transparent Parts.* Draft ASTM Standard Test Method (unpublished).

[4] American Society for Testing and Materials. *ASTM D 1003-61 Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics*, 1961.

[5] American Society for Testing and Materials. *ASTM F 733-81 Optical distortion and deviation of transparent parts using the double-exposure method*, August 1981.

[6] American Society for Testing and Materials. *ASTM F 801-83 Measuring Optical Angular Deviation of Transparent Parts*, March 1983.

[7] American Society for Testing and Materials. *ASTM F 943-85 Measuring Halation of Transparent Parts*, July 1985.

[8] American Society for Testing and Materials. *ASTM F 1165-88 Standard Test Method for Measuring Angular Displacement of Multiple Images in Transparent Parts*, October 1988.

[9] Louis V. Genco and Harry L. Task. Aircraft transparency optical quality: New methods of measurement. Technical Report AFAMRL-TR-81-21, Air Force Aerospace Medical Research Laboratory, 1981.

[10] Eugene Hecht. *Theory and Problems of Optics.* McGraw-Hill Book Company, New York, 1975.

[11] William N. Kama. Visual perception through windscreens: effects of minor occlusions and haze on operator performance, December 1983. Paper in: Conference on aerospace transparent materials and enclosures.

[12] Leslie Lamport. LaTeX *Users Guide & Reference Manual.* Addison-Wesley Publishing Company, Reading, Massachusetts, 1986.

[13] Peter T. Lapuma and John C. Bridenbaugh. Specifications and measurement procedures for aircraft transparencies. Technical Report AAMRL-TR-88-058, Air Force Aerospace Medical Research Laboratory, September 1988.

[14] Harry L. Task. Vision through aircraft transparencies, April 1988. Paper reprinted from AGARD Lecture Series No. 156.

[15] Harry L. Task and Louis V. Genco. The measurement of aircraft windscreen haze and its effect on visual performance. Technical Report AFAMRL-TR-85-016, Air Force Aerospace Medical Research Laboratory, February 1985.