Designation: F2156 – 17

Standard Test Method for Measuring Optical Distortion in Transparent Parts Using Grid Line Slope[1]

This standard is issued under the fixed designation F2156; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 When an observer looks through an aerospace transparency, relative optical distortion results, specifically in thick, highly angled, multilayered plastic parts. Distortion occurs in all transparencies but is especially critical to aerospace applications such as combat and commercial aircraft windscreens, canopies, or cabin windows. This is especially true during operations such as takeoff, landing, and aerial refueling. It is critical to be able to quantify optical distortion for procurement activities.

1.2 This test method covers the apparatus and procedures that are suitable for measuring the grid line slope (GLS) of transparent parts, including those that are small or large, thin or thick, flat or curved, or already installed. This test method is not recommended for raw material.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3.1 *Exception*—The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

F733 Practice for Optical Distortion and Deviation of Transparent Parts Using the Double-Exposure Method

F801 Test Method for Measuring Optical Angular Deviation of Transparent Parts

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *design eye, n*—the reference point in aircraft design from which all anthropometrical design considerations are taken.

3.1.2 *distortion, n*—the rate of change of deviation resulting from an irregularity in a transparent part.

3.1.2.1 *Discussion*—Distortion shall be expressed as the slope of the angle of localized grid line bending, for example, 1 in 5 (see Fig. 1).

3.1.3 *grid board, n*—an optical evaluation tool used to detect the presence of distortion in transparent parts.

3.1.3.1 *Discussion*—The grid board is usually, but not always, a vertical rectangular backboard with horizontal and vertical intersecting lines with maximum contrast between the white lines and the black background.

3.1.4 *grid line slope, n*—an optical distortion evaluation parameter that compares the slope of a deviated grid line to that of a nondeviated grid line.

3.1.4.1 *Discussion*—The degree of deviation shall be indicated by a ratio, for example, 1 in 2, 1 in 8, or 1 in 20 (the visual optical quality improves as the second number gets larger.)

[1] This test method is under the jurisdiction of ASTM Committee F07 on Aerospace and Aircraft, and is the direct responsibility of Subcommittee F07.08 on Transparent Enclosures and Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

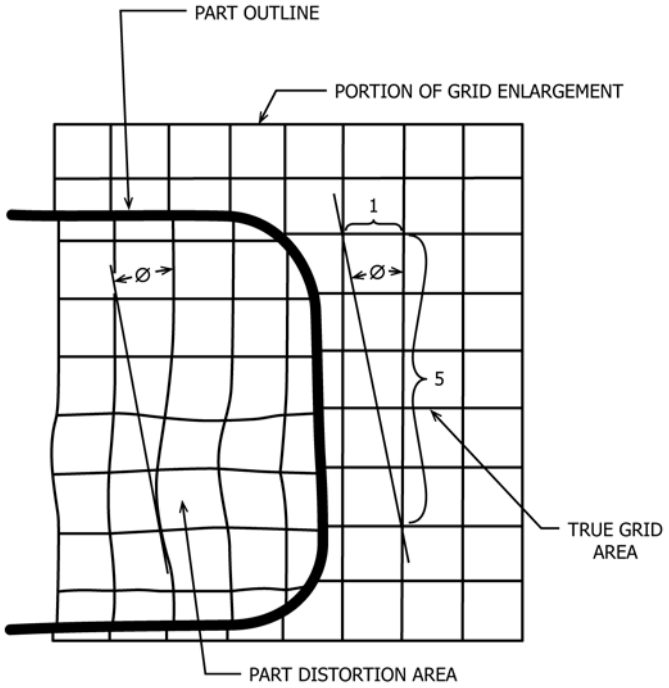

FIG. 1 Optical Distortion Represented By Tangent

3.1.5 *installed angle, n*—the transparency orientation as installed in the aircraft, defined by the angle between a horizontal line (line of sight) and a plane tangent to the surface of the transparency (see Fig. 2).

3.1.6 *repeatability limit (rL), n*—from Practice E177, 27.3.2, "approximately 95 % of individual test results from laboratories similar to those in an Inter-laboratory Study (ILS) are expected to differ in absolute value from their average value by less than 1.96*s* (about 2*s*)."

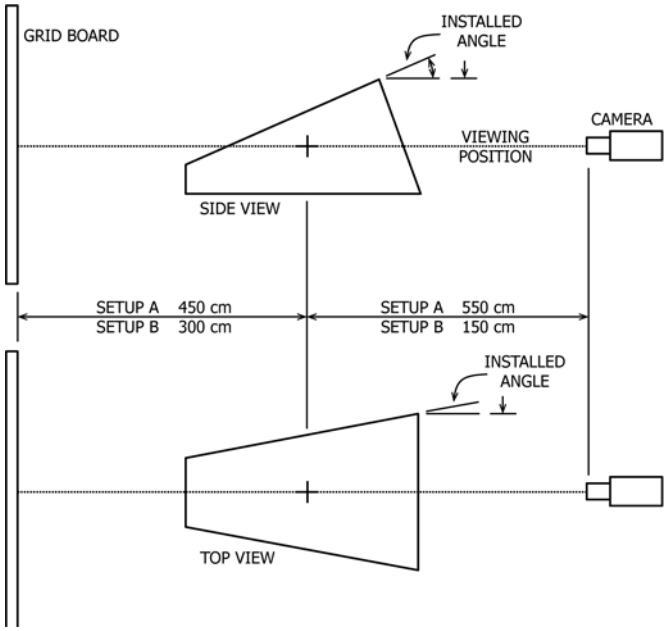

FIG. 2 Schematic Diagrams of GLS Photographic Recording Distances

3.1.6.1 *Discussion*—in terms of this test method, approximately 95 % of all pairs of replications from the same evaluator and the same photo differ in absolute value by less than the *rL*.

3.1.7 *reproducibility limit (RL), n*—from Practice E177, 27.3.3, "approximately 95 % of all pairs of test results from laboratories similar to those in the study are expected to differ in absolute value by less than $1.960\sqrt{2}s$ (about $2.0\sqrt{2}s$) = $2.77s$ (or about $2.8s$). This index is also known as the 95 % limit on the difference between two test results."

3.1.7.1 *Discussion*—in terms of this test method, approximately 95 % of all pairs of replications from different evaluators and the same photo differ in absolute value by less than the *RL*.

4. Summary of Test Method

4.1 The transparent part shall be mounted, preferably at the installed angle, at a specified distance from a grid board test pattern. A photographic camera shall be placed so as to record the grid pattern as viewed through the part from the design eye (or other specified) viewing position. If the viewing position is not defined, the values in Table 1 shall be used as photographic test geometry. The image is then analyzed to assess the level of optical distortion as measured by grid line slope.

4.2 Distortion shall be recorded using either a single-exposure photograph or a double-exposure photograph. The photographed grid shall then be measured using either a drafting machine procedure or a manual procedure. Each procedure has its own level of precision.

5. Significance and Use

5.1 Transparent parts, such as aircraft windshields, canopies, cabin windows, and visors, shall be measured for compliance with optical distortion specifications using this test method. This test method is suitable for assessing optical distortion of transparent parts as it relates to the visual perception of distortion. It is not suitable for assessing distortion as it relates to pure angular deviation of light as it passes through the part. Either Test Method F801 or Practice F733 is appropriate and shall be used for this latter application. This test method is not recommended for raw material.

6. Apparatus

6.1 *Test Room*—The test room shall be large enough to locate the required testing equipment properly.

TABLE 1 GLS Photographic Recording Distances

Setup A	
Camera-to-grid-board distance	1000 cm (32 ft 10 in.)[A]
Camera-to-part distance	550 cm (18 ft 1 in.)
Part-to-grid-board distance	450 cm (14 ft 9 in.)
Setup B	
Camera-to-grid-board distance	450 cm (14 ft 9 in.)
Camera-to-part distance	150 cm (4 ft 11 in.)
Part-to-grid-board distance	300 cm (9 ft 10 in.)
Setup C	
Camera-to-grid-board distance	User defined
Camera-to-part distance	User defined[B]
Part-to-grid-board distance	User defined

[A] All measurements shall be ±3 cm or ±3 %, whichever is smaller.
[B] It is recommended that the camera-to-part distance be the design eye distance.

6.1.1 Setup A requires a room approximately 12 m (40 ft) long.

6.1.2 Setup B requires a room approximately 7 m (23 ft) long.

6.1.3 Setup C: other distances shall be used if desired. GLS results will vary with different distances, which means that measurements of different parts taken at different distances cannot be compared.

6.1.4 The walls, ceiling, and floor shall have low reflectance. A flat black paint or coating is preferred though not required.

6.2 *Grid Board*—The grid board shall provide a defined pattern against which the transparent part is examined. Grid boards shall be one of the following types:

6.2.1 *Type 1*—The grid board shall be composed of white strings held taut, each spaced at a specific interval, with the strings stretched vertically and horizontally. The grid board frame and background shall have a flat black finish to reduce light reflection. A bank of fluorescent lights at each side or evenly distributed natural sunlight conditions provide illumination of the strings.

6.2.2 *Type 2*—The grid board shall be a transparent sheet having an opaque, flat black outer surface except for the grid lines. The grid lines remain transparent, and when backlit with fluorescent or incandescent lights, provide a bright grid pattern against a black background with excellent contrast characteristics.

6.2.3 *Type 3*—The grid board shall be a rigid sheet of material that has a grid pattern printed on the front surface. Details of the grid lines, pattern, and lighting shall be as specified by the procuring activity.

6.2.4 The grid board shall have a width and height large enough so that the area of the part to be imaged is superimposed within the perimeter of the grid board. Details of the grid square size shall be as specified by the procuring activity. The recommended grid line spacing shall be not less than 1.27 cm (½ in.) or more than 2.54 cm (1 in.).

6.3 *Camera*—The camera shall be used to photograph distortion for the evaluation of grid line slope. For highest resolution, it is recommended that a large format camera be used, although a 35-mm camera is also acceptable. Black-and-white film shall be 400 ASA (or slower). Use of a digital camera is permitted if it has sufficiently high resolution (that is, with no visible pixilation in the printed image). When using a double-exposure recording technique (Fig. 3), the film-based camera shall have a double-exposure capability. Separate digital images are superimposed using a computer-based photo editor. The camera lens shall have very low distortion characteristics. The camera shall be firmly mounted at design eye (or other specified viewing position) to prevent any movement during the photographic exposure.

6.4 *Drafting Machine Procedure*—The drafting machine shall consist of a vertical and horizontal scale attached to a rotating head that displays the angular position of the horizontal or vertical scale in degrees with a resolution of at least 1 arc minute or 1/100 of a degree. This common, commercially available apparatus, which is mounted to a drafting table, shall be used for the evaluation of grid line slope.

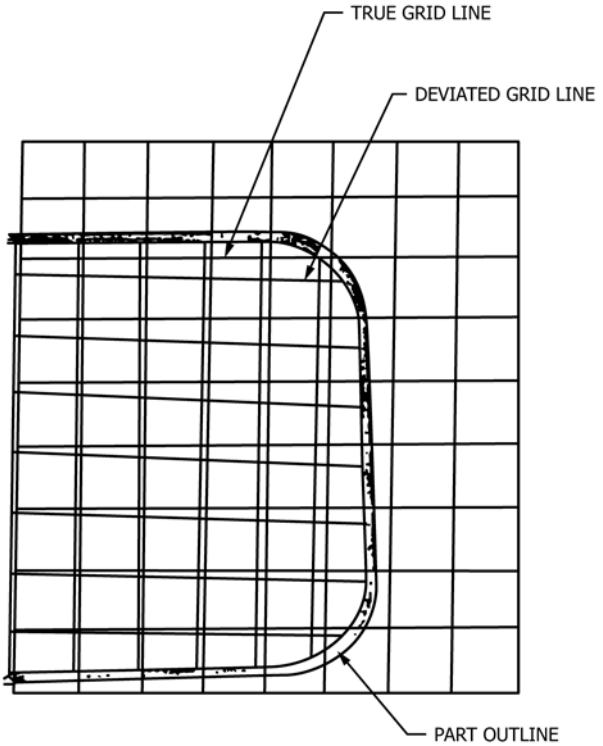

FIG. 3 GLS Double-Exposure Recording Technique

6.5 *Manual Procedure*—Measurements shall be made using high-quality drafting instruments (for example, metal scales, right triangle).

7. Test Specimen

7.1 The transparency to be measured shall be cleaned, using the manufacturer or procuring agency approved procedure, to remove any foreign material that might cause localized optical distortion. Unless specified by the procuring activity, no special conditioning, other than cleaning, shall be required and the part shall be at ambient temperature. If required, a mask shall be applied to the transparency to eliminate non-optical zones.

8. Calibration and Standardization

8.1 *Test Procedure Geometry*—Distance measurements shall be made using a high-quality tape measure.

8.2 *Drafting Machine Procedure*—Measurements shall be made using high-quality drafting instruments. The drafting machine shall be accurate to within its specified manufacturer's tolerances.

8.3 *Manual Procedure*—Measurements shall be made using high-quality drafting instruments (for example, metal scales, right triangle).

9. Procedure

9.1 *Photographic Recording Techniques:*

9.1.1 The procuring activity specifies whether Setup A, B, or C (other specified distances) shall be used to measure optical distortion. Table 1 contains the setup measurement distances. Fig. 2 illustrates the setup geometries. When the part is flat and mounted (nearly) vertically (for example, a passenger

window), Setup A is a more stringent test than Setup B. Use Setup C when the part is curved (for example, an aircraft canopy). It is recommended that measurements then be performed at the installed position and the camera be placed at the design eye location. Choose the test conditions that will most accurately simulate the actual field viewing conditions under which the part is used.

9.1.2 Firmly mount the transparent part to be examined to prevent movement during photographing. The mounted angle of the part shall be as specified by the procuring activity. It is recommended that the part be mounted at the installed angle. Record the mounted angle and report it with the results.

9.1.3 The camera shall be mounted at the design eye position (or other position as specified by the procuring activity). The optical axis of the camera shall be perpendicular to the grid board surface and shall be aimed at the target panel. See 6.3 for photographic recording requirements.

9.1.4 Place the grid board at a given distance (see Table 1) from the camera or as specified by the procurement agency, and ensure that the grid board pattern is in good focus at the focal plane of the camera. It is highly desirable (but not required) for part of the grid board target to be directly visible from the camera position without passing through the transparency. If this is possible, this undistorted section of the grid board serves as an alignment reference when determining the GLS of the transparency.

9.1.5 Photograph optical distortion through the part using one of two recording techniques. Both of these techniques record distortion of the grid. The distortion from these two photographic techniques shall be analyzed using either the drafting machine or manual measurement procedures.

9.1.5.1 *Single-exposure photograph*—Prepare a single-exposure photograph of the grid board viewed through the transparent part. The camera shall be focused on the grid board.

9.1.5.2 *Double-exposure photograph*—Photograph the grid board through the transparent part. Then, without allowing any movement of the camera or advancing the film, remove the part and make the second exposure of the grid board alone.

9.1.6 Develop the film and produce 8- by 10-in. matte finish prints (minimum size). The matte finish will reduce reflection problems during measurement. Alternatively, high quality printing paper can be used as well.

9.2 *Grid Line Slope Measurement Procedures:*

9.2.1 *Drafting Machine Procedure:*

9.2.1.1 Tape the photograph to the drafting board.

9.2.1.2 Align the horizontal scale of the drafting machine with a horizontal line of the grid board in the photo that is in the directly viewed section of the photo outside of the windscreen. If there is no such area, align the scale with the most undistorted horizontal grid board line within the picture, to serve as a reference.

9.2.1.3 Zero the drafting machine.

9.2.1.4 Systematically scan the photograph horizontally and vertically to find the most distorted area (the line with the greatest slope).

9.2.1.5 Place the horizontal straight edge tangent to the horizontal line displaying the maximum slope (bending from horizontal) within the area of the transparency to be measured.

9.2.1.6 Record the angle indicated on the drafting machine angle readout and convert the value to degrees if it is not in degrees already.

9.2.1.7 For vertical GLS, align the vertical scale of the drafting machine with the vertical line of the grid board target displaying the maximum slope (bending from vertical). Record the angle indicated on the drafting machine and convert the value to degrees if it is not in degrees already.

9.2.2 *Manual Procedure:*

9.2.2.1 Tape the photograph to the table.

9.2.2.2 Systematically scan the photograph horizontally and vertically for the most distorted area.

9.2.2.3 Align the scale along the tangent of the most distorted line.

9.2.2.4 Count the number of grid squares for both rise and run to obtain the GLS ratio (see Fig. 1).

10. Grid Line Slope Calculations

10.1 *Calculations Using Drafting-Machine-Derived Measurements:*

10.1.1 Converting degrees and minutes to degrees: If the drafting machine displays angles in degrees and minutes, then it will be necessary to convert this to decimal degrees before calculating GLS. Decimal degrees are calculated as follows:

$$DD = d + \left(\frac{m}{60}\right) \tag{1}$$

where:

DD = maximum angle in decimal degrees,
d = whole degree reading from the drafting machine display, and
m = minutes reading from the drafting machine display.

10.1.2 For example, if the drafting machine displays 3° (d) and 22' (m) then, using Eq 1, the decimal degrees would be:

$$DD = 3 + (22/60) = 3 + (0.37) = 3.37° \tag{2}$$

10.1.3 Calculate GLS as follows:

$$\text{GLS} = 1 \text{ in } \frac{1}{\tan(DD)} \tag{3}$$

10.1.4 Record GLS to the nearest tenth. For example, if DD is 3.37°, then the GLS would be:

$$\text{GLS} = 1 \text{ in } (1/\tan(3.37°)) = 1 \text{ in } (1/0.05889) = 1 \text{ in } 17.0 \tag{4}$$

since the tangent of 3.37° is 0.05889.

10.2 *Calculations Using Manually Derived Measurements:*

10.2.1 The photograph shall be examined to locate the area of maximum grid line distortion (slope) in either the horizontal or vertical direction. The slope of the distorted grid line shall be described in terms of grid squares of run for one grid square of rise. The example shown in Fig. 1 has a slope of 1 in 5. Standard nomenclature shall be used to express GLS, for example, 1 in 3 or 1 in 10.

11. Report

11.1 The following information shall be reported, unless otherwise specified:

11.1.1 Requesting organization,

11.1.2 Testing organization,

11.1.3 Transparency type,
11.1.4 Manufacturer,
11.1.5 Serial number,
11.1.6 Part number,
11.1.7 Manufactured date,
11.1.8 Material type(s),
11.1.9 Construction,
11.1.10 Coatings,
11.1.11 Defects (types and locations),
11.1.12 Geometrical setup (A, B, or C, installed angles; see Section 9 and Table 1),
11.1.13 Grid board type (line pattern and spacing), and
11.1.14 Photographic recording technique (camera type/serial number, lens *f*-value and focal length, shutter speed, film speed in ASA or DIN, GLS value[s]).

12. Precision and Bias[3]

12.1 An interlaboratory study (ILS) was conducted to determine the precision of Test Method F2156. Eighteen evaluators participated in a two-part study. In Part 1, seven computer-generated Gaussian curves of known GLS were given to the evaluators for measurement. Each curve was measured three times by each evaluator. Evaluators were instructed to measure the curves using their standard in-house measurement technique. Seven evaluators measured GLS using a drafting machine procedure and eleven evaluators used a manual procedure. The Gaussian curves were computer generated having known slopes. Use of these curves represented a well-controlled set of conditions for GLS measurements. In Part 2, ten aircraft windscreen distortion photographs (five with reference areas, five without reference areas), taken according to the procedures outlined in this test method using a Type 2 grid board, were given to the evaluators for measurement. The evaluators were again instructed to measure the photographs using their standard in-house measurement technique. Since the photographs were only measured once, there are no repeatability data from Part 2 of the study, only reproducibility data.

12.1.1 *Precision for Part 1, GLS of Gaussian Curves*—The statistical summary for repeatability limit (*rL*) and reproducibility limit (*RL*) derived from Gaussian curves is shown in Table 2. Statistical analyses (in accordance with Practices E177 and E691) revealed that in Part 1 of the ILS study, the *rL* was approximately 33 % of the mean for the manual procedure and approximately 12 % of the mean for the drafting machine procedure across GLS. The *RL* was approximately 40 % of the mean for the manual procedure and approximately 17 % of the mean for the drafting machine procedure across GLS. Results indicate that using a drafting machine instead of a manual procedure reduces both within and between evaluators' measurement variability by over 50 %.

12.1.2 *Precision for Part 2, GLS of Photographs*—The evaluators were asked to measure the largest slope angle they could find on each of ten photos. For half of the photographs, an undistorted area outside the windscreen was provided as a reference for measurements. The other half of the photographs had no undistorted reference area. For these photographs, the lowest distortion areas were used for reference. These two conditions were included to emulate field results. There are two questions of interest. First, is the variability of the evaluators for the measured ratios different between the drafting machine and manual procedures? Second, is the variability of the evaluators for the measured ratios different between the referenced and nonreferenced photos?

12.1.2.1 Table 3 shows the *RL* for this test method. This table contains both the mean ratios and the *RL* for each combination of procedure and reference. The general instructions to the evaluators were "to measure the area of highest distortion using your standard techniques." Note that *RL* is influenced by the distorted area chosen to measure as well as the variability among evaluators measuring the same distortion. Differences among pairs of measured distortions vary by as much as 100 %. There were no significant differences as a result of procedures or reference.

12.1.3 In general, there are other sources of variability in the measurement of distortion including, but not limited to: distances, camera lens distortion, film, and photographic processing. If not controlled for, these variables also contribute to increased distortion measurement variability.

12.2 The procedure in this test method has no bias since GLS is defined only in terms of the test method.

13. Keywords

13.1 canopy; distortion; grid board; grid line slope; transparency; window; windscreen

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:F07-1006.

TABLE 2 *rL* and *RL* for Gaussian Curve GLS Measurements

Procedure	*rL* % of Mean	*RL* % of Mean
Drafting machine	12	17
Manual	33	40

TABLE 3 Reproducibility Limits for Measured Ratio

Procedure	Reference D	Mean Ratio	*RL*	*RL* % of Mean
Drafting machine	no	9.4	8.4	89
Drafting machine	yes	10.4	10.9	105
Manual	no	10.8	11.4	106
Manual	yes	10.2	12.0	117