Designation: F1165 – 15

Standard Test Method for Measuring Angular Displacement of Multiple Images in Transparent Parts[1]

This standard is issued under the fixed designation F1165; 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 This test method covers measuring the angular separation of secondary images from their respective primary images as viewed from the design eye position of an aircraft transparency. Angular separation is measured at 49 points within a 20 by 20° field of view. This procedure is designed for performance on any aircraft transparency in a laboratory or in the field. However, the procedure is limited to a dark environment. Laboratory measurements are done in a darkened room and field measurements are done at night.

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

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

1.3 *This standard possibly involves hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, 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.*

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

3. Terminology (see Fig. 1)

3.1 *primary image*—the image formed by the rays transmitted through the transparency without being reflected (solid lines).

3.2 *secondary image*—the image resulting from internal reflections of light rays at the surfaces of the transparency (dashed lines).

3.3 *angular displacement*—the apparent angular separation of the secondary image from the primary image as measured from the design eye position (θ).

3.4 *installed angle*—the part attitude as installed in the aircraft; the angle between the surface of the windscreen and the pilot's 0° azimuth, 0° elevation line of sight.

4. Summary of Test Method

4.1 The procedure for determining the angular displacement of secondary images entails photographing a light array of known size and distance from the transparency. The photograph is then used to make linear measurements of the image separation, which can be converted to angular separation using a scale factor based on the known geometry.

5. Significance and Use

5.1 With the advent of thick, highly angled aircraft transparencies, multiple imaging has been more frequently cited as an optical problem by pilots. Secondary images (of outside lights), often varying in intensity and displacement across the windscreen, can give the pilot deceptive optical cues of his altitude, velocity, and approach angle, increasing his visual workload. Current specifications for multiple imaging in transparencies are vague and not quantitative. Typical specifications state "multiple imaging shall not be objectionable."

5.2 The angular separation of the secondary and primary images has been shown to relate to the pilot's acceptability of the windscreen. This procedure provides a way to quantify angular separation so a more objective evaluation of the transparency can be made. This procedure is of use for research of multiple imaging, quantifying aircrew complaints, or as the basis for windscreen specifications.

5.3 It is of note that the basic multiple imaging characteristics of a windscreen are determined early in the design phase and are virtually impossible to change after the windscreen has been manufactured. In fact, a perfectly manufactured windscreen has some multiple imaging. For a particular windscreen, caution is advised in the selection of specification criteria for

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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.

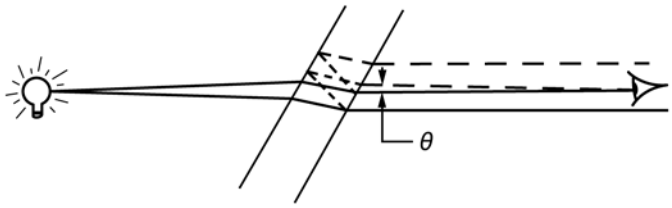

FIG. 1 Drawing of Light Ray Paths that Cause an Apparent Angular Separation (θ) Between the Primary Image and the Secondary Image

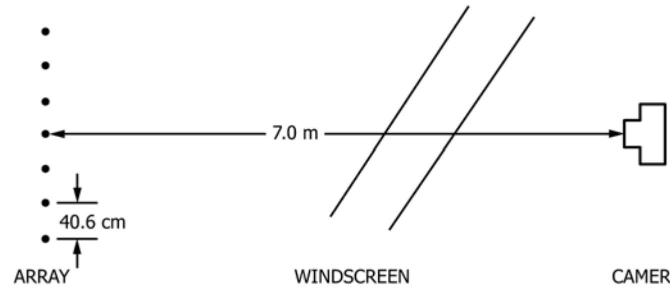

FIG. 2 Schematic Drawing of Component Layout for Measuring Multiple Imaging Angular Displacement

multiple imaging, as inherent multiple imaging characteristics have the potential to vary significantly depending upon windscreen thickness, material, or installation angle. Any tolerances that might be established are advised to allow for inherent multiple imaging characteristics.

6. Apparatus

6.1 *Light Array*—The light array is a 7 by 7 matrix of small incandescent lights (flashlight bulbs) mounted on a metal frame. The separation of the lights is 406.4 mm (16 in.) on center making the overall dimensions of the array 2.44 by 2.44 m (8 by 8 ft). A suitable power supply, such as a rechargable 12-V dc gel cell, is also required. A backdrop of nonreflective material (such as black velvet), placed several inches behind the array, blocks out background lights and prevents reflections.

6.2 *Camera/film*—No special camera or modification is needed for this process. A lens focal length of about 50 mm is preferred, to permit the light array to fill most of the field of view of the camera. Black and white film is preferred.[3] Digital cameras are an acceptable alternative to film-based cameras.

7. Test Specimen

7.1 Position the part to be measured in the installed angle (or installed in the aircraft for a field measurement) such that the camera lens is located in the pilot's design eye position. No special conditioning other than cleaning is required.

8. Procedure

8.1 The procedure for taking the multiple image photograph is optimally performed in a darkened room to reduce ambient light that decreases the visibility of the secondary images seen through the transparency. If the procedure is performed in the field at night, turn off nearby lights that affect the visibility of the secondary images.

8.2 Set up the light array so the center light is 7 m (23 ft ± 5 %) from the design eye position on the line of sight corresponding to 0 azimuth, 0 elevation (Fig. 2). Set the array perpendicular (±5°) to the line of sight. For field measurements, attach the array to a maintenance stand to elevate it to the appropriate height, if necessary. Ensure that the array is securely attached to the maintenance stand railing and avoid hitting the nose of the aircraft when moving the elevated array. If wind conditions present a hazard, do not attempt to measure.

8.3 Turn the array board on.

8.4 Place the camera in the design eye position and adjust the camera such that the array is centered in the field of view; focus the lens on the center light of the array.

8.5 Set the camera aperture to f/16 and the shutter speed to an appropriate setting.

8.6 Take the picture(s) and produce 8 by 10 prints or a suitable enlargement.

8.7 On the photograph, measure the distance (L) in mm from the second primary light image to the sixth primary light image on the middle row. To ensure accuracy, use a precision measuring device, such as a digital caliper.

8.8 For each light in the 8 by 10 print, measure the linear separation (r) in mm of the secondary image from the primary image using the calipers. Measure from the center of both spots when taking the measurement.

9. Calculation

9.1 To obtain the scale factor F, which relates the linear distances on the photograph to actual angular distances as measured from the design eye position, use the equation as follows:

$$F = \frac{230.4}{L} \text{ mrads/mm} \quad (1)$$

9.2 Compute the angular separation θ for each light of the array using the equation:

$$\theta = r \times F \quad (2)$$

9.3 Enter the angular separation data into a 7 by 7 table so the rows and columns correspond to the location of lights on the array.

10. Precision and Bias

10.1 *Precision*—An interlaboratory study[4] was conducted to determine the precision of this test method. Twenty laboratories (people) measured five different multiple image (MI)

[3] Kodak Tri-X ASA 400 has been found satisfactory. An equivalent film is also permitted.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: F07 – 1003.

photographic distances plus one scale factor, ten times each. Tables 1 and 2 and summarize the results.

10.1.1 Since the accuracy of the measurements is not expected to and in fact did not depend upon the size of the measured object, it is logical to take a mean of the six samples to derive the composite precision values indicative of this method.

The composite (mean repeatability (S_r) and reproducibility (S_R) values:

mean S_r = 0.128 mm and

mean S_R = 0.230 mm.

The composite (mean) 95 % limits for repeatability (r) and 95 % limits for reproducibility (R) values:

mean r = 0.353 mm and

mean R = 0.636 mm.

NOTE 1—The 95 % limits were calculated using the formulas below. Because the 95 % limits are based on the difference between two test results, the $\sqrt{2}$ factor was incorporated into the calculation (Practice E177; Section 27.3.3).

$$r = 1.960 * \sqrt{2} * S_r \quad (3)$$

where:

S_r = repeatability standard deviation and
r = 95 % repeatability limit (within laboratories).

$$R = 1.960 * \sqrt{2} * S_R \quad (4)$$

where:

S_R = reproducibility standard deviation and
R = 95 % reproducibility limit (between laboratories).

TABLE 1 Repeatability (S_r) and Reproducibility (S_R) Values in Millimetres

	Repeatability (S_r) Within Labs[A]	Reproducibility (S_R) Between Labs[B]
Sample 1	0.114	0.198
Sample 2	0.119	0.226
Sample 3	0.122	0.199
Sample 4	0.149	0.253
Sample 5	0.128	0.240
Scale factor	0.133	0.261
Mean	**0.128**	**0.230**

[A] S_r ranged from 0.114 to 0.149 mm.
[B] S_R ranged from 0.198 to 0.261 mm.

TABLE 2 95 % Repeatability (r) Limits and 95 % Reproducibility (R) Limits in Millimetres

	95 % r Limits Within Labs[A]	95 % R Limits Between Labs[B]
Sample 1	0.316	0.550
Sample 2	0.329	0.627
Sample 3	0.337	0.550
Sample 4	0.412	0.701
Sample 5	0.354	0.665
Scale factor	0.368	0.723
Mean	**0.353**	**0.636**

[A] r ranged from 0.316 to 0.412 mm.
[B] R ranged from 0.550 to 0.723 mm.

10.1.2 The final value determined by Test Method F1165 is angular displacement (in mrads). This final angular value depends upon and is relative to the original photographic geometry and enlargement size; therefore, no general precision value in terms of angular displacement can be calculated or expressed. The error in the method is due to people using calipers to make actual physical measurements of separated dots of lights on photographs, not in the calculation of angular displacement. The precision values in milliradians for any specific implementation of this test can be obtained by substituting the values of repeatability and reproducibility in 10.1.3 into Eq 2 once the scale factor, F, is known.

10.1.3 In summary, the statistical analysis (Practices E691 and E177) revealed that the method's mean repeatability (S_r) was 0.128 mm and the mean reproducibility (S_R) was 0.230 mm. The mean 95 % limits for repeatability (r) was 0.353 mm and the mean 95 % limits for reproducibility (R) was 0.636 mm.

10.2 *Bias*—The procedure in this test method has no known bias because the angular separation of the multiple image is defined only in terms of the test method.

11. Keywords

11.1 aircraft transparency; angular displacement; canopy; primary image; secondary image; transparent parts; windscreen

APPENDIXES

(Nonmandatory Information)

X1. DERIVATION OF EQUATIONS

X1.1 The angular separation between the lights of the array can be calculated by dividing the actual distance between adjacent lights (0.406 m) by the distance of the center light from the design eye position (7 m). Take the arctan of the result to get the angle in degrees:

$$A = \arctan(0.406/7) = 3.3° \quad (X1.1)$$

X1.2 Convert the angular separation from degrees to milliradians by multiplying by 17.45 mrads/°.

$$A = 3.3° \times 17.45 \text{ mrads/°} = 57.6 \text{ mrads} \quad (X1.2)$$

NOTE X1.1—If laboratory or field constraints require changing the size of the array or the distance from the array to the design eye position, it is necessary to recalculate a new value of A using Eq X1.1 and X1.2 and substituting in the appropriate values.

X1.3 Compute the average linear separation of lights on the photograph by dividing L (the distance from the second to the sixth light of the middle row) by 4 (the number of intervals between these lights).

X1.4 Divide the angular separation of the lights, *A*, by their average linear separation, *L*/4, to obtain the scale factor *F*, in units of mrads/mm.

$$F = A/(L/4) = 4A/L = 230.4 \text{ mrads/mm} \quad (X1.3)$$

X2. SELECTION OF ARRAY DISTANCE

X2.1 This procedure was developed to permit the evaluation of multiple image parameters both in the laboratory and in the field. Therefore, the equipment is portable in nature and accommodates measurements on a variety of aircraft.

X2.2 The selection of 7 m as the distance from the array to the design eye location was made considering several factors:

X2.2.1 The array is to clear the nose of large aircraft to permit field measurements of installed transparencies.

X2.2.2 The distance is advised not to be excessively long, so that laboratory measurements can be performed in a reasonably sized room.

X2.2.3 Shorter distances decrease the accuracy of the results because of the increased relative effect of lateral displacement.

X2.3 If necessary, change the 7 m distance to meet additional requirements. If this change is done, the calculations in Appendix X1 must be repeated using the new distance value.