Precise Measurement Device for Angular Deviation of Canopy Transparency in Fighter Aircraft

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The angular deviation (AD) of an aircraft cockpit transparency deteriorates the accuracy of the armament system because it introduces a difference between the actual and theoretical targets. To increase the accuracy, the AD of the transparency is measured and provided to the integrated mission-display computer as an AD coefficient. In this way, pilots can see the actual target accurately on their head-up display. To implement this mechanism, we have developed a new measurement system that automatically measures AD. This paper discusses the equations of the automatic system that measures AD, the development and operation of the system, and the verification of its accuracy and precision. The results showed that the accuracy has a maximum bias of ±0.04 mm, a percentage bias of 0.3, and a percentage linearity of 0.8 with 1% of criteria for each factor. The precision results showed a percentage contribution of dx 0.18 and dy 0.04, a percentage study variation of dx 4.24 and dy 2.08, and dx 33 and dy 67 for the number of distinct categories. These values satisfied our requirements: the percentage contribution should be less than 1, the percentage study variation less than 10, and the number of distinct categories greater than 10.

\textbf{NOMENCLATURE}

\begin{align*}
dx & \text{ measured horizontal movement of target} \\
dy & \text{ measured vertical movement of target} \\
Tdx & \text{ theoretical horizontal translation of line of sight} \\
Tdy & \text{ theoretical vertical translation of line of sight} \\
K & \text{ average part thickness in gun sight area (= 22.6 mm)} \\
Rx & \text{ misaligned distance for horizontal target movement} \\
Ry & \text{ misaligned distance for vertical target movement} \\
Az & \text{ azimuth viewing angle; positive when pilot's eyes move clockwise and negative when anticlockwise} \\
El & \text{ elevation viewing angle; positive when pilot looks up and negative when pilot looks down} \\
AzAD & \text{ azimuth angular deviation} \\
ElAD & \text{ elevation angular deviation}
\end{align*}

1. Introduction

The angular deviation (AD) is the angular change in direction of a ray of light through a transparent medium with a different refractive index from that of air.\textsuperscript{1} AD deteriorates an armament system’s accuracy because it introduces a difference between the actual and theoretical targets.\textsuperscript{2} For example, if the AD is 1 milliradian and an object is 3,000 ft away, this difference is 3 ft. The difference is very important especially for pilots of fighter aircrafts. In this paper, therefore, we study the TA-50 aircraft. To solve the AD problem, we must measure AD and revise the AD coefficient for the integrated mission-display computer and the head-up display.\textsuperscript{3} This paper presents the formulas for an automatic AD precision measuring device. It discusses the development and operation of the system and the verification of its accuracy and precision.

AD is expressed in terms of the angular change (degrees, minutes, or seconds) and increases with the index of refraction of the window material, the amount by which the surfaces deviate from parallelism, and the angle of incidence.\textsuperscript{1,2} Fig. 1 shows the definition of AD and the translation (displacement) by refraction; translation (Tdx, Tdy) is a linear shifting distance. In passing through a transparency (TP) with parallel surfaces, light rays are bent and displaced. The translation is zero for a zero-degree angle of incidence and increases as the angle of incidence, the thickness, or the index of refraction is increased.\textsuperscript{1,2} The translation is linear and usually measured in millimeters or fractional inches. It does not
increase with distance, and the effect on pilot vision is probably not significant.

Increasing the angle of incidence usually causes a number of adverse optical effects. Some of these effects are due to the increased thickness of the transparent material through which the light must pass. Others are due to a greater proportion of the light being reflected at surfaces, including surfaces of laminations. The most serious effects, however, result from the magnification of deviation and distortion caused by wedges and irregularities in the surfaces of the window. Fig. 2 shows the changes in deviation with angle of incidence. The deviation data are from the Air Force System Safety Design Handbook 2-1.

The curve shows the multiplication factor by which the value at the zero angle of incidence is increased. If, for example, a piece of glass caused a deviation of 10 minutes of arc at the zero angle of incidence, this value would be increased to approximately 50 minutes of arc at 70°. For this reason, for many years windshield design standards set the maximum angle of incidence at 60° and required the windshield to be flat. However, as aircraft speeds have increased, the Air Force has permitted higher angles of incidence and the use of curved windshield panels.1

In addition to the angle of incidence, the deviation depends upon the radius of curvature, the thickness of the window, and the index of refraction. Fig. 3 shows the effect of the thickness/curvature ratio, using data from Holloway (1970).5 As it can be seen these curves, a combination of a thick window, high angle of incidence, and short radius of curvature can result in high deviation.

It is therefore important, when curved windshields are used, to keep the radius of curvature as large as possible, and to position the windscreen so that the pilot’s eyes are at the center of the curvature. In addition, the curvature should be single rather than compound.1

Previously, all fighter aircraft operated in Korea received AD data from the manufacturer (Boeing, Lockheed Martin, etc.) and they did not open concretely an AD measurement method, because the export license of the US Air Force did not permit this. Therefore, there are few research papers about AD measurement methods for the windscreen TP of a canopy. Some organizations such as the University of Dayton Research Institute (UDRI)6 have developed automatic AD measurement devices. We conducted research for two years to improve the technological competitiveness of such devices. The result is a new automatic AD measurement device.

2. Conceptual design

2.1 AD measurement procedure and formula derivation

There are several methods for AD measurement. The collimated light theodolite method was used for F-5F fighter aircraft7 and the projected or printed double-exposure photograph was utilized for the ASTM F733-90 (2003) standard.8 AD measurement for the TA-50 is as follows: Install the TP on an angular deviation fixture, which supports the part in its rigged position and pivots every two degrees from +6° to -6° azimuths and from +4° to -14° elevation. The laser beam and target sensor are fixed as shown in Fig. 4. Before measuring the AD, we set the points to zero by removing the TP and measure the target movements in the horizontal (dx) and vertical (dy) directions, to an accuracy of 0.76 mm, at each of the seventy target locations.

We determine the misalignment (Rx and Ry) as shown in the formulas below. We convert these residuals to the AD for each target as follows. The AD formula was derived from Figs. 5 and 6.9 We assume $Tdx = Tdx'$ and $Tdy = Tdy'$; 1 radian is 57°17'45" ($\cong$ 57.29°).10

2.1.1 Derivation of azimuth AD formula

The meaning of each concept shown in Fig. 5 and the derivations of AzAD are as follows. Eq. (1) is the formula for AzAD.