Recommendations on Cockpit-Visibility Standards for Transport-Type Aircraft

by

Thomas M. Edwards

and

Wayne D. Howell

Aircraft Division

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TABLE OF CONTENTS

RECOMMENDATIONS ON COCKPIT-VISIBILITY STANDARDS FOR TRANSPORT-TYPE AIRCRAFT*

SUMMARY

The standards that are discussed in this report are recommended minimums for cockpit visual angles and were derived from technical information on the subject obtained through (1) an airline-pilot-questionnaire study, (2) a pilot-eye-movement study, (3) a collision-course study, and (4) development of a binocular camera for recording cockpit visual angles.

These standards, when applied to initial aircraft-cockpit design, will improve the present safety level by affording the pilots better cockpit visibility, thus reducing the mid-air collision hazard.

INTRODUCTION

In 1948 the Technical Development and Evaluation Center of the Civil Aeronautics Administration at Indianapolis initiated a program to study the cockpit-visibility problem at the request of the CAA Office of Aviation Safety. The purpose of this program was to determine and recommend minimum standards for visual cockpit openings, based upon accumulation and analysis of related scientific data, which would facilitate the handling of aircraft by pilots during all flight operations.

The first phase of the program was an airline-pilot-questionnaire study.[1] Questionnaires were sent out to several thousand airline pilots, requesting that they evaluate present-day aircraft from a visibility standpoint and suggest the size and location of windshield openings which they would recommend for incorporation in aircraft. The results of the questionnaire showed that pilots strongly believed improvement in cockpit visual openings was needed in most aircraft. From the answers to the questionnaires, it also was possible to establish the angles of vision which the pilots considered adequate and excellent.

The second phase of the program was the development of a photographic instrument for measuring aircraft cockpit-visibility limits.[2] Prior to the development of this binocular-strip-film camera, there was no instrument or method in use which would provide a quick and accurate means of measuring and recording cockpit-visibility limits in terms of angles of vision. This camera was designed to photograph the windshield limits while mounted in either the pilot's or co-pilot's seat at any desired eye-level position. It rotates 360° in azimuth and automatically superimposes a grid of horizontal and vertical lines on the negative in increments of 5.46° in the vertical and 5° in the horizontal. The camera utilizes two lenses spaced 2 1/2 inches apart (average separation distance between human eyes), thereby producing the binocular effect of obstructions to vision such as windshield posts and instruments. The binocular camera proved to be a valuable tool in the cockpit-visibility studies. It also can be used by industry and by regulatory personnel in the design and airworthiness certification of aircraft.

The third phase of the program was a study of pilots' eye-movements during visual-flight conditions.[3] In this study several subject pilots' eyes were photographed by use of motion-picture cameras and a special arrangement of mirrors while they performed flight maneuvers which demanded visual attention outside the cockpit. The analysis of the films revealed exactly

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*Manuscript submitted for publication July 1955.

[1]George L. Pigman and Thomas M. Edwards, "Airline Pilot Questionnaire Study on Cockpit Visibility Problems," CAA Technical Development Report No. 123, September 1950.

[2]Thomas M. Edwards, "Development of a Photographic Instrument for Measuring Aircraft Cockpit Visibility Limits," CAA Technical Development Report No. 153, January 1952.

[3]Thomas M. Edwards and Wayne D. Howell, "A Study of Pilot's Eye-Movements During Visual Flight Conditions," CAA Technical Development Report No. 179, January 1952.

through which portion of the windshield the pilot was looking and for what length of time during each phase of flight. The results indicated that the windshield area utilized in this study substantiated, to a great extent, the recommended cockpit openings as reported in the airline-pilot questionnaire. The results also indicated that if more windshield area had been available to the pilot he would have used it, especially when searching for other aircraft. At this point in the cockpit-visibility program it was possible to recommend a windshield opening based upon results obtained from the questionnaire and pilot-eye-movement study. Important information on the visual angles required while two airplanes are on a collision course, however, still was lacking.

The fourth and final phase of the program, therefore, was the determination of some geometric relationships relative to collision flight paths.[4] In this report, a series of charts and graphs is shown which the reader can enter with such collision flight-path parameters as the difference in heading between the two aircraft on collision courses, the aircraft speeds, and the type of maneuver. The visual angles required by the pilot of one aircraft to see the other aircraft at any time prior to collision, distance of separation, and relative closing speeds also can be determined. These charts and graphs were designed from derived formulas. Although it was not possible to investigate all possible collision courses, the study and analysis of the common probable ones represented in this report provided a much better understanding of the mid-air collision problem as related to the visual angles involved.

The recommendations made in this report on cockpit-visibility standards for transport-type aircraft are the result of an evaluation of the four phases of the problem investigated in this study.

RECOMMENDATIONS

1. When measured from a normal eye position with the aircraft in a level-flight attitude, the cockpit visibility should be such that the pilot in the left-hand seat, who is utilizing binocular vision and azimuthal eye-movement about a 3 5/16-inch radius, can command an area of clear vision of not less than:

A. Forward and above horizon 20°.

B. Forward and below horizon 15°.

C. To the left 90° and above horizon 35° (aircraft operational bank angles to be restricted to 35°).

D. To the left 90° and below horizon 35° (aircraft operational bank angles to be restricted to 35°).

E. To the left and rearward at horizon 135°. (This angle should be as large as possible, up to 170°.)

F. From 20° right to 30° left of straight ahead, with no obstructions to forward vision. (It will be difficult, if not impossible, to fulfill this recommendation and maintain the present requirement for a clear-vision panel imposed by Civil Air Regulation 4b.351b(2), unless it is possible for the side window to meet this need.)

These recommendations are illustrated in Fig. 1.

2. Forward visual angles should be such that the earth's horizon can be seen during a rated-power climb and a critical instrument-landing-system (ILS) approach, and there should be no obstructions to vision between the visual angles required for these maneuvers.

3. The 90° left upward and downward visual angles should be such that the earth's horizon is visible during maximum approved operational bank angles.

4. The windshields, in a horizontal plane through the pilot's eye level, should exhibit optical properties equivalent to those of flat panels to insure uniform visibility.

5. Windshield posts should not exceed 2.5 inches total obstruction area in projected width on the pilot's eye when they are located within a sector of 30° to 60° of azimuth to the left of the pilot's forward vision. Posts located within a sector of 60° to 135° of azimuth to the left of the pilot's forward vision could be larger.

6. Instruments and equipment should be located so that the area of vision outlined in the preceding recommendations is not impaired.

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[4] Wayne D. Howell and Thomas M. Edwards, "Determination of Some Geometric Relationships Relative to Collision Flight Paths," CAA Technical Development Report No. 259, June 1955.

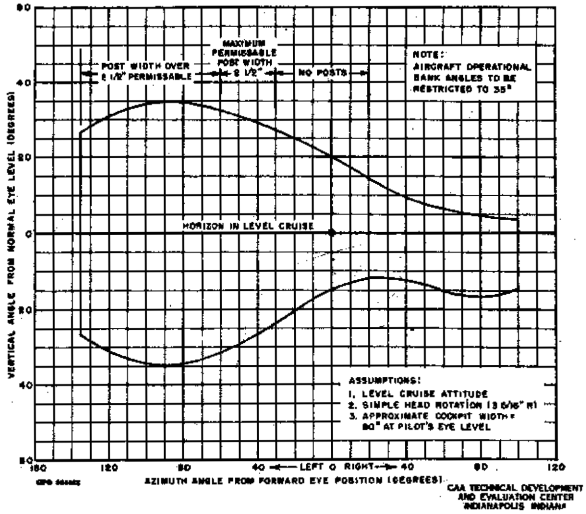


Fig. 1 Example of Cockpit Visual-Angle Requirements From Pilot's Viewpoint (Final)

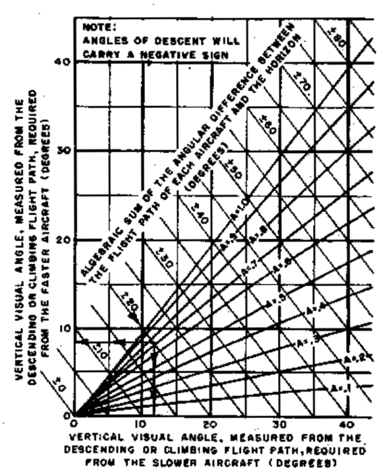
7. The windshield should be symmetrical about the centerline of the airplane.
8. The location of the eye level should be indicated by a placard in the airplane. (Seat and control adjustments should be such that pilots from five feet to six feet four inches in height can use the designed visual angles comfortably.)

JUSTIFICATION FOR RECOMMENDATION NO. 1

Parts 1A and 1B, Forward Visual Angles 20° Above and 15° Below the Horizon.

Visual angles in these directions are considered most important in enabling pilots to see other aircraft during head-on or near head-on collision courses.

Figure 2 is presented to show the relationship between flight-path angle and upward or downward visual angles required for pilots of two aircraft to see each other. An example of the use of the chart is shown on this figure. After solving a few hypothetical cases, it can be seen that the upward and downward visual angles selected are adequate.



Example:

Assume two aircraft (both climbing) approaching on a head-on collision course where

V_s (velocity of slower aircraft) = 150 mph
Angle of climb = +10°

V_f (velocity of faster aircraft) = 200 mph
Angle of climb = +10°

Algebraic sum of flight path angles = +20°

Speed relationship $(A) = \frac{V_s}{V_f} = \frac{150}{200} = .75$

Enter graph at point where algebraic sum of flight angles = +20° until A = .75 is intersected. At this point, follow vertical line down and read visual angle required from slower aircraft (12° down). Then follow horizontal line left and read visual angle required from faster airplane (8° down).

When the sign of the algebraic sum of the flight angles is positive, all required visual angles will fall in the lower (down vision) portion of the windshield. If it is negative, all required visual angles will fall in the upper (up vision) portion of the windshield.

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Fig. 2 Vertical Visual Angles Required for the Pilots of Two Aircraft to See Each Other While on a Head-on, Climbing, or Descending Collision Course

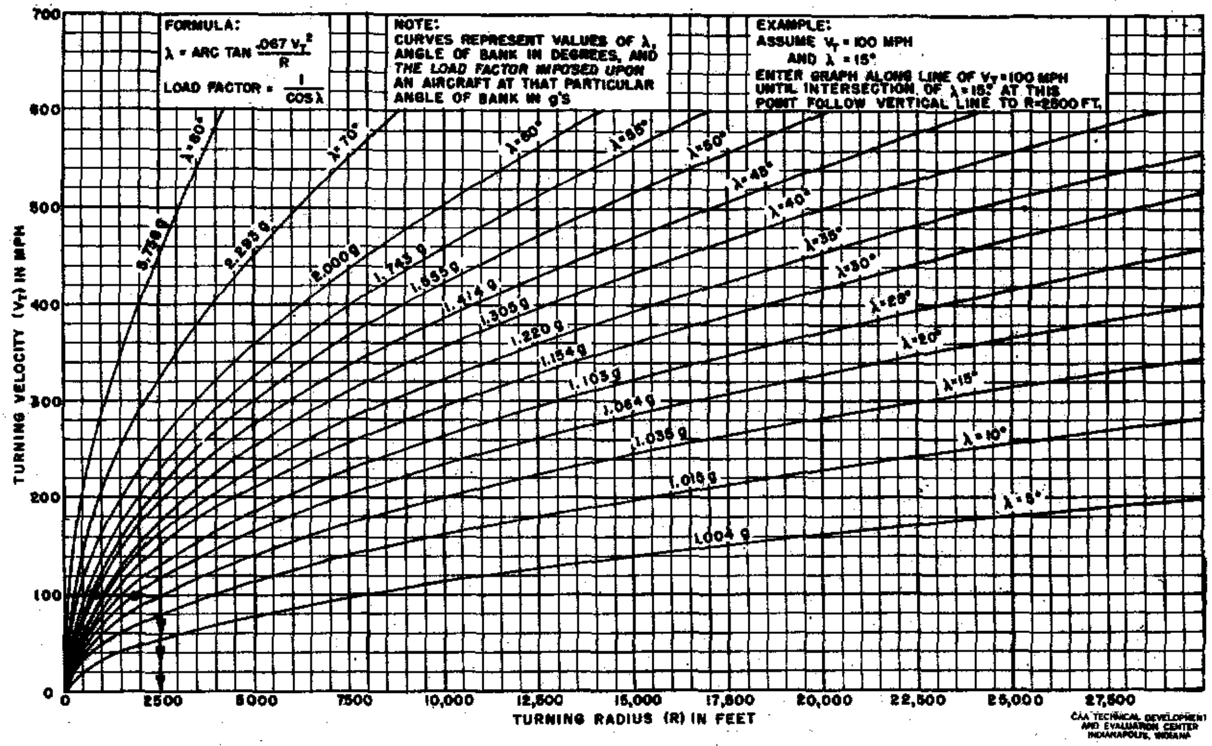

Fig. 3 Relationship Between Angle of Bank, Turning Radius, Speed, and Load Factor

The 20° upward visual-angle value was selected as being adequate as a result of the pilot-eye-movement study.

The 15° downward visual-angle value was indicated as being adequate by the pilot-questionnaire study. The pilot-eye-movement study, however, indicated that the pilots used more downward vision when it was available. More than 15° downward vision is not practical because of the location of the top row of instruments.

Parts 1C and 1D, Visual Angles 90° to the Left and 35° Above and Below the Horizon.

In evaluating visual-angle requirements in these directions, angle of bank in turning maneuvers is the most important consideration. Figure 3 is presented to show the relationships between angle of bank, turning radius, speed, and acceleration in gravities (G's).

During flight-path analysis in the collision-course study, the maximum angle of bank recorded was 40° with a Lockheed Constellation. The average angle for this airplane was 23°

The 35° upward value is a compromise; however, it is felt that this angle will permit the pilot to see the horizon and the path into which he is turning under most conditions of visual-flight-rule (VFR) flight.

The 35° downward value is needed mostly for navigating while in the air; for viewing the runway during landing approach, landing, or taxiing; and for communicating with ground personnel while on the ground. The airline-pilot-questionnaire study indicated that 35° downward represents minimum adequate vision.

It is suggested that the horizon should be visible during all turns and banks, and operational bank angles should be restricted accordingly.

The recommendations specify upward and downward visual-angle limits at certain points only; that is, straight ahead and 90° to the left. Figure 4 is presented to show what happens between these two extremes in a turn. It shows the vertical visual angle the pilot needs in order to see the horizon at various angles of azimuth and angles of bank.

Part 1E, Visual Angles to the Left and Rearward at Horizon 135°.

The percentage of total visibility required to prevent *all possible collisions* in the horizontal plane while flying straight and level has been plotted against left, rearward, and cutoff

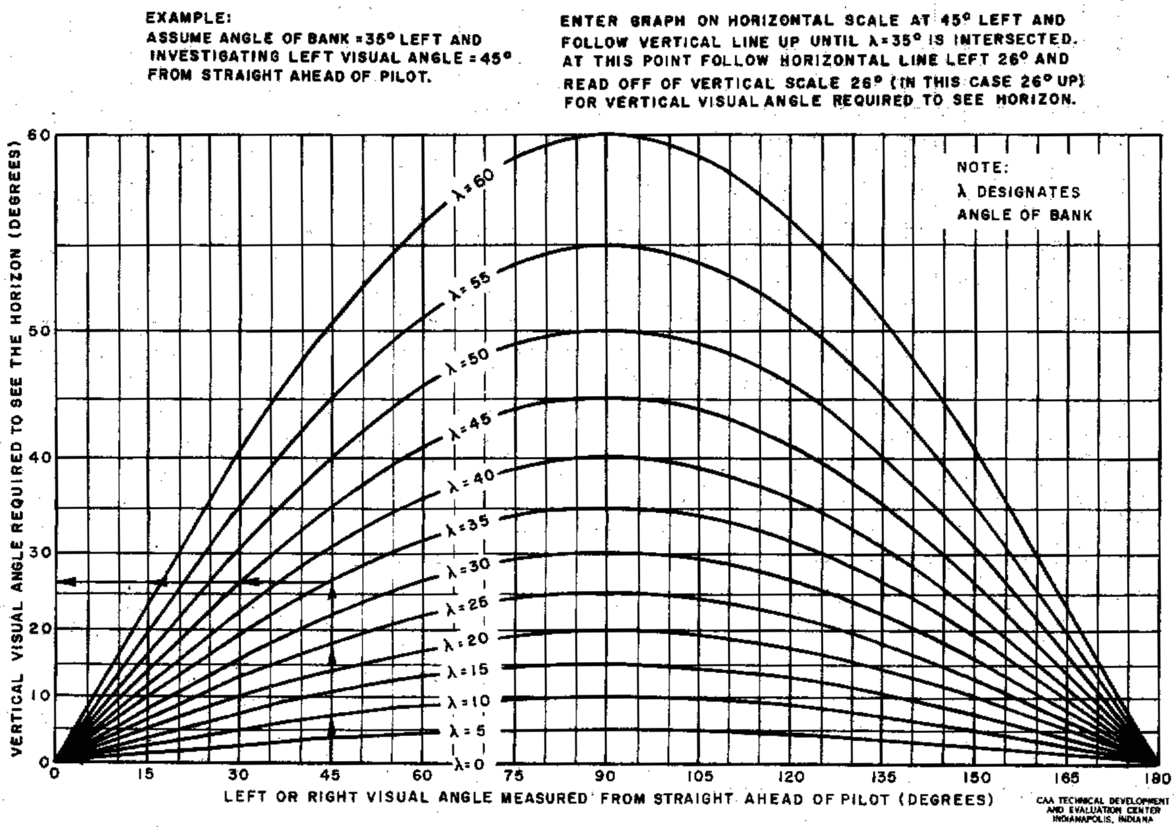

Fig. 4 Determination of Vertical Visual Angles Necessary to See the Horizon During Turning Collision Conditions

angles in Fig. 5. This curve shows that with a 135° cutoff angle, 87.5 per cent of the area can be scanned visually. Figure 5 also shows that a cockpit visual angle of 135° represents essentially a point of diminishing returns in additional protection received versus increasing cockpit visual angles.

An analysis of mid-air collision possibilities during the level-cruise condition shows that if the speed relationship between two aircraft flying on a collision course is 0.5, the 135° cutoff angle will permit the pilot of either airplane to see the other airplane from a heading difference of 25° up to and including 180°. If the speed relationship is 0.9, the 135° visual angle will permit observation from a heading difference of 5° up to and including 180°.

Collision-course charts for turning flight conditions were investigated, and the 135° value appeared to be adequate for those conditions. It is suggested, however, that this angle be made as great as possible up to 170° because, with the pilot's head turned, it is possible for his eyes to see objects back to 170° from straight ahead. With a 135° cutoff angle, therefore, vision is restricted when the head is turned.

Part 1F, No Obstructions to Forward Vision in Azimuth from 20° Right to 30° Left of Straight Ahead.

The pilot-questionnaire study pointed out that the pilots wanted 30° in each direction from straight ahead to be obstruction-free. This would be ideal. If an aircraft uses a center post, however, it is practically impossible to meet the 30° right requirement. The absolute minimum

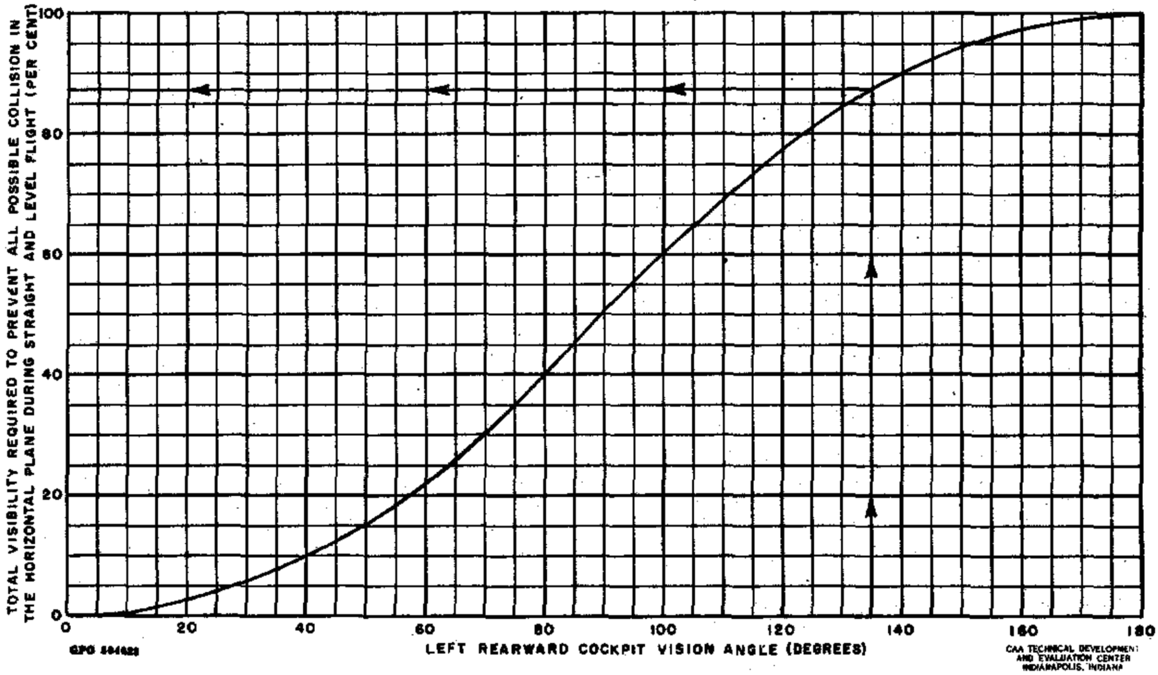

Fig. 5 Relationship Between Left Rearward Cutoff Angle and Total Visual Coverage Possible in the Horizontal Plane

allowable is 20°, mainly due to the blind spot (from about 12° to 18°) in the eye. In this area (about a 6° cone), the human has only monocular vision, and a post of any width causes a total obstruction to vision of which the pilot may not be aware.[5]

If the head is held fixed and the eyes are looking straight ahead, then at 30° off the center of vision the human eye can perceive an object that subtends an angle of 4.3° of arc. This is equivalent to a 100-foot object at 12 miles distance. Because the eye is so acute, and because at 30° left of straight ahead the closing speeds are nearly as great (96 per cent of head-on), this 30° area is extremely important. To accomplish the 30° left obstruction-free visual area, it may be necessary to re-evaluate the necessity for the clear-view panel. After interviewing several airline pilots who flew DC-3 airplanes with no clear-view windows on the left side, it is believed that in extreme emergencies visual contact during a landing could be made by openin the side sliding windows. The pilots interviewed were satisfied with the obstruction-free visual angles.

By requiring 20° right and 30° left obstruction-free vision from the left-hand seat and 20° right from the right-hand seat, the two pilots will not be blinded in the same direction at the same time; they would be blinded if both angles were the same.

[5]Arthur Linksz, "Psychology of the Eye, Vol. 2, Vision," Grune & Stratton, New York, p. 235, 1952.