DETERMINATION OF SOME GEOMETRIC RELATIONSHIPS PERTAINING TO COLLISION FLIGHT PATHS

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DETERMINATION OF SOME GEOMETRIC RELATIONSHIPS PERTAINING TO COLLISION FLIGHT PATHS*

SUMMARY

A study has been made to develop a basic means, in the form of graphs and charts, for permitting a better understanding of cockpit visual problems and aircraft conspicuity problems as they are related to mid-air collisions

Formulas are derived and visual-angle and distance charts are presented for certain combinations of straight-and-level, climbing, descending, and turning flight conditions Using only aircraft headings and speeds, the visual angles and distances between aircraft at assumed instances of time prior to collision may be determined from these charts It is also possible to obtain critical collision-course headings by entering the charts with the effective cockpit cut-off vision angles and speeds

Tables are presented showing actual airplane attitudes during flight

Actual flight paths recorded in the vicinity of airports are presented Some performance parameters used in the design of the visual-angle charts contained in this report were established from these flight-path data

From the graphs contained in this report, it is evident that

1 No apparent motion from pilots' viewpoints exists between two aircraft which are flying straight and level on collision courses at constant speeds

2 The most severe mid-air collision hazard from a visual-angle standpoint exists between aircraft that are flying at small differences of heading and speed During this condition, even when the closing rates are small and much time is available for evasive maneuver, the visual-angle restrictions of present-day transport aircraft do not permit the pilots to observe each other

3 Mid-air collisions cannot be avoided by use of the windshield area alone, since extreme visual angles may be required during many collision conditions However, certain minimum visual angles in aircraft-cockpit design will tend to decrease the probability of mid-air collisions

INTRODUCTION

The danger of aircraft colliding in mid-air is becoming increasingly serious as speeds nd traffic densities increase Cockpit visibility angles, or angles of vision required by the pilot of one aircraft to see another aircraft, and pilot alertness are two major factors in mid-air collisions Another major factor is the conspicuity of aircraft

During 1948, the Technical Development and Evaluation Center of the Civil Aeronautics Administration commenced an investigation of the cockpit-visibility problem Since that time, much work has been accomplished and reported[1,2,3] in an effort to arrive at a basis for establishing minimum cockpit-visibility standards for aircraft and thus to improve the safety of aircraft

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*Manuscript submitted for publication December 1954

[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 an Instrument for Measuring Aircraft Cockpit isibility Limits," CAA Technical Development Report No 153, January 1952

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

Since 1938, development activities designed for the improvement of aircraft conspicuity have been in progress To date, these have chiefly involved external aircraft lighting Two technical reports covering this work have been published [4,5]

Continued work in these fields of cockpit visibility and aircraft conspicuity requires the solution of equations showing the relationship that exists among the fundamental parameters of aircraft in flight on collision courses

The ultimate objective of this report is to present a simple means of calculating cockpit visual angles and distance-time separation as they are related to collision courses In order to accomplish this task, a series of formulas was developed From these formulas, charts and nomographs were designed to simplify and facilitate their solutions

The information and data of this report are presented as follows

Collision Condition A - Straight-and-Level Flight
Collision Condition B - Straight Climb and Descent
Collision Condition C - One Aircraft Turning and One Flying Straight and Level
Collision Condition D - Two Aircraft Turning in Same Direction

Graphical presentations covering two aircraft turning in opposite directions were found to vary over such wide limits that it was preferable to achieve solutions by the use of the equations rather than by graphical methods These equations are presented in the Appendix

Each collision condition is discussed separately and is presented to conform to the following outline

1 Description
2 Procedure and Formulas
3 Sample Solution
4 Additional Considerations
5 Discussion of Significant Trends

The derivation of the formulas and the actual measured flight paths in the vicinity of airports are presented in the Appendix

This report is limited to a study of collision courses It is primarily intended to serve as a basic tool to aid in the solution of cockpit-vision and aircraft-conspicuity problems from the standpoint of collision avoidance Its intended utility also includes investigations of mid-air collision accidents

GENERAL PRESENTATION AND LIMITATIONS OF BASIC DATA

Charts were drawn to facilitate the calculation of the visual angles required for the pilots of each of two aircraft on a collision course to see the other aircraft The charts are designed to encompass a wide range of aircraft speeds and collision approach angles, and it is assumed that the aircraft are point sources It is also possible to determine the distance separating two airplanes at any particular instant of time prior to collision

Charts for determining separation distances and visual angles were drawn for the most common collision courses Simple charts shown in Figs 1, 2, and 3 cover straight-and-level flight conditions Charts for climbing and descending conditions are shown in Figs 1, 2, 5, and 6 A more complicated system of charts is presented for computation of distance of separation and visual angles from aircraft, one of which is flying straight and level and one of which is turning, and also from aircraft which are both turning These families of charts are shown in Figs 10 through 21 and 28 through 82, respectively In all cases, sample calculations showing the manner in which the charts are used are presented

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[4] Cecil B Phillips and Alan L Morse, "A Review of Aircraft External Lighting Activities, CAA Technical Development Report No 215, September 1953

[5] Marvin J Anderson and Cecil B Phillips, "Development of Blade Tip Lighting," CAA Technical Development Report No 248, October 1954

It was possible to limit the coverage of the charts for straight-and-level, climbing, and descending flight by the assumption of logical limits for the data However, it was much more difficult to establish practical parameters for the turning conditions of flight The limits for turning flight were therefore established from recordings of 250 flight paths of aircraft in the vicinity of airports These flight-path data are shown in the Appendix The collision cases presented in this report are designed around the assumption that the airplanes are flying at constant speeds, constant rates of climb or descent, and constant angles of bank during level turns, as these conditions are applicable By necessity, the collision conditions covered by ' s report constitute only a small part of the total number of possible collision cases

In using this report as a tool for determining the visual angles required for the pilot of one airplane to see the other airplane and determining the distances between airplanes, the ccuracy of the results obtained will sometimes be limited by the authenticity of the input parameters rather than by the design of the charts themselves If it is found that none of the collision cases represented in this report apply exactly to the one being investigated, the selection of the collision case that is most similar will provide approximate visual-angle requirements

COLLISION CONDITION A
STRAIGHT-AND-LEVEL FLIGHT

Description

Calculation of visual angles to the right or left required for the pilots of each airplane to see the other airplane is facilitated by the use of the charts designed for the straight-and-level flight condition These charts are designed around the hypothesis that two airplanes are flying along straight lines and on a collision course in the same horizontal plane and that they are approaching each other from any direction at any relative speed

Procedure and Formulas

The level-cruise charts are shown in Figs 1, 2, and 3 The procedure for using these charts is as follows

1 To determine speed relationship A, enter Fig 1 with the true air speeds of the two ircraft A is simply the ratio of the speed of the slower airplane to the speed of the faster irplane

2 To determine visual angles θ (for the faster airplane) and ϕ (for the slower airplane) t which it is possible for the pilot of each aircraft to see the other aircraft, enter Fig 2 with he absolute difference in the true headings ψ, and the value of A.

3 To determine the distance Z between the airplanes at any instant of time prior to collision, enter Fig. 3 with the velocity V_s of the slower airplane, time t before collision, the ' ' -e difference in true heading ψ, and the visual angle θ required from the faster airplane

4 To determine closing velocity between the two aircraft, enter Fig 3 with the distance Z ' tween the aircraft and the time t before collision

5 To determine the blind areas caused by specific cockpit cutoff angles of any two aircraft, enter the chart shown in Fig 2 with the visibility cutoff angle of the slower airplane, proceed rd to the intersection of the relative speed A in question, and follow up the diagonal line to ψ absolute difference in true heading This value of ψ will be the minimum absolute difference in heading of the two aircraft that will permit them to be visible to each pilot

The speed-relationship chart shown in Fig 1 is presented for the convenience of the reader and is constructed to permit a speed relationship value to be obtained for any speeds as long as the same scale is used on both axes This chart was constructed from the equation

$$A = \frac{V_s}{V_f} \qquad (1)$$

Where

A = Speed relationship

V_s = Velocity of slower airplane, true air speed, in mph

V_f = Velocity of faster airplane, true air speed, in mph

The visual-angle chart shown in Fig 2 for straight-and-level flight was constructed by substituting example values in Equation (2)·

$$\theta = \arc \sin \left(\frac{A \sin \psi}{\sqrt{A^2 + 1 - 2A \cos \psi}} \right) \qquad (2)^*$$

and $\phi = 180° - (\psi + \theta)$

Where

θ = Visual angle from longitudinal axis required from fast airplane, in degrees

ϕ = Visual angle from longitudinal axis required from slow airplane, in degrees

A = Speed relationship (Fig 1)

ψ = Absolute difference in true heading of two aircraft, in degrees (always 180° or less)

The distance-of-separation nomograph shown in Fig 3 was constructed by using Equation (3)

$$Z = \frac{V_s t \sin \psi}{60 \sin \theta} \qquad (3)$$

Where

V_s = Velocity of slower airplane, true air speed, in mph

t = Time of investigation before collision, in minutes

ψ = Absolute difference in true heading of two airplanes, in degrees

θ = Visual angle required from faster airplane, in degrees

Z = Distance between airplanes at time t of investigation, in miles

Sample Solution

It is desired to know the visual angles that are required for the pilots of each of two aircraft to see the other aircraft while on a collision course and to determine the distance between them at a given time t Refer to Fig 4. In this case, both airplanes are flying strai_' and level

Given

V_s = 180 mph, velocity of slower airplane, true air speed

V_f = 200 mph, velocity of faster airplane, true air speed

*Equations (2) through (6), (8) through (14), (16), and (20) through (29) have their derivations in the Appendix.

$\psi = 45°$, absolute difference in true heading of two aircraft

n this case, assume that the slower aircraft is on the left of the faster aircraft

= 1 minute, time of investigation before collision

olution

1 Enter Fig 1 with V_s = 180 mph and V_f = 200 mph and determine the speed relationship = 0 90

2 Enter the chart shown in Fig 2 with the difference in true heading $\psi = 45°$ and follow down this diagonal line until an intersection is made with the speed-relationship curve A = 0 9 Follow the horizontal line from this point and read the angle $\theta = 60°$ This is the angle required for the pilot of the faster airplane to see the slower airplane Follow the vertical ne from this point and read the angle $\phi = 75°$. This is the angle required for the pilot of the lower airplane to see the faster airplane

3 The distance between the two aircraft at t = 1 minute, or one minute before collision, is found by using the nomograph shown in Fig 3

a Enter nomograph with V_s = 180 mph

b Connect 180 to t = 1 minute, find T_1°

c. Connect T_1 intersection with $\psi = 45°$ (absolute difference in true heading) and find T_2

d Connect T_2 intersection with $\theta = 60°$ (visual angle required from the faster airplane)

e Read Z = 2 5 miles apart

4. The closing velocity at t = 1, one minute before collision, is found by using the nomograph hown in Fig 3

a Enter nomograph with Z = 2 5 miles

b Connect 2 5 to t = 1 minute

c Read V_c = 220 feet per second, or 150 mph

Additional Considerations

The formulas and charts are designed for using true air speed and true heading of the ircraft In the event that the ground track and ground speeds are used, it is necessary to correct the visual angles by adding or subtracting the crab angle or wind-drift angle

Discussion of Significant Trends

By inspecting the curves shown in Fig 2, it is evident that the mid-air collision problem s greatest at small differences in heading and at small differences in speed These are the conditions that make the chances of either pilot seeing the other airplane very small

Since time is not involved in obtaining visual angles from Fig 2, it is evident that as the me from collision varies the visual angles obtained from this chart will remain constant hroughout the specific collision course being investigated If the required visual angle remains constant, there is no relative motion between the airplanes flying on a straight-and-level collision course

For any possible combination of speed relationship and absolute difference in heading that vould result in a collision, the visual angle required from the faster airplane will always be ess than 90° while the visual angle required from the slower airplane could be as great as 180° These maximum visual angles do not occur at the same time

The locus line drawn on Fig 2 indicates that the maximum visual angle required from the ister airplane occurs when a 90° visual angle is required from the slower airplane

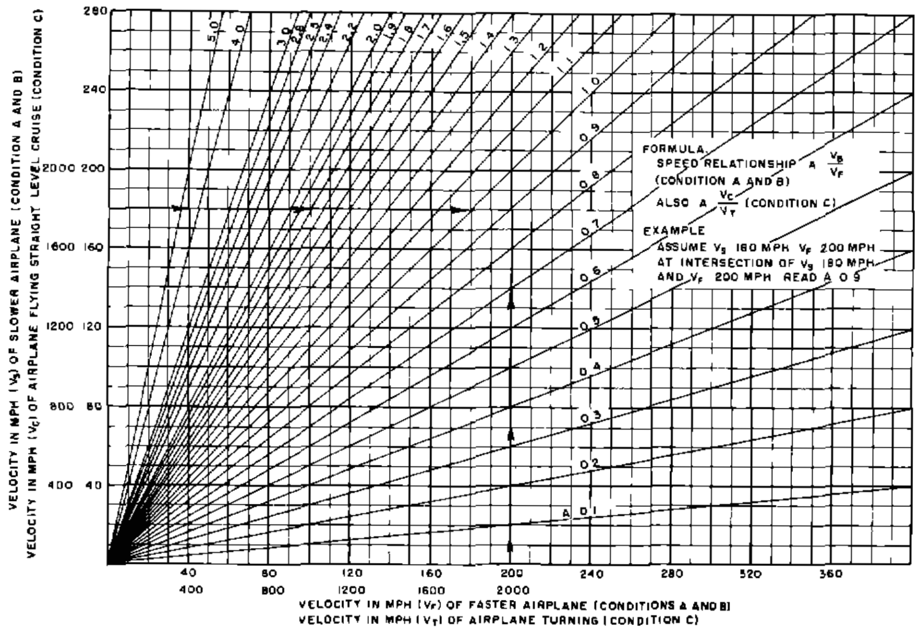

Fig 1 Determination of Speed Relationship

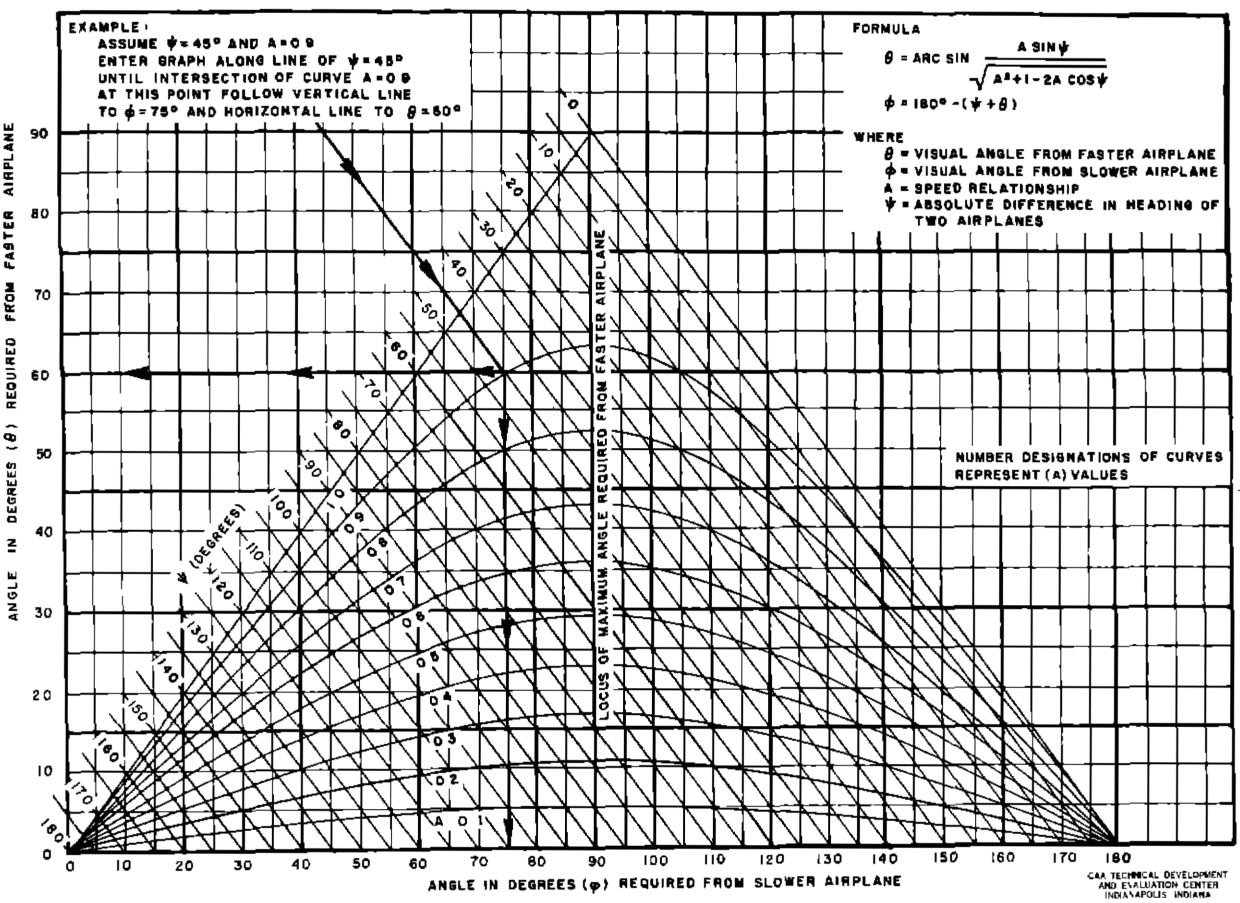

Fig 2 Horizontal Visual Angles Required From Two Airplanes for Level-Flight, Climb, and Descent Collision Conditions

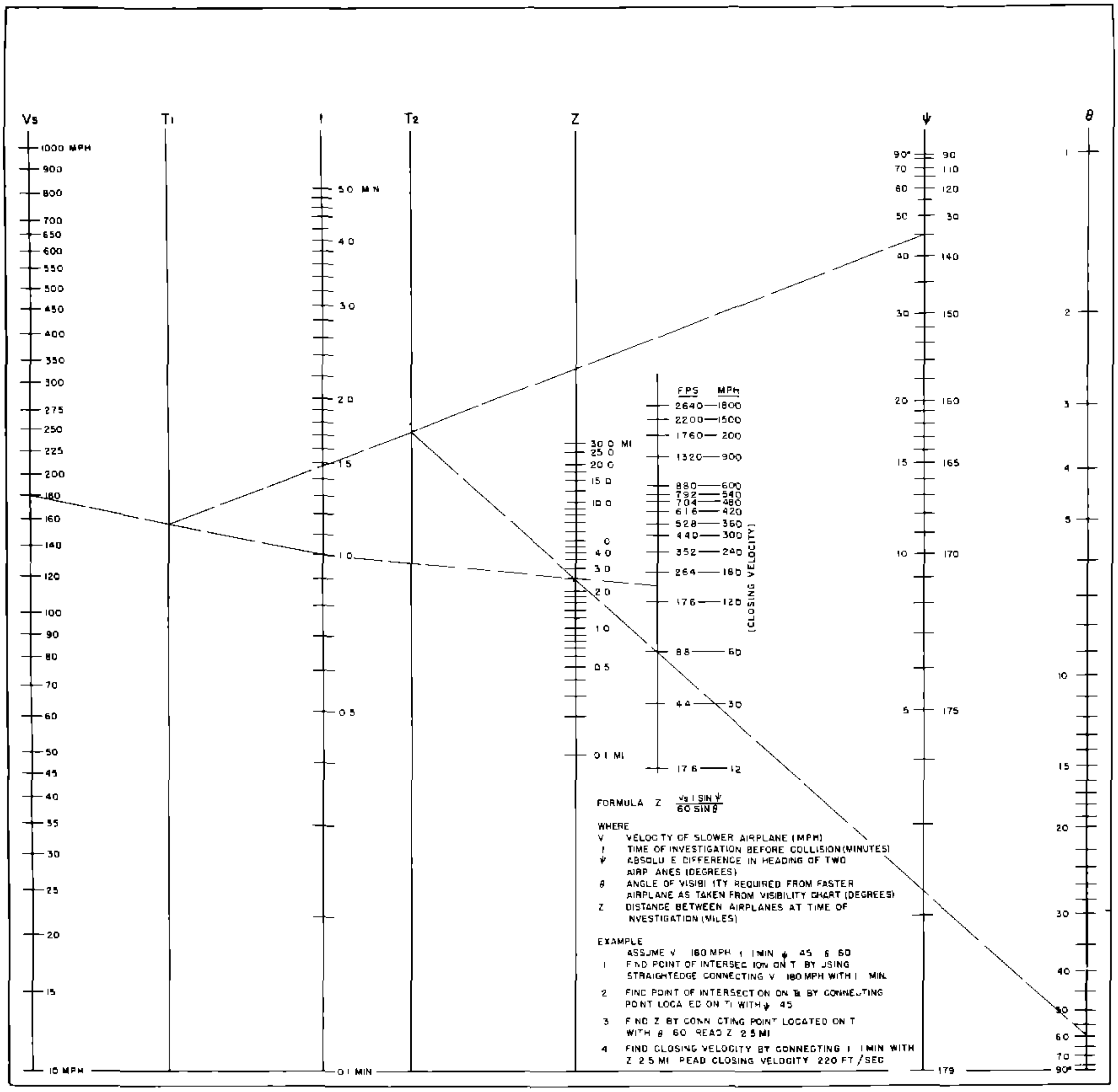

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Fig 3 Determination of Distance of Separation for Level-Flight Condition

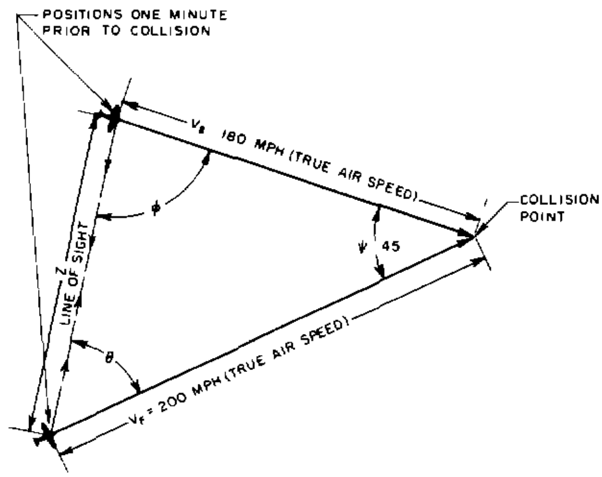

Fig 4 Vector Diagram of Sample Solution for Level-Flight Collision Condition

COLLISION CONDITION B
STRAIGHT CLIMB AND DESCENT

Description

Calculation of visual angles to right or left and up or down for the pilots of each aircraft to see the other aircraft is facilitated by the use of the charts designed for the climb-and-descent condition These charts are designed around the hypothesis that two airplanes are climbing or descending relative to one another and that they are approaching each other on straight courses from any direction at any relative speed

Procedure and Formulas

The climb and descent charts are shown in Figs 1, 2, 5, and 6 The procedure for using these charts is as follows

1 To determine speed relationship A, enter Fig 1 with the true airspeeds of the two aircraft

2 To determine horizontal visual angles θ and ϕ required for the pilots of each aircraft to see the other aircraft, enter Fig 2 with the absolute difference in true heading ψ and the value of A

3 To determine V, the projection upon the horizontal plane of the closing velocity (Fig 8), enter Fig 5 with horizontal visual angle θ required from faster airplane, velocity V_s of the slower airplane, and the absolute difference in true heading ψ

4 To determine the vertical angle ρ (which is measured from the horizon and is equal and opposite from each airplane), enter Fig 6 with the algebraic sum of the rate of change of altitudes between the two aircraft $\Delta_1 \pm \Delta_2$ and V, the projection upon the horizontal plane of the closing velocity

5 To determine the true vertical visual angle required, the fuselage attitude with respect to the horizon must be considered and the correction must be applied to the vertical angle ρ The fuselage attitude with respect to the horizon during climb or descent varies with different airplanes A listing of aircraft attitudes during climb or descent, as compiled from studies made at Indianapolis and Chicago airports, may be found on Table I The data for this table were computed from photographs of the flight paths as illustrated in Fig 7 These data are presented in order to obtain a sample of fuselage attitudes with respect to the horizon for different types of aircraft

6 To determine the distance Z between the airplanes at any instant of time prior to collision, enter Fig 5 with time t before collision, the vertical angle ρ, and V, the projection upon the horizontal plane of the closing velocity

7 To determine the closing velocity between the two aircraft, enter Fig 5 with the distance Z between aircraft and time t before collision

In determining the velocity V, the quantity needed for entering the vertical-angle chart (Fig 6), the nomograph[6] shown in Fig 5 was constructed by using Equation (4)

$$V = \frac{V_s \sin \psi}{\sin \theta} \tag{4}$$

Where

V = Vertical projection of the closing velocity upon the horizontal plane, in mph

V_s = Velocity of the slower airplane, in mph

ψ = Absolute difference in true heading of the two aircraft, in degrees

θ = Horizontal visual angle required from the faster airplane, in degrees

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[6] Lee H Johnson, "Nomography and Empirical Equations," John Wiley & Sons, Inc , New York, pp 33-43, 1952

The vertical-angle chart, shown in Fig 6, was constructed by substituting example values in the following equation

$$\rho = \arc \tan \frac{\Delta_1 \pm \Delta_2}{88V} \quad (5)$$

Where

Δ_1 or Δ_2 = Rate of climb or rate of descent of the respective airplanes, in feet per minute

$\Delta_1 \pm \Delta_2$ = The algebraic sum of the rate of change of altitude between the two airplanes, in feet per minute (If both Δ_1 and Δ_2 are rate of climb or if both are rate of descent, then a minus sign is used, for any other combination, a plus sign is used)

ρ = The vertical angle measured from the horizon, in degrees

V = Vertical projection of the closing velocity upon the horizontal plane, in mph

For determination of the distance between the aircraft at time t, Fig 5 was constructed by using Equation (6)

$$Z = \frac{Vt}{60 \cos \rho} \quad (6)$$

Where

V = Vertical projection of the closing velocity upon the horizontal plane, in mph

t = Time of investigation before collision, in minutes

ρ = Vertical angle, in degrees

Z = Distance between aircraft at time of investigation, in miles

Sample Solution

It is desired to know the visual angles that are required for the pilots of each aircraft to see the other aircraft while flying on a collision course and to determine the distance they are apart at a given time t Refer to Fig 8 In this case, one airplane is climbing and one is descending

V_s = 200 mph, the velocity (true air speed) of the slower airplane, which is climbing

Δ_1 = 1220 fpm, the rate of climb

V_f = 220 mph, the velocity (true air speed) of the faster airplane, which is descending

Δ_2 = 2000 fpm, the rate of descent

ψ = 45°, the absolute difference in true heading of the two aircraft

In this case, the climbing airplane is approaching the descending airplane from the right

t = 0 5 minute, the time of investigation before collision

Solution

1 Enter Fig 1 with V_s = 200 mph and V_f = 220 mph, and read A = 0 9

2 Enter horizontal-visual-angle chart, Fig 2, with ψ = 45° and A = 0 9 Read θ = 60° right, the horizontal visual angle (measured from straight ahead of the pilot-eye position) required for the slower airplane to be seen from the faster airplane Read ϕ = 75° left, the horizontal visual angle (measured from straight ahead of the pilot-eye position) required for the faster airplane to be seen from the slower airplane

3 Enter nomograph, Fig 5, with θ = 60°, V_s = 200 mph, and ψ = 45°, and read V = 160 mph, the velocity needed for entering the vertical-angle chart

4 Enter Fig 6, the vertical-angle chart, with $\Delta_1 + \Delta_2$ = 3220 feet per minute, which is the rate of change of altitude added algebraically between the two aircraft, and V = 160 mph Read ρ = 13°, the vertical angle (measured from the horizon) required for either airplane to be seen from the other The airplane descending would require 13° down from the horizon, and the airplane climbing would require 13° up from the horizon

5 To determine the true vertical visual angle required from each airplane, the fuselage attitude with respect to the horizon must be considered

For example, if it is assumed that the fuselage of the airplane climbing is in a 2° nose-up attitude, then the true vertical visual angle required from this airplane with respect to the cockpit would be 13° - 2°, or 11° up Also, if it is assumed that the fuselage of the airplane descending is in a 5° nose-down attitude, then the true vertical visual angle required from airplane with respect to the cockpit would be 13° - 5°, or 8° down Table I, which shows a variety of attitudes compiled from photographic studies made of actual take-off and landing-approach flight paths at Indianapolis and Chicago airports, is presented for the convenience of the reader

6 Enter nomograph, Fig 5, with V = 160 mph, previously determined in Step 3 In this case, t = 0 5 minute and ρ = 13° Read Z = 1 40 miles, the distance between the airplanes at time = 0 5 minute Note There can be similar solutions for other conditions such as both aircraft climbing, both aircraft descending, one airplane flying level and one climbing, or one airplane flying level and one descending

If the airplanes are climbing or descending on a difference in heading equal to 0° or 180°, the visual angles required from either airplane will be in the vertical plane only This condition, then, becomes the same as Condition A, except that in this case the relative motion occurs in the vertical plane while in Condition A the relative motion occurs in the horizontal plane If the vertical plane is rotated 90°, it becomes coincident with the horizontal plane, therefore, Condition B becomes hypothetically the same as Condition A and the visual-angle chart designed for Condition A can be used In using this chart, the difference in heading in this condition is determined by the angle of climb or descent of each airplane

Additional Considerations

The same additional considerations that were discussed in Condition A apply similarly to this collision condition

Discussion of Significant Trends

The trends discussed in Condition A apply similarly to this collision condition The vertical-visual-angle requirements from both airplanes are greatest at small differences in heading and small differences in speed

TABLE I

TYPICAL FLIGHT-PATH ANGLES AND FUSELAGE-LONGITUDINAL-AXIS ATTITUDES

Aircraft Type	Flight-Path Angle Relative to Horizon		Fuselage Attitude Relative to Flight-Path Angle		Fuselage Attitude Relative to Horizon	
	Takeoff (degrees)	Landing (degrees)	Takeoff (degrees)	Landing (degrees)	Takeoff (degrees)	Landing (degrees,
Martin 404	+ 7	- 5 25	-6	+0 75	+ 1	- 4 50
	6	- 8 0	-3	-3 75	+ 3	-11 75
	4 5	- 5 0	-4 5	-4 25	0	- 9 25
	5 25	- 4 0	-3 25	-3 0	+ 2	- 7 0
	4	- 5 0	-2 5	-4 0	+ 1 5	- 9 0
	4 75	- 7 5	-4 5	-8 0	+ 0 25	-15 5
	5	- 8 25	-4	-3 5	+ 1	-11 75
	7		0		+ 7	
	6		-4 5		+ 1 5	
	5		+2 5		+ 7 5	
	5		+2 5		+ 7 5	
Average	5 41	- 6 14	-2 48	-3 68	2 93	- 9 82
Convair 240	11	-10	+1	+1	12	- 9
	6 25	- 4	+1	-1	7 25	- 5
	1 50	- 5	0	+1	1 5	- 4
	5 0	- 5 75	+0 25	0	5 25	- 5 75
Average	5 94	- 6 19	±0 56	+0 25	6 50	- 5 94
Douglas DC-3	4 5	- 4 0	0	+1 5	4 5	- 2 5
	5 25	- 6 0	0	+2 0	5 25	- 4
	1 5	- 5 5	-0 5	2 75	1 0	- 2 75
	4 0	- 6 0	0	0	4 0	- 6
	4 0	- 5 5	-2 0	0	2 0	- 5 5
	4 5	- 5	-3	0	1 5	- 5
	4 0	- 5	+3	+2	7 0	- 3
	2 0	- 5	±3 5	1 5	5 5	- 3 5
	4 0		2 5		6 5	
Average	3 75	- 5 3	0 39	+1 22	+4 14	- 4 03
Lockheed Constellations	+ 3	- 5	-2 5	-1 0	+0 5	- 6 0
	+ 4	- 5 5	+1	-6 0	+5	-11 5
	+ 5		0		+5	
	+ 6		+2 5		+8 5	
Average	+ 4 5	- 5 25	+0 25	-3 5	4 75	- 8 75
Douglas DC-4	5 5		+1 0		4 5	
Douglas DC-6	3 5		0		3 5	
	4		3 5		7 5	
Average	+ 3 7		+1 7		+5 5	
Beech D-18S	+ 5 0	- 4	-5 0	-2	0	- 6 0
	3		0		3	
Average	+ 4	- 4	-2 5	-2	+1 5	- 6

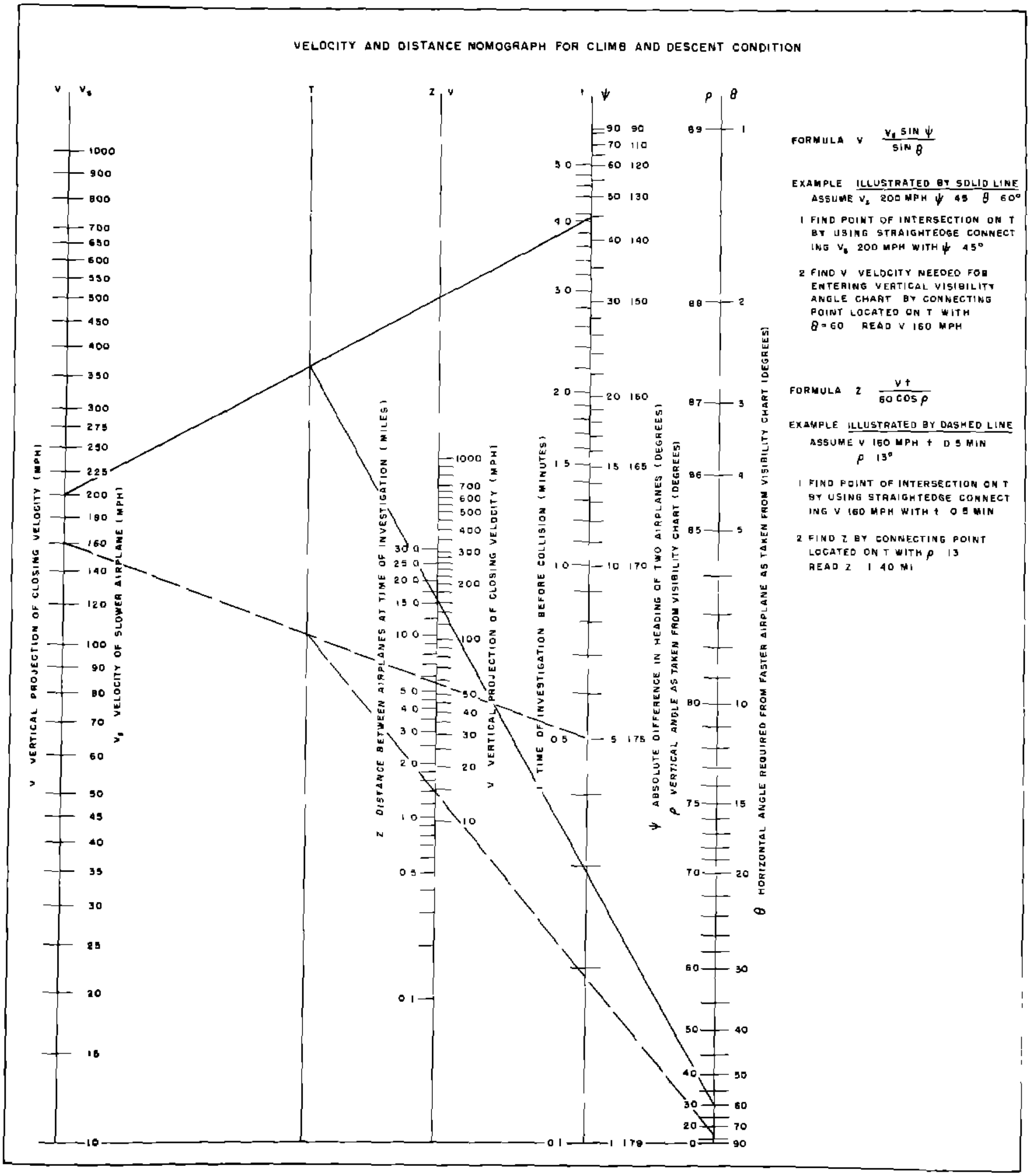

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Fig 5 Determination of Velocity and Distance of Separation for Climb-and-Descent Conditions

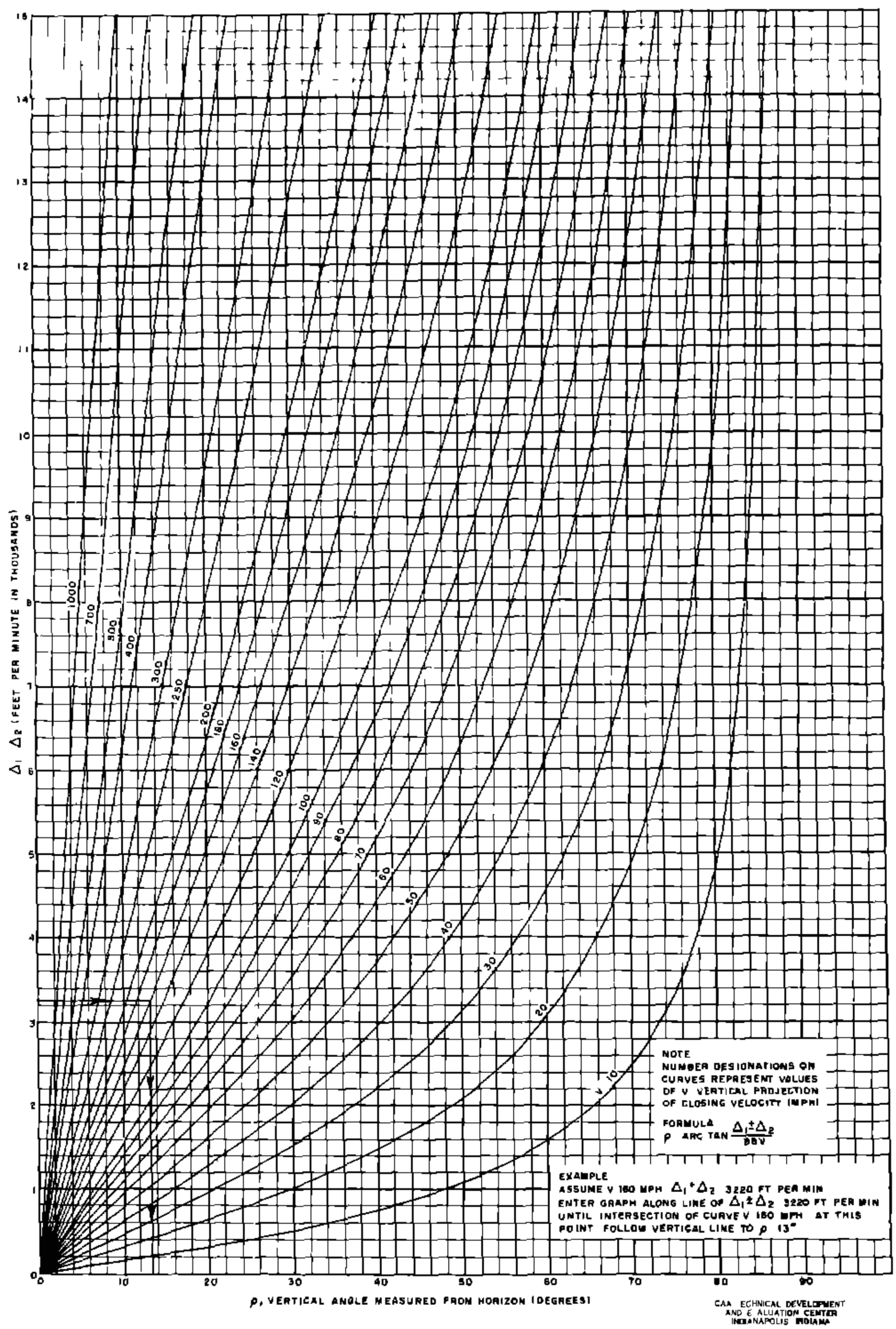


Fig 6 Vertical Angle, Measured From Horizon, Required From Two Airplanes for Climb-and-Descent Collision Condition

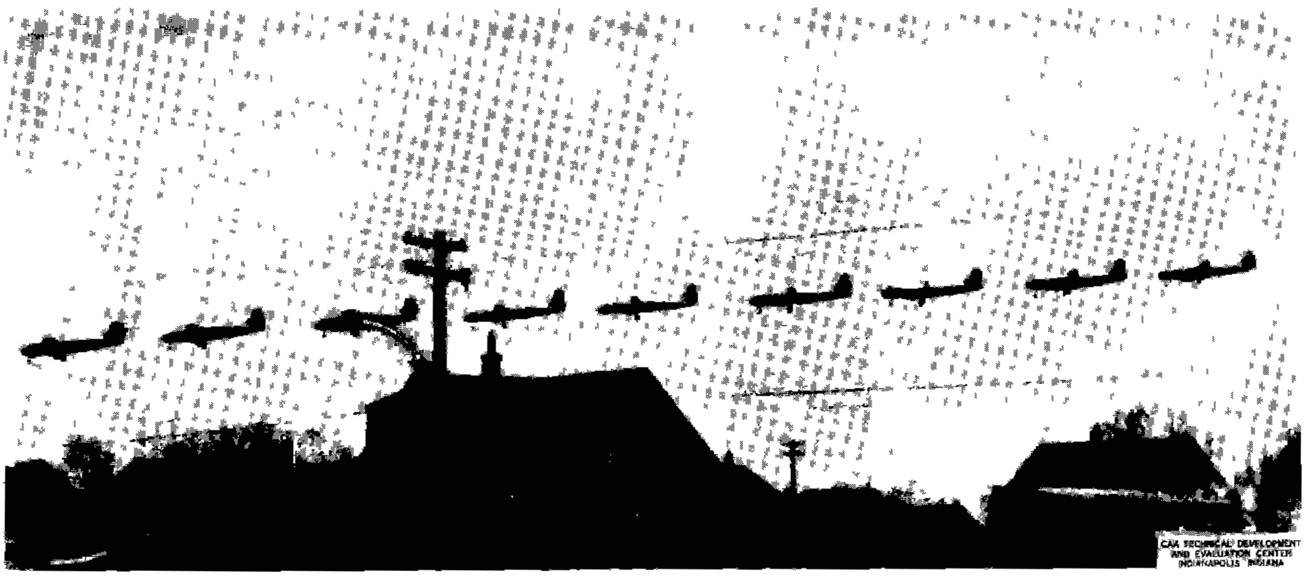


Fig 7 Example of Flight-Path Attitude Analysis

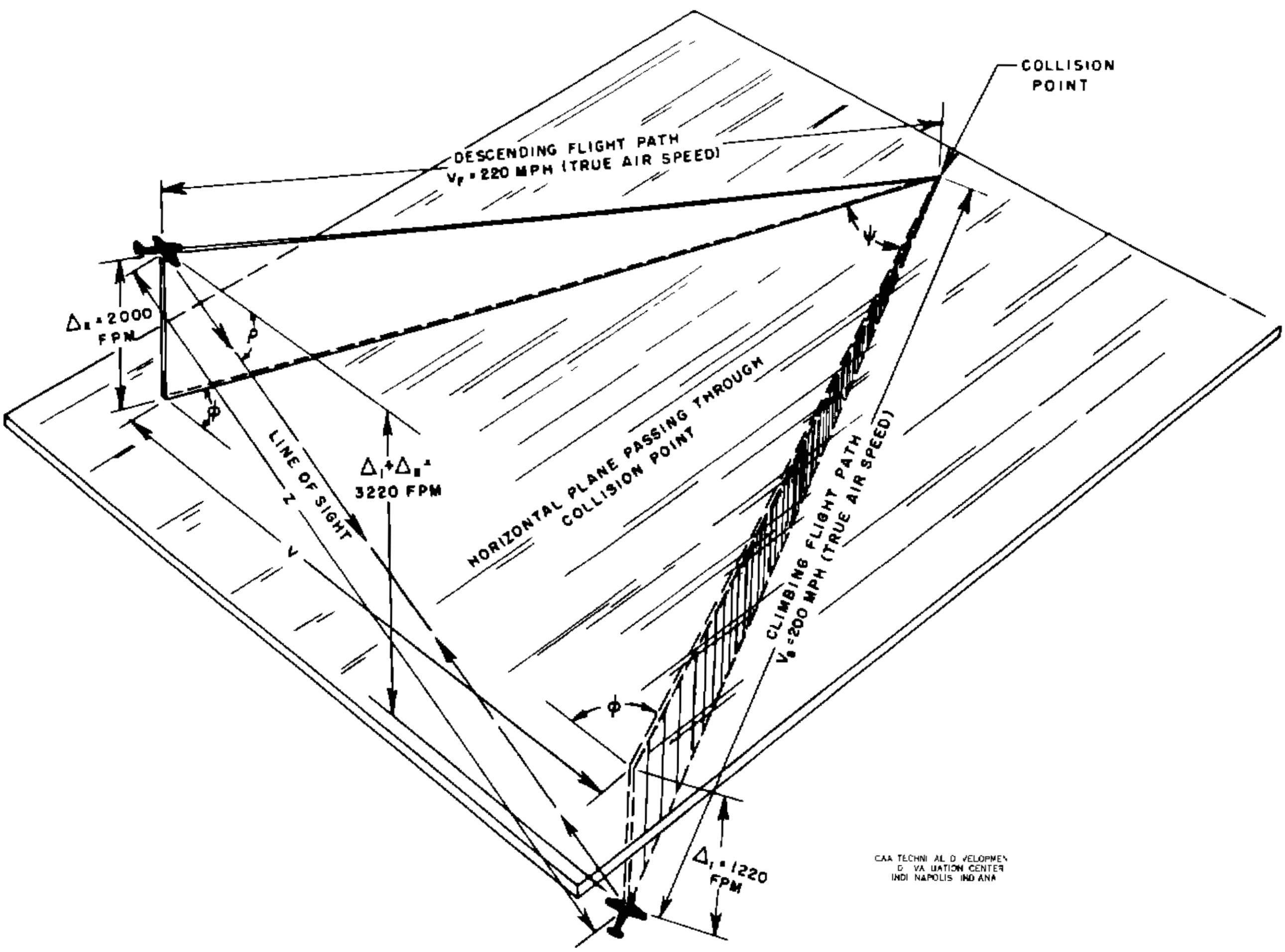


Fig 8 Vector Diagram of Sample Solution for Climb-and-Descent Collision Conditions

COLLISION COURSE C
ONE AIRPLANE TURNING AND ONE FLYING STRAIGHT AND LEVEL

Description

Calculation of the visual angles to the right or left which are required for the pilots of each airplane to see the other airplane is facilitated by the use of the charts designed for one airplane turning left and one airplane flying straight and level For the solution of a condition involving a right turn, see page 22

The turning-and-level-flight visual-angle charts are designed around the hypothesis that one airplane is flying straight and level while another airplane is making a left turn and both are on a collision course, flying in the same horizontal plane, and approaching each other at any relative speed from any direction

Procedure and Formulas

The turning and straight-and-level charts are shown in Figs 1 and 9 through 25 The procedure for using these charts is as follows

1 To determine speed relationship A, enter Fig 1 with the true air speeds of the two aircraft

2 To determine the time value t_0 required for entering the horizontal-visual-angle charts, enter Fig 25 with the angle of bank λ of the turning airplane, the velocity V_T of the turning airplane, and the time t of investigation before collision

3 To determine horizontal visual angles α and β (where α = the visual angle for the airplane flying straight and level and β = the visual angle for the turning airplane) required for the pilots of each aircraft to see the other aircraft, select from Figs 10 through 21 the horizontal-visual-angle chart that applies to the absolute difference in heading between the two aircraft at collision points Enter this chart with the time value t_0 and the speed relationship A

4 To determine the distance factor Z_0, enter with speed relationship A and time value t_0 the Z_0 table located on the same horizontal-visual-angle chart that was selected in Step C-3

5 To determine actual distance separation Z between aircraft at any time prior to collision, enter Fig 24 with distance factor Z_0 and radius of turn R_T If the radius of turn is not known, enter Fig 23 with the angle of bank λ and the velocity in turn V_T

6 To determine the vertical visual angle μ as affected by the angle of bank λ , enter Fig 22 with the angle of bank λ and the horizontal visual angle β

The speed-relationship chart, designed for Conditions A and B and shown in Fig 1, is used to obtain the speed relationship A In this case, however,

$$A = \frac{V_c}{V_T} \tag{7}$$

Where

V_c = Velocity of the airplane flying straight and level, in mph

V_T = Velocity of the airplane turning, in mph

The t_0 nomograph shown in Fig 25 was constructed by using the equation

$$t_0 = \frac{209\ 2 \tan \lambda\ t}{V_T} \tag{8}$$

Where

V_T = Velocity of the turning airplane, in mph

λ = Angle of bank of turning airplane, in degrees

t = Actual time of investigation before collision, in minutes

t_0 = Required time value for entering visual-angle charts, in minutes

The quantity t_0 is a relative time value determined by proportional analysis as described in the Appendix

The visual-angle charts shown in Figs 10 through 21 were constructed by substituting example values in the following equations

$$\alpha = \arc \tan \frac{Y}{X} \qquad (9)$$

$$\beta = \alpha + \omega - 90° \qquad (10)$$

$$Z = \sqrt{X^2 + Y^2} \qquad (11)$$

To solve Equations (9), (10), and (11), the following has to be known

$$X = V_c t + R_T (\cos \psi - \cos \omega) \qquad (12)$$

$$Y = R_T (\sin \psi + \sin \omega) \qquad (13)$$

$$\omega = Kt - \psi \qquad (14)$$

Where

α = the horizontal visual angle that is needed from straight ahead for the turning airplane to be seen from the airplane flying straight and level, in degrees

β = the horizontal visual angle that is needed from straight ahead for the airplane flying straight and level to be seen from the turning airplane, in degrees

Z = Distance between the aircraft at time t, in feet

t = Time before collision, in minutes

V_c = Velocity (true air speed) of airplane flying straight and level, in feet per minute

R_T = Radius of flight path of turning aircraft, in feet

K = Rate of turn of the turning aircraft, in degrees per minute

ψ, ω, X, and Y are illustrated in Fig 86 of the Appendix

Note In case it is necessary to calculate visual angles by using the formulas, use of Table II will be necessary to determine that value of ψ which corresponds to the absolute difference in heading at collision point

The vertical-visual-angle chart shown in Fig 22 was constructed by passing a horizontal plane, which simulates the plane of the horizon, through a right cylinder at different bank angles and then plotting the points of intersection The plane of the horizon is the horizontal plane in which both aircraft are flying, therefore, the pilot flying either aircraft must look to the horizon to see the other aircraft

TABLE II

RELATIONSHIP BETWEEN ψ AND ACTUAL HEADING DIFFERENCE

ψ (degrees)	Difference in Heading at Collision Point (degrees)	Condition
0	90	With turning airplane on the left of cruising airplane at collision point
30	60	With turning airplane on the left of cruising airplane at collision point
60	30	With turning airplane on the left of cruising airplane at collision point
90	0	Both airplanes heading in the same direction
120	30	With turning airplane on the right of cruising airplane at collision point
150	60	With turning airplane on the right of cruising airplane at collision point
180	90	With turning airplane on the right of cruising airplane at collision point
210	120	With turning airplane on the right of cruising airplane at collision point
240	150	With turning airplane on the right of cruising airplane at collision point
270	180	Head on
300	150	With turning airplane on the left of cruising airplane at collision point
330	120	With turning airplane on the left of cruising airplane at collision point

---

The radius-of-turn chart shown in Fig 23 was constructed by substituting example values in the equation[7]

$$\tan \lambda = \frac{0\ 067\ V_T^{\ 2}}{R_T} \qquad (15)$$

Where

λ = Angle of bank, in degrees

V_T = Velocity of turning airplane, in mph

R_T = Radius of turn, in feet

[7] Bradley Jones, "Elements of Practical Aerodynamics," Eqn (22 2 1) p 365, John Wiley & Sons, Inc , New York, 1950

The distance chart shown in Fig 24 was constructed by substituting values in the equation

$$Z = \frac{Z_0 R_T}{2801\ 1} \qquad (16)$$

Where

Z = Actual distance between aircraft at time t before collision, in feet

Z_0 = Proportional distance between aircraft as obtained from visual-angle chart, in feet

R_T = Radius of turn of turning airplane, in feet

Sample Solution

It is desired to know what visual angles are required for the pilots of each aircraft to see the other aircraft while on a collision course and to determine the distance they are apart at a given time Refer to Fig 9 In this case, one airplane is flying straight and level and one airplane is turning left

V_c, the velocity of the airplane cruising straight and level, = 250 mph, true air speed

V_T, the velocity of the turning airplane, = 100 mph, true air speed

λ , the angle of bank of the turning airplane, = 20°

t, the time before collision to be investigated, = 0 5 minute

absolute difference in heading at collision point = 90°

Solution

1 Enter Fig 1 with V_c = 250 mph and V_T = 100 mph, and read A = 2 5
2 Enter Fig 25 with λ = 20°, t = 0 5 minute, and V_T = 100 mph, and read t_0 = 0 38
3 Since the absolute difference in heading at collision is 90° with the turning airplane on the left at collision point, Fig 13 of the horizontal-visual-angle charts is selected Enter this chart with t_0 = 0 38 and A = 2 5, and read α , which is the horizontal visual angle required from the airplane flying straight and level, equal to 4° left, also read β , which is the horizontal visual angle required from the turning airplane, equal to 52° left

To find the distance between the aircraft at 0 5-minute separation, enter the Z_0 table on Fig 13 with A equal to 2 5 and t_0 equal to 0 38 No value of t_0 equal to 0 38 appears, therefore, the following interpolation is made

A = 2 5	t_0 = 0 40	Z_0 = 22,727
A = 2 5	t_0 = 0 30	Z_0 = 17,076
		5,651 = Difference

Since 0 38 is 0 8 of the interval between 0 30 and 0 40, 0 8 x 5651 = 4521 for t_0 = 0 38 and A = 2 5, Z_0 = 17,076 + 4521 = 21,597 feet, or approximately 21,600 feet This is not a true distance but a proportional distance which will be used in Step 5 to determine Z, the true distance

If the absolute difference in heading at collision does not exactly correspond to one of the charts, then a similar interpolation between charts is necessary

4 If R_T the radius of turn of the turning aircraft is not known, Fig 23 is entered with λ equal to 20° and V_T equal to 100 mph, and read R_T equal to 1840 feet

5 Enter Fig 24 with Z_0 equal to 21,600 feet, previously determined, and R_T equal to 1840 feet Read Z = 14,000 feet

6 To find the vertical visual angle μ, required at 0 5 minute from the turning aircraft while it is in a 20° bank, enter Fig 22 with λ equal to 20° and β equal to 52° left and read vertical visual angle required equal to 16° up

Additional Considerations

The formulas and charts are designed for using true air speed and true heading of the aircraft In the event that ground track and ground speeds are used, it is necessary to correct the visual angles by adding or subtracting the crab angle or the wind-drift angle

Visual angles may be determined from one airplane flying straight and level and one airplane making a right turn instead of a left turn by using the following procedure

Given

The absolute difference in heading at collision point is equal to 150° with the turning airplane on the right of the cruising airplane at the collision point and making a right turn

1 Enter the horizontal-visual-angle chart designed for a difference in heading at collision point equal to 150° and with the airplane making a turn on the left of the airplane flying straight and level at the collision point This chart is entered with the parameters determined by the given condition, the only difference being that left is substituted for right in using the charts as related to heading at collision point

2 In reading α and β, the magnitudes of the angles are correct but the directions of the angles need to be reversed to apply correctly to the given condition

3 The distance between the airplanes at a specified time before collision and the vertical visual angles are determined in the same manner as described for one airplane flying straight and level and one airplane making a left turn

Discussion of Significant Trends

The rate of change of the horizontal visual angle required from the airplane flying at level cruise is greatest when the velocity of the turning airplane is the greater of the two

The rate of change of the horizontal visual angle required from the turning airplane is greatest and varies over the widest range when the velocity of the airplane flying at level cruise is the greater of the two

When both airplanes are traveling at the same speed, the rate of change of the horizontal visual angle required from the turning airplane is generally greater than that of the airplane flying at level cruise

When the rate of change of the horizontal visual angle required is the greatest from one airplane, it is a minimum for the other airplane

In analyzing all horizontal-visual-angle charts for Condition C, it will be noted that when all curves cross at one common intersection point then the turning airplane is directly ahead or directly behind the airplane flying straight and level

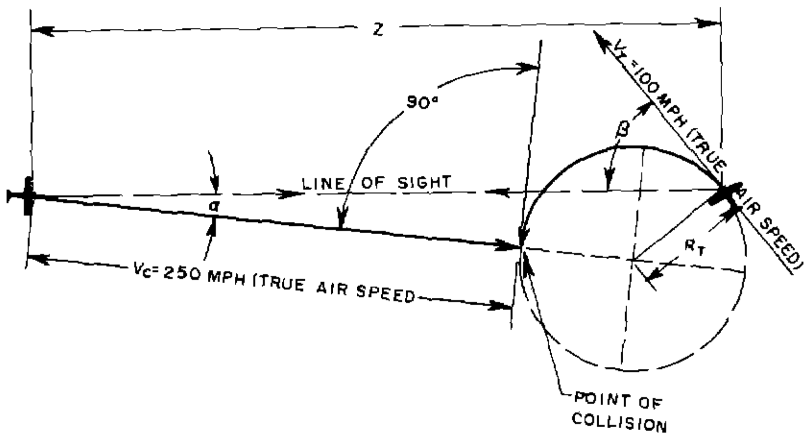
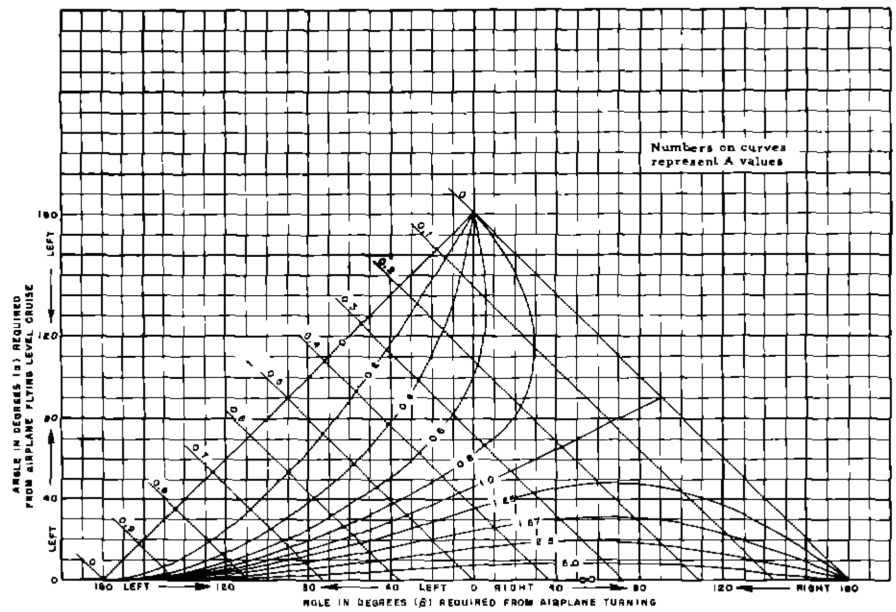


Fig 9 Vector Diagram of Sample Solution for One Airplane Turning Left and One Airplane Flying Straight and Level

The following charts are designed for the determination of horizontal-visual-angle requirements and distance factors for one airplane turning and one airplane flying straight and level

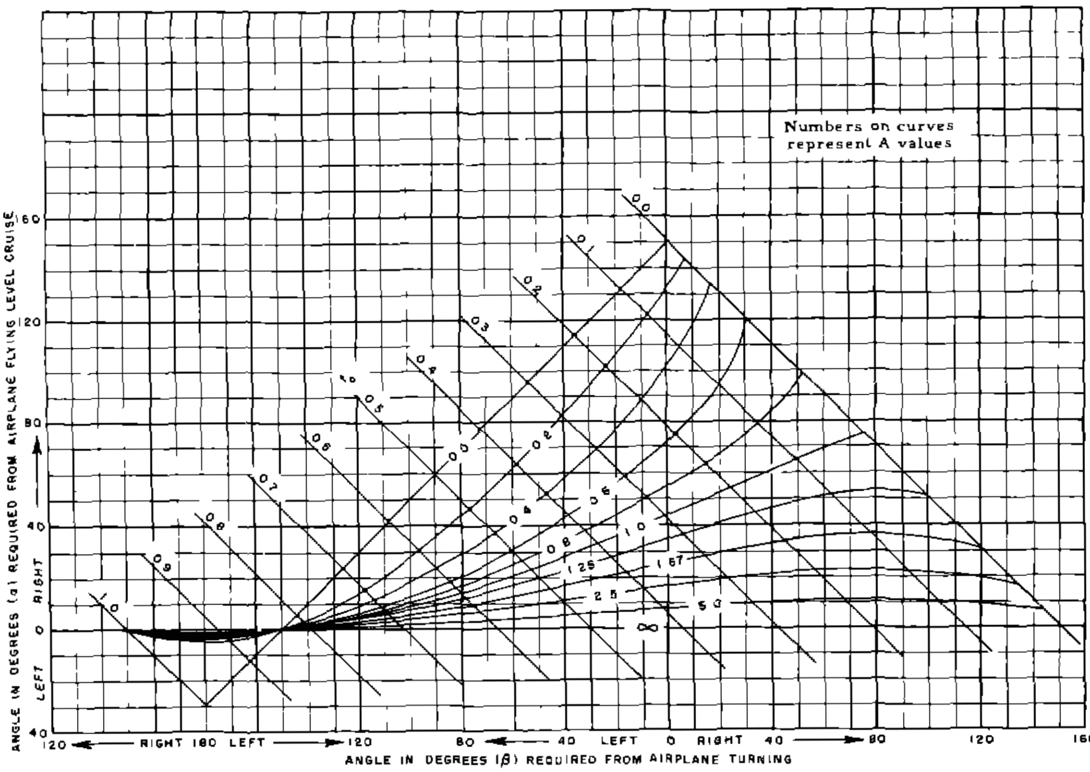


ω_0 Values

t_0

		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
	0 2	1401	2755	4004	5073	5872	6309	6304	5612	4844	3520
	0 4	1084	2307	3708	5200	6616	7755	8431	8519	8000	7040
	0 6	797	2013	3701	5685	7698	9455	10704	11279	11163	10560
	0 8	586	1941	3985	6447	8997	11295	13046	14062	14328	14080
A	1 0	547	2116	4504	7400	10432	13216	15426	16856	17495	17600
	1 25	769	2600	5379	8766	12344	15687	18432	20356	21453	22000
	1 67	1394	3742	7148	11268	15700	19902	23425	26202	28052	29333
	2 5	2805	6434	11156	16739	22702	28501	33664	37913	41250	44000
	5 0	7173	15061	24018	33934	44355	54682	64369	73090	80848	88000

Fig 10 At Collision Point, the Difference in Heading = 0° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

		t_0									
		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
	0 2	1518	3075	4545	5787	6659	7041	6857	6101	4675	3520
	0 4	1364	3009	4796	6524	7968	8926	9254	8914	8037	7040
	0 6	1290	3106	5251	7456	9426	10895	11679	11727	11203	10560
	0 8	1310	3351	5864	8520	10972	12910	14117	14543	14370	14080
A	1 0	1420	3716	6580	9672	12575	14951	16563	17358	17537	17600
	1 25	1655	4292	7606	11195	14629	17526	19627	20878	21496	22000
	1 67	2192	5436	9468	13858	18129	21852	24743	26744	28096	29333
	2 5	3488	8044	13501	19420	25271	30568	34989	38476	41295	44000
	5 0	7749	16537	26315	36680	47052	56871	65766	73676	80894	88000

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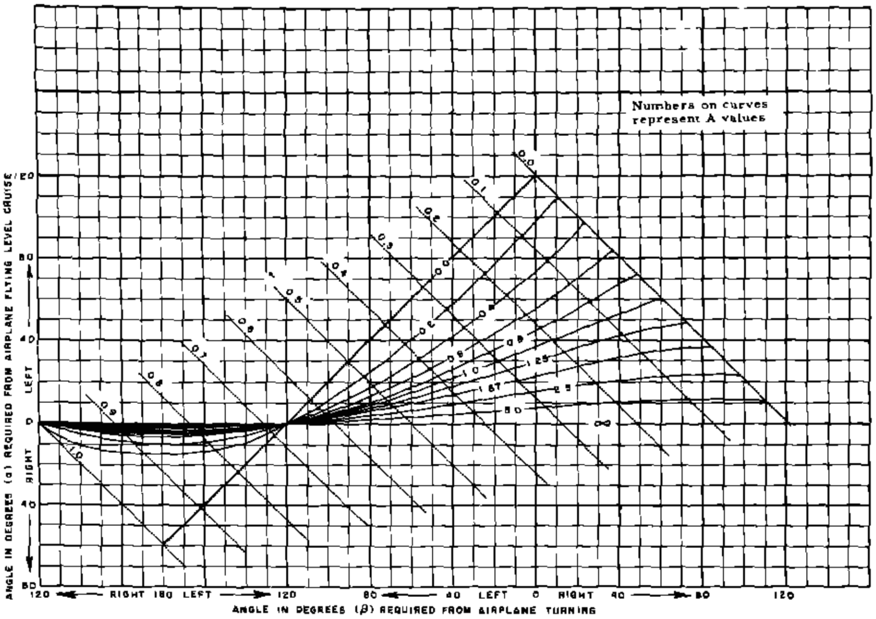
Fig 11 At Collision Point, the Difference in Heading = 30° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

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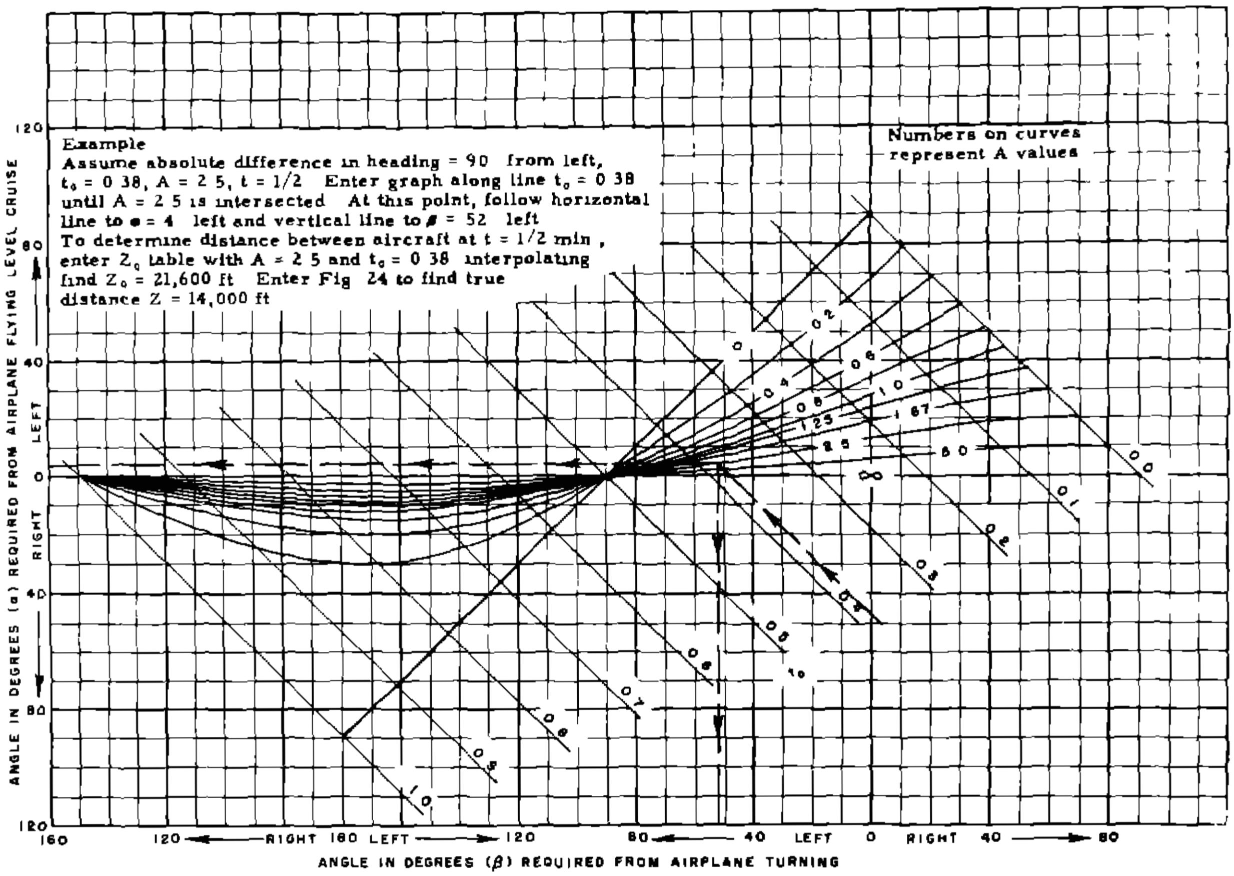
t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1693	3439	5055	6357	7181	7440	7020	6000	4620	3520
0 4	1728	3714	5726	7510	8828	9500	9447	8743	7710	7040
0 6	1831	4094	6501	87 8	10512	11601	11909	11934	10853	10560
0 8	1991	4551	7346	10013	12217	13704	14371	14335	14007	14080
◄ 1 0	2197	5065	8239	11320	13936	15812	16834	17141	17166	17600
1 25	2501	5765	9404	12984	16097	18445	19913	20652	21118	22000
1 67	3080	7021	11420	15803	19718	22839	25045	26509	27711	29333
2 5	4381	9713	15603	21532	26997	31631	35311	38232	40903	44000
5 0	8608	18241	28545	38967	48932	58022	66109	73420	80495	86000

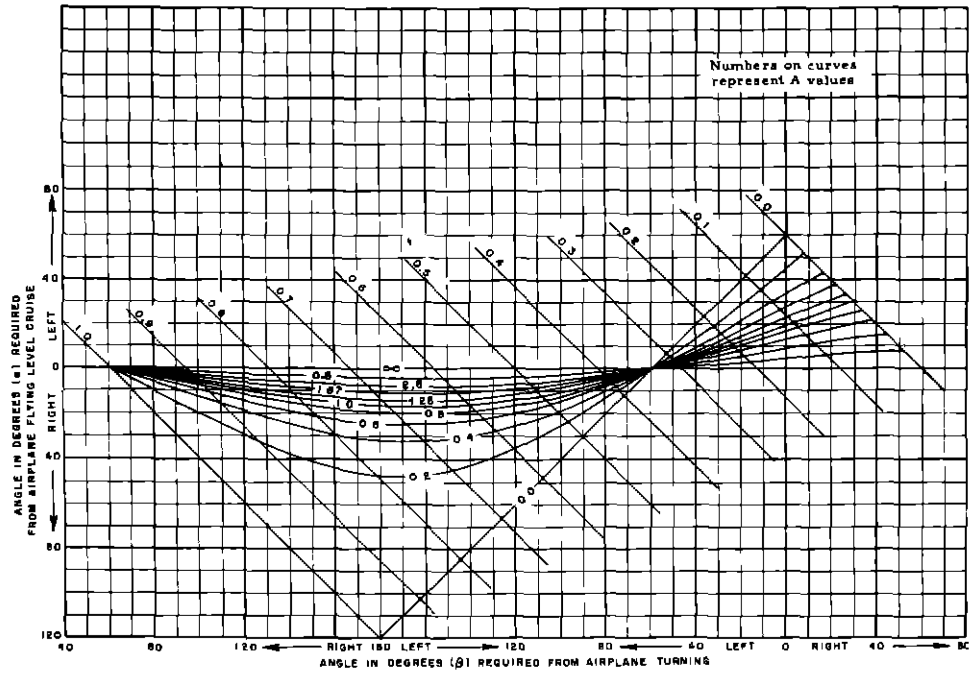
Fig 12 At Collision Point, the Difference in Heading = 60° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1870	3750	5422	6681	7362	7366	6685	5447	4053	3520
0 4	2061	4275	6363	8053	9122	9436	8998	8023	7065	7040
0 6	2290	4846	7336	9436	10882	11522	11375	10720	10173	10560
0 8	2547	5447	8328	10825	12642	13615	13783	13466	13309	14080
< 1 0	2825	6071	9335	12219	14402	15714	16207	16236	16458	17600
1 25	3192	6873	10607	13965	16602	18341	19252	19716	20402	22000
1 67	3839	8244	12748	16881	20269	22727	24346	25542	26985	29333
2 5	5202	11061	17076	22727	27602	31510	34570	37231	40169	44000
5 0	9479	19716	30185	40301	49602	57891	65321	72385	79752	88000

Fig 13 At Collision Point, the Difference in Heading = 90° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	2007	3947	5584	6712	7181	6922	5975	4551	3279	3520
0 4	2303	4615	6636	8104	8828	8738	7937	6815	6211	7040
0 6	2613	5293	7690	9500	10512	10664	10121	9382	9300	10560
0 8	2933	5976	8744	10900	12217	12649	12411	12061	12428	14080
◄ 1 0	3259	6664	9799	12302	13936	14670	14756	14791	15572	17600
1 25	3674	7528	11118	14055	16097	17226	17734	18241	19514	22000
1 67	4376	8975	13316	16981	19718	21532	22757	24035	26095	29333
2 5	5803	11884	17714	22839	26997	30226	32905	35695	39277	44000
5 0	10153	20652	30911	40427	48932	56504	63578	70820	78858	88000

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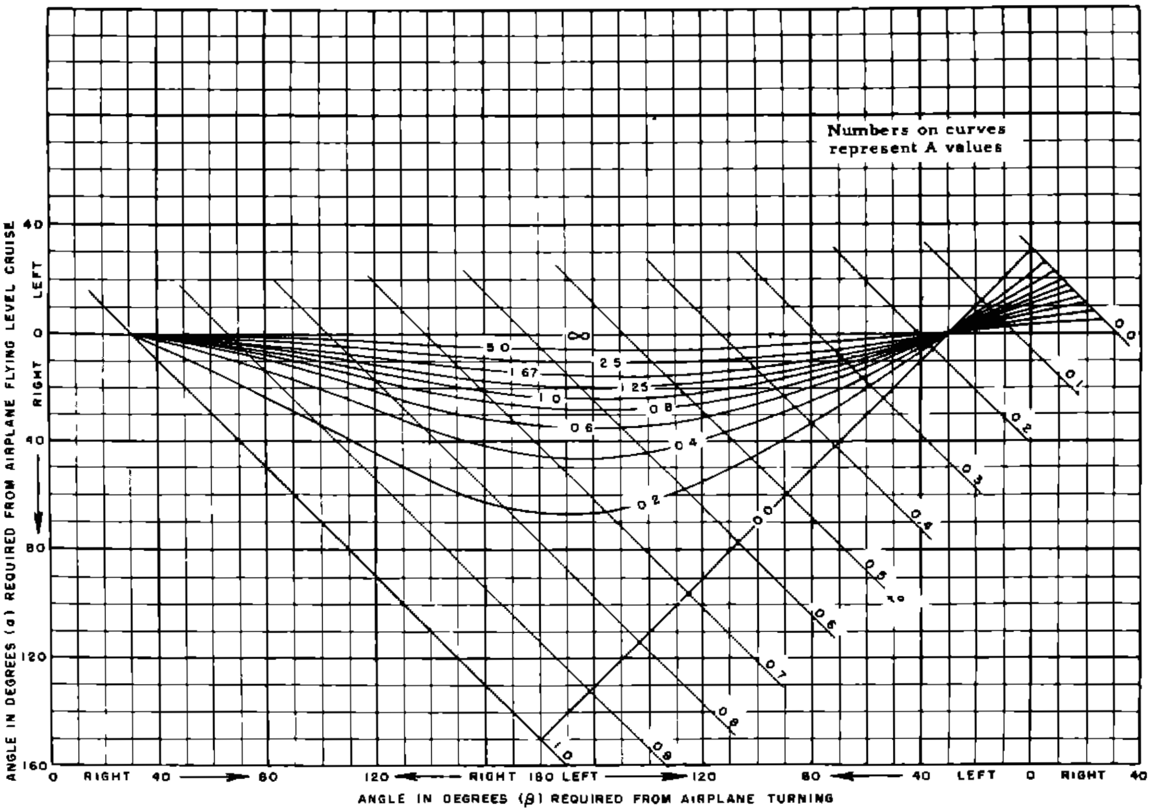
Fig 14 At Collision Point, the Difference in Heading = 120° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	2077	3994	5514	6444	6659	6126	4927	3351	2386	3520
0 4	2424	4695	6519	7656	7968	7456	6337	5242	5335	7040
0 6	2773	5398	7537	8926	9426	9087	8257	7719	8444	10560
0 8	3122	6101	8565	10233	10972	10885	10409	10371	11585	14080
1 0	3472	6804	9599	11563	12575	12779	12675	13091	14738	17600
1 25	3910	7683	10898	13248	14629	15227	15592	16537	18686	22000
1 67	4641	9148	13071	16093	18129	19420	20560	22331	25274	29333
2 5	6104	12080	17438	21852	25271	27997	30659	33994	38463	44000
5 0	10500	20878	30596	39321	47052	54159	61292	69126	78052	88000

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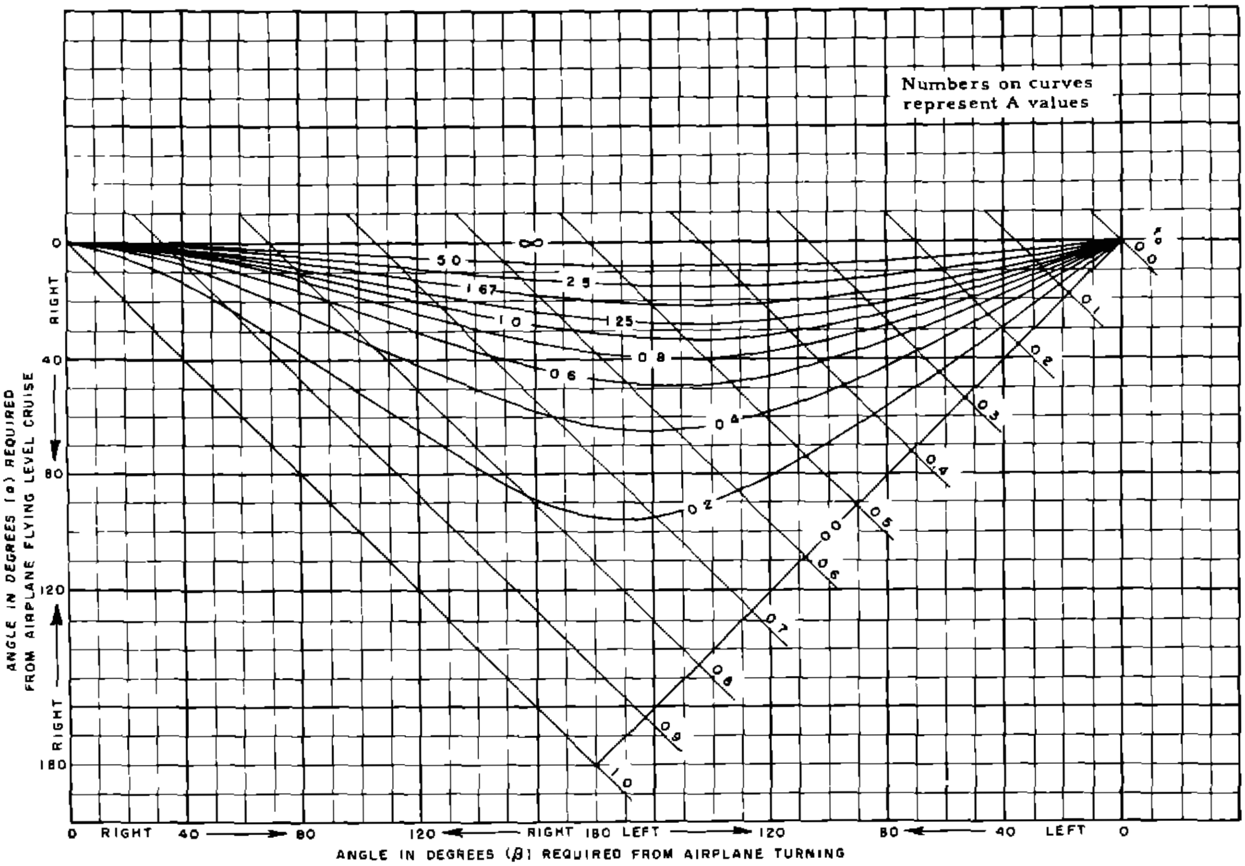
Fig 15 At Collision Point, the Difference in Heading = 150° and the Turning Airplane is on the Left of the Airplane Flying Straight and Level



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	2069	3885	5223	5917	5872	5089	3672	1941	1613	3520
0 4	2411	4509	6021	6752	6616	5685	4309	3543	4720	7040
0 6	2755	5153	6889	7755	7698	6904	5983	6099	7876	10560
0 8	3101	5812	7803	8869	8997	8482	8073	6815	11039	14080
∢ 1 0	3448	6480	8749	10056	10432	10253	10329	11579	14204	17600
1 25	3883	7324	9963	11611	12344	12616	13253	15061	18161	22000
1 67	4611	8748	12036	14307	15700	16739	18242	20892	24759	29333
2 5	6070	11626	16282	19902	22702	25267	28374	32593	37957	44000
5 0	10460	20356	29294	37193	44355	51404	59050	67764	77555	88000

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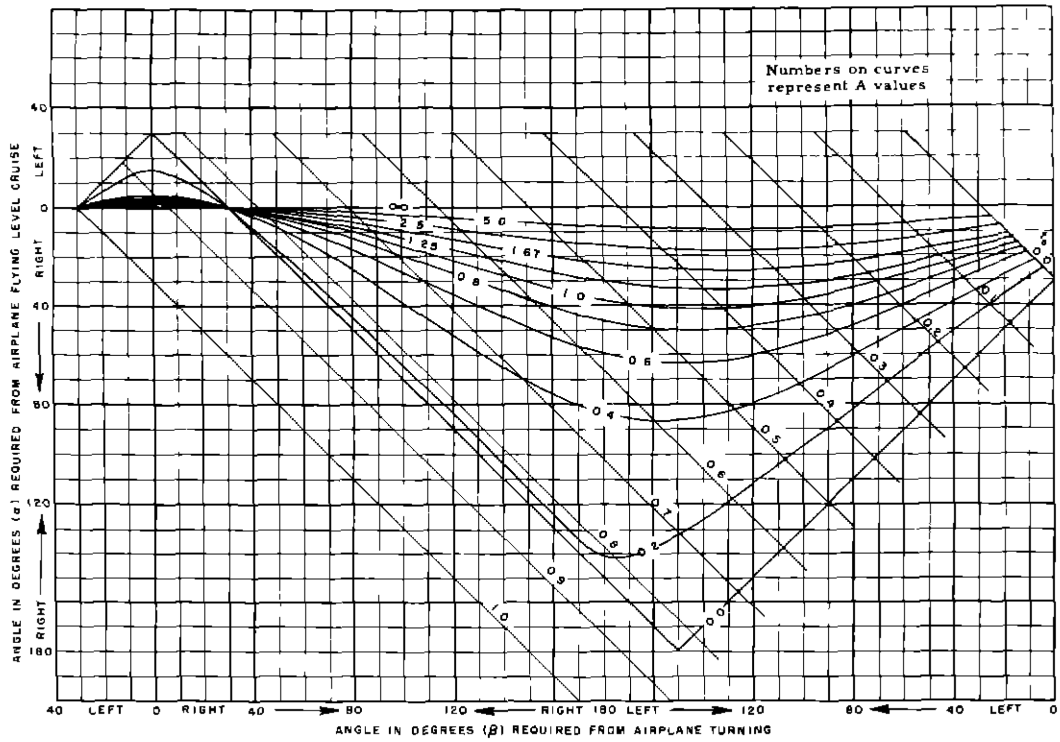
Fig 16 At Collision Point, the Difference in Heading = 180° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level

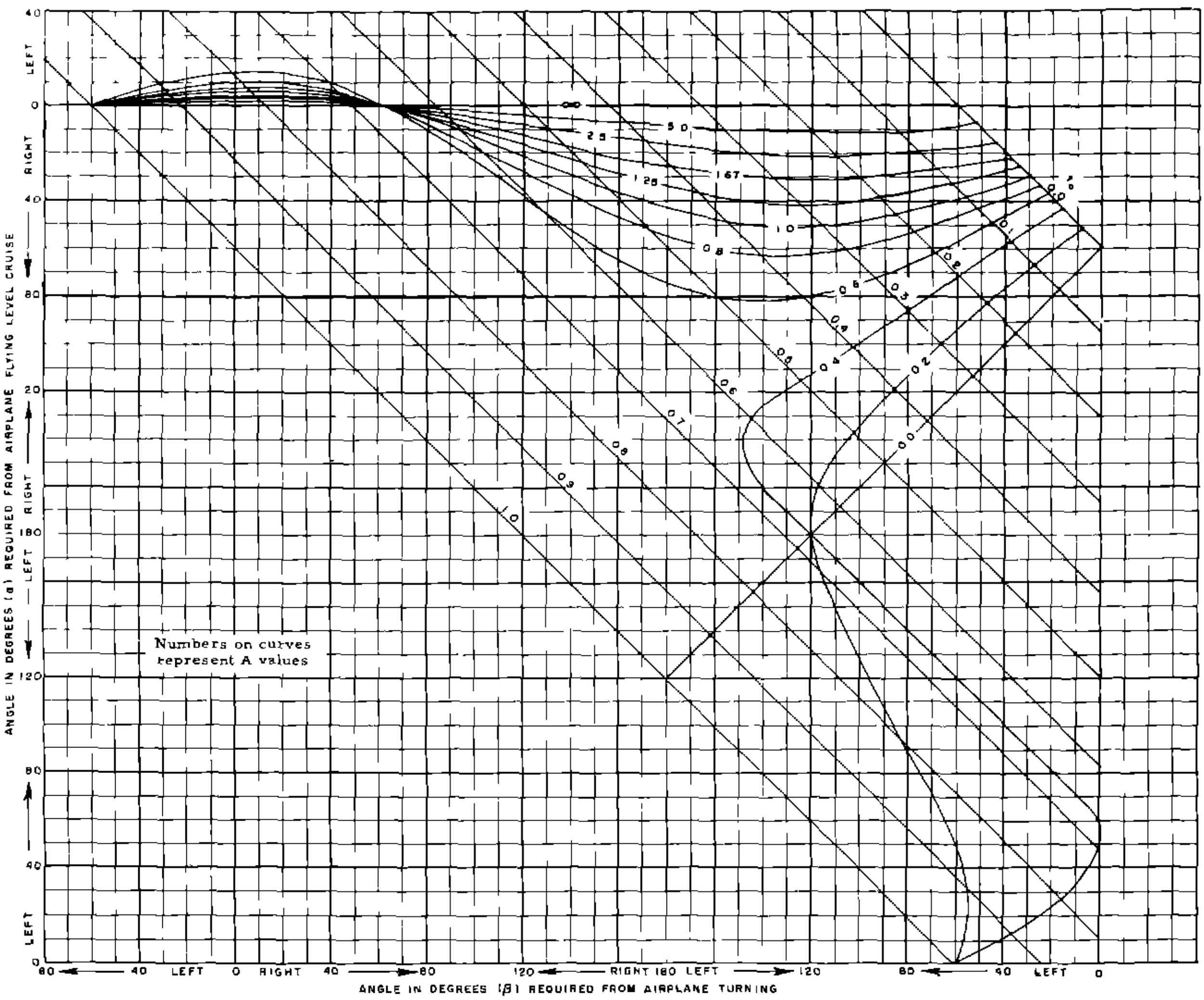


Z_0 Values

t_0

A		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
	0 2	1984	3637	4760	5220	4962	4015	2492	574	1518	3520
	0 4	2263	4074	5197	5484	4905	3575	2004	2382	4657	7040
	0 6	2561	4578	5795	6072	5448	4285	3738	5185	7819	10560
	0 8	2871	5130	6511	6901	6443	5732	6005	7997	10985	14080
	1 0	3189	5715	7309	7896	7715	7502	8385	10811	14151	17600
	1 25	3596	6480	8388	9291	9527	9904	11409	14329	18110	22000
	1 67	4289	7809	10311	11835	12819	14099	16496	20195	24709	29333
	2 5	5705	10576	14398	17296	19802	22722	26723	31927	37908	44000
	5 0	10041	19177	27249	34488	41484	48970	57489	67126	77507	88000

Fig 17 At Collision Point, the Difference in Heading = 150° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1837	3295	4215	4509	4172	3292	2098	1353	2210	3520
0 4	2000	3443	4149	4030	3101	1484	633	2946	5181	7040
0 6	2207	3722	4347	4014	2834	1578	2923	5602	8299	10560
0 8	2448	4103	4776	4467	3555	3421	5369	8364	11444	14080
◄ 1 0	2713	4562	5381	5268	4841	5462	7827	11152	14599	17600
1 25	3069	5213	6306	6564	6756	8065	10903	14653	18550	22000
1 67	3703	6421	8095	9077	10207	12438	16033	20502	25140	29333
2 5	5052	9068	12088	14583	17376	21217	26297	32220	38331	44000
5 0	9315	17564	24903	31882	39248	47601	57094	67405	77922	88000

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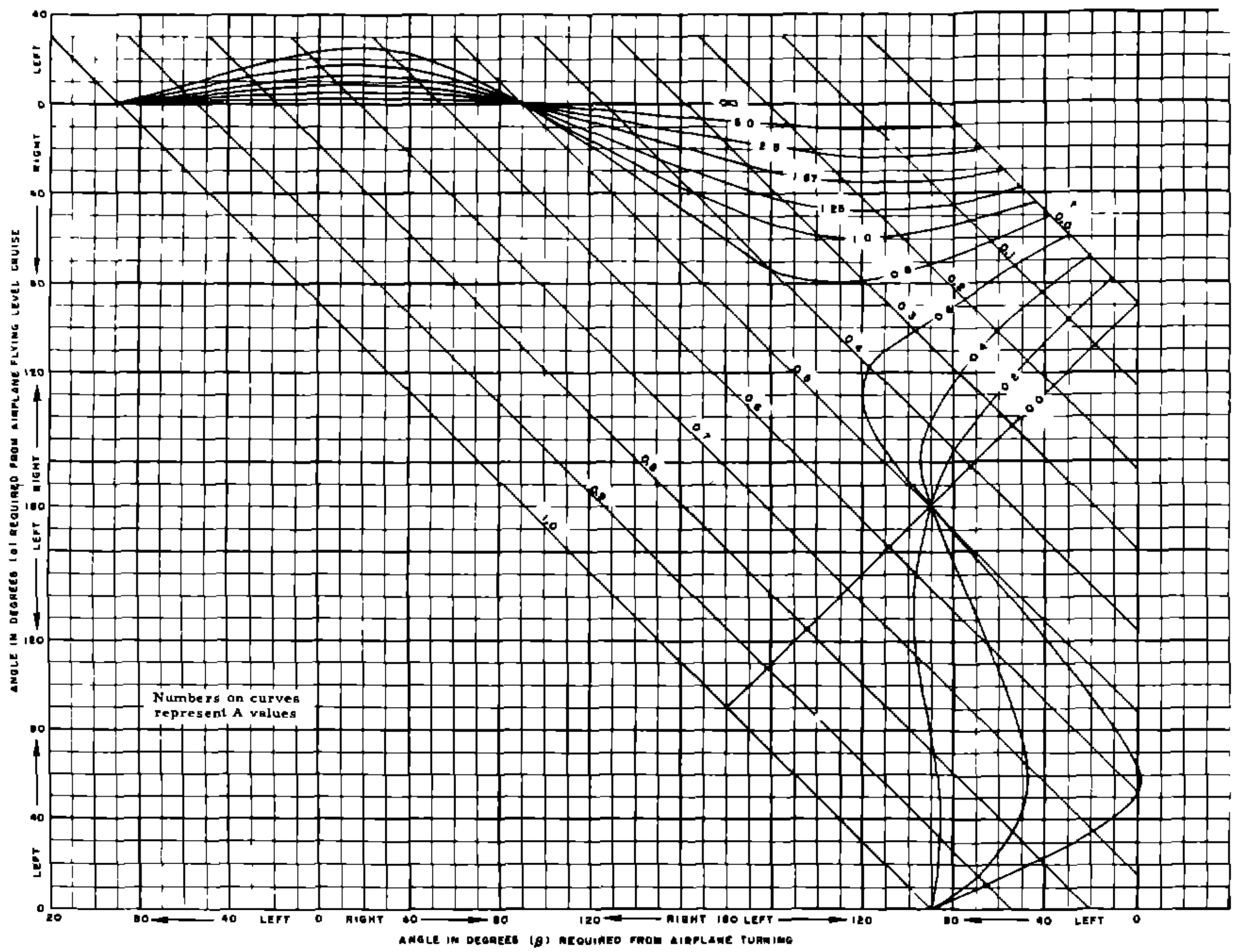
Fig 18 At Collision Point, the Difference in Heading = 120° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level



Z$_0$ Value

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1657	2935	3730	4013	3842	3383	2923	2806	3105	3520
0 4	1655	2716	3084	2789	2082	1850	2948	4556	6030	7040
0 6	1727	2670	2710	1850	322	2079	4580	7036	9119	10560
0 8	1864	2806	2722	1741	1438	3760	6738	9701	12248	14080
< 1 0	2052	3100	3114	2570	3198	5734	9054	12433	15393	17600
1 25	2342	3629	3962	4080	5398	8298	12032	15889	19335	22000
1 67	2909	4749	5783	6866	9064	12640	17076	21695	25917	29333
2 5	4201	7363	9898	12640	16398	21396	27264	33371	39100	44000
5 0	9427	15889	22889	30178	38398	47761	57994	68516	78682	88000

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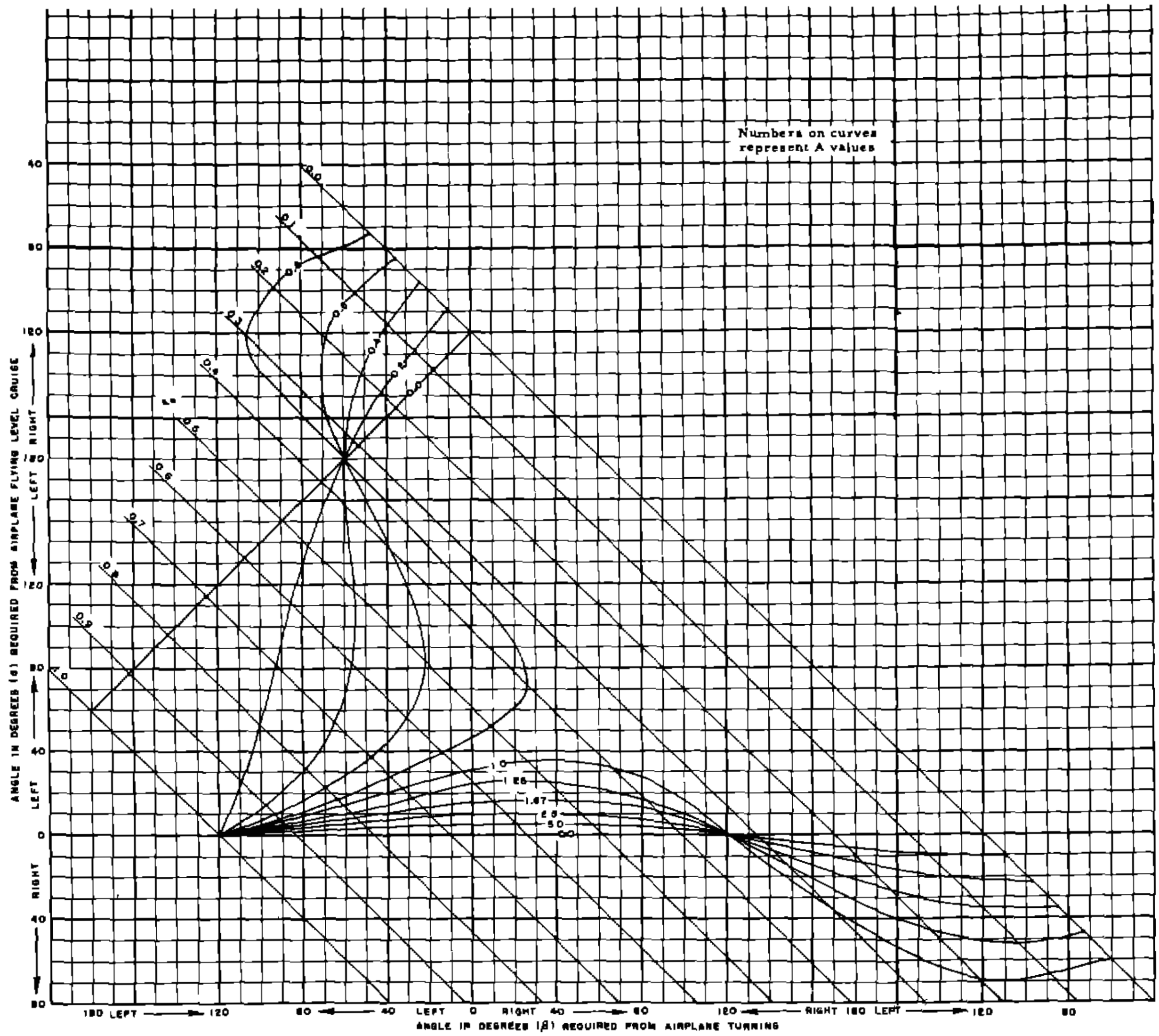
Fig 19 At Collision Point, the Difference in Heading = 90° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level



Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1488	2665	3484	3962	4172	4218	4187	4103	3913	3520
0 4	1297	2087	2442	2639	3101	4014	5163	6220	6907	7040
0 6	1181	1612	1421	1484	2834	4833	6923	8741	10008	10560
0 8	1165	1353	551	1185	3555	6286	9019	11400	13141	14080
1 0	1251	1434	906	2138	4841	8038	11265	14121	16288	17600
1 25	1475	1932	2145	3755	6756	10417	14175	17564	20231	22000
1 67	2013	3157	4319	6615	10207	14583	19143	23353	26813	29333
2 5	3322	5945	8705	12438	17376	23176	29251	35009	39996	44000
5 0	7602	14653	21898	30009	39248	49394	59900	70132	79578	88000

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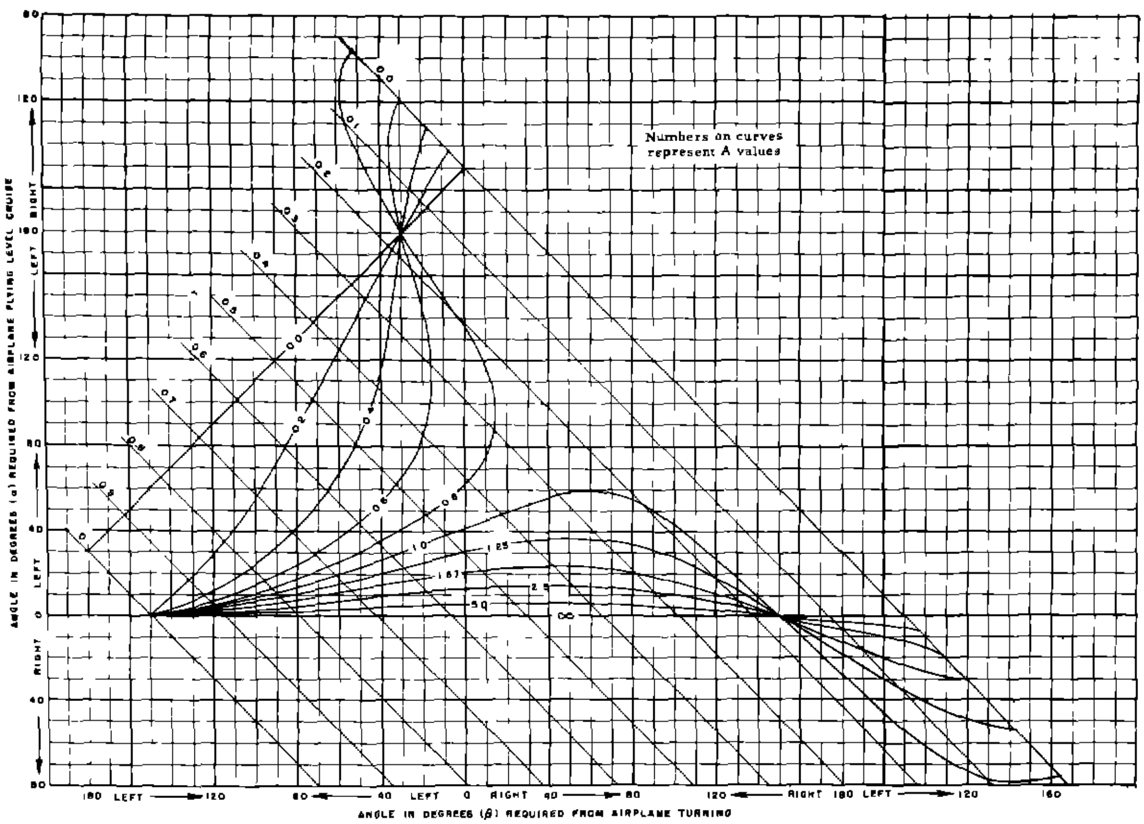
Fig. 20 At Collision Point, the Difference in Heading = 60° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1389	2594	3593	4384	4962	5307	5380	5130	4514	3520
0 4	1053	1898	2741	3744	4905	6072	7035	7593	7604	7040
0 6	732	1212	2084	3575	5448	7382	9066	10239	10740	10560
0 8	459	574	1849	3938	6443	9002	11270	12957	13890	14080
< 1 0	366	422	2167	4712	7715	10794	13565	15710	17047	17600
1 25	622	1176	3074	6012	9527	13168	16501	19177	20998	22000
1 67	1292	2614	5011	8552	12819	17296	21485	24988	27588	29333
2 5	2731	5536	9245	14099	19803	25824	31597	36663	40779	44000
5 0	7116	14129	27136	31443	41484	51954	62237	71802	80369	88000

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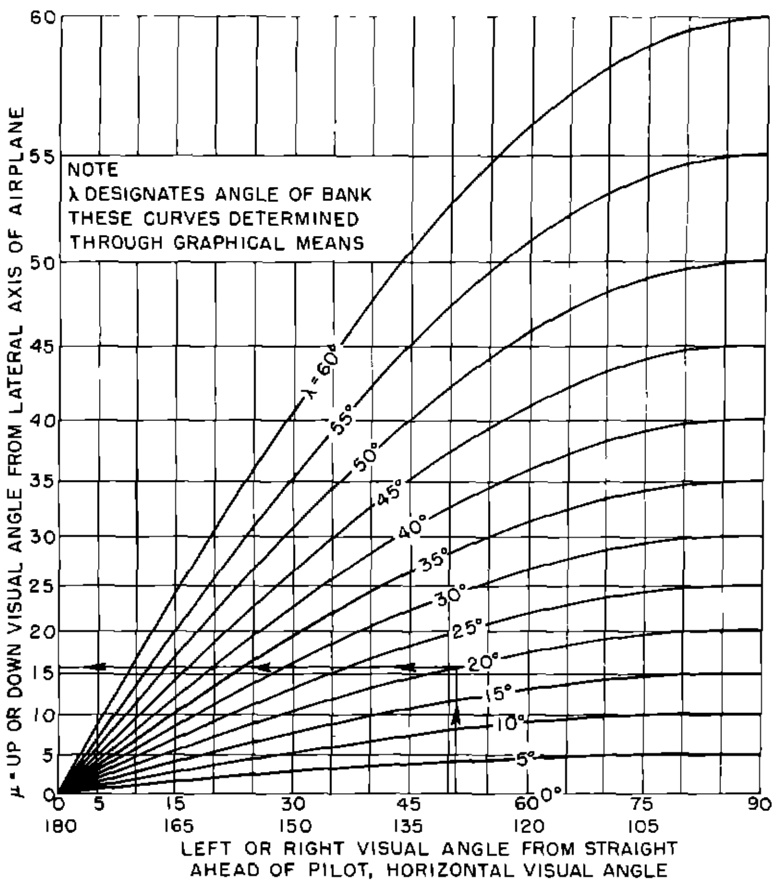
Fig 21 At Collision Point, the Difference in Heading = 30° and the Turning Airplane is on the Right of the Airplane Flying Straight and Level



EXAMPLE
ASSUME λ = 20° LEFT AND VISIBILITY ANGLE = 52° LEFT
ENTER GRAPH ALONG LINE OF LEFT VISIBILITY ANGLE = 52°
UNTIL λ = 20° IS INTERSECTED AT THIS POINT, FOLLOW
HORIZONTAL LINE OVER TO UP VISIBILITY ANGLE = 16°
FROM LATERAL AXIS OF AIRPLANE

Fig 22 Determination of Vertical Visual Angle During Turning Collision Conditions

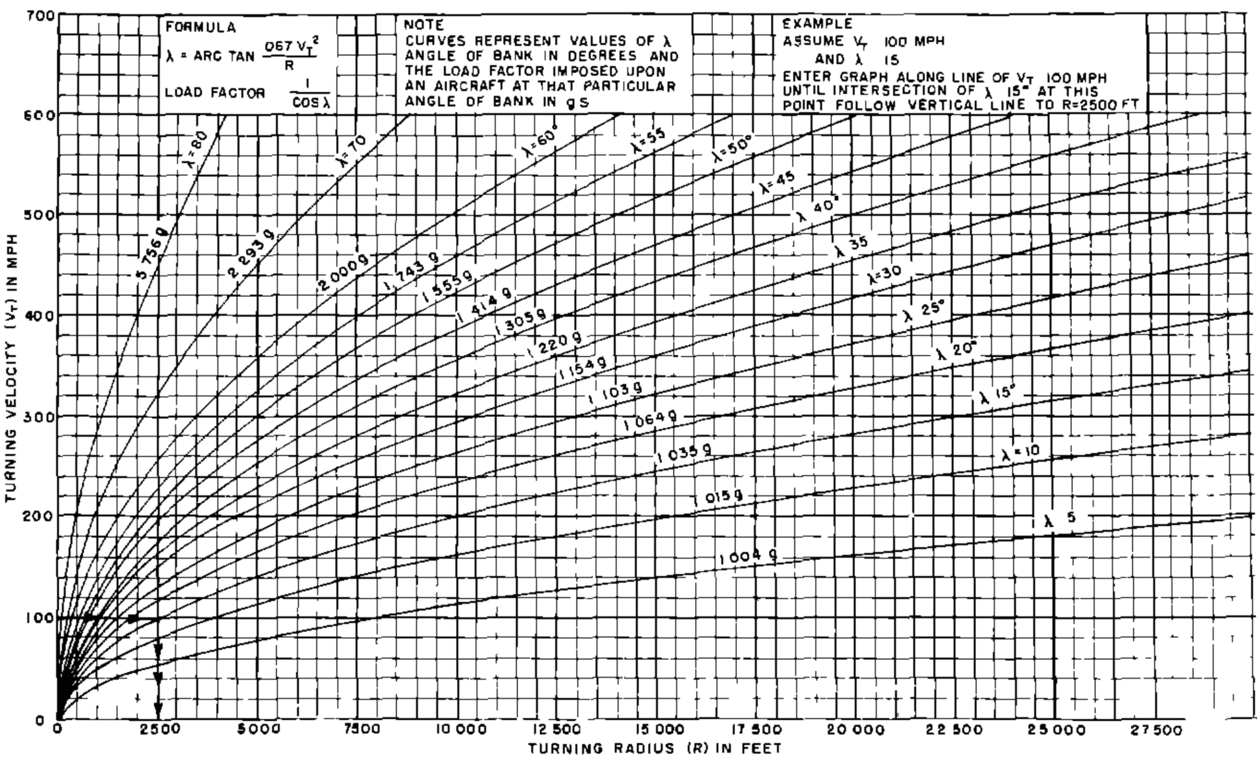


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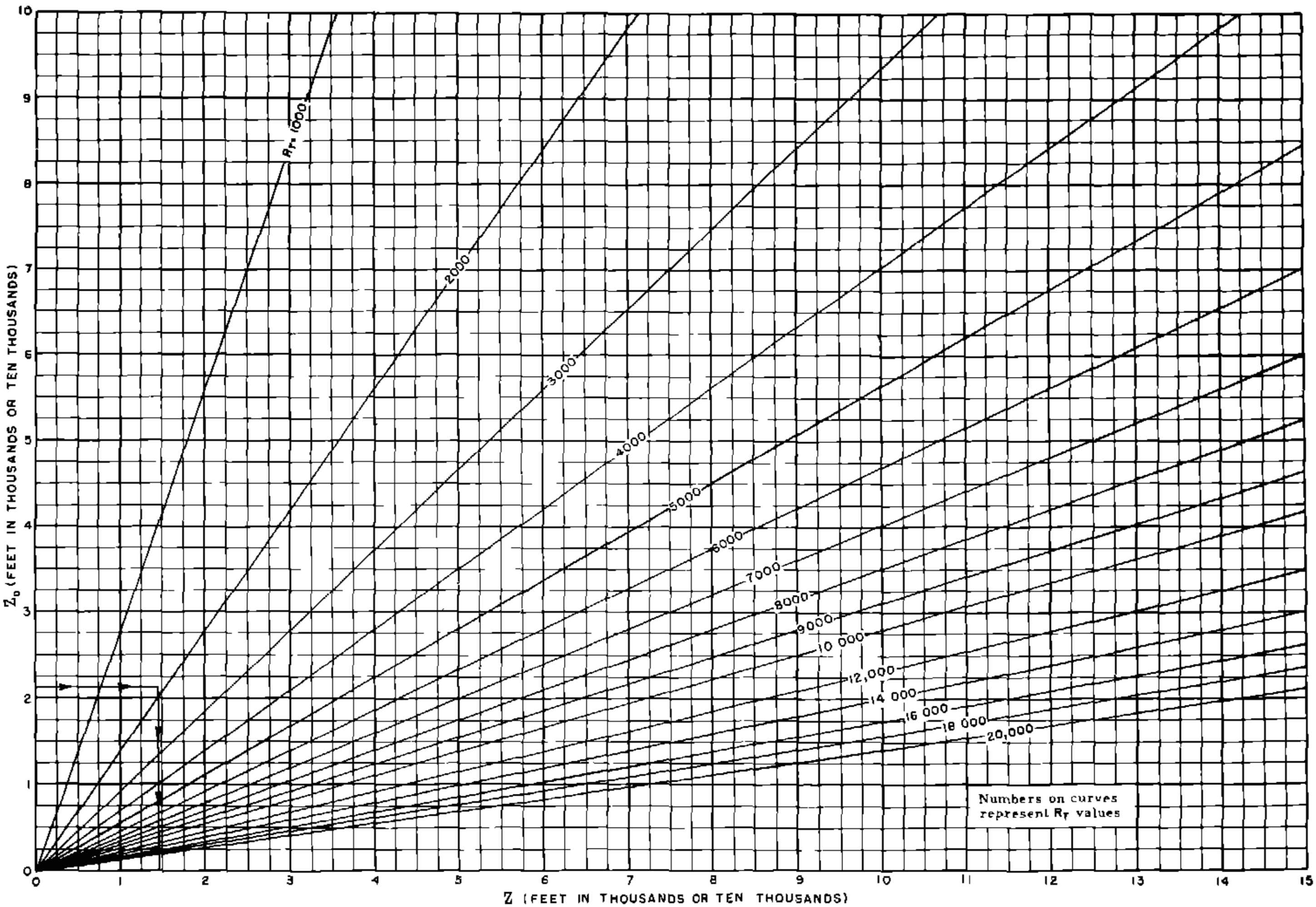
Fig 23 Determination of Turning Radius



NOTE

$Z \quad \frac{Z_0 R_T}{280115}$ (FORMULA)

NUMBER DESIGNATIONS OF LINES REPRESENT R_T, RADIUS OF AIRPLANE TURNING IN FEET

EXAMPLE
ASSUME Z_0 21,600 FEET AND R = 1840 FEET ENTER GRAPH ALONG LINE Z_0 = 2 16
WHICH IS 21 600 FEET, UNTIL LINE R_T = 1840 IS INTERSECTED AT THIS POINT FOLLOW
VERTICAL LINE TO 1 4, OR Z = 14,000 FEET

Fig 24 Determination of Distance of Separation for One Airplane Turning and One Airplane Flying Straight and Level

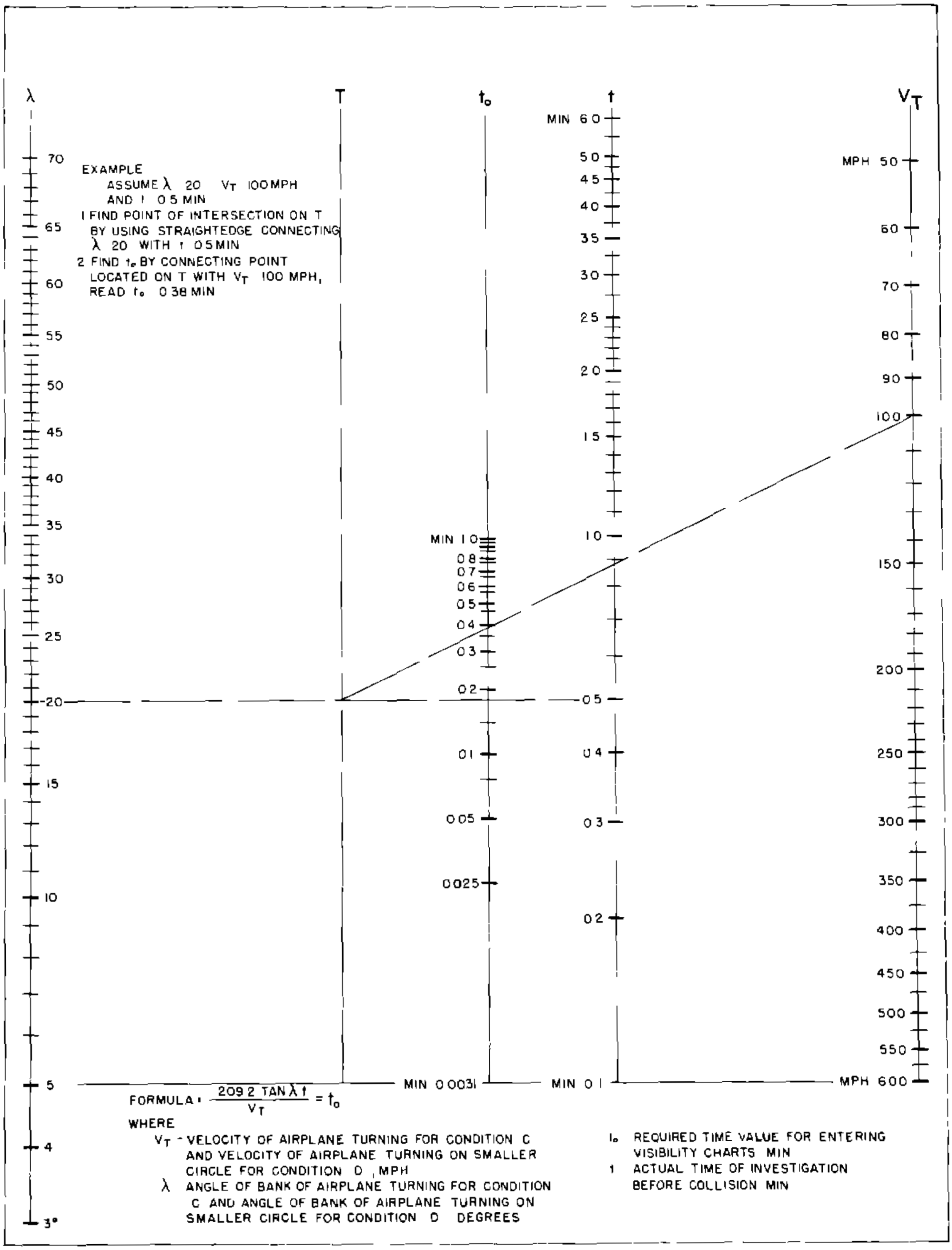


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Fig. 25 Determination of t_0 Value for Turning Collision Conditions

COLLISION CONDITION D
TWO AIRPLANES TURNING IN THE SAME DIRECTION

Description

The calculation of visual angles required to the right or left for the pilot of each airplane to see the other airplane is facilitated by the use of the charts designed for two airplanes turning in the same direction. The turning-visual-angle charts are designed around the hypothesis that both airplanes are making a turn to the left on a collision course, flying in the same horizontal plane, and approaching each other at any relative speed and direction.

Procedure and Formulas

The turning charts are shown in Figs. 23, 25, 26, and 28 through 83. The procedure for using these charts is as follows.

Solution 1

$R/A \gtrsim 1.0$

Where

R = Ratio of turning radii

A = Ratio of speeds (speed relationship)

1. To determine the turning radii R_2 and R_3, enter Fig. 23 with the turning velocities V_{T_2} and V_{T_3} and with the angles of bank λ_2 and λ_3.
2. To determine speed relationship A, ratio of radii R, and ratio of radii to ratio of velocities R/A, enter Fig. 26 with the turning velocities V_{T_2} and V_{T_3} and with the turning radii R_2 and R_3. See notes on Fig. 26. Note: If R/A is less than one, follow the procedure for Solution 2.
3. To determine the time value t_0 required for entering the horizontal-visual-angle charts, r Fig. 25 with the angle of bank λ_2 of the airplane turning on the smaller circle, the velocity V_{T_2} of the airplane turning on the smaller circle, and the actual time t of investigation fore collision.
4. To determine the horizontal visual angles α and β required for the pilot of each aircraft to see the other aircraft, select that horizontal-visual-angle chart from Fig. 28 through 82 which applies to the absolute difference in heading between the two aircraft at collision point and the R/A value as determined in Step 6. Enter this chart with time value t_0 and with the peed relationship A.
5. To determine the distance factor Z_0, enter, with speed relationship A and with the time value t_0, the Z_0 table located on the same horizontal-visual-angle chart that was selected in Step 4.
6. To determine actual distance of separation Z between aircraft, enter Fig. 83 with istance factor Z_0 and with the smaller turning radius R_2.
7. To determine the vertical visual angle μ, as affected by the angles of bank of the turning airplanes, enter Fig. 22 with the angles of bank λ_2 and λ_3 and with their respective visual ngles α and β.

Solution 2

$R/A < 1.0$

The procedure for Solution 2 is the same as that for Solution 1 except that the values which pply to the airplane turning on the smaller circle are substituted for the values of the airplane turning on the larger circle when all charts designed for this condition are entered.

The chart shown in Fig. 26 is constructed in the same manner as the speed-relationship chart used in Conditions A, B, and C, but with the change in nomenclature shown in Equation (17).

$$A = \frac{V_{T_3}}{V_{T_2}} \qquad (17)$$

Where

V_{T_3} = Velocity of airplane turning on larger circle, in mph

V_{T_2} = Velocity of airplane turning on smaller circle, in mph

$$R = \frac{R_3}{R_2} \qquad (18)$$

Where

R_3 = Radius of the larger circle, in feet

R_2 = Radius of the smaller circle, in feet

Therefore,

$$R/A = \frac{R_3/R_2}{V_{T_3}/V_{T_2}} \qquad (19)$$

For determination of t_0, the same four-parallel-scale nomograph constructed for Condition C, Fig 25, will be used The formula remains the same

$$t_0 = \frac{209\ 2 \tan \lambda\ t}{V_T} \qquad (8$$

Where

$V_{T_2} = V_T$ = Velocity of the airplane turning on the smaller circle, in mph

$\lambda_2 = \lambda$ = Angle of bank of the airplane turning on the smaller circle, in degrees

t = Actual time of investigation before collision, in minutes

t_0 = Required time value for entering visual-angle charts, in minutes

The visual-angle charts shown in Figs 28 through 82 were constructed for this condition by substituting example values in the following equations See Fig 89 in the Appendix

$$\alpha = \omega_0 - \theta - 90° \qquad (20$$

$$\beta = \omega_1 - \theta + 90° \qquad (21$$

$$Z = \sqrt{(X_0 - X_1)^2 + (Y_1 - Y_0)^2} \qquad (22$$

To solve these equations, the following must be known

$$X_1 = R_1(\cos \psi - \cos \omega_1) \tag{23}$$

$$Y_1 = R_1(\sin \psi - \sin \omega_1) \tag{24}$$

$$\omega_1 = K_1 t - \psi \tag{25}$$

$$X_0 = R_0(1 - \cos \omega_0) \tag{26}$$

$$Y_0 = -R_0 \sin \omega_0 \tag{27}$$

$$\omega_0 = K_0 t \tag{28}$$

$$\theta = \arc\tan \frac{Y_1 - Y_0}{X_0 - X_1} \tag{29}$$

Where

α = The horizontal visual angle (from straight ahead) needed for the airplane turning on the larger circle to be seen from the airplane turning on the smaller circle, in degrees

β = The horizontal visual angle (from straight ahead) needed for the airplane turning on the smaller circle to be seen from the airplane turning on the larger circle, in degrees

Z = The distance between the aircraft at time t, in feet

R_1 = The turning radius of the airplane flying on the larger circle, in feet

R_0 = The turning radius of the airplane flying on the smaller circle, in feet

t = The time before collision, in minutes

K_1 = The rate of turn of the airplane flying on the larger circle, in degrees per minute

K_0 = The rate of turn of the airplane flying on the smaller circle, in degrees per minute

e In case it is necessary to calculate visual angles by means of the formulas, use of Table III will be necessary to determine the relationship between ψ and the absolute difference in heading t collision point ω_0, ω_1, X_0, Y_0, Y_1, and θ are illustrated in Fig 89 of Appendix I

The chart shown in Fig 83 was constructed by substituting values in the equation

$$Z = \frac{Z_0 R_2}{1400.56} \tag{30}$$

Where

Z = The actual distance between aircraft at time t before collision, in feet

Z_0 = The proportional distance between aircraft as obtained from the visual-angle chart, in feet

R_2 = The radius of turn of the airplane flying on the smaller circle, in feet

TABLE III

RELATIONSHIP BETWEEN ψ AND ACTUAL HEADING DIFFERENCE

ψ (degrees)	Difference in Heading at Collision Point (degrees)	Condition
0	0	Heading in same direction
45	45	With airplane turning on the larger circle on the right of airplane turning on smaller circle at collision point
90	90	With airplane turning on the larger circle on the right of airplane turning on smaller circle at collision point
135	135	With airplane turning on the larger circle on the right of airplane turning on smaller circle at collision point
180	180	Head on
225	135	With airplane turning on the larger circle on the left of airplane turning on smaller circle at collision point
270	90	With airplane turning on the larger circle on the left of airplane turning on smaller circle at collision point
315	45	With airplane turning on the larger circle on the left of airplane turning on smaller circle at collision point

---

Sample Solution

It is desired to know what visual angles are required for the pilots of each aircraft to see the other aircraft while on a collision course and to determine the separation of the aircraft at a given time Refer to Fig 27 In this case, both airplanes are turning in the same direction

Solution 1

Let

V_{T_2}, the velocity of the airplane flying on the smaller circle, = 100 mph, true air speed,

λ_2, the angle of bank of the airplane turning on the smaller circle, = 15°,

V_{T_3}, the velocity of the airplane flying on the larger circle, = 100 mph, true air speed,

λ_3, the angle of bank of the airplane turning on the larger circle, = 7 5°,

t, the time before the collision to be investigated, = 1 minute

The absolute difference in heading at collision point = 45° with the airplane that is turning on the larger circle on the right of the airplane turning on the smaller circle

1 Enter Fig 23 with V_{T_2} = 100 mph and with λ_2 = 15°, and read R_2 = 2500 feet Also enter with V_{T_3} = 100 mph and with λ_3 = 7 5°, and read R_3 = 5000 feet

2 Enter Fig 26 with V_{T_2} = 100 mph and with V_{T_3} = 100 mph, and read A = 1 0, enter with

R_2 = 2500 feet and with R_3 = 5000 feet, and read R = 2 0, then enter with R = 2 0 and with A = 1 0, and read R/A = 2 0 Note If R/A becomes less than 1 0, use Solution 2

3 Enter Fig 25 with λ_2 = 15°, V_{T_2} = 100 mph, and t = 1 minute, and read t_0 = 0 56 minute

4 Since the absolute difference in heading at collision point = 45° and R/A = 2 0 and since the airplane turning on larger circle is on the right of the airplane turning on the smaller circle, Fig 36 of the visual-angle charts is selected and is entered with A = 1 0 and t_0 = 0 56 Read α, which is the horizontal visual angle required from the airplane turning on the smaller circle, equal to 46° left, also read β, which is the horizontal visual angle required from the airplane turning on the larger circle, equal to 80° left If the distance between the aircraft at 1 minute is also desired, then enter the Z_0 chart on the same figure with A = 1 0 and t_0 = 0 56 No value of t_0 equal to 0 56 appears, therefore, the following interpolation is made

A = 1 0	t_0 = 0 60	Z_0 = 5620
A = 1 0	t_0 = 0 50	Z_0 = 4872
		748 = Difference

Since 0 56 is 0 6 of the interval between 0 50 and 0 60, then 0 6 x 748 = 448 8 or approximately 449

For

t_0 = 0 56 and A = 1 0, Z_0 = 4872 + 449 = 5321 feet, or approximately 5300 feet

This is not a true distance but is a proportional distance and is used in the following step

5 Enter Fig 83 with Z_0 = 5300 feet and R_2 = 2500 feet, and read Z = 9400 feet

6 To find the vertical visual angle μ at 1 minute before collision required from the airplane turning on the smaller circle at a 15° bank angle, enter Fig 22 with λ_2 = 15° and α = 46° left and read required vertical visual angle μ = 11° up Also, to find the vertical visual angle at 1 minute prior to collision required from the airplane turning on the larger circle, enter Fig 22 with λ_3 = 7 5° and β = 80° left and read required vertical visual angle μ = 7 5° up

Solution 2

If the R/A value is computed to be less than 1 0 by using procedures outlined in sample Solution 1, then the following process is to be used in computing the visual angles required from two airplanes making a left turn

Given (Reference Fig 27)

V_{T_2}, the velocity of the airplane flying on the smaller circle, = 100 mph, true air speed

λ_2, the angle of bank of the airplane turning on the smaller circle, = 5°

V_{T_3}, the velocity of an airplane flying on the larger circle, = 250 mph, true air speed

λ_3, the angle of bank of the airplane turning on the larger circle, = 22°

t, the time before collision to be investigated, = 1 minute

The absolute difference in heading at collision point = 45°, with the airplane turning on the larger circle on the right of the airplane turning on the smaller circle

1 Enter Fig 23 with V_{T_2} = 100 mph and λ_2 = 5°, and read R_2 = 8000 feet Also enter V_{T_3} = 250 mph and λ_3 = 22°, and read R_3 = 10,000 feet

2 Enter Fig 26 with V_{T_2} = 100 mph and V_{T_3} = 250 mph, and read A = 2 5, then also enter with R_2 = 8000 feet and R_3 = 10,000 feet, and read R = 1 25, then enter with R = 1 25 and A = 2 5, and read R/A = 0 5

Since there are no visual-angle charts designed for an R/A value less than 1 0, the following procedure is to be followed The ratios R, A, and R/A are inverted, that is, enter Fig 26 with V_{T_2} = 250 mph instead of 100 mph and V_{T_3} = 100 mph instead of 250 mph and read A = 0 40

Also enter with R_2 = 10,000 feet instead of 8000 feet and R_3 = 8000 feet instead of 10,000 feet, and read R = 0 8 Then entering Fig 26 with R = 0 8 and A = 0 4, read R/A = 2 0

3 Enter Fig 25 with λ_3 = 22°, V_{T_3} = 250 mph, and t = 1 minute, and read t_0 = 0 34

4 The absolute difference in heading at collision point = 45°, with the airplane turning on the larger circle at the right of the airplane turning on the smaller circle at collision point For this situation, however, is selected the horizontal-visual-angle chart that was designed for an absolute difference in heading at collision point = 45° but with the airplane turning on the larger circle at the left of the airplane turning on the smaller circle at collision point Since R/A = 2 0, Fig 77 is selected and is entered with A = 0 4 and t_0 = 0 34 Read α, which is the horizontal visual angle required from the airplane turning on the larger circle, equal to 74° left Also read β, which is the horizontal visual angle required from the airplane turning on the smaller circle, equal to 123° right

Normally, α is the visual angle required from the airplane turning on the smaller circle, and β is the visual angle required from the airplane turning on the larger circle, but, as the note on Fig 77 indicates, when entering with an A value less than 0 5, α becomes the visual angle required from the airplane turning on the larger circle and β becomes the visual angle required from the airplane turning on the smaller circle

5 In determining the distance between the aircraft at 1 minute, the Z_0 table on Fig 77 is entered with t_0 = 0 34 and A = 0 4 No value of t_0 equal to 0 34 appears, therefore, the following interpolation is made

A = 0 4	t_0 = 0 40	Z_0 = 1383
A = 0 4	t_0 = 0 30	Z_0 = 1346
		37 = Difference

Since 0 34 is 0 4 of the interval between 0 30 and 0 40, 0 4 x 37 = 14 8, or approximately 15 Then, because t_0 = 0 34 and A = 0 4, Z_0 = 1346 + 15 = 1361 feet

This is not a true distance but is a proportional distance and is used in the following step

6 Enter Fig 83 with Z_0 = 1361 feet and R_3 = 10,000 feet, and read Z = 9800 feet Normally, R_2, the radius of the smaller circle, is used in entering Fig 83, but for this solution R_3, the radius of the larger circle, is used

7 The vertical visual angles are determined in the same manner as described in Solution 1, Step 6

Additional Considerations

Visual angles may be determined from two airplanes making a right turn instead of from both making a left turn by using the following procedure.

Given

The absolute difference in heading at collision point is equal to 45°, with the airplane turning on the larger circle on the right of the airplane turning on the smaller circle at the point of collision and with both airplanes making right turns

1 Enter the horizontal-visual-angle chart designed for a difference in heading at collision point equal to 45° with the airplane that is turning on the larger circle on the left of the airplane turning on the smaller circle at the collision point This chart is entered with the parameters determined by the given condition, the only difference being that in using the charts left is substituted for right as related to the collision point

2 In reading α and β, the magnitudes of the angles are correct but the directions of the angles need to be reversed to apply correctly to the given condition

3 The distance between the airplanes at a specified time before collision and the vertical visual angles are determined in the same manner as described for two airplanes making left turns

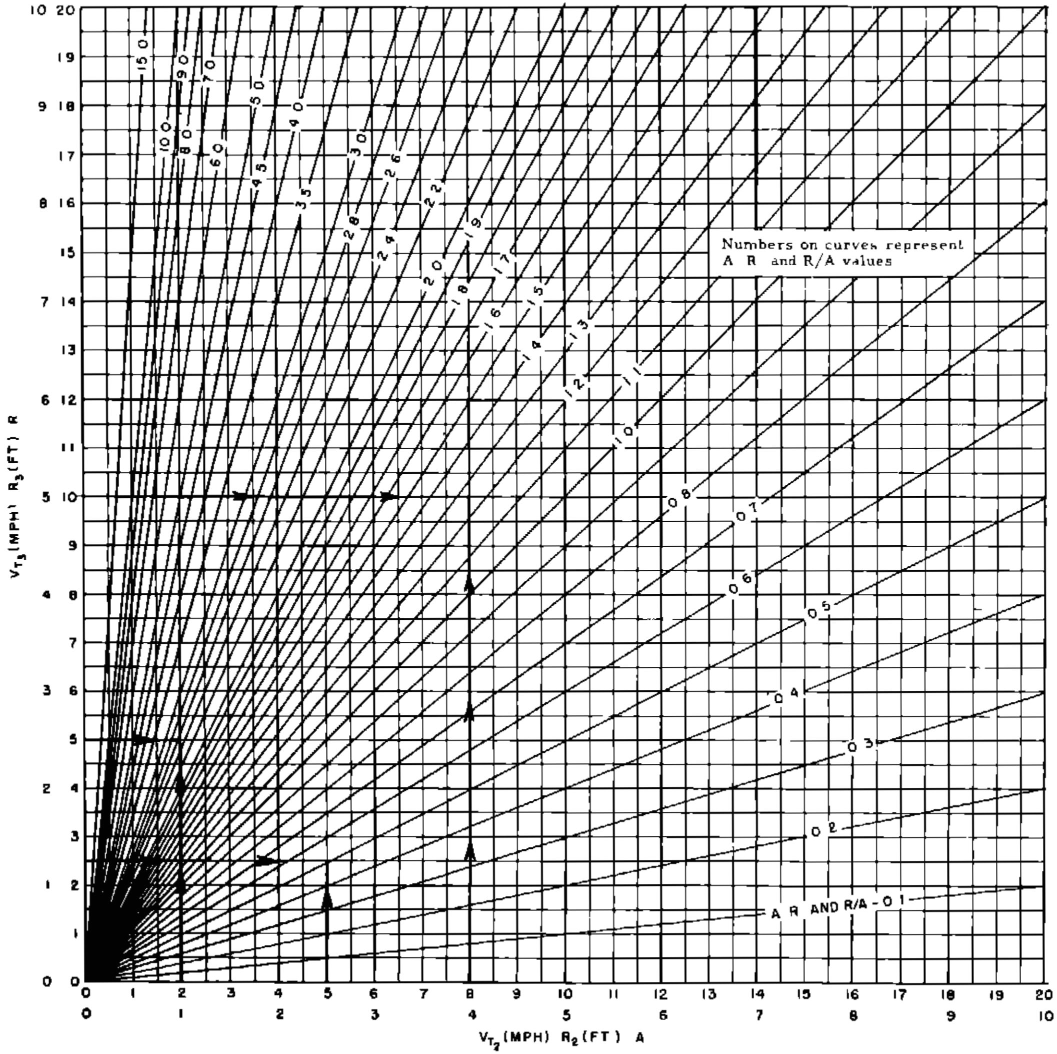
4 Additional considerations mentioned in Collision Condition C apply similarly to this condition

Visual angles for two airplanes turning in opposite directions may be determined as indicated in the Appendix

Discussion of Significant Trends

The rate of change of the horizontal visual angle is generally greater from the airplane turning on the smaller circle

In a condition where the curves cross, it indicates that a straight line can be drawn through the two turning airplanes and the collision point at that instant of time before collision



EXAMPLES

To determine speed relationship A $\frac{V_{T_3}}{V_{T_2}}$

Where V_{T_3} velocity of airplane turning on larger circle

V_{T_2} velocity of airplane turning on smaller circle

Example

Assume V_{T_3} - 250 mph and V_{T_2} - 100 mph

Using larger scales read A - 2 5

To determine radius relationship $R = \frac{R_3}{R_2}$

Where R_3 radius of larger circle

R_2 radius of smaller circle

Example

Assume R_3 = 10 000 ft and R_2 = 8000 ft

Using smaller scales read R - 1 25

To determine the ratio of radius relationship to speed relationship

$$R/A = \frac{R_3/R_2}{V_{T_3}/V_{T_2}}$$

Example

Since R - 1 25 and A = 2 5 using larger scales read R/A = 0 5

Note

If R/A ≥ 1 0 the actual value of R/A is used in connection with the charts (Figs 28-82) See solution 1 of collision condition D

If R/A is < 1 0 the reciprocal value of R/A is used in connection with the charts (Figs 28-82) See solution 2 of collision condition "D

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Fig 26 Determination of A, R, and R/A for Two Turning Airplanes

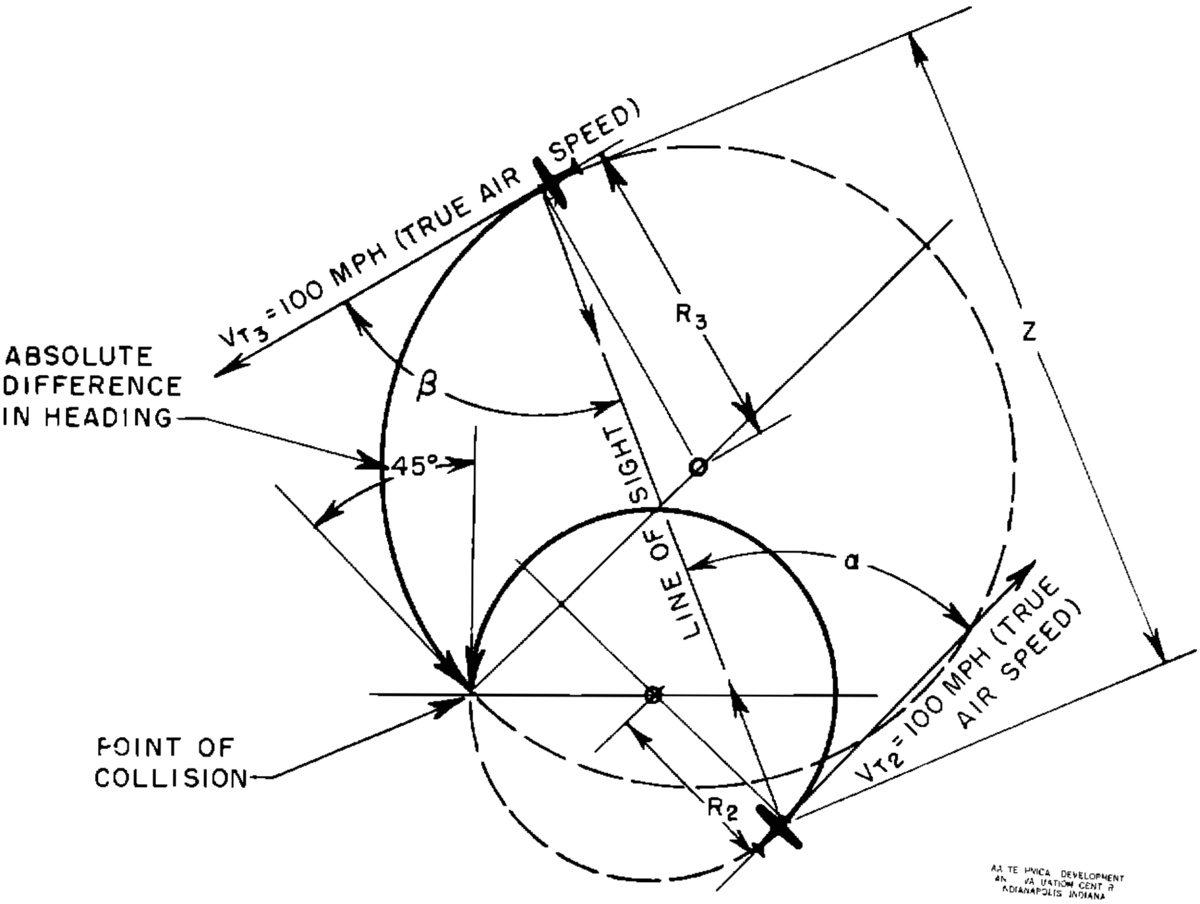
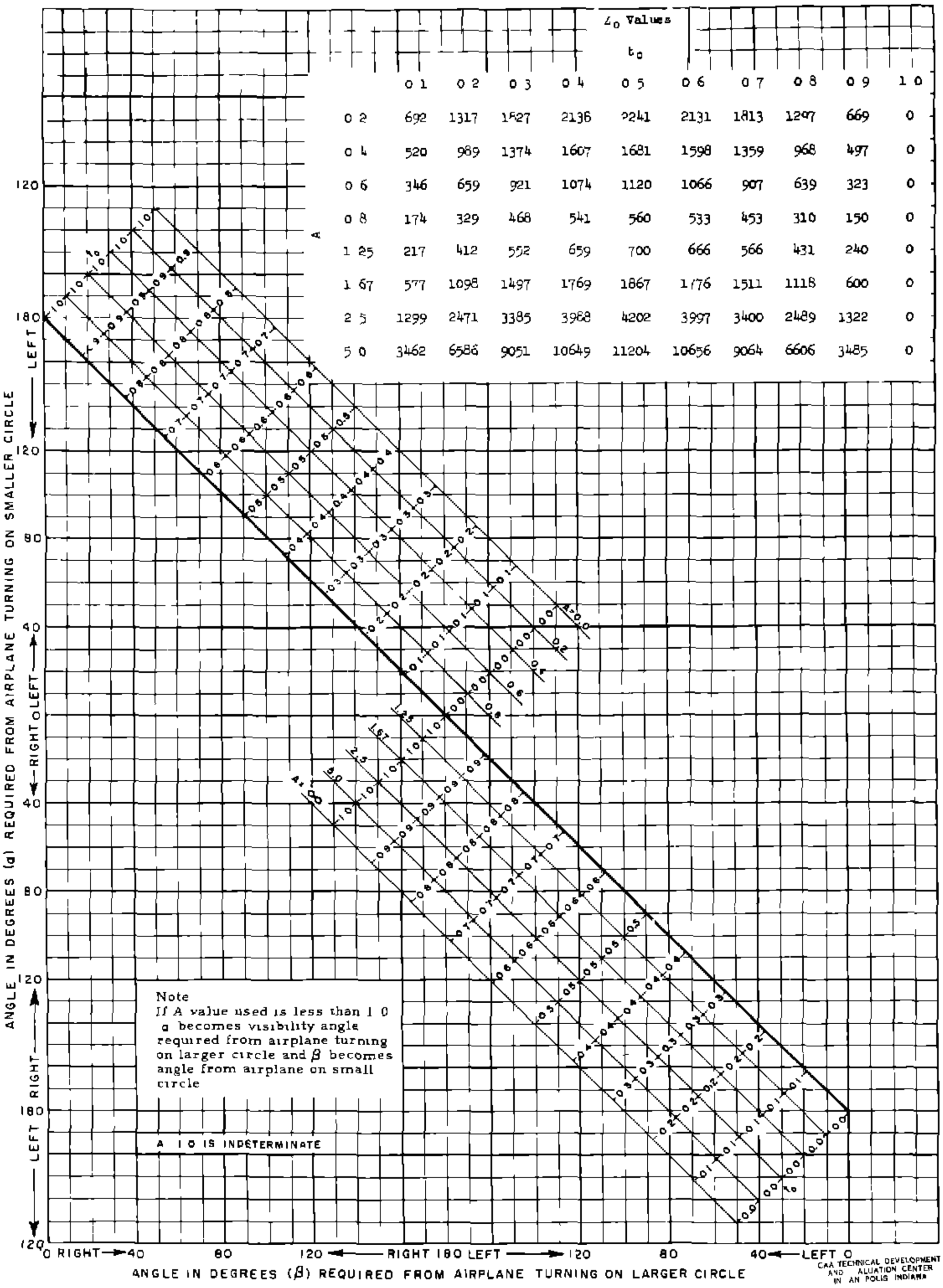


Fig 27 Vector Diagram of Sample Solution for Two Airplanes Turning Left

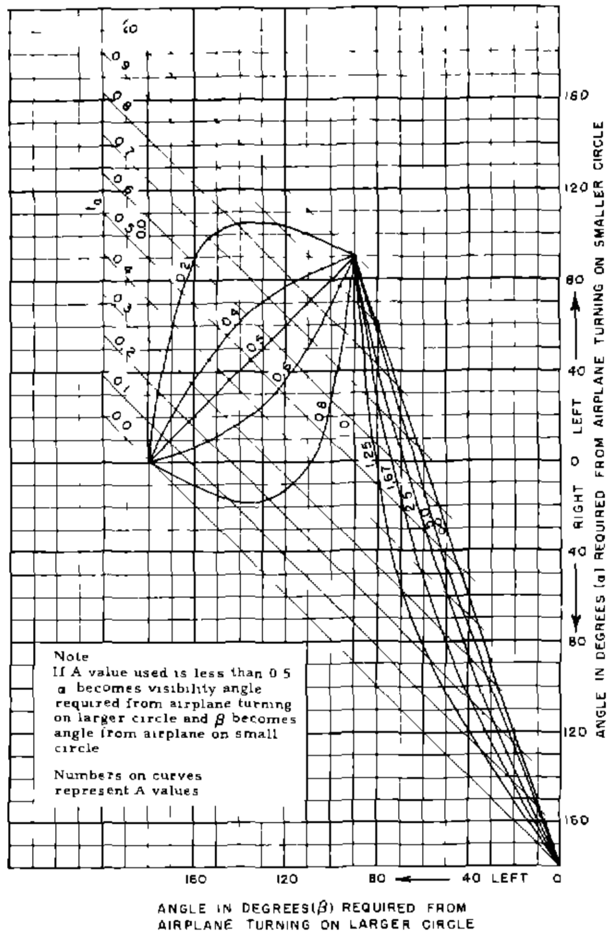
The following charts are designed for the determination of horizontal-visual-angle requirements and distance factor for two airplanes turning in same direction



L_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	692	1317	1527	2136	2241	2131	1813	1297	669	0
0 4	520	989	1374	1607	1681	1598	1359	968	497	0
0 6	346	659	921	1074	1120	1066	907	639	323	0
0 8	174	329	468	541	560	533	453	310	150	0
1 25	217	412	552	659	700	666	566	431	240	0
1 67	577	1098	1497	1769	1867	1776	1511	1118	600	0
2 5	1299	2471	3385	3988	4202	3997	3400	2489	1322	0
5 0	3462	6586	9051	10649	11204	10656	9064	6606	3485	0

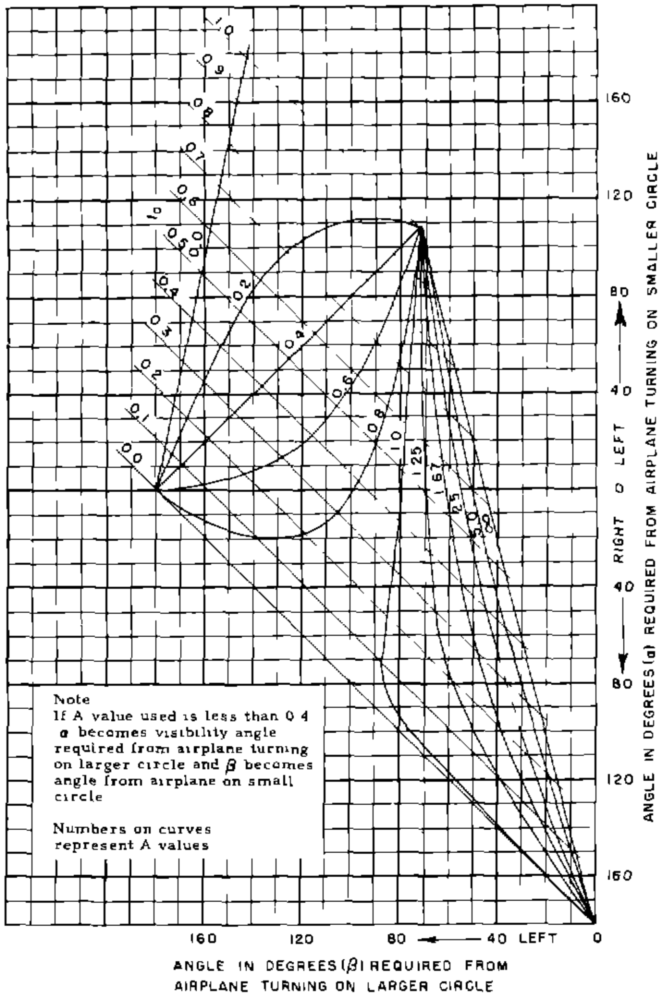
Fig 28 At Collision Point, the Difference in Heading = 0°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	693	1322	1845	2178	2310	2253	2020	1655	1288	1120
0 4	523	1011	1456	1792	2020	2170	2239	2259	2249	2241
0 6	356	733	1164	1599	2020	2444	2818	3120	3302	3361
0 8	205	539	1053	1662	2310	2982	3588	4080	4382	4482
A 1 0	128	520	1152	1920	2801	3660	4440	5072	5468	5602
1 25	277	785	1564	2530	3571	4631	5589	6363	6843	7003
1 67	620	1414	2453	3670	5028	6364	7566	8534	9136	9338
2 5	1342	2809	4462	6289	8166	10000	11627	12925	13733	14006
5 0	3529	7109	10746	14405	17936	21205	24014	26197	27555	28011

Fig 29 At Collision Point, the Difference in Heading = 0°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

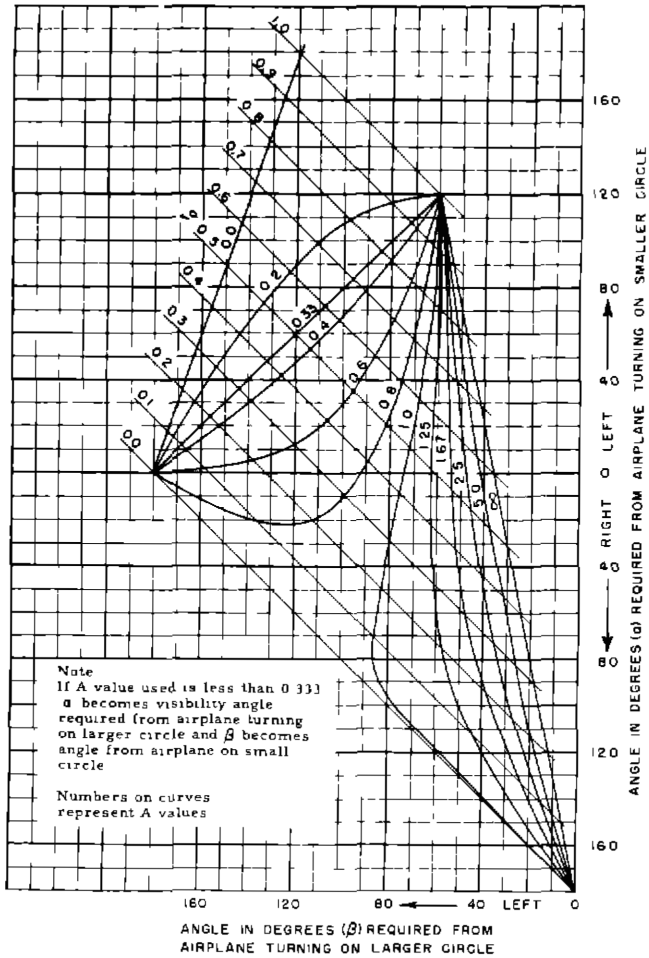


Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	695	1329	1868	2233	2412	2417	2254	1959	1613	1333
0 4	525	1031	1522	1935	2266	2535	2713	2796	2776	2664
0 6	362	778	1292	1848	2412	2974	3460	3822	4002	3997
0 8	219	622	1248	1999	2801	3620	4348	4918	5249	5328
A 1 0	165	642	1405	2342	3352	4382	5308	6047	6503	6661
1 25	295	886	1802	2938	4168	5424	6560	7481	6077	8325
1 67	633	1499	2685	4128	5685	7266	8711	9900	10706	11101
2 5	1354	2887	4696	6759	8936	11116	13110	14784	15975	16650
5 0	3542	7202	11044	15051	19069	22961	26506	29520	31805	33301

Fig 30 At Collision Point, the Difference in Heading = 0°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



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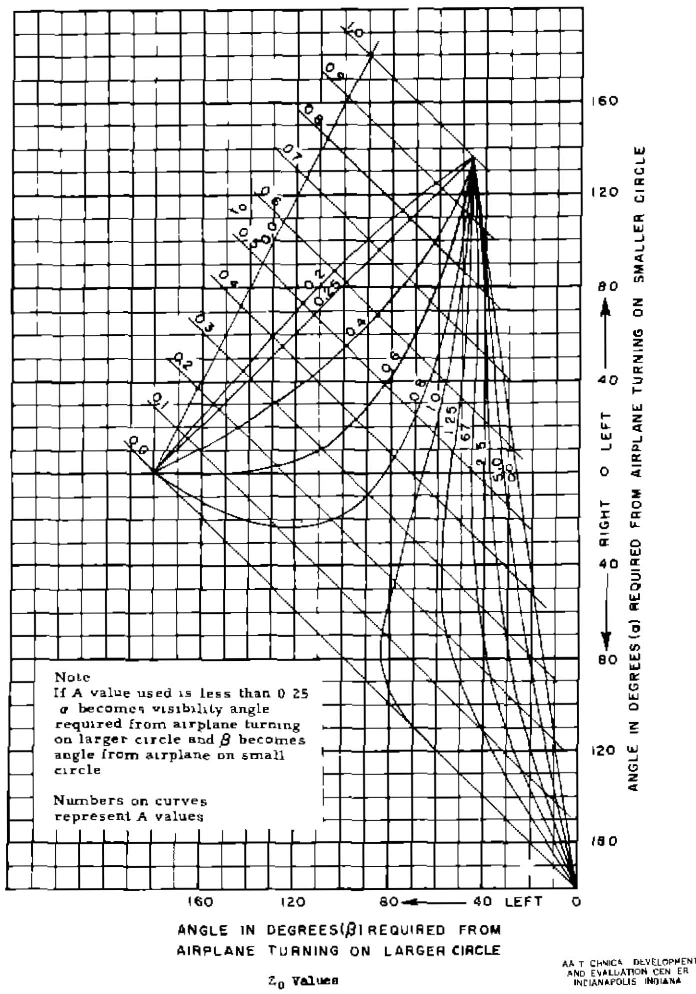
Z_0 Values

	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	695	1335	1889	2277	2490	2538	2423	2160	1813	1456
0 4	527	1047	1571	2041	2442	2784	3022	3131	3092	2911
0 6	368	810	1384	2021	2672	3317	3862	4251	4419	4367
0 8	231	679	1379	2221	3120	4025	4821	5426	5762	5822
A 1 0	182	713	1557	2592	3705	4833	5839	6629	7111	7277
1 25	309	954	1959	3203	4552	5920	7157	8152	8802	9097
1 67	643	1560	2839	4407	6105	7830	9409	10715	11625	12129
2 5	1362	2940	4852	7064	9421	11801	14003	15879	17283	18194
5 0	3550	7263	11233	15450	19757	24008	27969	31450	34268	36387

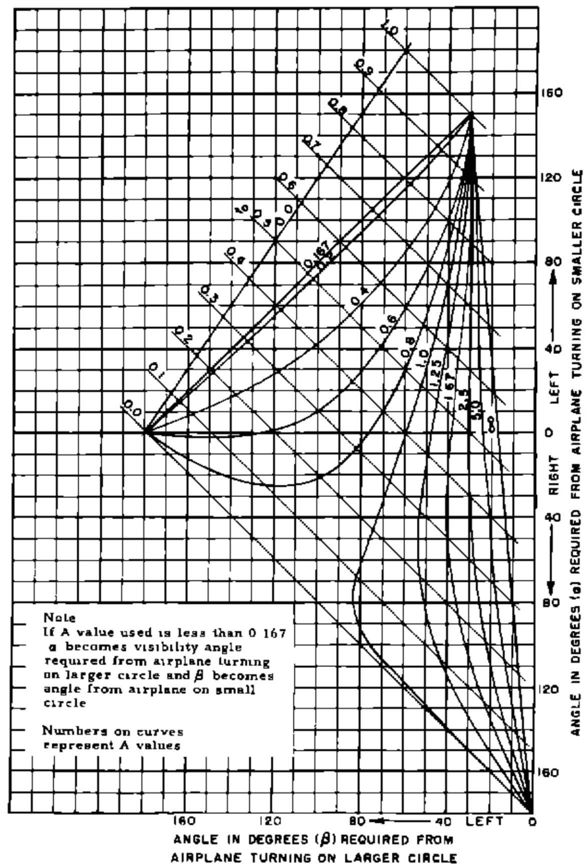
Fig 31 At Collision Point, the Difference in Heading = 0°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

		t_0									
		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
	0 2	696	1344	1916	2338	2597	2699	2631	2395	2032	1585
	0 4	531	1071	1641	2182	2666	3089	3384	3508	3432	3169
	0 6	374	856	1504	2238	2991	3724	4328	4726	4865	4754
	0 8	245	750	1542	2493	3502	4502	5360	5987	6308	6338
α	1 0	206	800	1744	2896	4127	5360	6441	7268	7755	7923
	1 25	326	1040	2154	3526	5009	6498	7829	8884	9569	9903
	1 67	655	1635	3033	4747	6603	8479	10188	11596	12594	13205
	2 5	1372	3009	5044	7430	9988	12578	14985	17050	18653	19807
	5 0	3560	7335	11455	15910	20531	25155	29536	33481	36836	39614

Fig 32 At Collision Point, the Difference in Heading = 0°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



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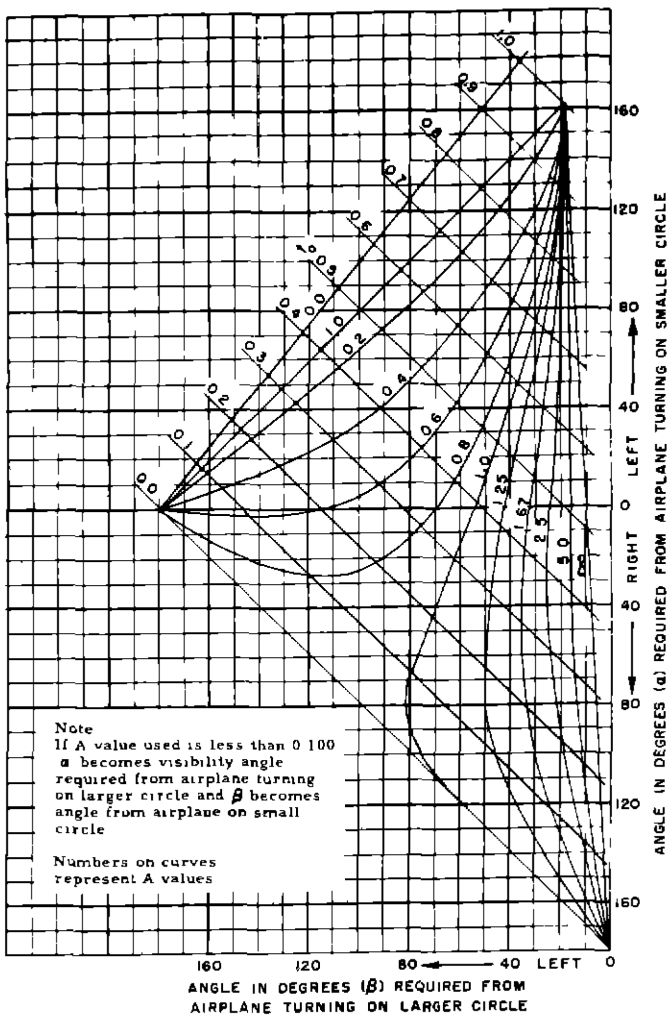
Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	696	1354	1949	2406	2709	2859	2828	2602	2207	1680
0 4	534	1096	1716	2327	2890	3379	3710	3826	3700	3362
0 6	381	903	1626	2453	3298	4100	4737	5123	5212	5042
0 8	261	823	1704	2756	3861	4935	5832	6449	6731	6723
1 0	228	887	1926	3187	4523	5838	6963	7788	8252	8403
1 25	346	1127	2344	3837	5434	7017	8406	9475	10155	10504
1 67	669	1713	3224	5073	7064	9057	10848	12299	13331	14005
2 5	1381	3079	5234	7775	10504	13255	15796	17971	19685	21008
5 0	3569	7404	11661	16323	21198	26104	30780	35034	38756	42017

Fig 33 At Collision Point, the Difference in Heading = 0°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

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	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	698	1362	1976	2462	2801	2984	2972	2740	2311	1732
0 4	537	1119	1779	2445	3063	3592	3938	4032	3855	3462
0 6	388	944	1726	2622	3529	4373	5018	5373	5411	5194
0 8	273	683	1831	2959	4131	5247	6150	6737	6968	6924
A 1 0	246	956	2069	3409	4817	6177	7313	8110	8529	8056
1 25	361	1197	2494	4074	5749	7384	8787	9834	10479	10819
1 67	680	1776	3374	5321	7401	9458	11277	12719	13734	14426
2 5	1390	3133	5381	8036	10874	13713	16310	18504	20243	21641
5 0	3577	7457	11614	16616	21649	26709	31521	35899	39778	43279

Fig 34 At Collision Point, the Difference in Heading = 0°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9
0 2	754	1433	1969	2330	2437	2318	1972	1416	732
0 4	668	1270	1767	2070	2159	2093	1747	1256	648
0 6	6_8	1177	1644	1925	2004	1905	1621	1170	605
0 8	6_8	117L	1641	1922	1998	1900	161?	1173	610
A 1 0	663	1260	1759	2063	2144	2038	1734	1267	661
1 25	772	1468	2042	2399	2497	2375	2021	1480	776
1 67	1032	1963	2719	3197	3339	3176	2702	1980	1043
2 5	1669	3174	4361	5152	5399	5135	4367	3194	1685
5 0	3767	7163	9867	11005	1218?	11591	9860	7186	3786

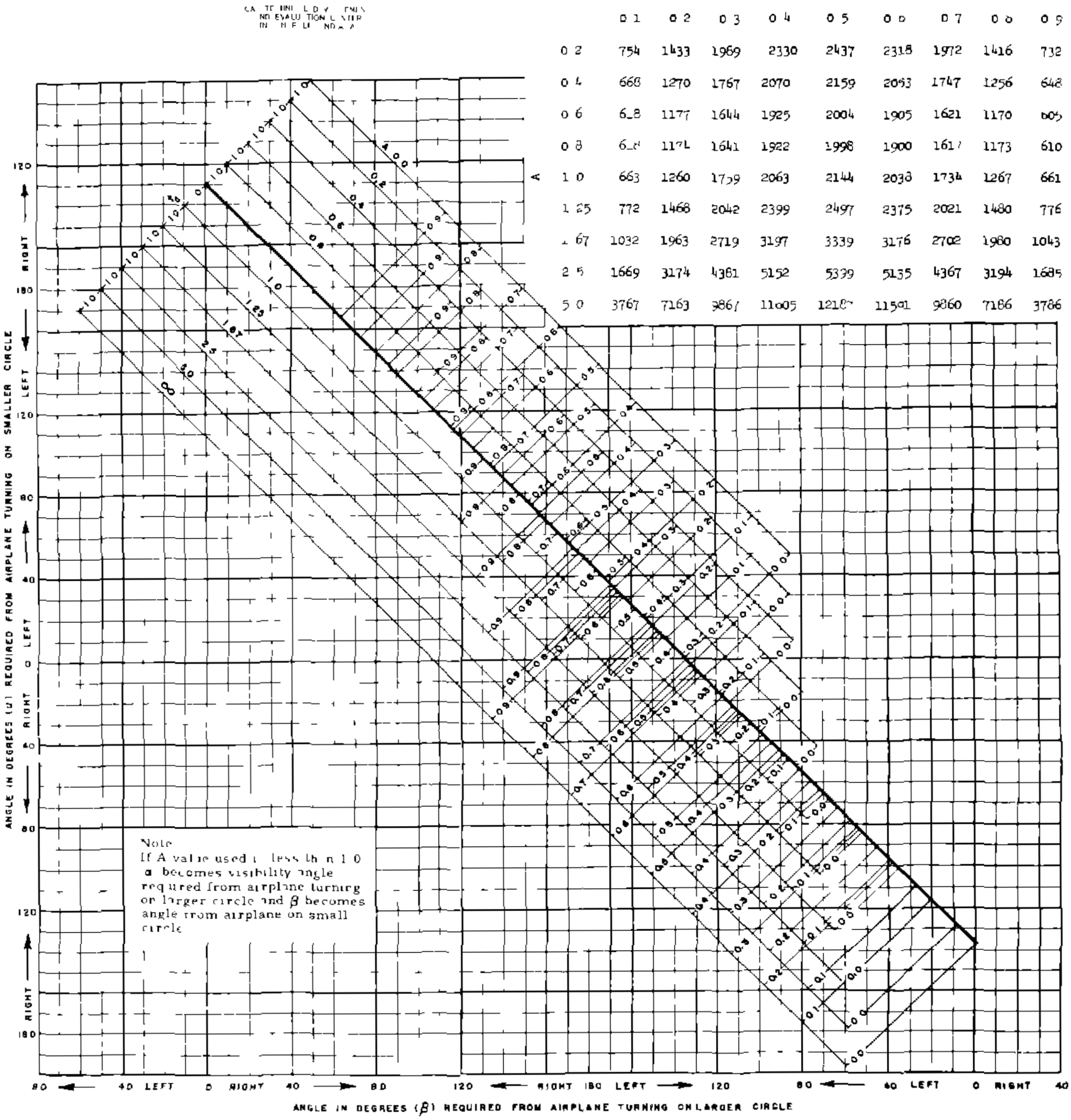
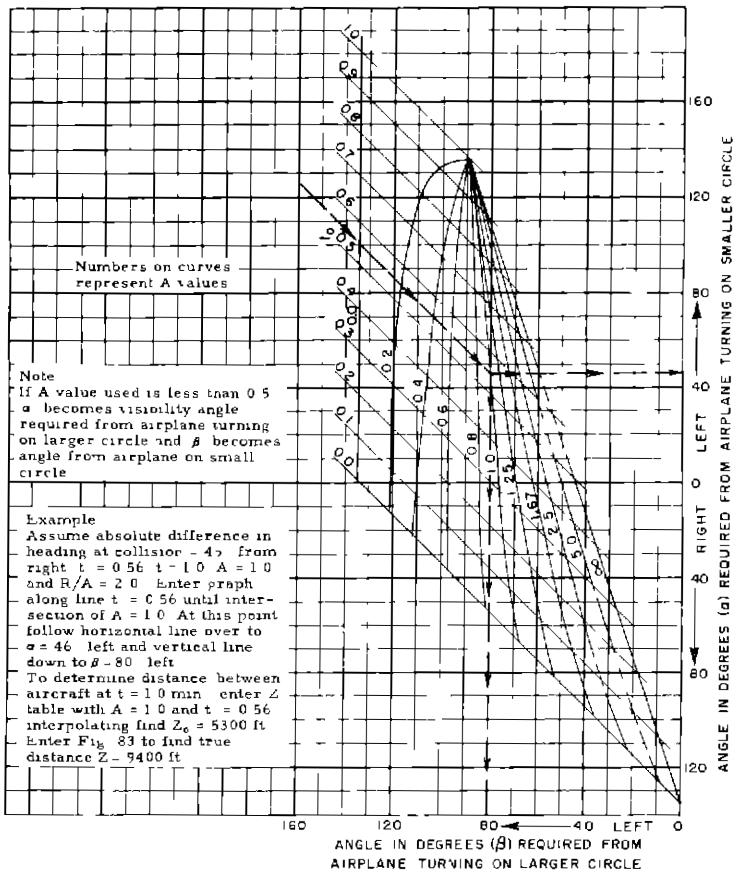


Fig 35 At Collision Point, the Difference in Heading = 45°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

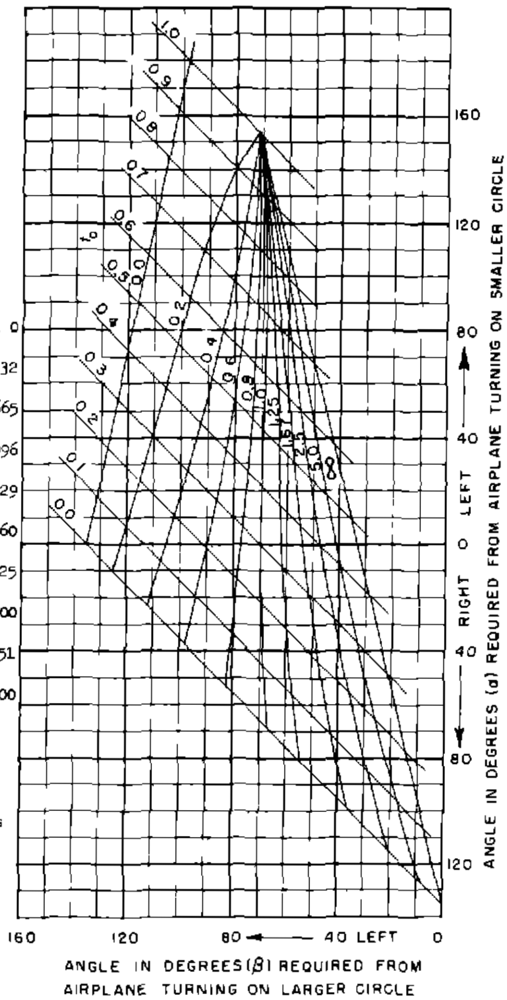
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	[illegible]	1521	2182	2656	2911	2945	2744	2319	1745	1121
0 4	718	1469	2200	2798	[illegible]	3449	3453	3223	2797	2240
0 6	701	1496	2331	3079	3674	4094	4278	4203	3880	3361
0 8	726	1600	2560	3463	4230	4824	5165	5217	4975	4482
→ 1 0 →	800 →	1760 →	2660 →	3920 →	4872 ↓	5620	6096	6240	6080	5600
1 25	914	2040	3308	4564	5690	6627	7267	7551	7449	7004
1 67	1182	2593	4160	[illegible]	[illegible]	8394	9273	9739	9747	9337
2 5	1823	3869	6076	8271	10292	12038	13354	14146	14350	14005
5 0	[illegible]	8044	12226	16285	20004	23228	25749	27430	28176	28011

Fig 36 At Collision Point, the Difference in Heading = 45°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	781	1542	2231	2741	3041	3123	2965	2572	2004	1332
0 4	729	1511	2297	2966	3464	3773	3843	3658	3245	2665
0 6	718	1561	2472	3314	4014	4534	4805	4790	4502	3996
0 8	748	1682	2735	3754	4645	5360	5808	5942	5762	5329
< 1 0	816	1862	3004	4256	5329	6224	6834	7104	7025	6660
1 25	941	2145	3536	4941	6231	7336	8135	8564	8605	8325
1 67	1211	2709	4422	6170	7805	9239	10333	11007	11242	11100
2 5	1851	3996	6370	8789	11080	13128	14773	15914	16518	16651
5 0	3967	8194	12611	17018	21201	24997	28199	30673	32356	33300



Note
If A value used is less than 0 4 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

Fig 37 At Collision Point, the Difference in Heading = 45°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

t_0

		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
	0 2	784	1556	2263	2798	3126	3235	3100	2718	2147	1456
	0 4	716	1541	2362	3074	3621	3973	4076	3905	3493	2912
	0 6	728	1604	2565	3466	4226	4801	5113	5121	4847	4367
	0 8	762	1737	2849	3938	4901	5680	6181	6351	6204	5822
A	1 0	833	1923	3102	4465	5621	6591	7265	7585	7562	7277
	1 2	958	2214	3681	5175	6561	7756	8637	9135	9260	9097
	1 67	1230	2784	4585	6438	8188	9735	10940	11725	12090	12129
	2 5	1872	4079	6556	9107	11550	13764	15583	16915	17755	18194
	5 0	3988	8289	12847	17458	21901	26015	29594	32513	34748	36388

Note
If A value used is less than 0 333 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

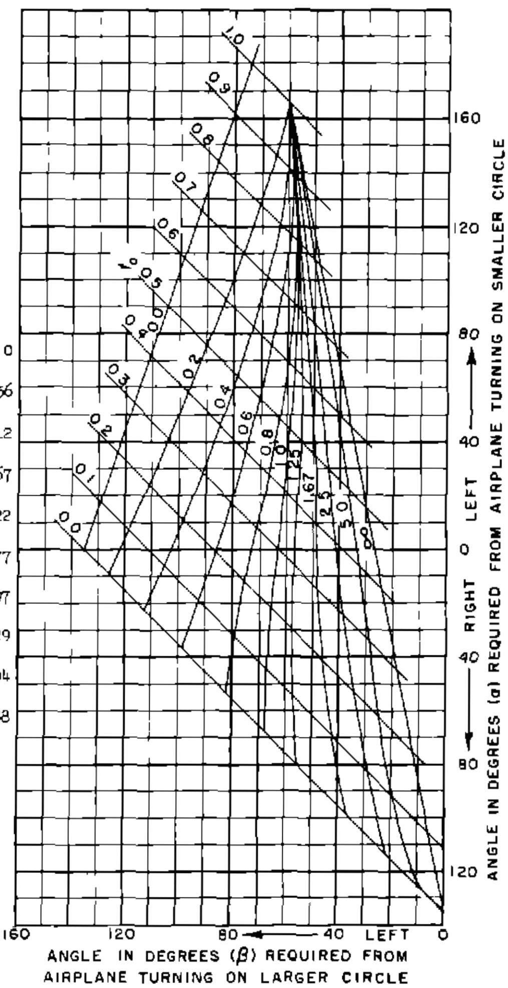


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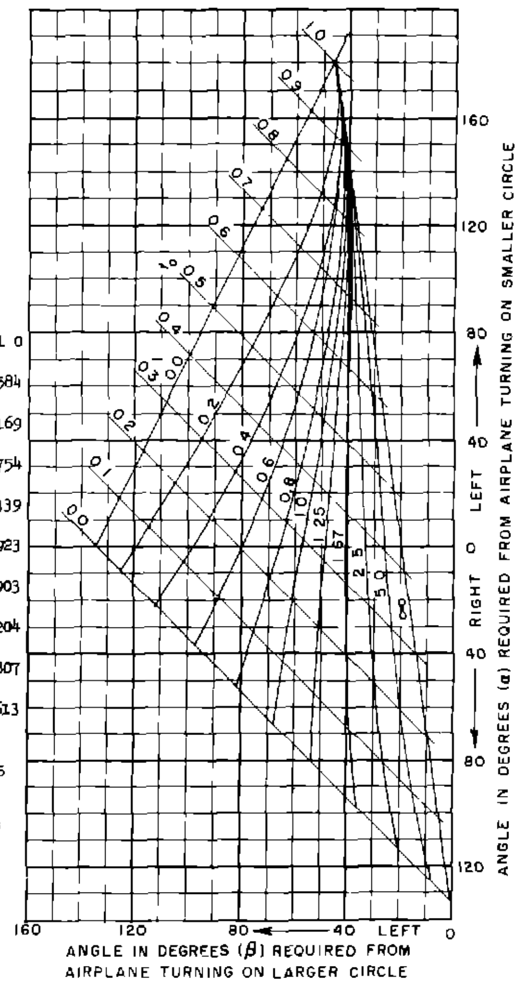
Fig 38 At Collision Point, the Difference in Heading = 45°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	788	1574	2304	2868	3228	3365	3247	2866	2285	1584
0 4	745	1577	2442	3206	3804	4197	4323	4154	3736	3169
0 6	742	1657	2677	3645	4470	5095	5439	5456	5190	4754
0 8	779	1804	2985	4154	5193	6033	6574	6763	6644	6339
1 0	853	2000	3348	4710	5952	6993	7720	8074	8100	7923
1 25	982	2299	3853	5448	6934	8213	9161	9715	9918	9903
1 67	1253	2876	4777	6748	8616	10273	11574	12453	12950	13204
2 5	1895	4178	6773	9471	12072	14444	16425	17936	19014	19807
5 0	4012	8402	13118	17948	22659	27086	31030	34393	37204	39613



Note
If A value used is less than 0 25 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

Fig 39 At Collision Point, the Difference in Heading = 45°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z₀ Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	793	1592	2345	2937	3323	3478	3364	2970	2369	1661
0 4	754	1614	2520	3330	3968	4365	4517	4328	3694	3361
0 6	756	1710	2785	3812	4688	5343	5690	5692	5420	5042
0 8	797	1868	3115	4352	5450	6326	6875	7056	6947	6722
◄ 1 0	872	2073	3495	4933	6242	7324	8066	8421	8472	8404
1 25	1003	2380	4017	5697	7255	8585	9559	10128	10380	10504
1 67	1276	2965	4958	7027	8984	10707	12054	12975	13559	14005
2 5	1919	4274	6976	9794	12512	14987	17058	18669	19918	21008
5 0	4035	8508	13362	18367	23278	27915	32097	35757	38993	42017

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Note
If A value used is less than 0 167 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

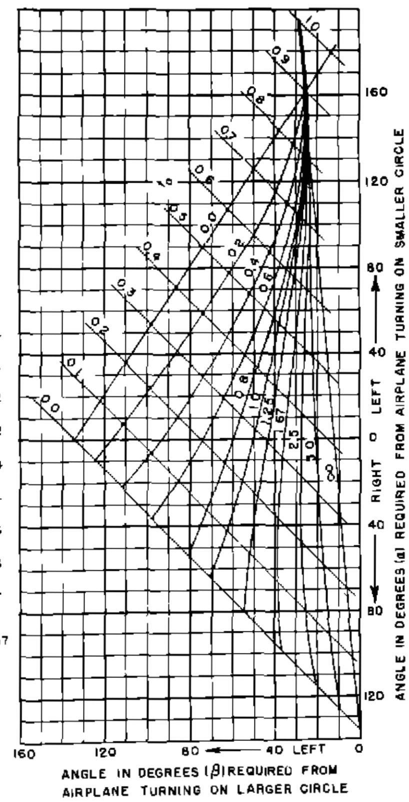
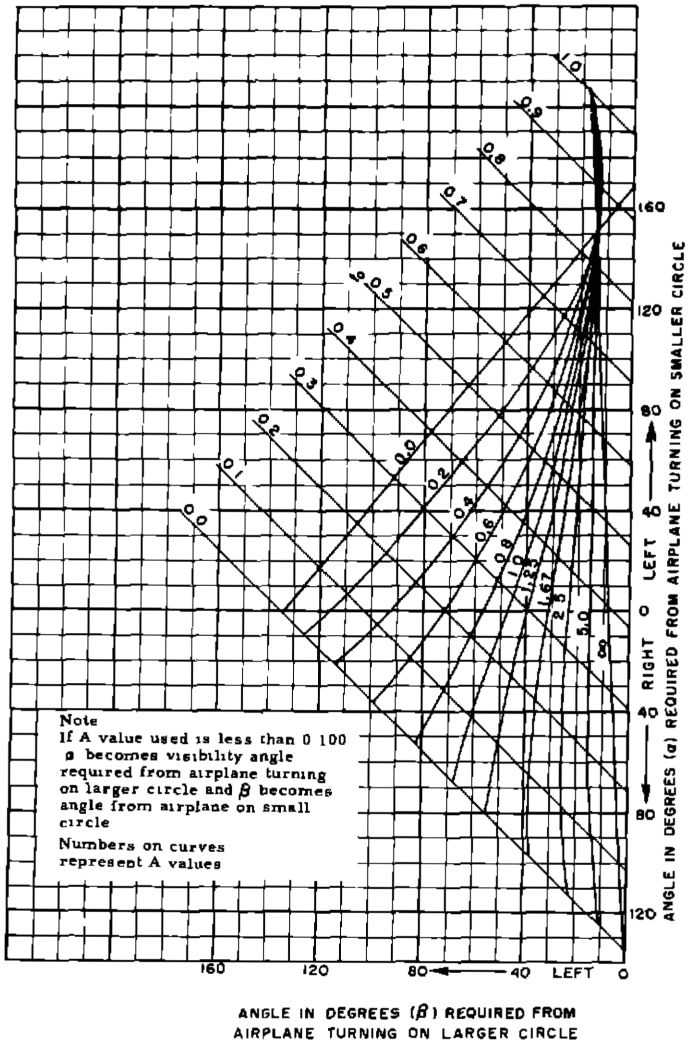


Fig 40 At Collision Point, the Difference in Heading = 45°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	796	1607	2378	2989	3391	3552	3433	3018	2396	1731
0 4	762	1643	2581	3423	4086	4511	4627	4409	3956	3463
0 6	767	1751	2866	3934	4839	5503	5833	5802	5517	5194
0 8	811	1918	3214	4498	5628	6512	7045	7194	7079	6925
< 1 0	889	2132	3606	5097	6440	7533	8260	8588	8642	8656
1 25	1021	2442	4139	5877	7476	8818	9781	10329	10596	10819
1 67	1295	3033	5093	7227	9232	10976	12320	13232	13852	14426
2 5	1937	4346	7126	10022	12804	15314	17403	19036	20364	21640
5 0	4054	8586	13536	18650	23665	28396	32671	36451	39901	43280

Fig 41 At Collision Point, the Difference in Heading = 45°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	884	1679	2329	2729	2857	2717	2311	1663	062	0
0 4	932	1773	2461	2884	3017	2869	2441	1760	914	0
0 6	1010	1921	2665	3125	3267	3106	2643	1910	993	0
0 8	1108	2109	2925	3432	3587	3412	2902	2101	1094	0
1 0	1225	2328	3230	3789	3961	3768	3205	2325	1214	0
1 25	1386	2636	3652	4288	4484	4264	3627	2634	1377	0
1 67	1684	3200	4429	5202	5444	5178	4405	3202	1677	0
2 5	2331	4434	6125	7198	7542	7173	6102	4439	2329	0
5 0	4414	0395	11578	13609	14283	13584	11555	8405	4417	0

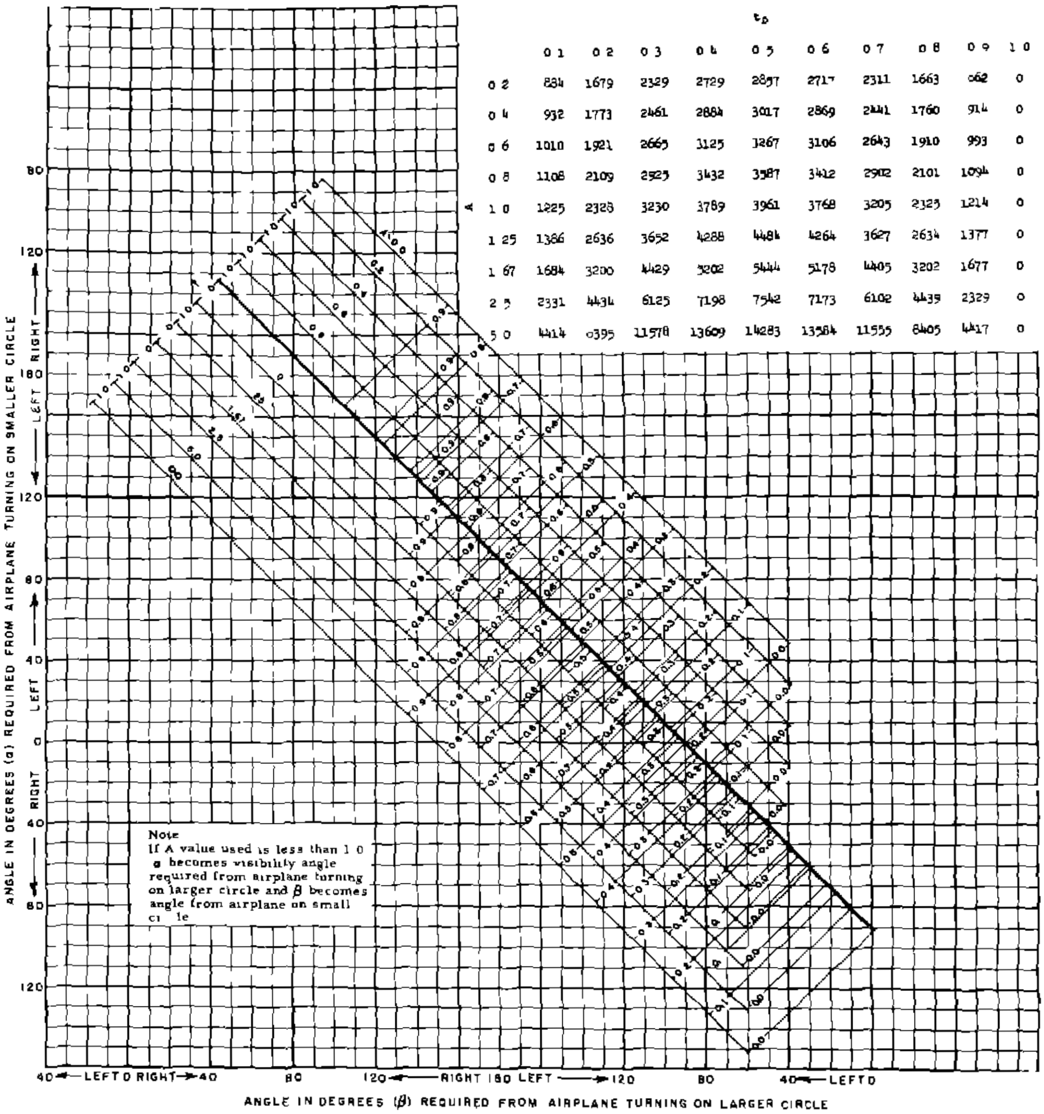
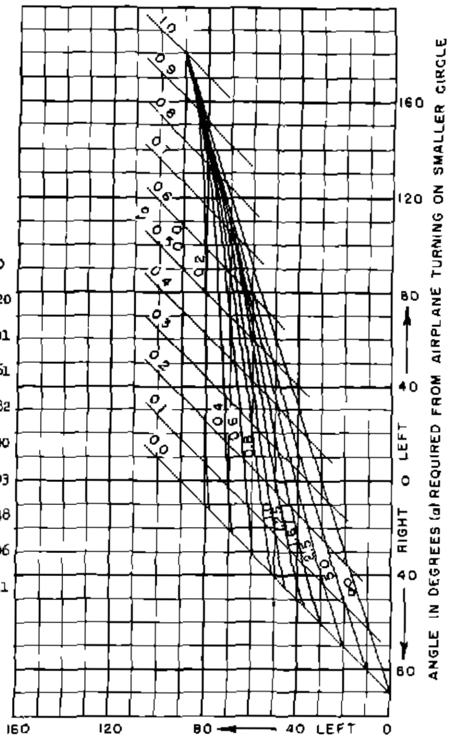


Fig 42 At Collision Point, the Difference in Heading = 90°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0: 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	910	1784	2555	3109	3408	3438	3188	2662	1944	1120
0 4	984	1973	2895	3614	4078	4266	4145	3715	3048	2241
0 6	1081	2201	3277	4163	4787	5120	5118	4773	4155	3361
0 8	1196	2458	3691	4738	5518	5990	6100	5834	5261	4482
1 0	1352	2744	5000	5316	6280	6872	7080	6920	6400	5600
1 25	1499	3099	4691	6096	7210	7976	8323	8226	7750	7003
1 67	1811	3738	5665	7396	8808	9834	10390	10444	10056	9338
2 5	2478	5084	7683	10054	12048	13576	14535	14880	14667	14006
5 0	4597	9298	13918	18181	21877	24867	26997	28196	28499	28011



Note
If A value used is less than 0 5 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

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Fig 43 At Collision Point, the Difference in Heading = 90°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	915	1804	2597	3175	3501	3555	3322	2808	2105	1333
0 4	993	2010	2970	3734	4245	4474	4390	3990	3371	2664
0 6	1095	2252	3380	4326	5015	5407	5461	5173	4638	3997
0 8	1212	2519	3816	4938	5798	6347	6536	6355	5904	5328
1 0	1343	2802	4270	5565	6592	7293	7612	7538	7172	6661
1 25	1520	3177	4855	6363	7592	8479	8958	9015	8757	8325
1 67	1834	3826	5857	7714	9274	10462	11203	11479	11395	11101
2 5	2505	5191	7918	10460	12664	14440	15694	16407	16677	16650
5 0	4630	9439	14257	18813	22906	26403	29179	31188	32516	33301

Note
If A value used is less than 0 4 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

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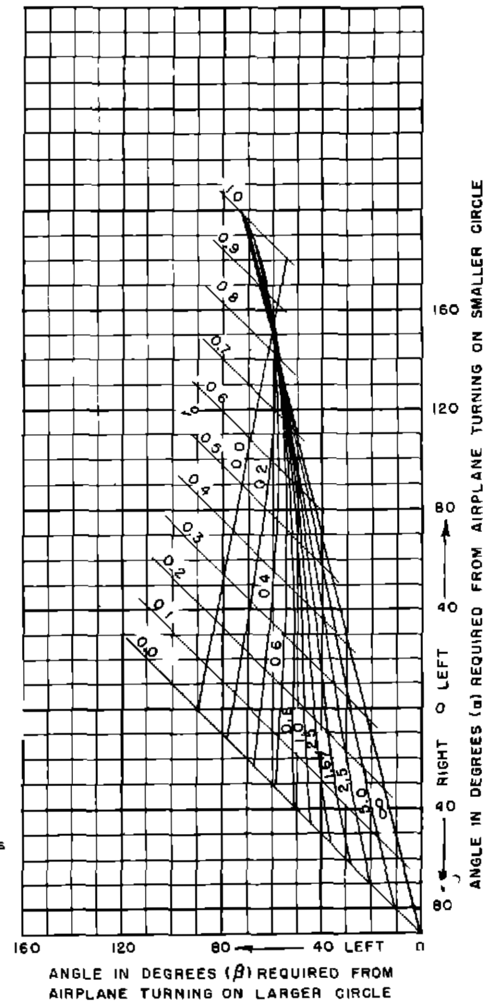


Fig 44 At Collision Point, the Difference in Heading = 90°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	919	1817	2623	3215	3554	3617	3387	2871	2175	1456
0 4	1001	2033	3016	3805	4338	4584	4509	4118	3528	2911
0 6	1103	2284	3444	4422	5142	5559	5632	5367	4886	4367
0 8	1223	2557	3892	5056	5955	6538	6756	6614	6243	5822
< 1 0	1356	2847	4358	5701	6774	7518	7881	7863	7602	7277
1 25	1534	3225	4954	6518	7805	8747	9286	9425	9300	9097
1 67	1850	3885	5973	7899	9532	10797	11629	12026	12133	12129
2 5	2522	5258	8060	10694	13005	14905	16313	17230	17797	18194
5 0	4650	9525	14457	19172	23476	27243	30369	32841	34793	36387

Note
If A value used is less than 0 333 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

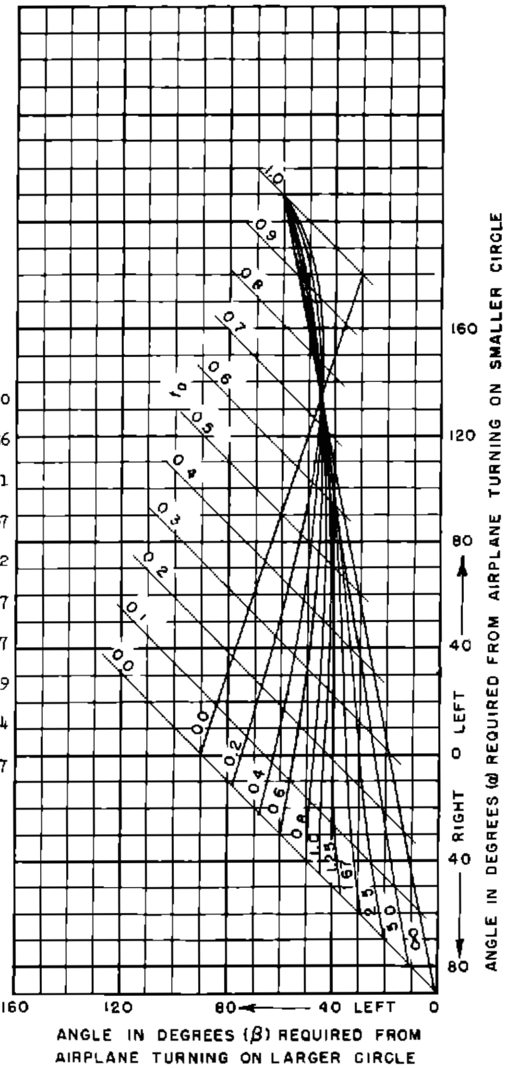
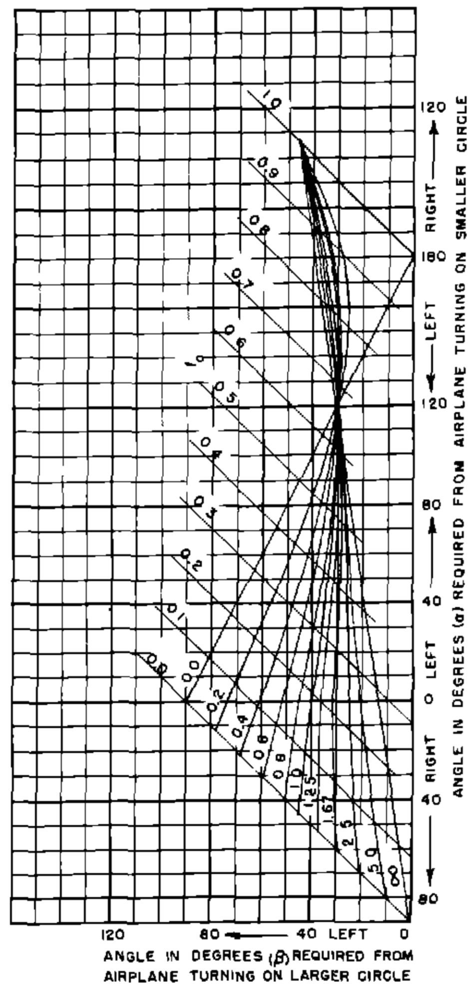


Fig 45 At Collision Point, the Difference in Heading = 90°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

τ_0 Values

$|t_0|$

A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	923	1832	2653	3260	3609	3672	3435	2905	2216	1585
0 4	1007	2061	3070	3884	4434	4684	4605	4208	3652	3169
0 6	1113	2322	3515	4527	5271	5699	5774	5518	6000	4754
0 8	1236	2603	3979	5182	6113	6714	6944	6831	6551	6338
1 0	1371	2899	4458	5846	6958	7729	8115	8145	8004	7923
1 25	1549	3284	5068	6685	8020	8999	9579	9768	9820	9903
1 67	1868	3951	6102	8096	9793	11118	12018	12530	12850	13205
2 5	2543	5335	8218	10941	13350	15354	16896	18014	18911	19807
5 0	4674	9623	14675	19549	24051	28067	31531	34476	37101	39614



Note
If A value used is less than 0 25 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

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Fig 46 At Collision Point, the Difference in Heading = 90°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

t_0

A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
2 0	926	1848	2681	3297	3648	3702	3444	2889	2200	1680
4 0	1016	2089	3119	3948	4504	4742	4636	4218	3692	3362
6 0	1124	2358	3580	4614	5365	5780	5833	5565	5203	5042
8 0	1250	2646	4058	5288	6228	6819	7032	6920	6721	6723
1 0	1384	2949	4546	5967	7093	7858	8233	8279	8243	8403
1 25	1566	3338	5166	6822	8175	9155	9736	9981	10146	10504
1 67	1885	4013	6218	8255	9982	11320	12241	12821	13321	14005
2 5	2563	5407	8354	11139	13600	15648	17256	18511	19675	21008
5 0	4697	9712	14858	19840	24466	28632	32309	35591	38745	42017

Note
If A value used is less than 0 167 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

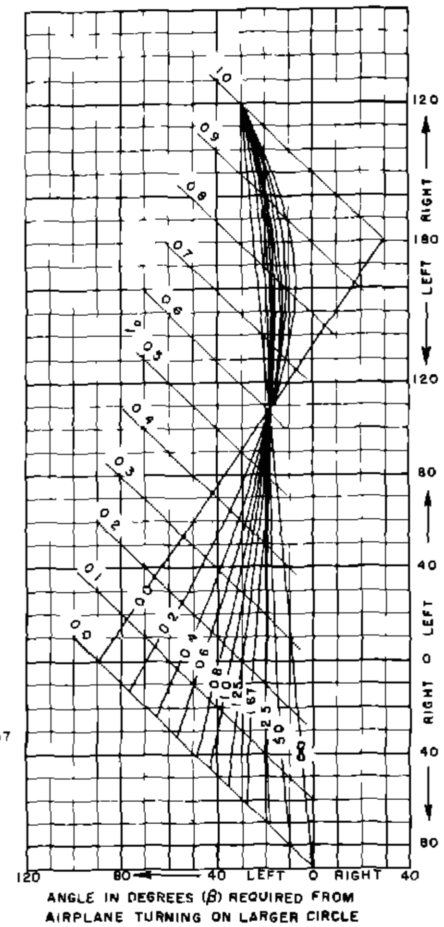
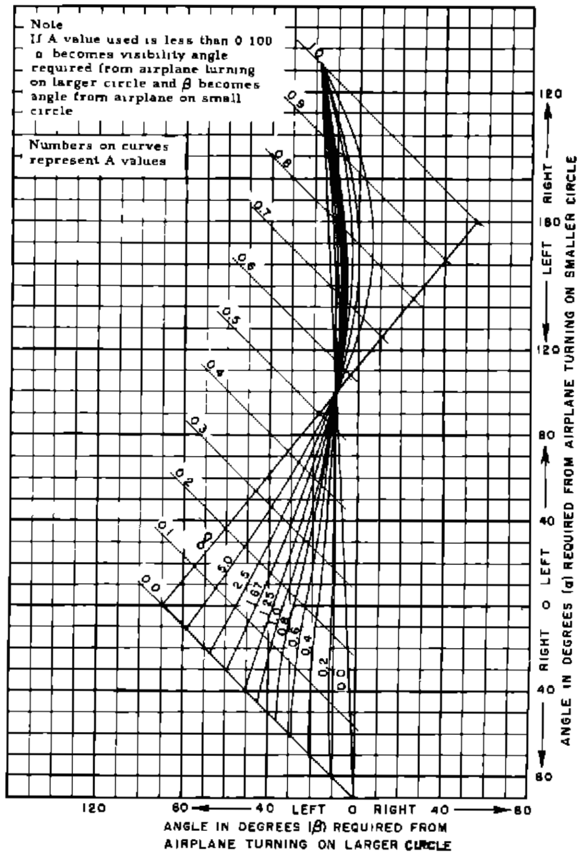


Fig 47 At Collision Point, the Difference in Heading = 90°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

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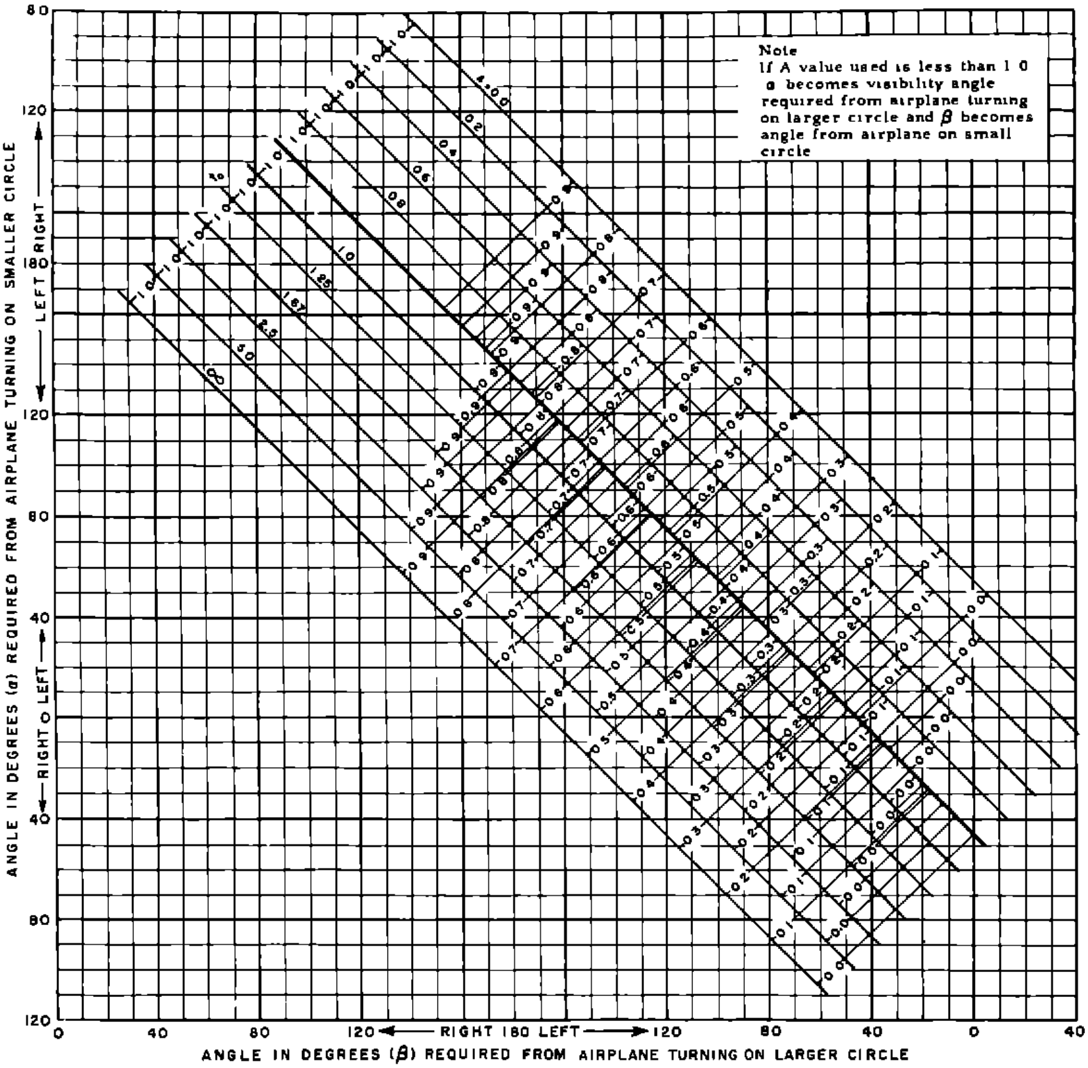
A	t_0: 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	931	1859	2701	3323	3669	3707	3423	2838	2149	1732
0 4	1021	2109	3154	3991	4541	4755	4613	4164	3661	3462
0 6	1133	2385	3627	4669	5413	5802	5816	5524	5204	5194
0 8	1259	2679	4114	5354	6287	6850	7026	6897	6756	6924
1 0	1396	2984	4608	6042	7162	7898	8240	8277	8312	8656
1 25	1578	3381	5236	6907	8256	9211	9759	10007	10261	10819
1 67	1900	4059	6297	8353	10079	11395	12296	12897	13510	14426
2 5	2579	5459	8447	11259	13728	15768	17380	18689	20017	21641
5 0	4715	9776	14979	20012	24680	28889	32645	36090	39548	4327

Fig 48 At Collision Point, the Difference in Heading = 90°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	995	1894	2623	3074	3222	3065	2607	1876	974	0
0 4	1137	2163	2995	3512	3680	3499	2976	2147	1116	0
0 6	1286	2447	3388	3973	4164	3959	3368	2432	1266	0
0 8	1441	2741	3793	4450	4662	4435	3773	2726	1422	0
◄ 1 0	1600	3042	4208	4938	5179	4923	4187	3030	1580	0
1 25	1801	3426	4737	5561	5829	5543	4716	3415	1783	0
1 67	2144	4078	5635	6616	6938	6599	5614	4068	2127	0
2 5	2843	5408	7465	8767	9200	8749	7442	5398	2827	0
5 0	4978	9469	13055	15340	16108	15321	13033	9461	4964	0

Fig 49 At Collision Point, the Difference in Heading = 135°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1012	1961	2770	3325	3594	3562	3230	2618	1853	1121
0 4	1168	2286	3265	3979	4385	4464	4211	3652	2934	2240
0 6	1328	2615	3764	4635	5178	5367	5198	4700	4029	3361
0 8	1491	2948	4264	5291	5971	6271	6189	5754	5128	4482
1 0	1648	3288	4760	5944	6768	7192	7200	6840	6260	5600
1 25	1867	3708	5399	6770	7754	8307	8424	8137	7610	7004
1 67	2221	4416	6450	8141	9403	10194	10498	10351	9912	9337
2 5	2936	5843	8560	10882	12704	13969	14651	14781	14520	14005
5 0	5108	10151	14907	19111	22608	25296	27123	28093	28348	28011

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Note
If A value used is less than 0 5 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

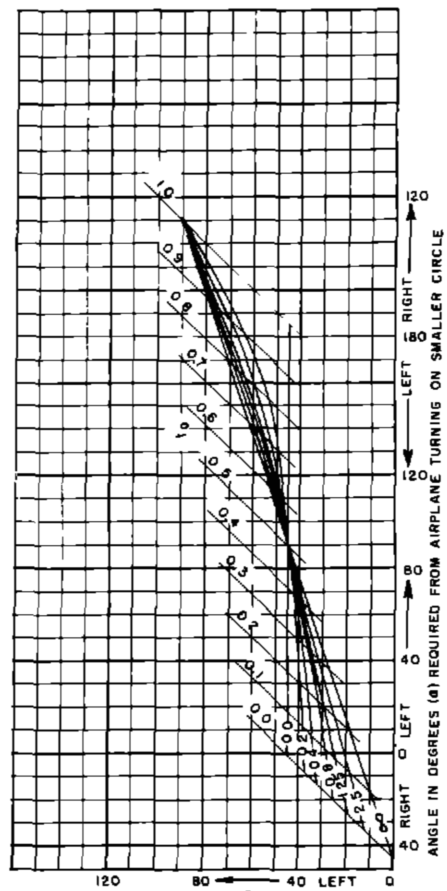
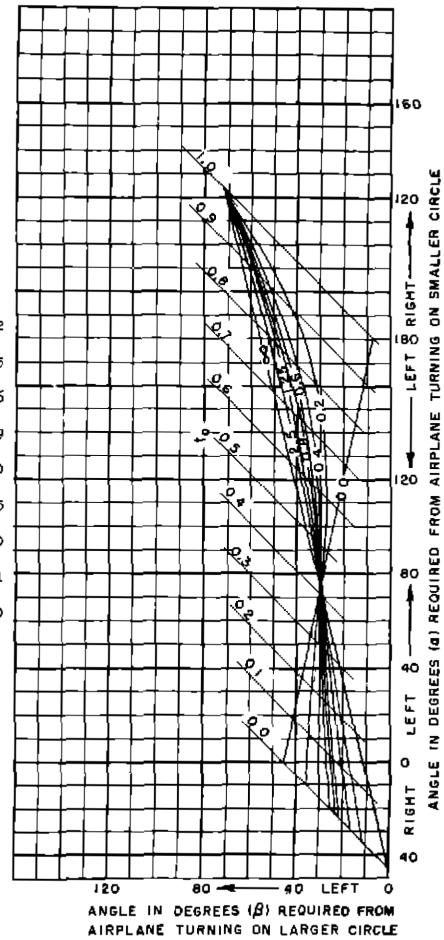


Fig 50 At Collision Point, the Difference in Heading = 135°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1016	1971	2786	3346	3617	3580	3242	2628	1900	1332
0 4	1172	2302	3296	4021	4435	4515	4267	3737	3119	2665
0 6	1334	2638	3806	4695	5255	5458	5315	4880	4364	3996
0 8	1499	2977	4318	5370	6075	6406	6372	6039	5620	5329
1 0	1666	3317	4832	6045	6897	7356	7437	7205	6880	6660
1 25	1877	3745	5473	6889	7923	8546	8771	8670	8458	8325
1 67	2232	4462	6544	8293	9637	10535	11005	11118	11091	11100
2 5	2951	5902	8688	11105	13064	14519	15484	16029	16366	16651
5 0	5127	10239	15127	19539	23352	26490	28952	30793	32199	33300



Note
If A value used is less than 0 4 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

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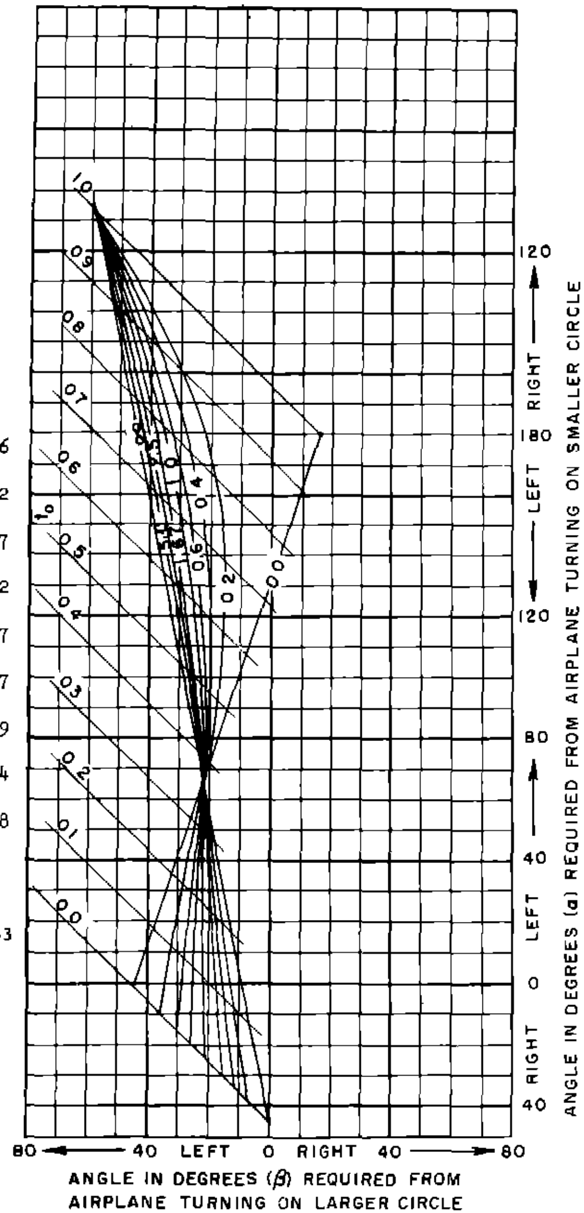
Fig 51 At Collision Point, the Difference in Heading = 135°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 = 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1018	1977	2795	3355	3620	3573	3219	2595	1893	1456
0 4	1176	2313	3311	4037	4446	4514	4257	3735	3186	2912
0 6	1339	2652	3829	4720	5277	5473	5330	4927	4519	4367
0 8	1505	2994	4346	5403	6110	6440	6419	6142	5863	5822
1 0	1672	3337	4864	6087	6946	7412	7520	7368	7214	7277
1 25	1884	3767	5512	6941	7991	8633	8905	8910	8906	9097
1 67	2240	4489	6592	8364	9736	10675	11223	11492	11732	12129
2 5	2961	5935	8754	11213	13229	14771	15882	16673	17389	18194
5 0	5139	10290	15243	19757	23725	27098	29909	32262	34377	36388



Note
If A value used is less than 0 333 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

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Fig 52 At Collision Point, the Difference in Heading = 135°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 = 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1020	1983	2803	3357	3609	3538	3155	2508	1839	1584
0 4	1180	2323	3326	4044	4434	4473	4185	3662	3208	3169
0 6	1343	2668	3848	4733	5271	5438	5274	4898	4629	4754
0 8	1511	3012	43 1	5423	6113	6418	6392	6169	6067	6339
1 0	1678	3358	4893	6113	6958	7409	7527	7455	7512	7923
1 25	1892	3792	5546	6978	8020	8657	8958	9076	9321	9903
1 67	2249	4516	6637	8417	9793	10746	11360	11792	12345	13204
2 5	2970	5969	8816	11299	13350	14954	16199	17251	18400	19807
5 0	5153	10342	15354	19952	24051	27634	30792	33686	36583	39613

Note
If A value used is less than 0 25 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

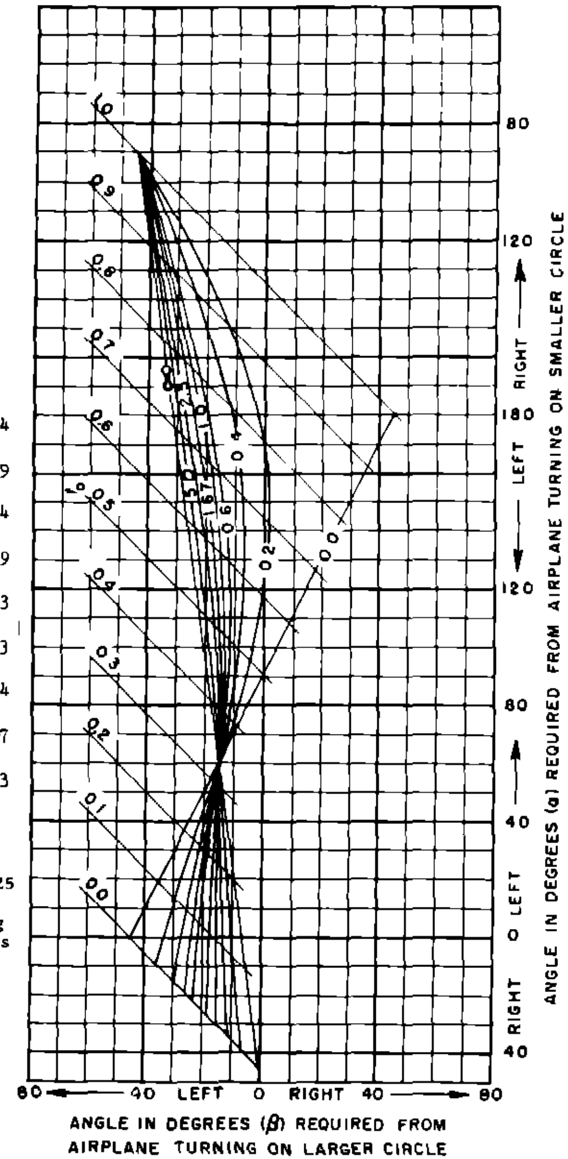

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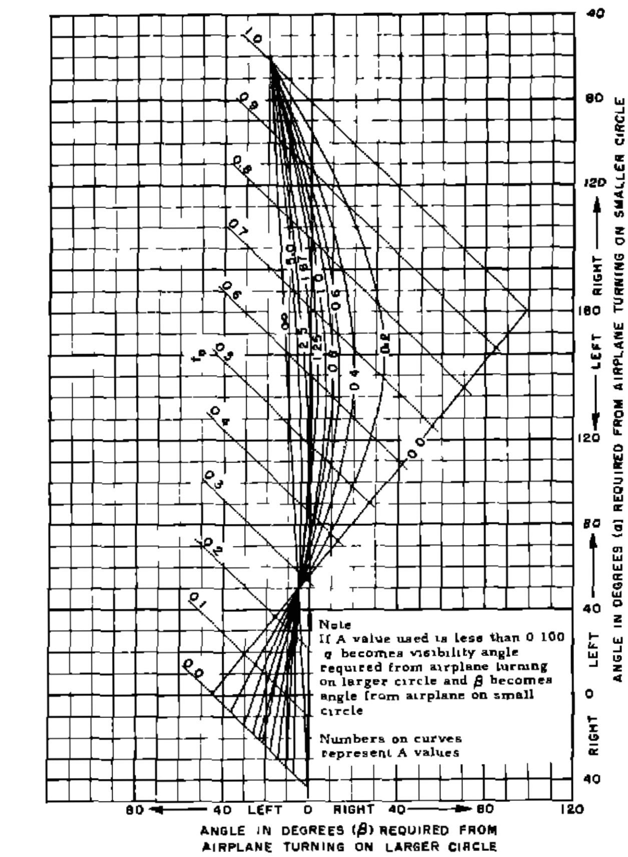
Fig 53 At Collision Point, the Difference in Heading = 135°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle



Z_0 Values

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A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1024	1991	2807	3339	3547	3410	2945	2231	1624	1731
0 4	1186	2338	3333	4019	4344	4285	3898	3344	3074	3463
0 6	1353	2686	3860	4705	5165	5225	4969	4613	4599	5194
0 8	1521	3036	4387	5395	6002	6200	6098	5937	6143	6925
1 0	1691	3385	4913	6088	6849	7197	7258	7288	7695	8656
1 25	1904	3823	5572	6956	7917	8460	8731	8994	9639	10819
1 67	2264	4552	6670	8408	9710	10592	11219	11861	12886	14426
2 5	2988	6014	8866	11321	13324	14904	16247	17628	19390	21640
5 0	5175	10408	15456	20081	24232	27956	31456	35007	38918	43280

Fig 54 At Collision Point, the Difference in Heading = 135°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Right of the Airplane Turning on the Smaller Circle

Z_0 Values

	ε_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1038	1975	2733	3204	3361	3197	2719	1957	1015	0
0 4	1212	2305	3187	3738	3922	3730	3173	2285	1189	0
0 6	1386	2635	3640	4270	4482	4262	3626	2614	1362	0
0 8	1558	2964	4093	4802	5042	4795	4079	2943	1535	0
1 0	1732	3293	4547	5335	5602	5328	4532	3273	1707	0
1 25	1948	3705	5113	6002	6303	5994	5099	3684	1924	0
1 67	2309	4391	6057	7111	7469	7104	6043	4371	2285	0
2 5	3029	5763	7946	9332	9804	9325	7932	5743	3006	0
5 0	5194	9876	13612	15991	16807	15984	13597	9859	5171	0

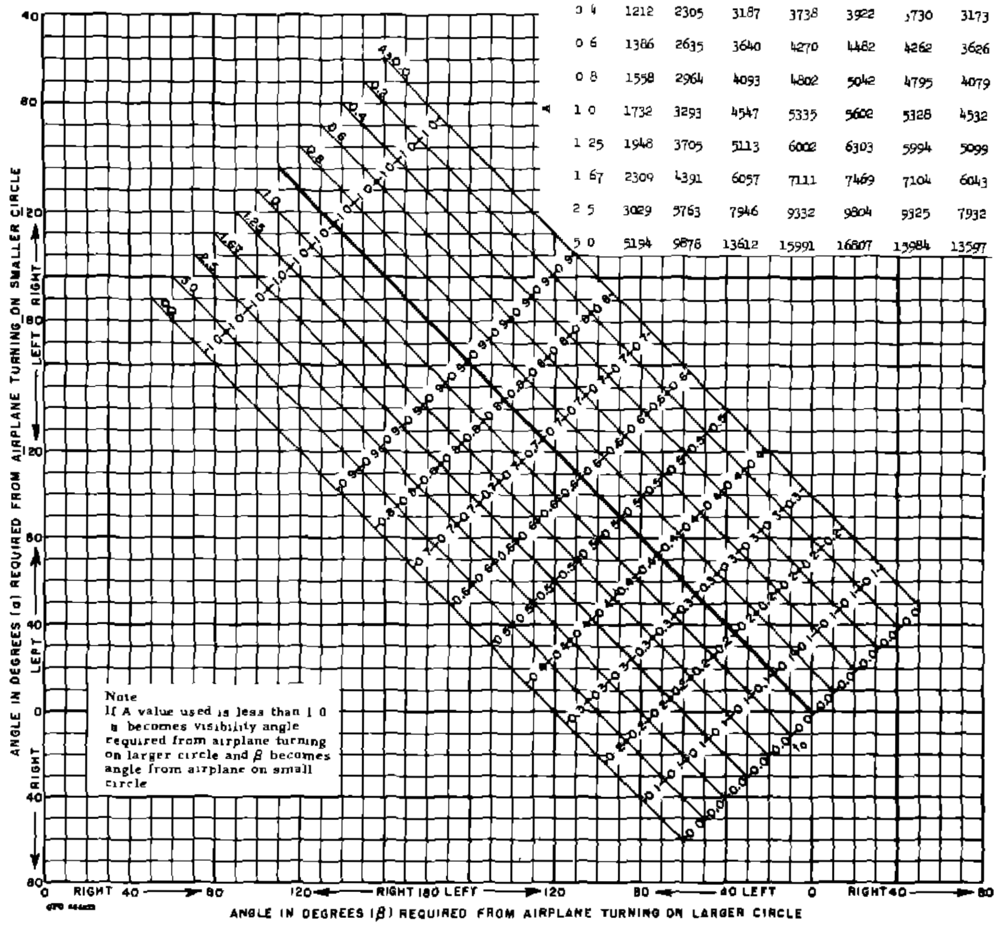

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Fig 55 At Collision Point, the Difference in Heading = 180°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1039	1978	2742	3225	3406	3280	2661	2196	1486	1120
0 4	1213	2315	3217	3811	4078	4007	3637	3046	2482	2241
0 6	1388	2653	3701	4419	4787	4797	4501	3999	3544	3361
0 8	1562	2995	4192	5039	5518	5621	5414	4999	4627	4482
1 0	1740	3340	4672	5680	6270	6480	6360	6040	5728	5600
1 25	1955	3765	5307	6462	7210	7546	7544	7316	7091	7003
1 67	2320	4480	6350	7800	8808	9370	9564	9496	9383	9378
2 5	3049	5916	8448	10501	12048	13076	13656	13896	13902	14006
5 0	5239	10235	14778	18680	21877	24323	26065	27174	27604	28011

Note
If A value used is less than 0 5 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

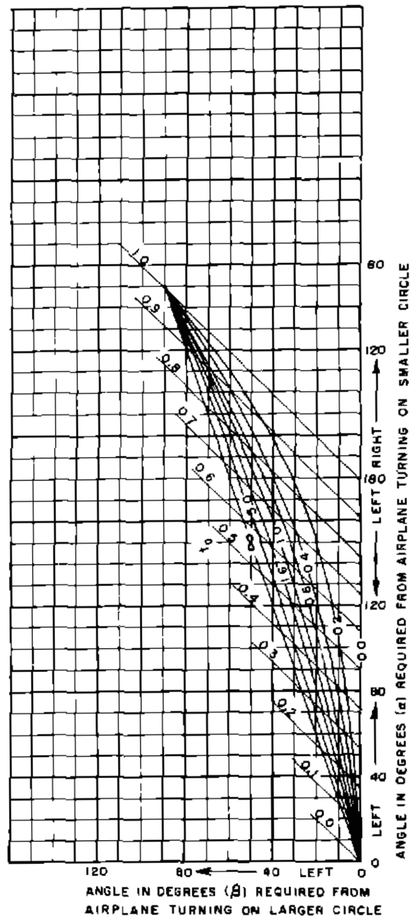

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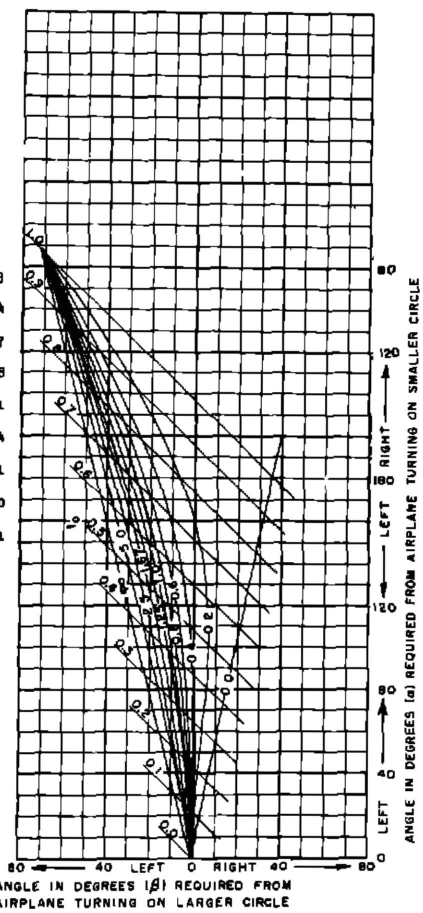
Fig 56 At Collision Point, the Difference in Heading = 180°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

t_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 6	0 6	0 7	0 8	0 9	1 0
0 2	1038	1975	2728	3193	3353	3193	2742	2062	1425	1333
0 4	1213	2309	3196	3764	3997	3889	3496	2942	2561	2664
0 6	1387	2647	3676	4366	4700	4679	4389	3982	3782	3997
0 8	1561	2987	4166	4985	5434	5522	5352	5084	5026	5328
1 0	1736	3329	4660	5617	6193	6399	6352	6217	6280	6661
1 25	1954	3758	5285	6420	7159	7523	7632	7653	7852	8324
1 67	2319	4474	6334	7777	8804	9437	9806	10074	10482	11101
2 5	3049	5916	8451	10529	12150	13339	14223	14958	15750	16650
5 0	5241	10256	14856	18890	22342	25219	27630	29696	31580	33301



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Note
If A value used is less than 0 4
α becomes visibility angle
required from airplane turning
on larger circle and β becomes
angle from airplane on small
circle

Numbers on curves
represent A values

Fig 57 At Collision Point, the Difference in Heading = 180°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

		t_0									
		0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
A	0 2		1971	2715	3167	3303	3115	2633	1935	1353	1456
	0 4	1211	2303	3176	3721	3921	3775	3356	2823	2580	2911
	0 6	1385	2639	3653	4313	4611	4556	4256	3913	3894	4367
	0 8	1560	2978	4139	4929	5345	5405	5244	5075	5233	5822
	1 0	1735	3319	4633	5561	6105	6295	6278	6273	6580	7271
	1 25	1954	3748	5258	6365	7082	7442	7607	7791	8270	9097
	1 67	2317	4467	6309	7730	8746	9404	9869	10351	11093	12129
	2 5	3048	5910	8435	10507	12149	13413	14471	15512	16748	18194
	5 0	5243	10262	14878	18965	22539	25646	28441	31082	33734	36387

Note
If A value used is less than 0 333 α becomes visibility angle required from airplane turning on larger circle and β becomes angle from airplane on small circle

Numbers on curves represent A values

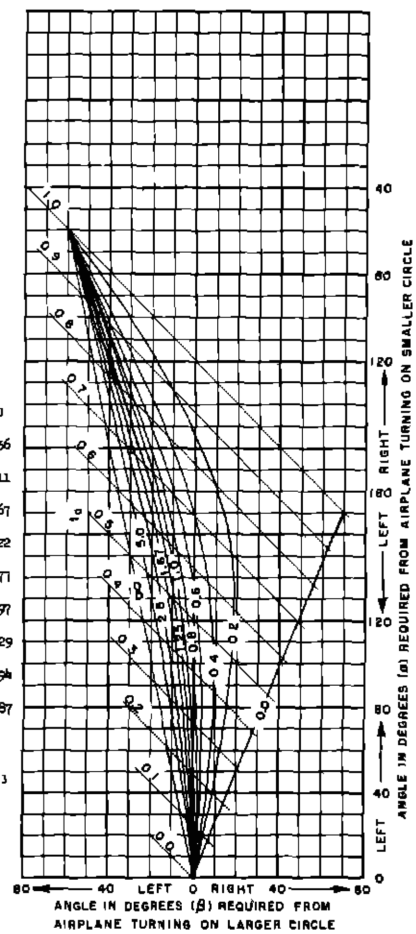

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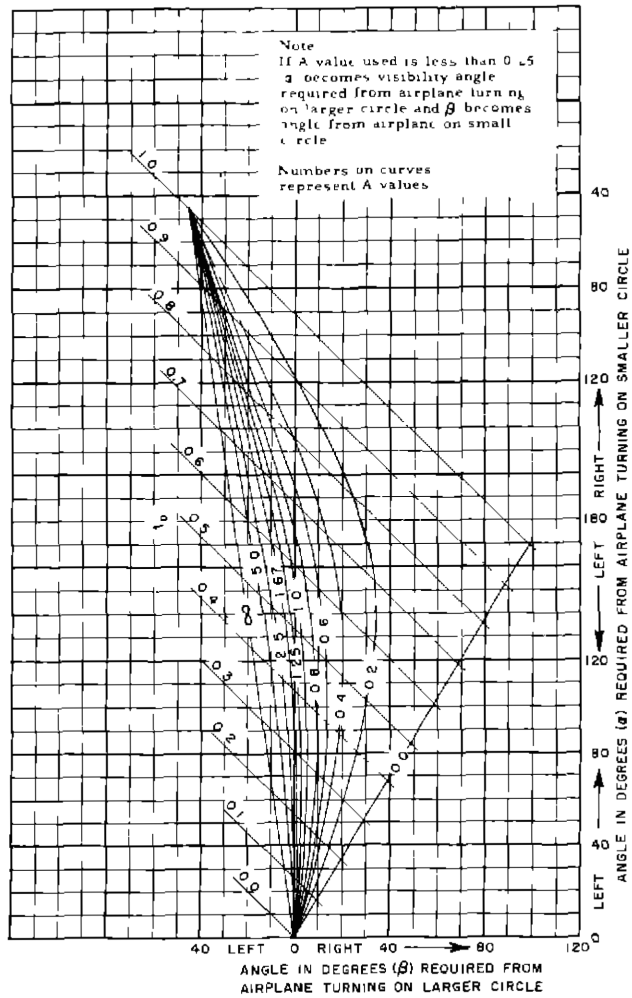
Fig 58 At Collision Point, the Difference in Heading = 180°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

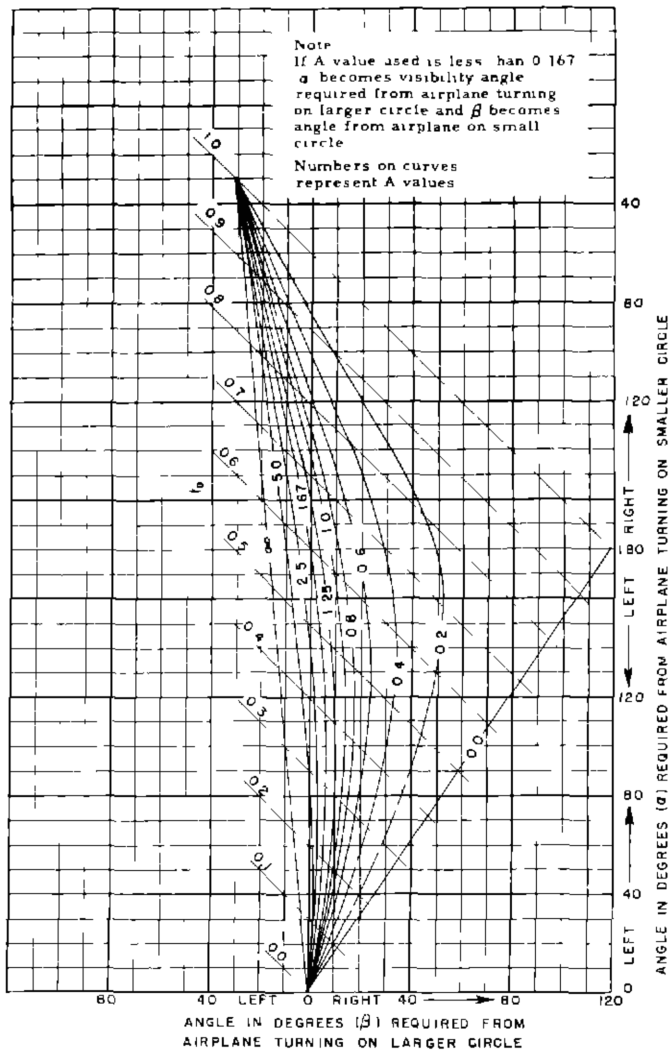


Z_0 Values

t_0

A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1038	1965	2698	3125	3228	2997	2468	1738	1237	1585
0 4	1210	2294	3146	3654	3804	3597	3129	2620	2567	3160
0 6	1384	2628	3614	4231	4470	4354	4027	3766	3985	4754
0 8	1557	2965	4096	4838	5193	5201	5040	4997	5422	6338
1 0	1733	3305	4588	5465	5952	6100	6110	6263	6867	7923
1 25	1951	3734	5211	6269	6934	7268	7489	7869	8679	9903
1 67	2316	4451	6262	7638	8616	9276	9842	10574	11704	13205
2 5	3046	5896	8394	10437	12072	13394	14633	16023	17760	19807
5 0	5242	10258	14874	18988	22659	25984	29181	32450	35944	39614

Fig 59 At Collision Point, the Difference in Heading = 180°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



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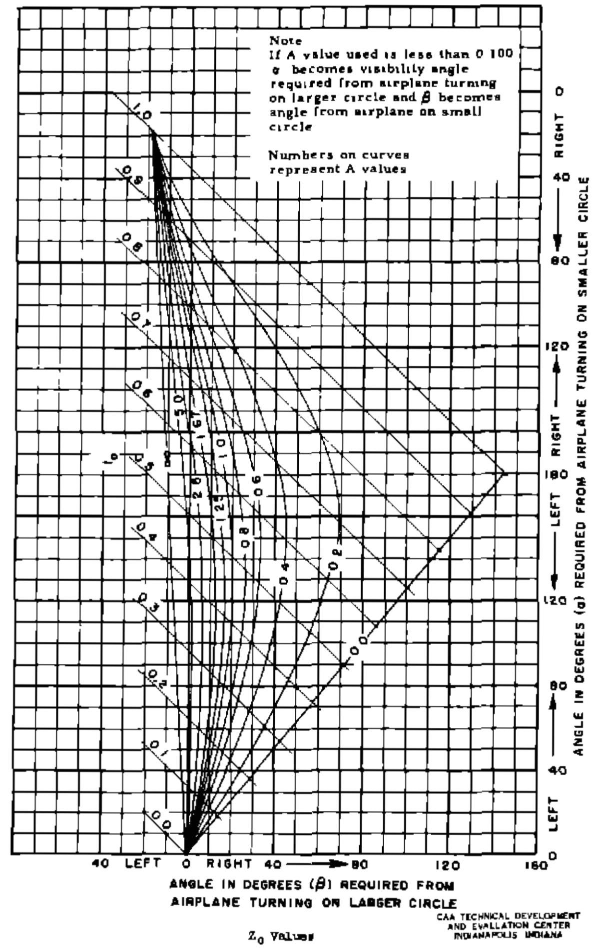
t_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1036	1959	2675	3077	3141	2859	2274	1502	1098	1680
0 4	1209	2282	3109	3574	3661	3378	2849	2369	2521	3362
0 6	1382	2614	3568	4129	4294	4100	3736	3564	4021	5042
0 8	1557	2949	4044	4723	5000	4936	4765	4851	5536	6723
1 0	1730	3268	4530	5342	5751	5837	5061	6171	7055	8403
1 25	1949	3714	5149	6141	6730	7017	7276	7845	8957	10504
1 67	2313	4431	6198	7509	8422	9057	9702	10660	12131	14005
2 5	3044	5876	8332	10317	11911	13255	14636	16325	18484	21008
5 0	5239	10242	14834	18931	22637	26105	29610	33384	37554	42017

Fig 60 At Collision Point, the Difference in Heading = 180°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

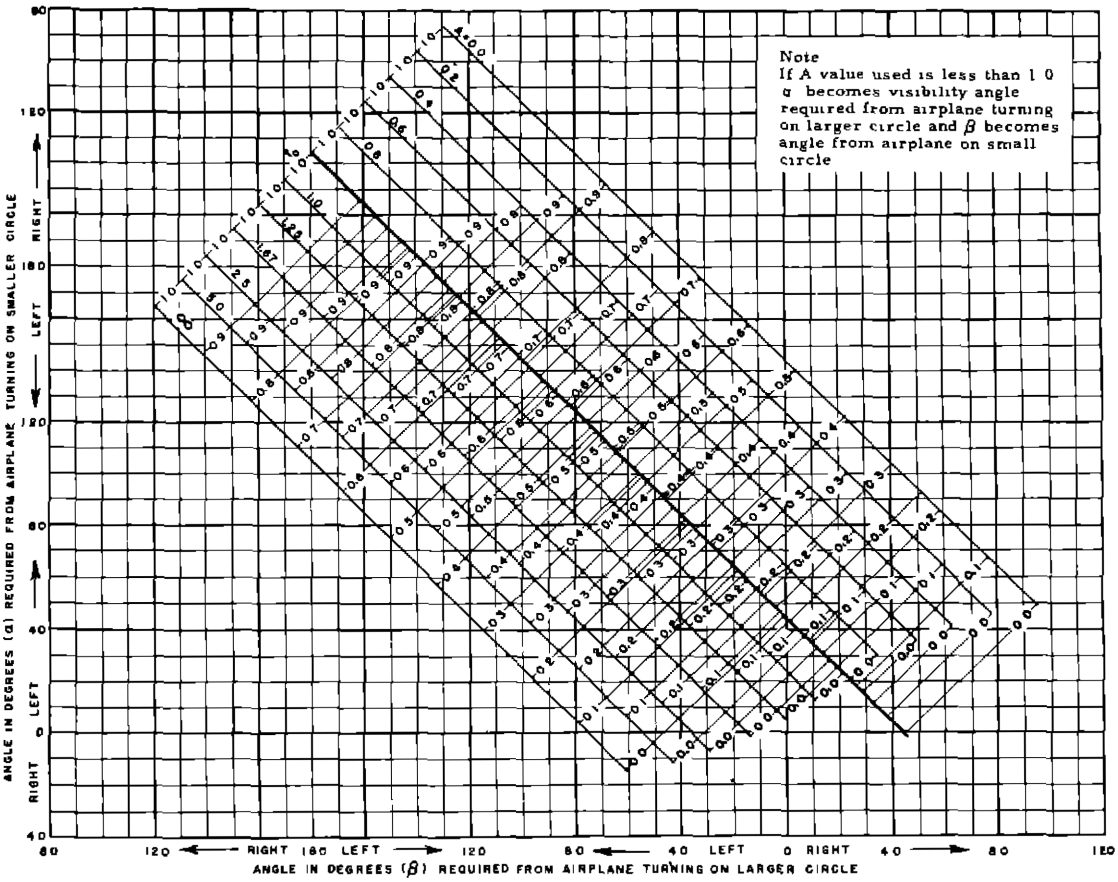


Z_0 Values

t_0

A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	1035	1953	2655	3033	3063	2738	2104	1292	980	1732
0 4	1208	2272	3075	3499	3529	3179	2591	2138	2470	3462
0 6	1381	2599	3525	4035	4131	3861	3461	3370	4015	5194
0 8	1554	2933	3993	4615	4818	4682	4498	4694	5571	6924
1 0	1729	3270	4474	5225	5557	5580	5611	6047	7130	8656
1 25	1947	3696	5089	6016	6531	6765	7052	7760	9080	10819
1 67	2310	4411	6134	7378	8221	8820	9514	10636	12333	14426
2 5	3041	5854	8265	10187	11724	13058	14525	16414	18842	21641
5 0	5236	10223	14775	18827	22519	26044	29725	33805	38377	43279

Fig 61 At Collision Point, the Difference in Heading = 180°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

α	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	996	1893	2618	3069	3222	3064	2607	1872	972	0
0 4	1137	2163	2987	3503	3680	3500	2977	2140	1113	0
0 6	1286	2447	3376	3960	4164	3959	3368	2424	1262	0
0 8	1441	2741	3779	4434	4662	4435	3773	2717	1416	0
1 0	1600	3042	4194	4920	5175	4923	4187	3019	1575	0
1 25	1801	3427	4720	5541	5829	5544	4716	3402	1777	0
1 67	2145	4078	5616	6594	6938	6599	5614	4054	2120	0
2 5	2844	5407	7444	8743	9200	8749	7442	5382	2819	0
5 0	4978	9469	13031	15312	16108	15320	13033	9444	4955	0

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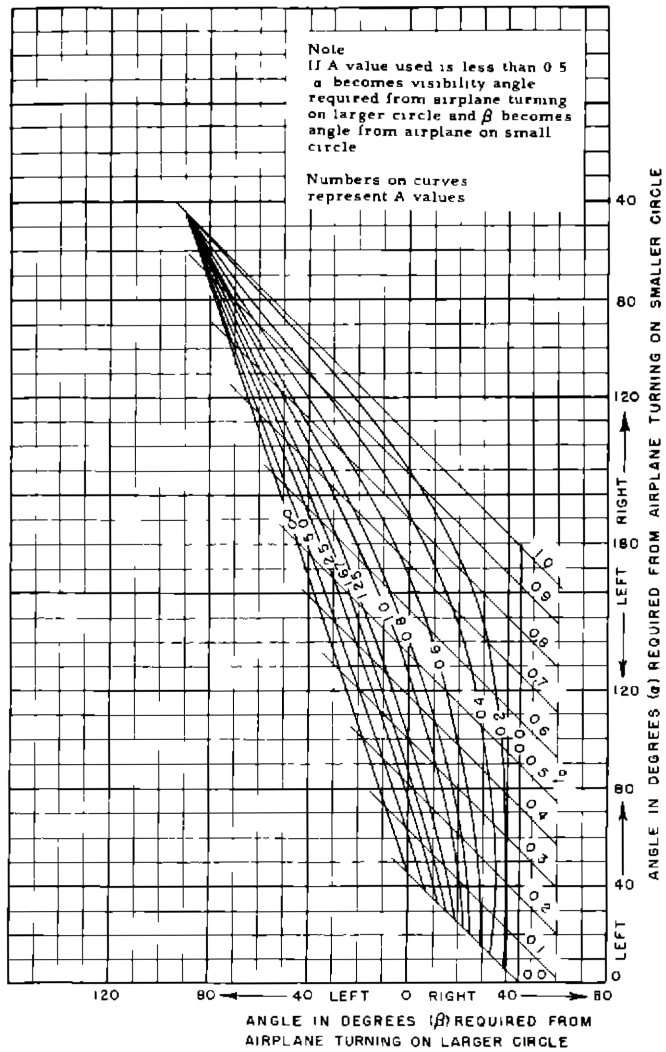
Fig 62 At Collision Point, the Difference in Heading = 135°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

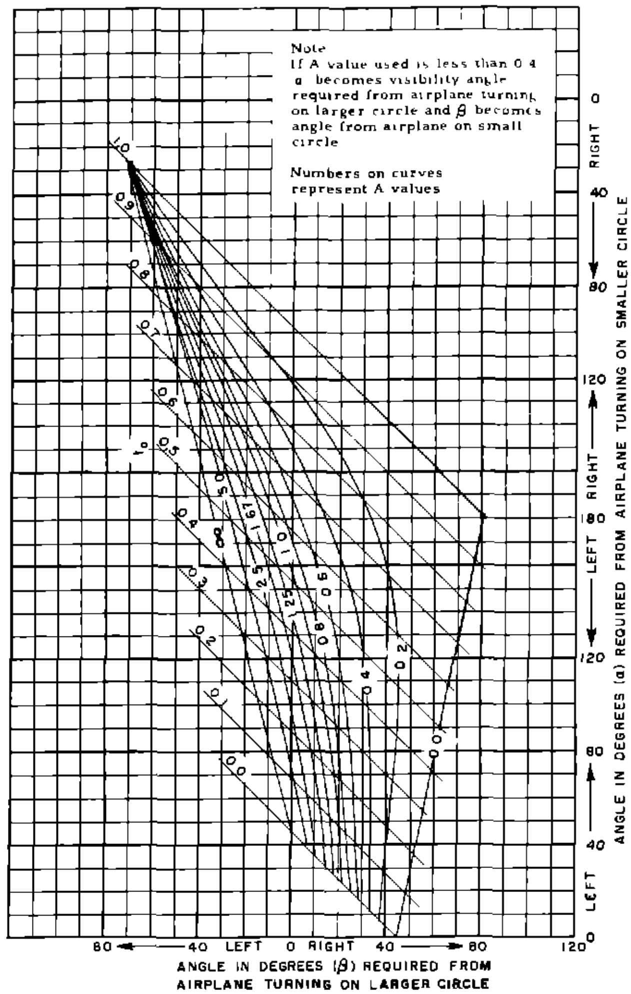


Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	979	1830	2461	2845	2911	2676	2175	1477	908	1121
0 4	1108	2056	2762	3149	3218	2979	2516	1996	1842	2240
0 6	1250	2312	3102	3550	3674	3497	3149	2840	2899	3361
0 8	1398	2588	3483	4019	4230	4150	3936	3796	3984	4482
< 1 0	1560	2880	3892	4552	4800	4880	4800	4820	5000	5600
1 25	1751	3261	4434	5228	5690	5872	5944	6083	6452	7004
1 67	2091	3918	5384	6449	7172	7607	7918	8256	8747	9337
2 5	2789	5284	7372	9023	10292	11227	11974	12652	13349	14005
5 0	4941	9518	13578	17066	20004	22399	24354	25930	27174	28011

Fig 63 At Collision Point, the Difference in Heading = 135°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

	0 1	0 2	0,3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	975	1813	2440	2770	2793	2508	1953	1215	785	1332
0 4	1102	2026	2692	3020	3019	2704	2194	1762	1933	2665
0 6	1241	2273	3012	3389	3433	3191	2855	2744	3172	3996
0 8	1388	2544	3380	3841	3975	3858	3716	3840	4429	5329
1 0	1541	2832	3783	4351	4603	4629	4669	4976	5689	6660
1 25	1738	3209	4320	5043	5459	5674	5921	6421	7268	8325
1 67	2077	3864	5270	6280	6993	7517	8078	8851	9904	11100
2 5	2775	5231	7274	8904	10234	11362	12489	13748	15179	16651
5 0	4927	9483	13552	17138	20332	23201	25898	28502	31016	33300

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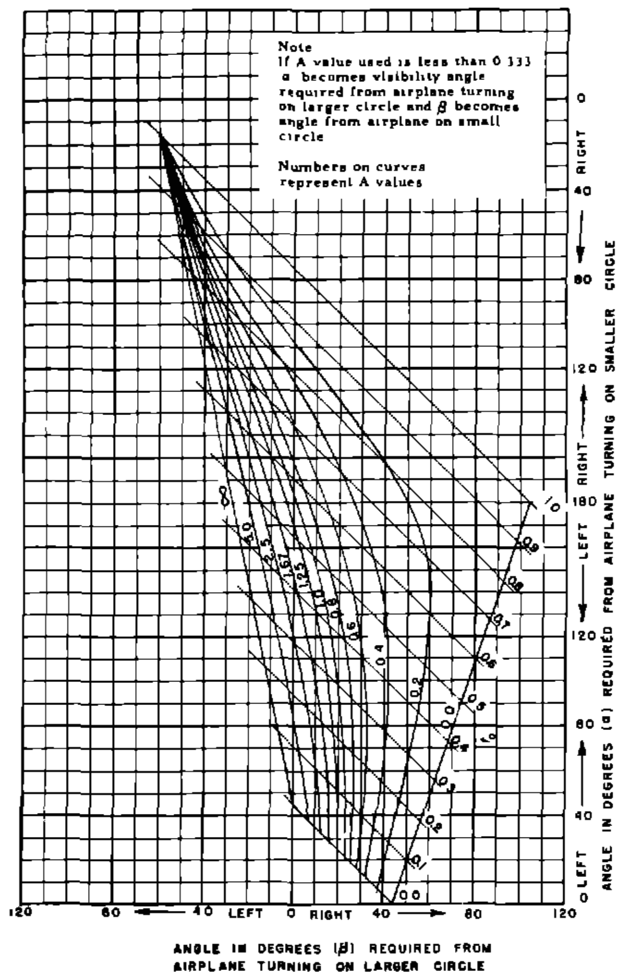
Fig 64 At Collision Point, the Difference in Heading = 135°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	972	1801	2412	2716	2709	2384	1787	1013	713	1456
0 4	1098	2007	2642	2926	2869	2494	1944	1590	2001	2912
0 6	1234	2247	2947	3268	3248	2951	2626	2673	3347	4367
0 8	1381	2513	3304	3704	3778	3627	3541	3859	4700	5822
< 1 0	1532	2797	3701	4208	4406	4422	4551	5074	6057	7277
1 25	1729	3172	4234	4899	5274	5502	5873	6611	7753	9097
1 67	2067	3825	5182	6143	6837	7414	8138	9191	10584	12129
2 5	2764	5191	7192	8795	10146	11388	12753	14374	16246	18194
5 0	4918	9451	13511	17135	20463	23608	26746	29968	33241	36388

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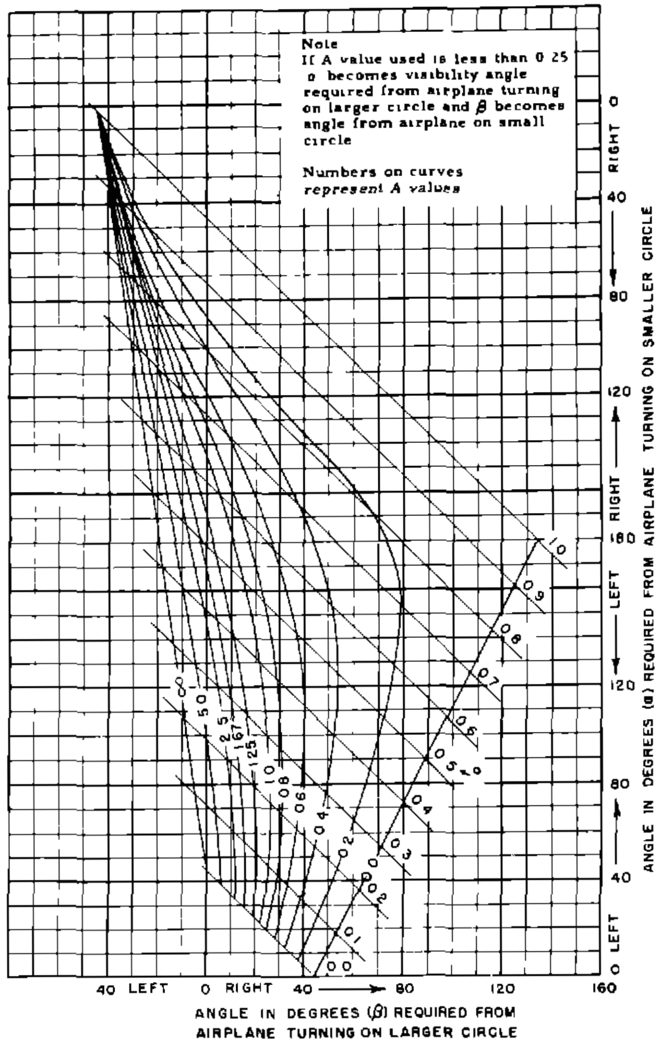
Fig 65 At Collision Point, the Difference in Heading = 135°, R/A = 3.0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

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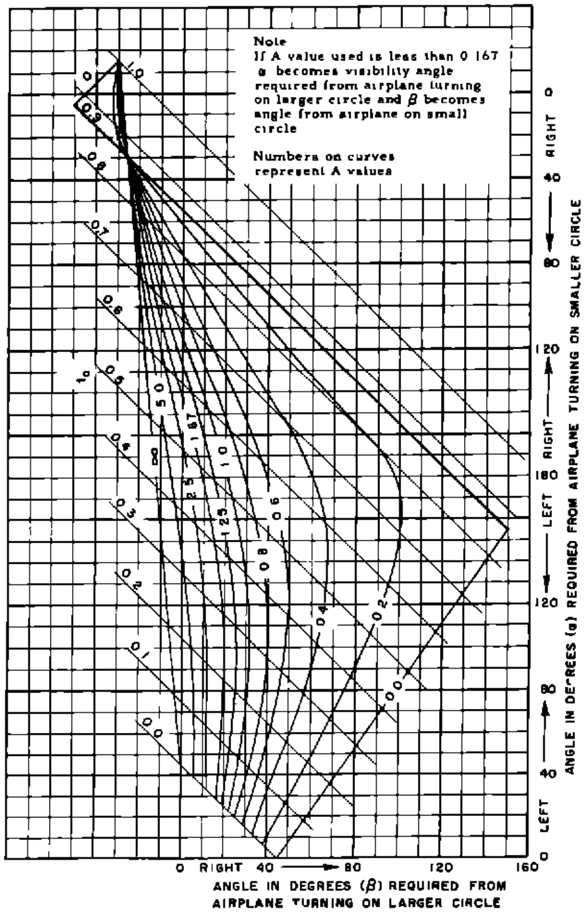
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	969	1787	2375	2647	2597	2225	1572	738	662	1584
0 4	1092	1979	2574	2799	2666	2206	1597	1384	2098	3169
0 6	1226	2211	2857	3102	2991	2619	2318	2599	3550	4754
0 8	1372	2471	3200	3517	3502	3304	3306	3881	5004	6338
α 1 0	1522	2751	3588	4009	4127	4128	4385	5181	6459	7923
1 25	1717	3122	4115	4696	5009	5255	5786	6815	8278	9903
1 67	2054	3771	5058	5946	6603	7240	8168	9548	11309	13204
2 5	2751	5135	7073	8627	9986	11358	12996	15027	17372	19807
5 0	4903	9403	13431	17075	20531	23965	27587	31483	35563	39613

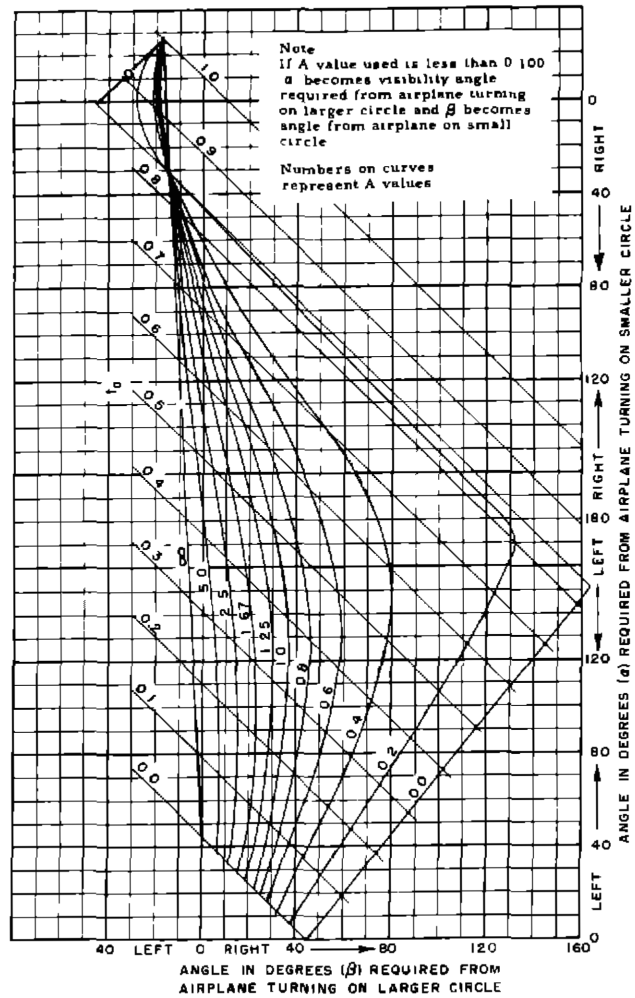
Fig 66 At Collision Point, the Difference in Heading = 135°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	965	1770	2336	2574	2483	2064	1363	458	684	1681
0 4	1086	1950	2503	2664	2450	1894	1217	1229	2210	3361
0 6	1219	2173	2762	2922	2711	2252	2003	2560	3735	5042
0 8	1361	2426	3090	3311	3196	2450	3073	3915	5261	6722
1 0	1512	2701	3465	3789	3819	3808	4216	5277	6788	8404
1 25	1705	3067	3984	4470	4709	4978	5681	6982	8696	10504
1 67	2042	3713	4922	5722	6332	7029	8155	9827	11875	14005
2 5	2737	5074	6938	8425	9779	11259	13145	15520	18234	21008
5 0	4888	9346	13322	16955	20494	24157	28175	32607	37309	42017

Fig 67 At Collision Point, the Difference in Heading = 135°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



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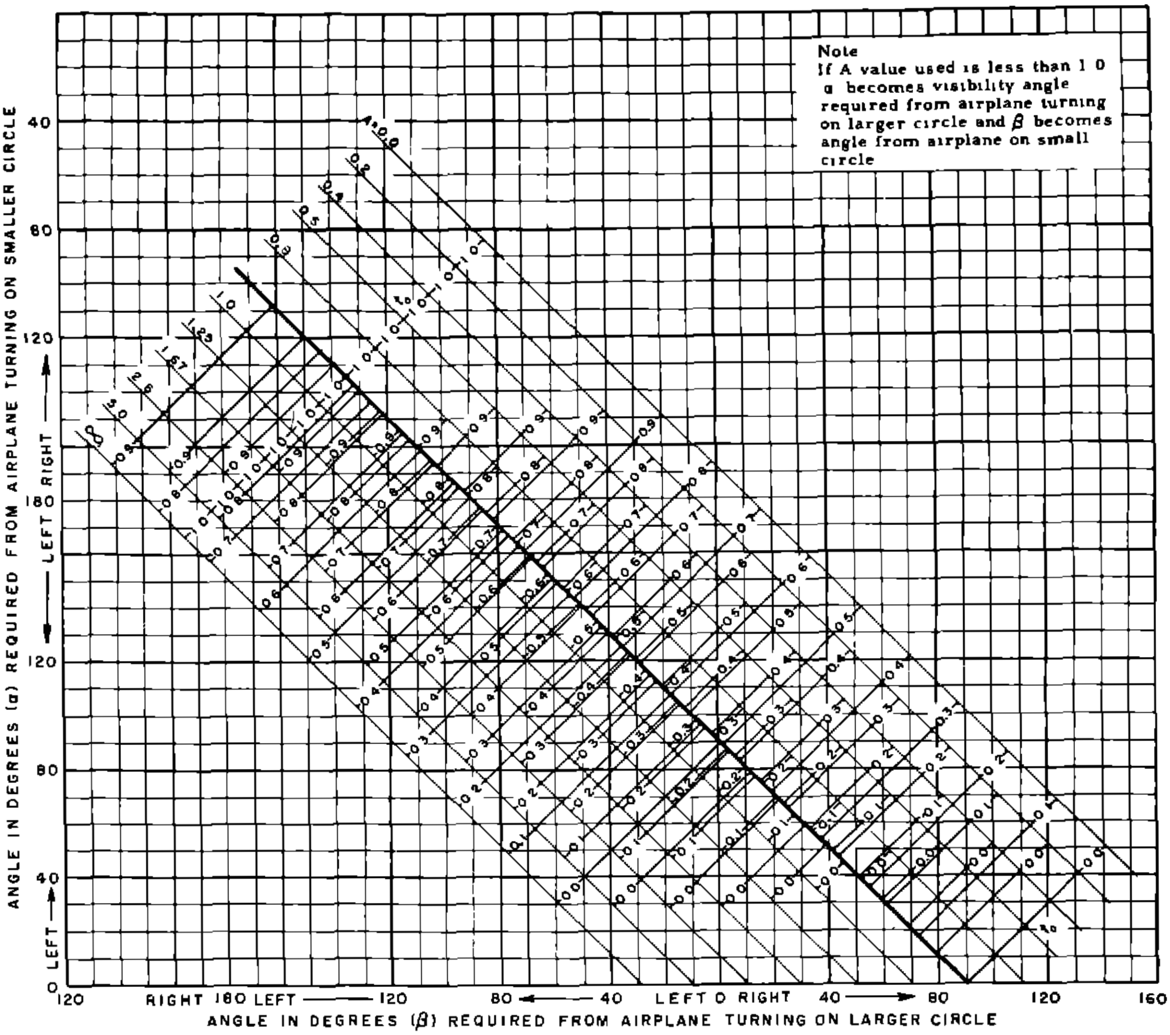
Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	962	1758	2304	2516	2393	1945	1217	266	755	1731
0 4	1080	1927	2444	2551	2269	1632	899	1174	2305	3463
0 6	1212	2140	2681	2769	2471	1938	1768	2563	3866	5194
0 8	1353	2388	2994	3133	2931	2656	2904	3954	5429	6925
◄ 1 0	1503	2659	3360	3599	3552	3543	4090	5348	6991	8656
1 25	1696	3021	3870	4273	4451	4746	5594	7088	8945	10819
1 67	2031	3662	4804	5526	6094	6841	8119	9991	12200	14426
2 5	2725	5020	6818	8240	9581	11137	13195	15795	18712	21640
5 0	4876	9293	13215	16815	20390	24194	28457	33210	38249	43280

Fig 68 At Collision Point, the Difference in Heading = 135°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	883	1679	2320	2720	2857	2717	2311	1657	858	0
0 4	932	1774	2446	2867	3017	2869	2440	1750	908	0
0 6	1009	1921	2645	3102	3267	3107	2643	1896	986	0
0 8	1109	2109	2901	3403	3587	3411	2902	2084	1086	0
◄ 1 0	1225	2328	3202	3757	3961	3768	3205	2305	1203	0
1 25	1386	2636	3621	4251	4484	4265	3628	2612	1366	0
1 67	1683	3200	4395	5162	5444	5178	4405	3178	1665	0
2 5	2331	4434	6089	7154	7542	7174	6102	4413	2315	0
5 0	4414	8395	11539	13563	14283	13584	11555	8378	4402	0

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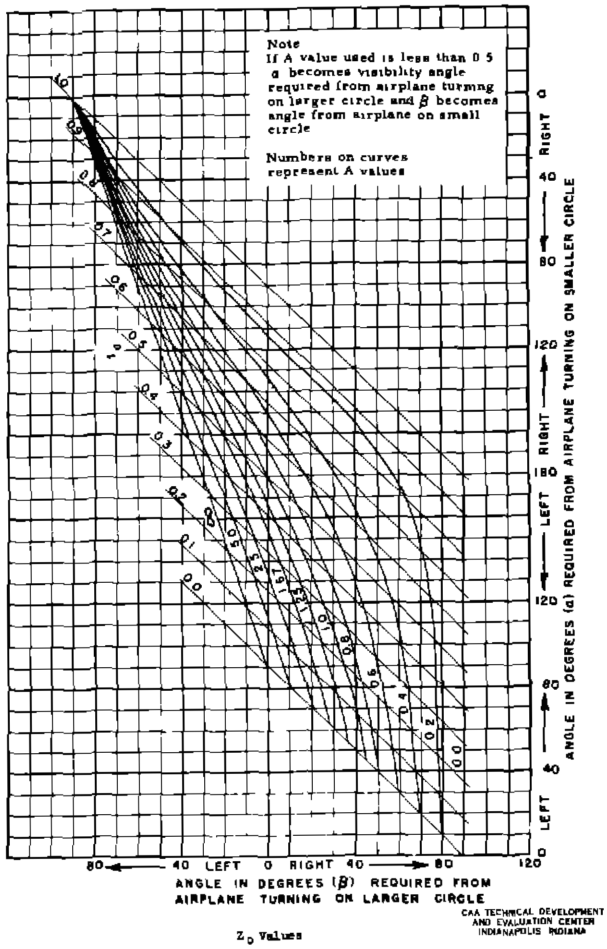
Fig 69 At Collision Point, the Difference in Heading = 90°, R/A = 1 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

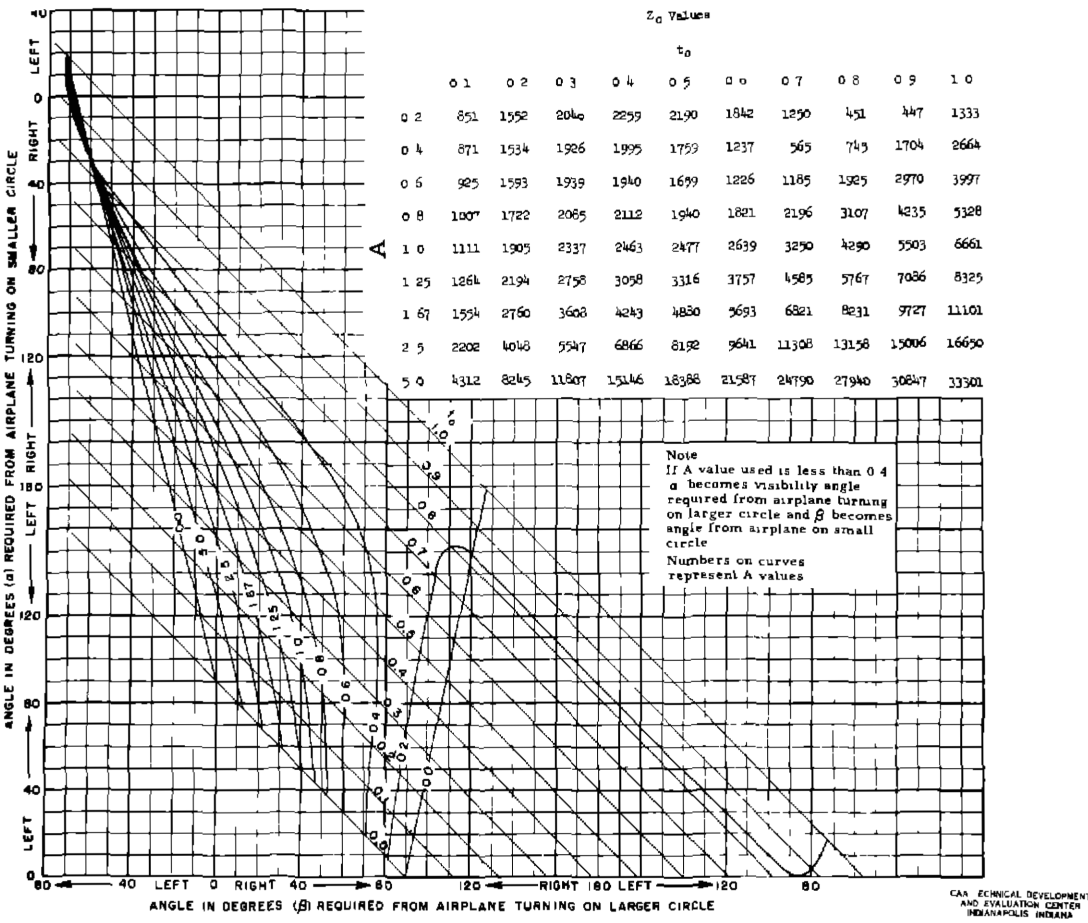


Z_0 Values

t_0

A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	855	1575	2094	2341	2310	2003	1449	689	301	1120
0 4	882	1577	2022	2164	2020	1602	1029	759	1385	2241
0 6	941	1653	2077	2182	2020	1665	1418	1716	2490	3361
0 8	1025	1795	2248	2388	2310	2149	2226	2755	3596	4482
1 0	1052	2000	2520	2760	2800	2848	3152	3800	4688	5600
1 25	1286	2279	2935	3316	3571	3844	4344	5132	6085	7003
1 67	1577	2846	3774	4452	5028	5622	6384	7346	8390	9338
2 5	2227	4128	5679	6982	8167	9308	10511	11780	13001	14006
5 0	4331	8297	11839	15029	17936	20566	22962	25094	26834	28011

Fig 70 At Collision Point, the Difference in Heading = 90°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 0	0 7	0 8	0 9	1 0
0 2	851	1552	2046	2259	2190	1842	1250	451	447	1333
0 4	871	1534	1926	1995	1759	1237	565	749	1704	2664
0 6	925	1593	1939	1940	1699	1226	1185	1925	2970	3997
0 8	1007	1722	2065	2112	1940	1821	2196	3107	4235	5328
1 0	1111	1905	2337	2463	2477	2639	3250	4290	5503	6661
1 25	1264	2194	2758	3058	3316	3757	4585	5767	7086	8325
1 67	1554	2760	3608	4243	4830	5693	6821	8231	9727	11101
2 5	2202	4048	5547	6866	8192	9641	11308	13158	15006	16650
5 0	4312	8245	11807	15146	18388	21587	24790	27940	30847	33301

Fig 71 At Collision Point, the Difference in Heading = 90°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	844	1528	1994	2171	2068	1699	1113	477	758	1533
0 4	856	1483	1814	1800	1467	833	39	1066	2112	3067
0 6	908	1521	1775	1648	1216	726	1191	2319	3516	4598
0 8	987	1635	1886	1772	1500	1544	2344	3597	4927	6132
1 0	1088	1809	2123	2125	2114	2503	3296	[illegible]	6341	7665
1 25	1238	2091	2541	2751	3047	3736	4937	6491	8111	9582
1 67	1527	2656	3405	3994	4725	5814	7339	9176	11062	12775
2 5	2174	3952	5382	6714	8202	9991	12141	14548	16964	19163
5 0	4286	8174	11738	15211	18784	22552	26547	30671	34678	38325

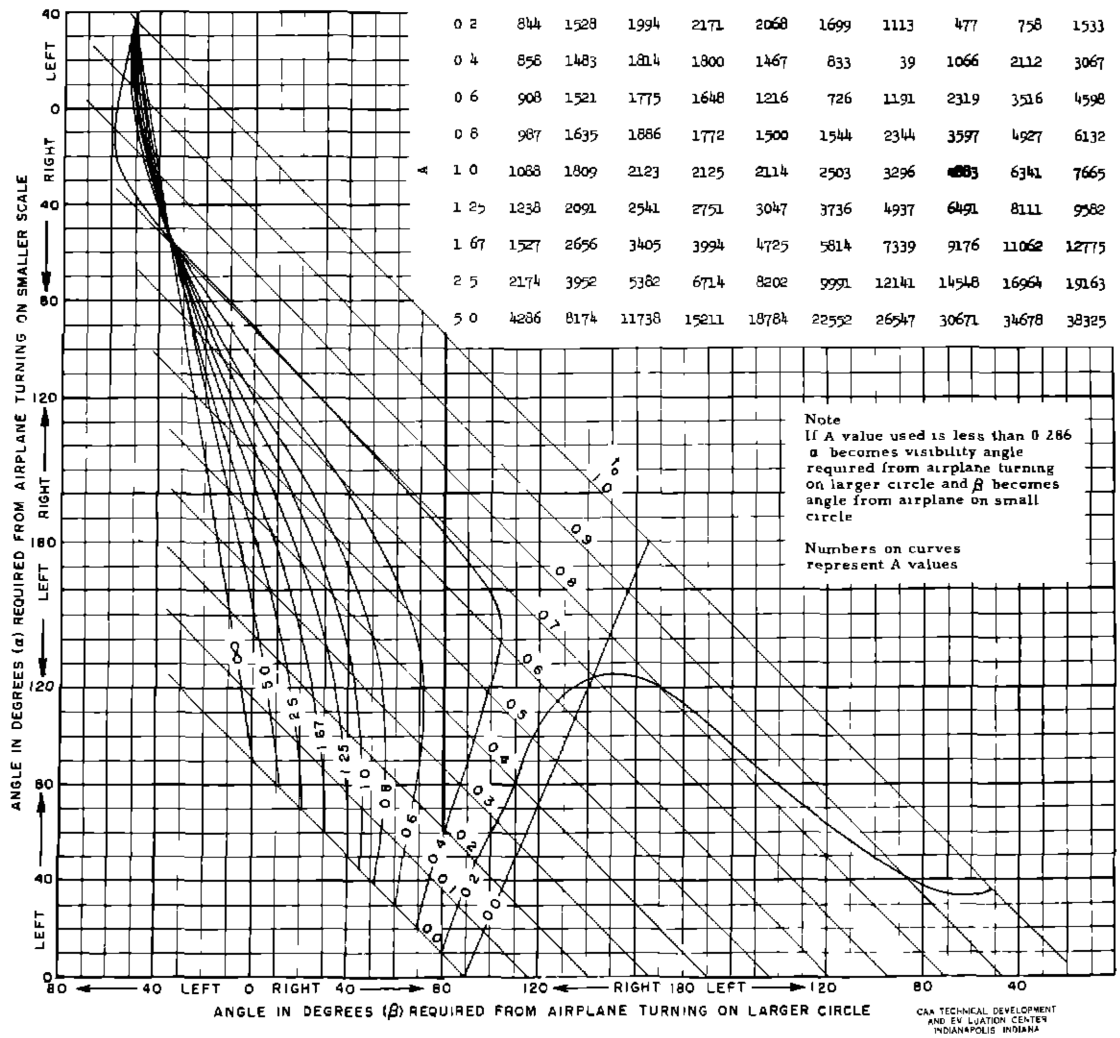


Fig 72 At Collision Point, the Difference in Heading = 90°, R/A = 3 5, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

A	t_0: 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	843	1520	1977	2146	2035	1667	1102	563	865	1585
0 4	856	1467	1779	1741	1383	728	197	1207	2241	3169
0 6	902	1499	1722	1555	1072	593	1265	2464	3679	4754
0 8	980	1607	1821	1662	1363	1497	2430	3762	5127	6338
1 0	1030	1779	2054	2017	2010	2491	3600	5070	6578	7923
1 25	1229	2058	2472	2655	2973	3750	5062	6710	8394	9903
1 67	1518	2622	3341	3916	4683	5862	7500	9448	11422	13205
2 5	2166	3919	5328	6664	8202	10094	12378	14931	17483	19807
5 0	4277	8149	11709	15217	18881	22806	27013	31391	35672	39614

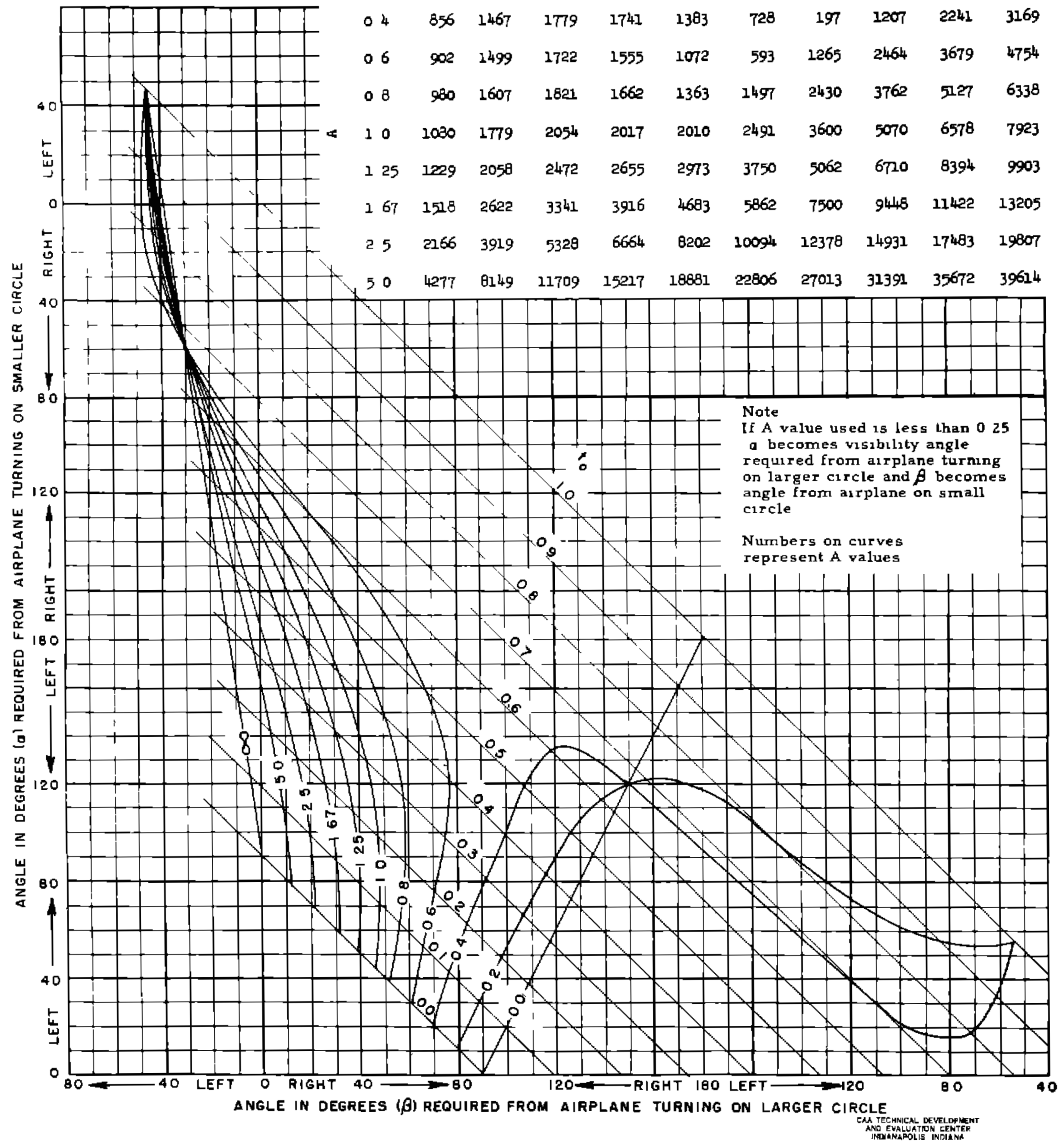


Fig 73 At Collision Point, the Difference in Heading = 90°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	837	1502	1941	2091	1974	1626	1146	827	1112	1680
0 4	846	1432	1699	1609	1208	586	627	1568	2534	3362
0 6	890	1445	1600	1336	731	452	1541	2824	4033	5042
0 8	964	1540	1667	1398	1061	1490	2694	4151	5546	6723
1 0	1063	1704	1887	1759	1797	2530	3879	5498	7065	8403
1 25	1211	1979	2305	2429	2826	3828	5373	7191	8968	10504
1 67	1497	2542	3186	3738	4602	5992	7871	10026	12141	14005
2 5	2145	3844	5199	6544	8201	10320	12882	15711	18494	21008
5 0	4257	8087	11630	15203	19058	23305	27932	32789	37565	42017

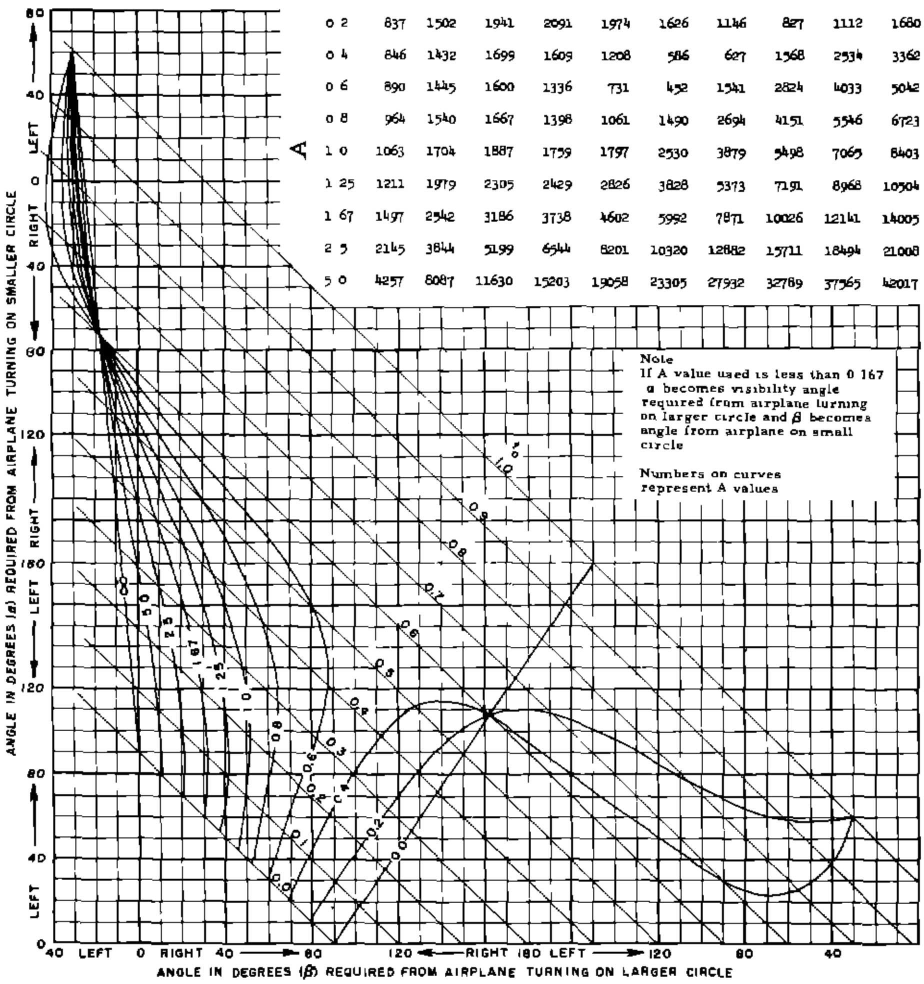


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Fig 74 At Collision Point, the Difference in Heading = 90°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

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z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	834	1488	1914	2055	1940	1628	1243	1058	1301	1732
0 4	839	1402	1636	1513	1105	638	970	1865	2749	3462
0 6	880	1400	1500	1161	460	607	1824	3117	4279	5194
0 8	951	1486	1542	1180	859	1591	2949	4454	5827	6924
< 1 0	1049	1643	1750	1556	1673	2627	4130	5817	7380	8656
1 25	1195	1915	2168	2256	2746	3933	5630	7537	9327	10819
1 67	1481	2477	3059	3602	4557	6114	8154	10419	12578	14426
2 5	2127	3779	5090	6447	8199	10484	13228	16204	19083	21641
5 0	4241	8034	11554	15167	19148	23603	28487	33602	38613	43279

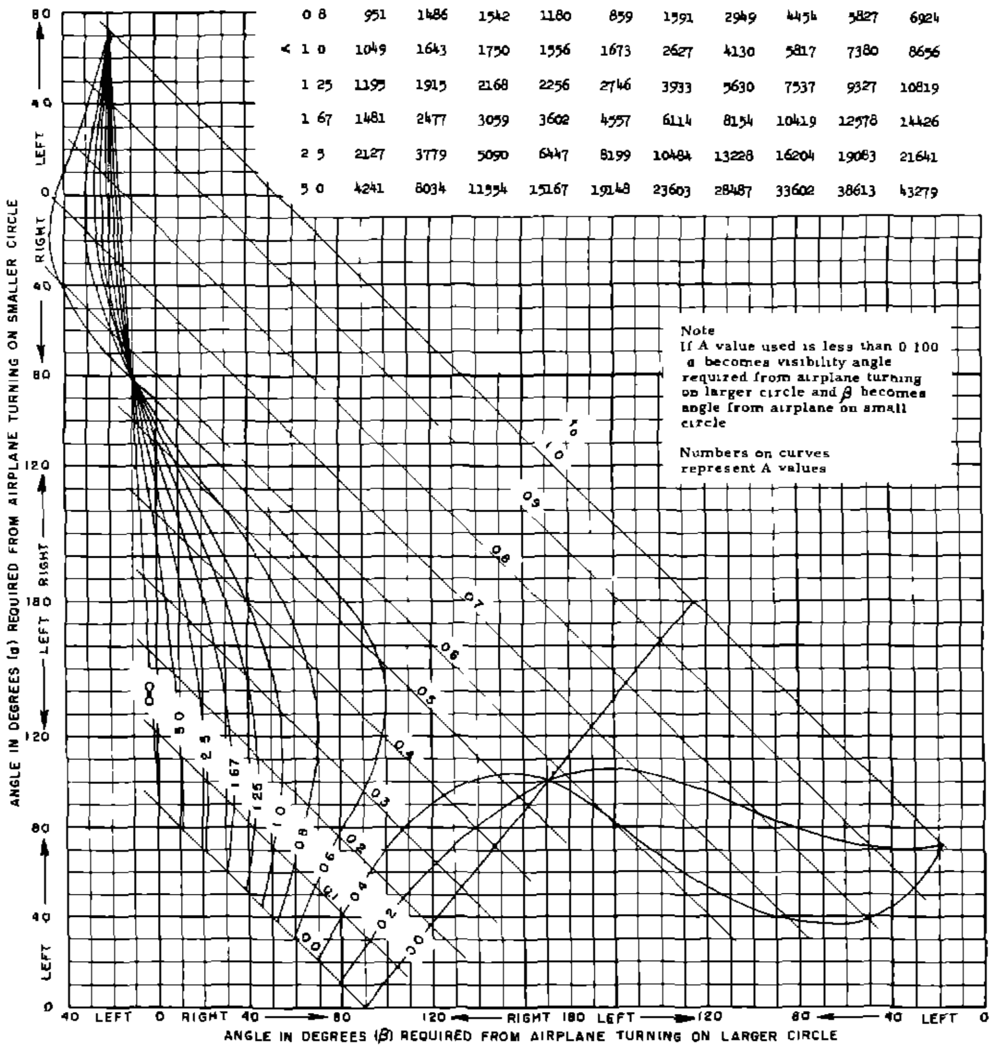

Fig 75 At Collision Point, the Difference in Heading = 90°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

	t_0									
A	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	754	1432	1983	2321	2437	2318	1972	1410	730	0
0 4	668	1270	1753	2052	2159	2054	1747	1246	643	0
0 6	620	1178	1620	1898	2004	1905	1620	1153	596	0
0 8	617	1174	1609	1885	1998	1900	1617	1152	597	0
1 0	663	1260	1722	2020	2144	2039	1735	1239	648	0
1 25	771	1467	2002	2353	2497	2376	2021	1451	762	0
1 67	1032	1963	2679	3152	3339	3176	2702	1952	1029	0
2 5	1669	3173	4344	5111	5399	5134	4367	3168	1671	0
5 0	3765	7164	9835	11567	12187	11590	9860	7163	3774	0

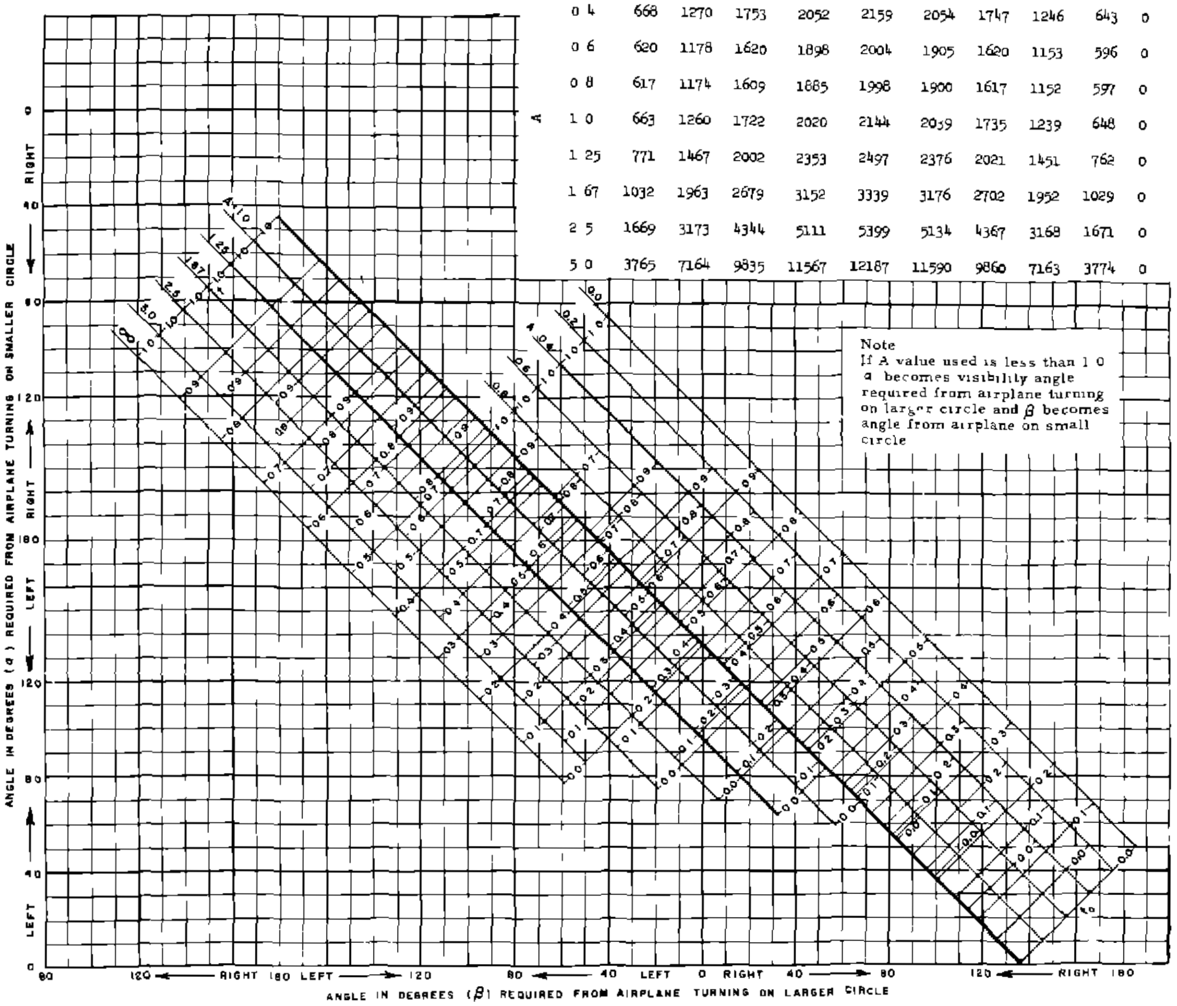

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Fig 76 At Collision Point, the Difference in Heading = 45°, R/A = 1 0, and the Airplane Turnir on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

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Z_0 Values

	t_0 0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	731	1348	1801	2023	2008	1775	1352	840	659	1121
0 4	618	1077	1346	1383	1217	919	719	1018	1616	2240
0 6	538	861	944	775	424	426	1094	1908	2690	3361
0 8	509	752	700	395	368	1079	1967	2918	3783	4482
1 0	520	792	796	780	1164	1964	2920	3920	4868	5600
1 25	644	1023	1216	1527	2151	3062	4144	5271	6259	7004
1 67	915	1604	2175	2873	3801	4940	6204	7475	8560	9337
2 5	1576	2957	4239	5604	7102	8710	10348	11902	13166	14005
5 0	3716	7228	10564	13828	17006	20034	22814	25209	26993	28011

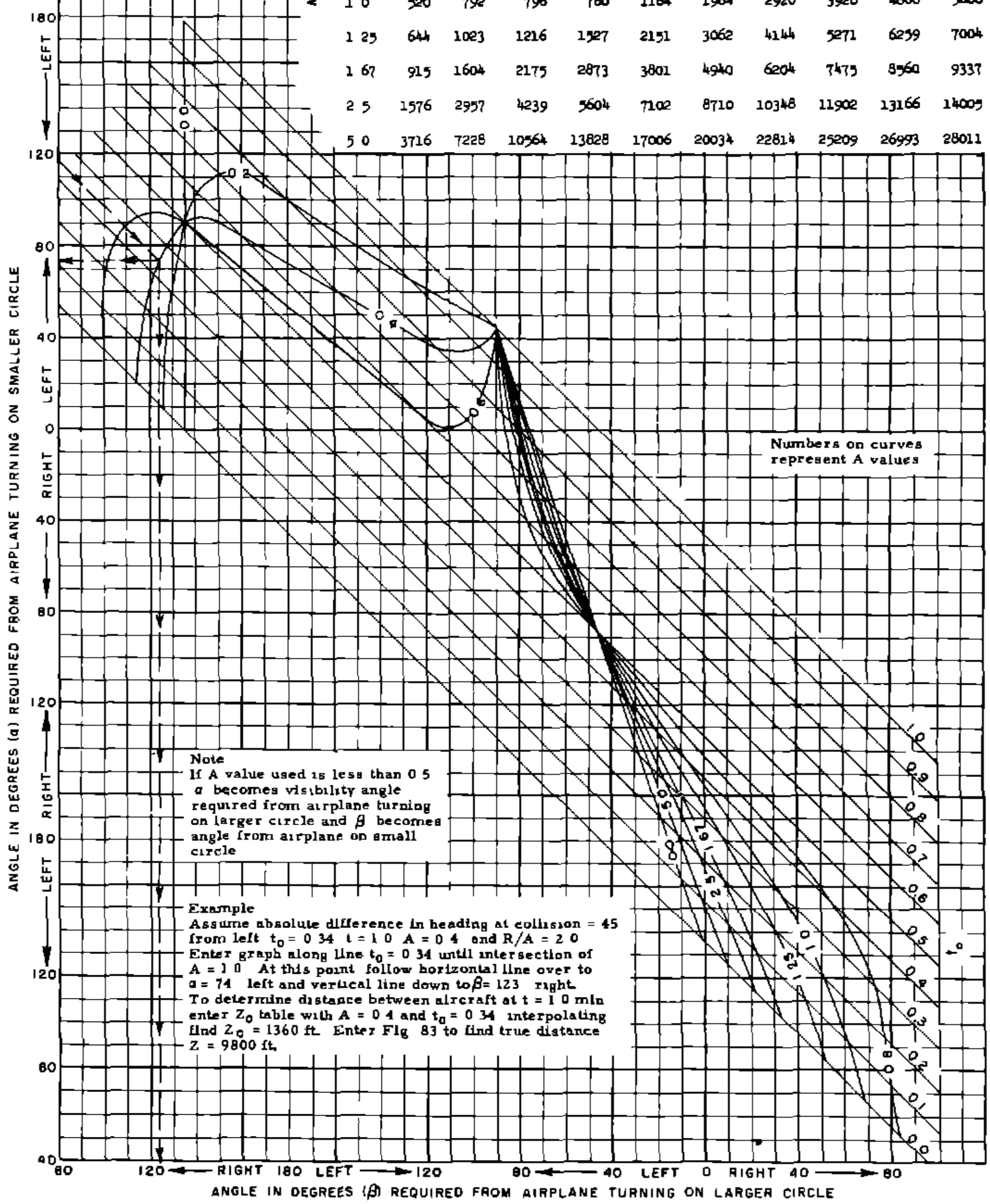
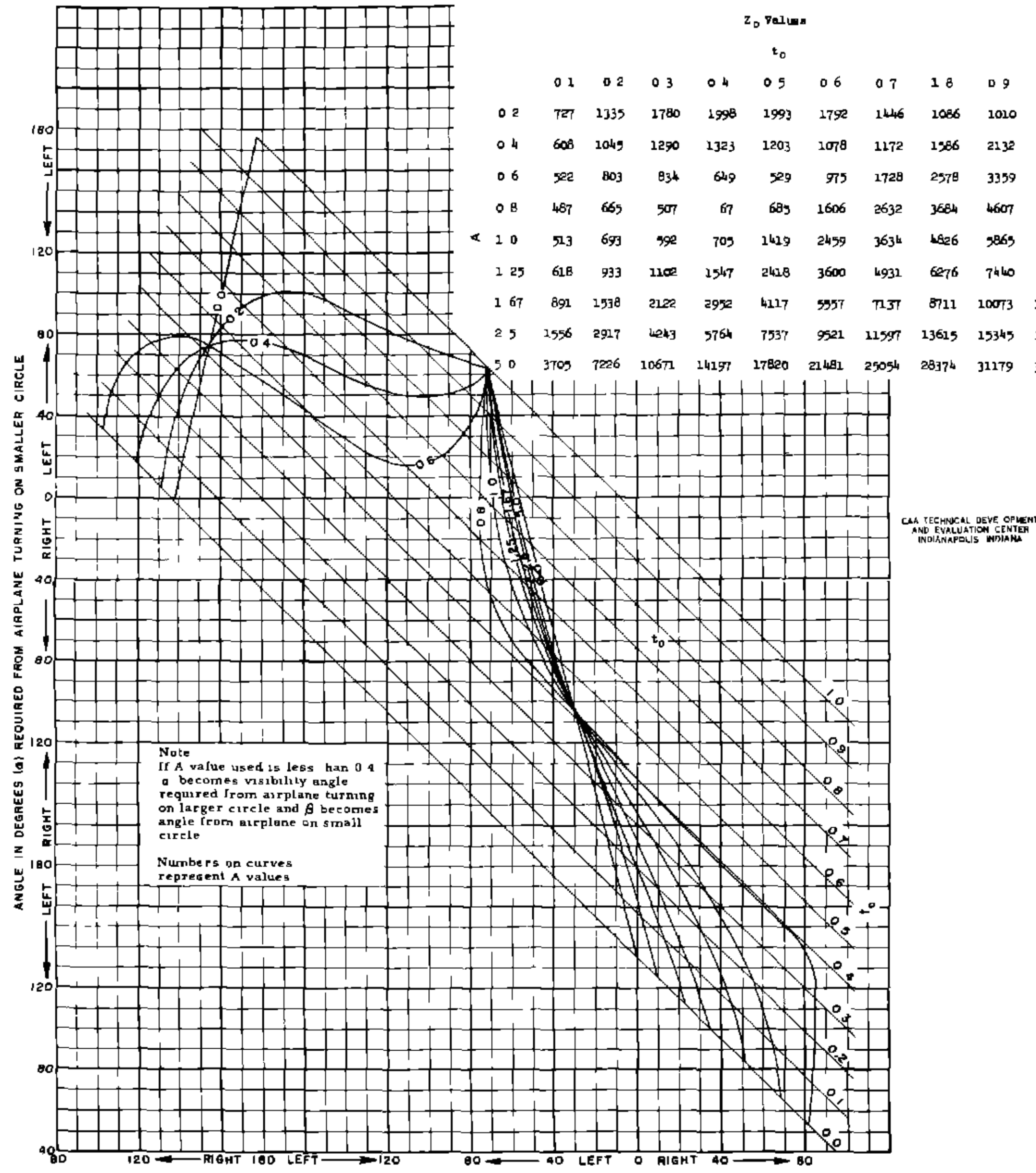


Fig 77 At Collision Point, the Difference in Heading = 45°, R/A = 2 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle



Z_D Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	1 8	0 9	1 0
0 2	727	1335	1780	1998	1993	1792	1446	1086	1010	1332
0 4	608	1045	1290	1323	1203	1078	1172	1586	2132	2665
0 6	522	803	834	649	529	975	1728	2578	3359	3996
0 8	487	665	507	67	685	1606	2632	3684	4607	5329
1 0	513	693	592	705	1419	2459	3634	4826	5865	6660
1 25	618	933	1102	1547	2418	3600	4931	6276	7440	8325
1 67	891	1538	2122	2952	4117	5557	7137	8711	10073	11100
2 5	1556	2917	4243	5764	7537	9521	11597	13615	15345	16651
5 0	3705	7226	10671	14197	17820	21481	25054	28374	31179	33300

Fig 78 At Collision Point, the Difference in Heading = 45°, R/A = 2 5, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	725	1326	1768	1990	2001	1839	1562	1295	1240	1456
0 4	602	1025	1263	1310	1256	1274	1507	1956	2462	2912
0 6	512	767	775	637	748	1346	2153	3016	3780	4367
0 8	472	607	381	177	977	1988	3086	4182	5119	5822
1 0	495	626	479	769	1663	2837	4116	5384	6466	7277
1 25	600	876	1046	1615	2648	3988	5458	6913	8157	9097
1 67	875	1496	2100	3034	4358	5983	7743	9482	10981	12129
2 5	1544	2892	4249	5881	7833	10048	12378	14656	16637	18194
5 0	3696	7223	10734	14425	18317	22357	26392	30238	33625	36388

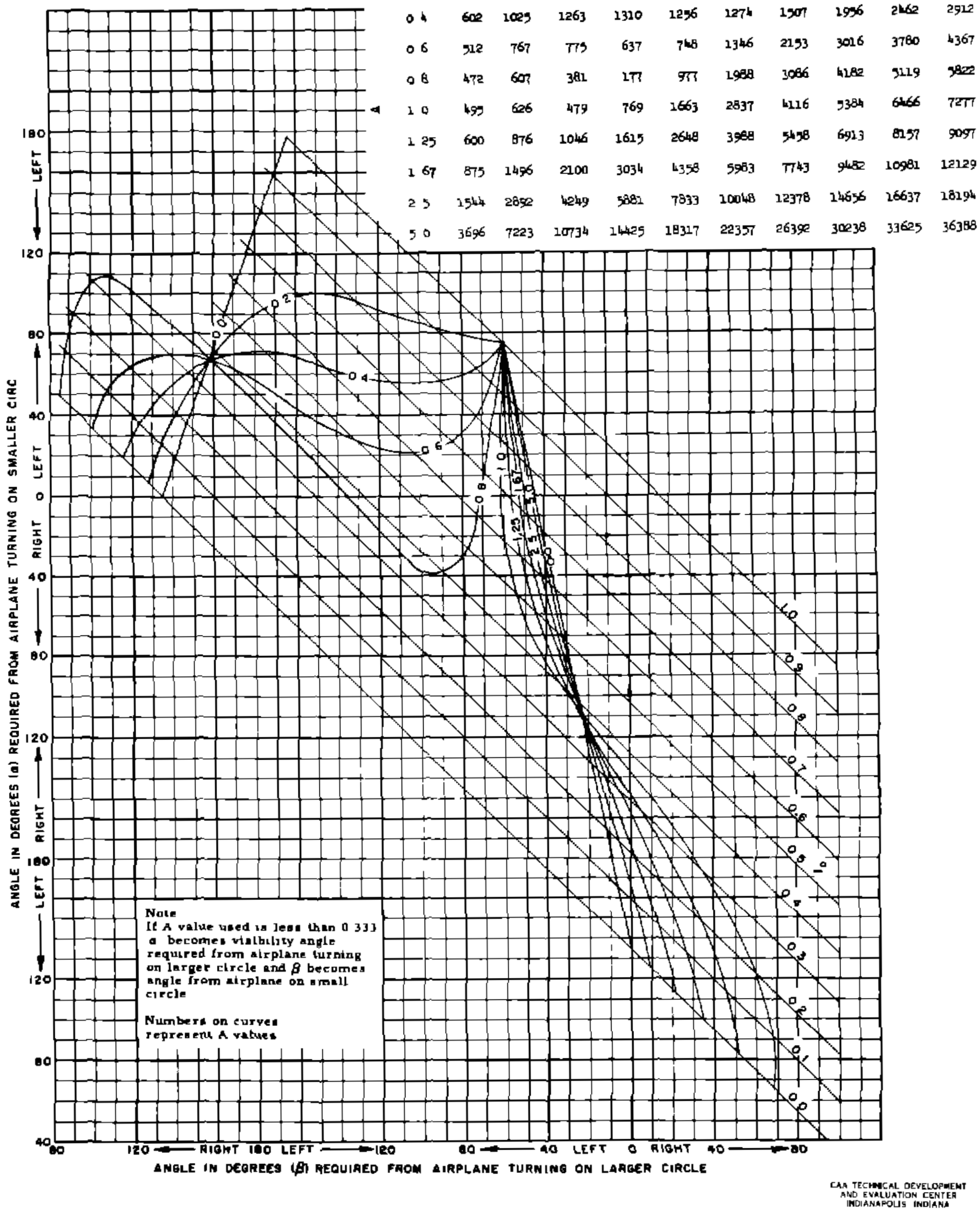
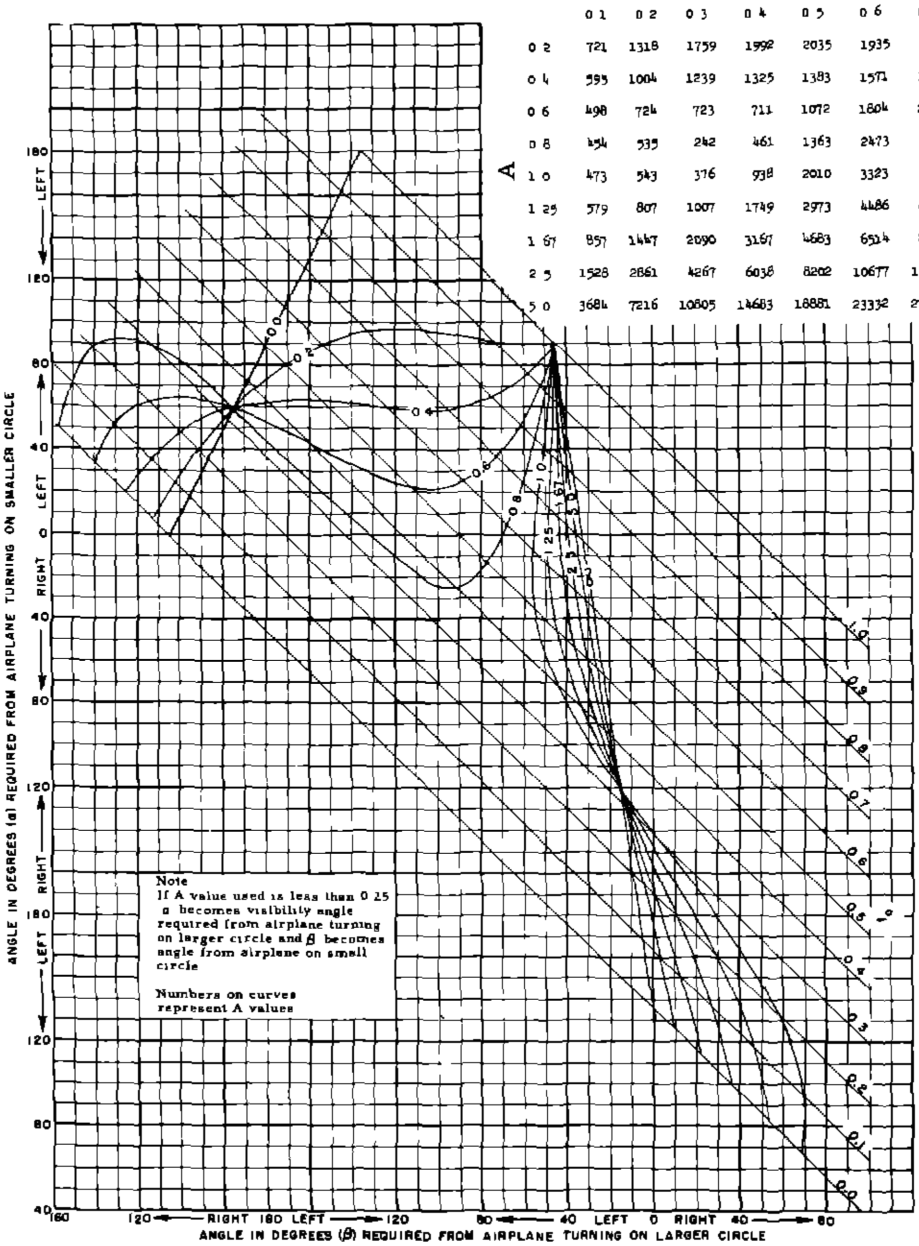


Fig 79 At Collision Point, the Difference in Heading = 45°, R/A = 3 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

A \ t_0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	721	1318	1759	1992	2035	1935	1749	1572	1508	1584
0 4	595	1004	1239	1325	1383	1571	1930	2400	2843	3169
0 6	498	724	723	711	1072	1804	2672	3539	4257	4754
0 8	454	535	242	461	1363	2473	3646	4770	5692	6339
1 0	473	543	376	938	2010	3323	4710	6038	7135	7923
1 25	579	807	1007	1749	2973	4486	6095	7646	8945	9903
1 67	857	1447	2090	3167	4683	6514	8462	10353	11967	13204
2 5	1528	2861	4267	6038	8202	10677	13276	15807	18021	19807
5 0	3684	7216	10805	14683	18881	23332	27854	32237	36204	39613



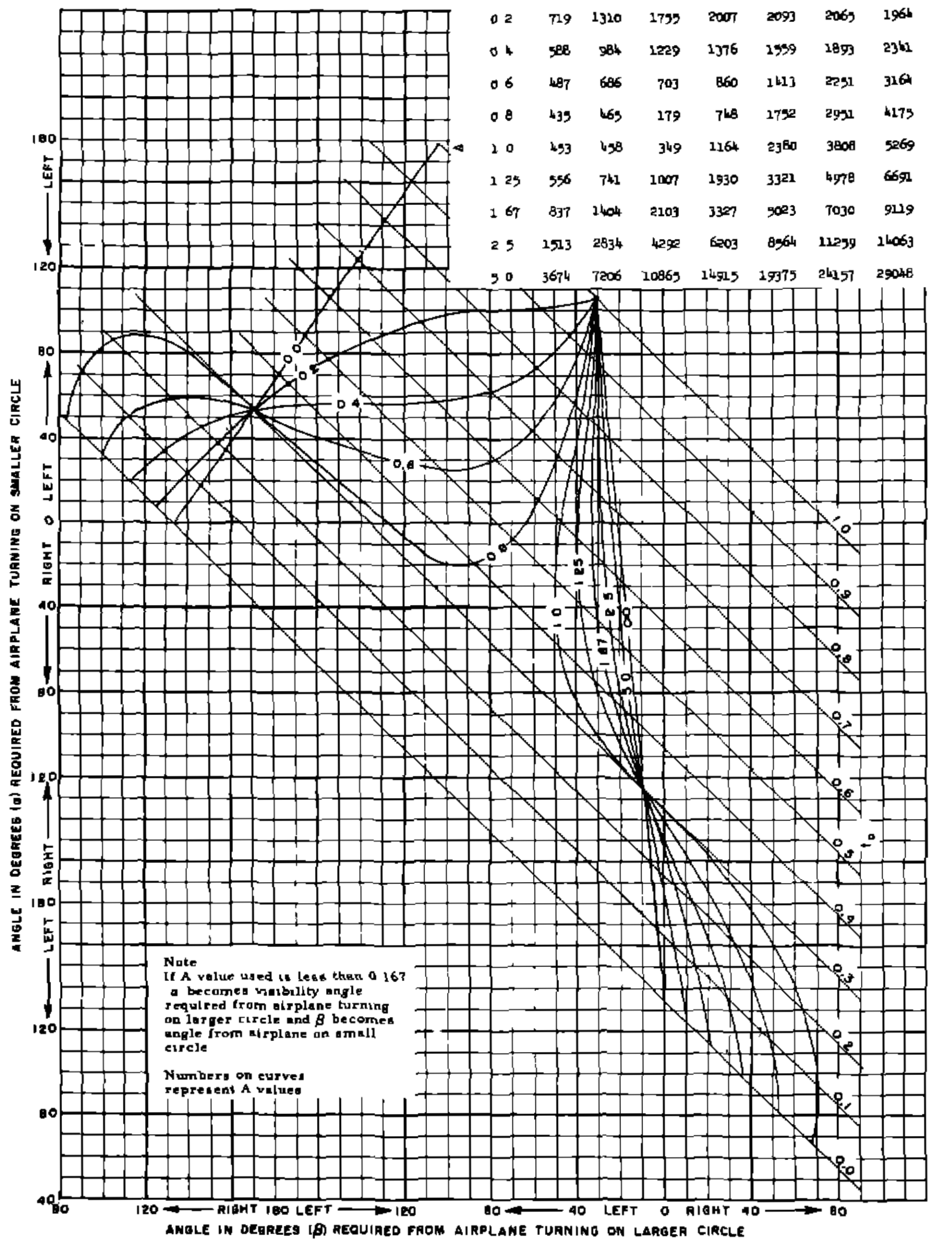
CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

Fig 80 At Collision Point, the Difference in Heading = 45°, R/A = 4 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

t_0

	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	719	1310	1755	2007	2093	2065	1964	1844	1749	1681
0 4	588	984	1229	1376	1559	1893	2341	2809	3174	3361
0 6	487	686	703	860	1413	2251	3164	4016	4662	5042
0 8	435	465	179	748	1752	2951	4175	5301	6169	6722
1 0	453	458	349	1164	2380	3808	5269	6619	7683	8404
1 25	556	741	1007	1930	3321	4978	6691	8288	9582	10505
1 67	837	1404	2103	3327	5023	7030	9119	11098	12752	14005
2 5	1513	2834	4292	6203	8564	11259	14063	16756	19101	21008
5 0	3674	7206	10865	14915	19375	24157	29048	33809	38167	42017

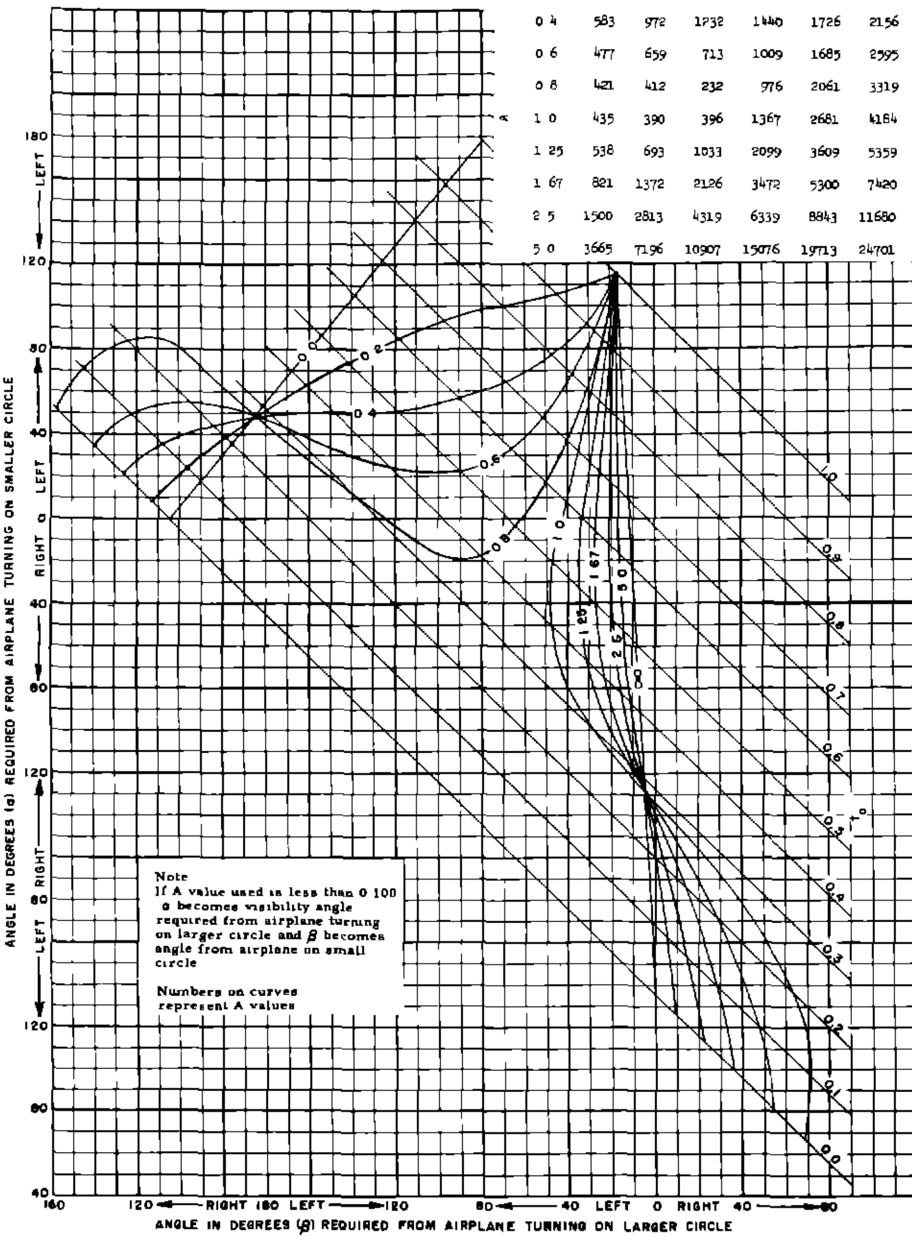


CAA TECHNICAL DEVELOPMENT AND EV LUATION CENTER INDIANAPOLIS INDIANA

Fig 81 At Collision Point, the Difference in Heading = 45°, R/A = 6 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

Z_0 Values

	t_0									
	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	1 0
0 2	717	1306	1756	2028	2155	2184	2143	2050	1915	1731
0 4	583	972	1732	1440	1726	2156	2652	3104	3393	3463
0 6	477	659	713	1009	1685	2595	3530	4354	4924	5194
0 8	421	412	232	976	2061	3319	4569	5671	6470	6925
α 1 0	435	390	396	1367	2681	4184	5682	7017	8023	8656
1 25	538	693	1033	2099	3609	5359	7123	8720	9968	10819
1 67	821	1372	2126	3472	5300	7420	9585	11585	13216	14426
2 5	1500	2813	4319	6339	8843	11680	14595	17353	19719	21640
5 0	3665	7196	10907	15076	19713	24701	29792	34729	39248	43280



CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS INDIANA

Fig 82 At Collision Point, the Difference in Heading = 45°, R/A = 10 0, and the Airplane Turning on the Larger Circle is on the Left of the Airplane Turning on the Smaller Circle

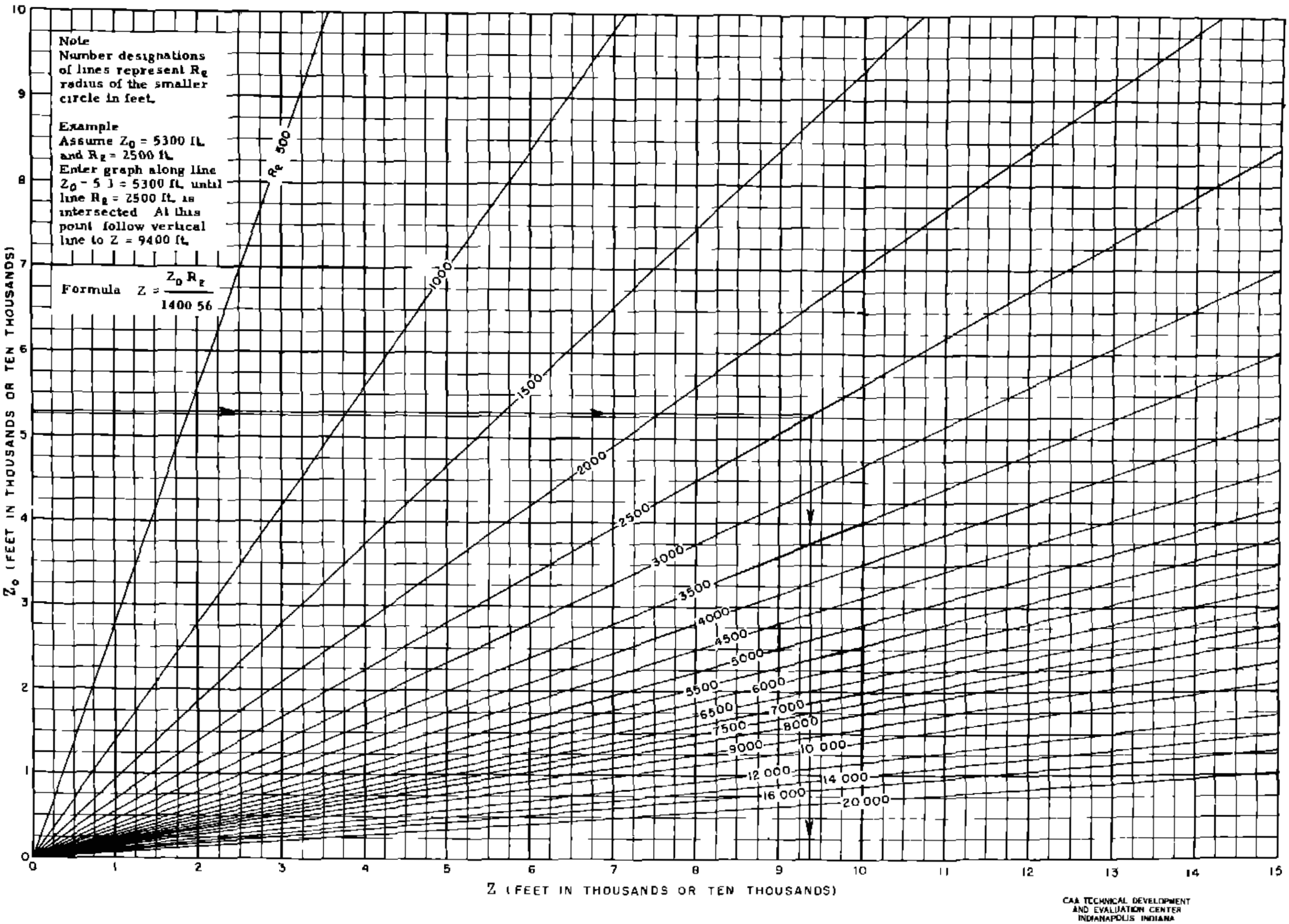


Fig 83 Determination of Distance of Separation for Two Airplanes Turning

CONCLUSIONS

1 It is apparent from studying the visual-angle curves that, to prevent all mid-air collisions, it is necessary for a pilot to be able to see or detect the approach of aircraft from any direction Since this cannot be accomplished by adding windshield area alone, it must be done by other means

2 Since the visual angle does not change during Collision Conditions A and B, there is no apparent motion of the other aircraft to be observed by either pilot This is true only if both aircraft are flying on straight courses and at constant speeds The closing speeds also remain constant

3 This study has pointed out that a severe collision hazard exists where aircraft are flying in the same general direction and at approximately the same speeds It must also be pointed out, however, that during this critical condition the closing rate is small and, if an auxiliary means of viewing this area were available, the pilots would have sufficient time to execute evasive maneuvers in time to avoid collision

4 In the turning collision conditions, both the visual angles and the closing rate are constantly varying Under these circumstances, there is apparent relative motion between the aircraft which will tend to increase the noticeability in the peripherial field of vision When the airplane is turning, however, it is possible for the cockpit structure to completely block out the horizon and, consequently, to block out another aircraft at the same altitude even though the area was cleared as carefully as possible prior to the turn It is noteworthy that maximum collision protection can be obtained in present-day airplanes only if both pilots clear the area to their rear prior to a turn in either direction

5 In the event of a mid-air collision, the scratch angle or the angle of physical marks on both damaged aircraft, when measured from the longitudinal axis, are the same as the visual-angle requirements of each aircraft to see the other immediately prior to the collision In making this statement, it is assumed that neither aircraft is deflected or bumped from its original heading during the collision impact

ACKNOWLEDGEMENTS

Acknowledgement is made to the United States Naval Ordnance Plant, Numerical Analysis Branch, Indianapolis, Indiana, who made the visual-angle curves for Collision Condition C possible by computing the values on their digital electronic computers Also thanks are due the airport managers and the CAA air traffic controllers at Municipal Airport, Birmingham, Alabama, Weir Cook Municipal Airport, Indianapolis, Indiana, and the Midway Airport, Chicago, Illinois, who co-operated wholeheartedly during flight-path measurements recorded at those airports

APPENDIX I

DERIVATION OF FORMULAS FOR COLLISION CONDITION A

For this condition, two airplanes are assumed to be on a collision course, flying on straight courses in the same horizontal plane, and approaching each other from any direction at any relative speed Figure 84 shows the physical significance of the horizontal visual angles and distances involved

Using the law of sines

$$\frac{V_s}{\sin \theta} = \frac{V_c}{\sin \psi} \tag{31}$$

Solving for V_c from the law of cosines

$$V_c = \sqrt{V_s^2 + V_f^2 - 2\, V_s\, V_f \cos \psi} \tag{32}$$

Substituting Equation (32) in Equation (31)

$$\sin \theta = \frac{V_s \sin \psi}{\sqrt{V_s^2 + V_f^2 - 2\, V_s\, V_f \cos \psi}} \tag{33}$$

Since $A = \frac{V_s}{V_f}$, Equation (33) may be written

$$\theta = \arc\sin \frac{A \sin \psi}{\sqrt{A^2 + 1 - 2A \cos \psi}} \tag{2}$$

From the geometry of Fig 84,

$$\phi = 180° - (\psi + \theta)$$

Solving for the distance between the airplanes at time t minutes before collision, we have, using the law of sines,

$$Z = \frac{V_s\, t \sin \psi}{60 \sin \theta} \tag{3}$$

where 60 is the factor for changing mph to mpm

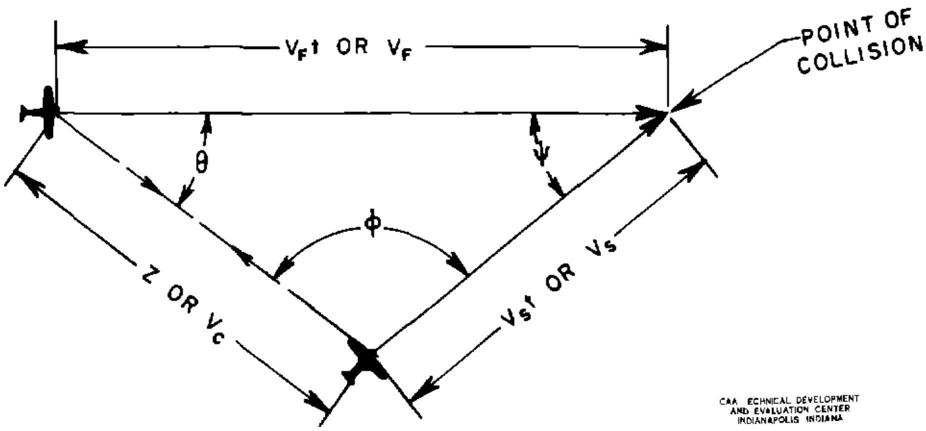


Fig 84 Vector Diagram for Derivation of Formulas for Level-Flight Collision Condition

DERIVATION OF FORMULAS FOR COLLISION CONDITION B

For this condition, two airplanes are assumed to be on a collision course with one airplane climbing and one airplane descending, with both airplanes climbing, or with both airplanes descending, also, one airplane can be flying at level cruise and the other one either climbing or descending Figure 85 shows the physical significance of the visual angles and of the distances involved in this condition

In order to use the visual-angle chart designed for Condition A in determining the horizontal visual angles required from the climbing and descending airplanes, V_{CL_H}, the vertical projection of the climbing velocity onto the horizontal plane passing through the collision point, and V_{D_H}, the vertical projection of the descending velocity onto the horizontal plane passing through the collision point, should be determined, however, for simplicity the values of V_{CL} and V_D are used In using V_{CL} and V_D instead of V_{CL_H} and V_{D_H}, very little error is introduced into the visual angles obtained since the angles at which airplanes climb and descend are relatively small, and small climb and descent angles make the difference very small between V_{CL} and V_{CL_H} or V_D and V_{D_H} Consequently, V_{CL} and V_D, either of which can be entered as slower or faster, and ψ, which is the absolute difference in heading, can be used in Fig 2 for determining the horizontal visual angles with a relative degree of accuracy

Referring to Fig 85 and using the law of sines

$$V = \frac{V_s \sin \psi}{\sin \theta} \qquad (4)$$

V_s, the velocity of the slower airplane, is V_D in the figure

Solving for ρ, the vertical angle measured from the horizon and required from either airplane,

$$\rho = \arc \tan \frac{\Delta_1 \pm \Delta_2}{88V} \qquad (5)$$

If both airplanes are descending or climbing, then Δ_1 and Δ_2 are added, and if one is descending and one is climbing, then the difference between Δ_1 and Δ_2 is used

Solving for Z, the distance between the airplanes at time t measured along the line of sight,

$$Z = \frac{Vt}{60 \cos \rho} \qquad (6)$$

The factor 60 is used to change mph to mpm

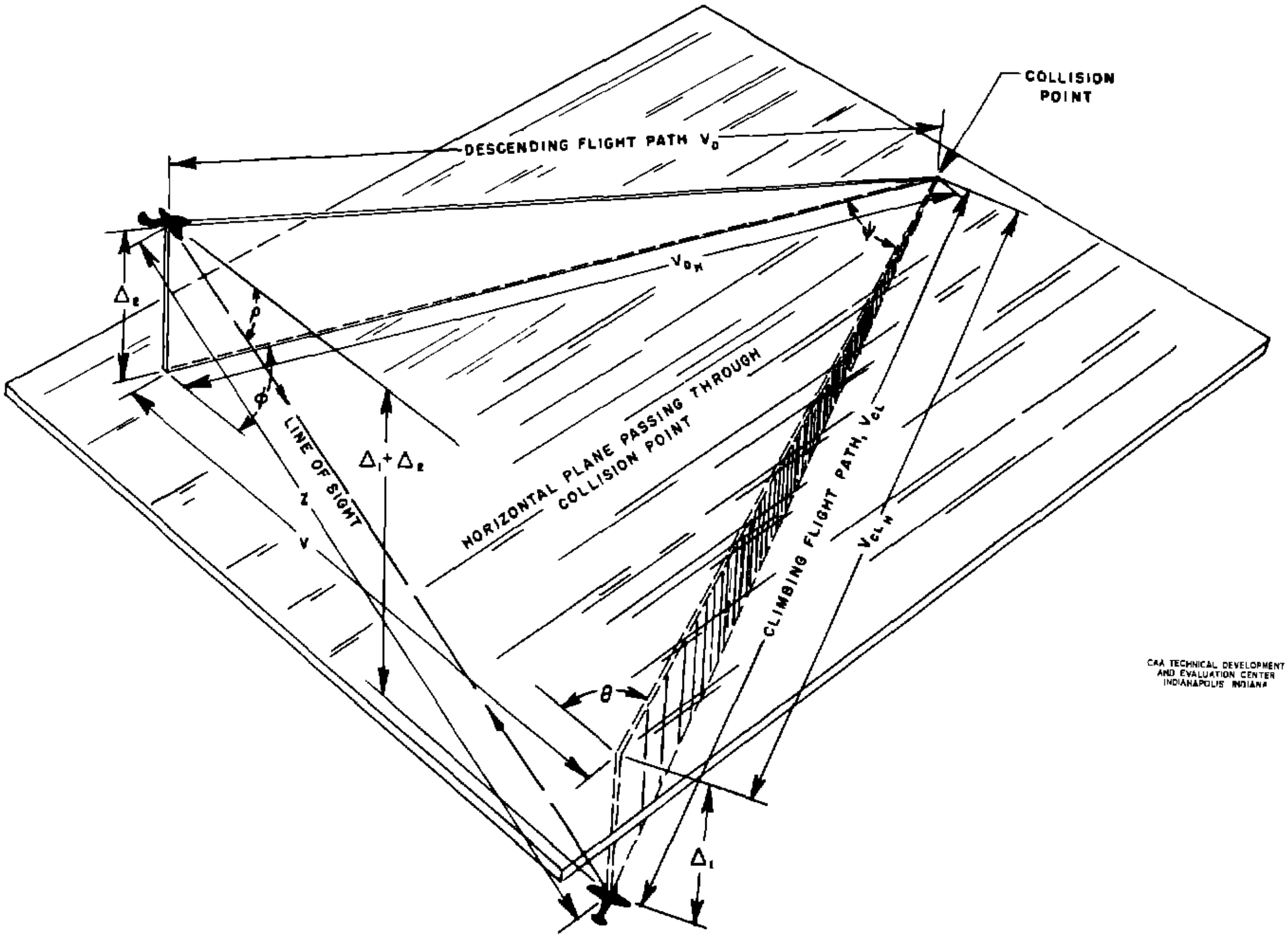


Fig. 85 Vector Diagram for Derivation of Formulas for Climb-and-Descent Conditions

DERIVATION OF FORMULAS FOR COLLISION CONDITION C

For this condition, two airplanes are assumed to be on a collision course, one flying straight and level (cruising) and the other making a left turn Figure 86 shows the physical significance of the horizontal visual angles and of the distances involved in this condition Horizontal visual angles are measured from straight ahead of the pilot at the time of investigation

Locating the center of the circle of the turning airplane with respect to the cruising airplane (the origin of the X and Y axis)

$$a = R_T \sin \psi \tag{34}$$

Distance traveled, from time t to collision,

$$D = V_c t$$

$$E = R_T \cos \psi$$

since

$$b = D + E$$

Then

$$b = V_c t + R_T \cos \psi \tag{35}$$

If K = rate of turn, in degrees per minute,

Then

$$\theta = Kt$$

Also

$$\theta = \psi + \omega$$

Therefore

$$\omega = Kt - \psi \tag{14}$$

The co-ordinates of the turning airplane with respect to the cruising airplane at time t before collision are then given by,

$$X = b - X_1$$

Also

$X_1 = R_T \cos \omega$

Substituting for b, Equation (35), and X_1

$$X = V_c t + R_T(\cos \psi - \cos \omega) \quad (12)$$

$Y = a + Y_1$

Also

$Y_1 = R_T \sin \omega$

Substituting for a, Equation (34), and Y_1

$$Y = R_T(\sin \psi + \sin \omega) \quad (13)$$

Solving for the horizontal visual angle α, measured from straight ahead of the cruising airplane,

$$\alpha = \arc \tan \frac{Y}{X} \quad (9)$$

Substituting in Equation (12) and Equation (13)

$$\alpha = \arc \tan \frac{R_T(\sin \psi + \sin \omega)}{V_c t + R_T(\cos \psi - \cos \omega)} \quad (36)$$

From the geometry of Fig 86 the horizontal visual angle β, measured from straight ahead of the turning airplane, is

$$\beta + (90° - \alpha) + (90° - \omega) = 90°$$

Simplifying

$$\beta = \alpha + \omega - 90° \quad (10)$$

Distance between airplanes at time t is

$$Z = \sqrt{X^2 + Y^2} \quad (11)$$

After developing the formulas, it was noted that several visual-angle charts would be required to represent all possible combinations that could occur between the variables involved in this condition To construct a minimum number of charts that represent all possible combinations of the variables, the law of geometric similarity was applied Figures 87 and 88 are geometrically similar Therefore, the corresponding angles are equal and the corresponding sides are proportional

The charts for Condition C were developed with the use of assumed specific values of V_{T0}, V_{c0}, t_0, R_{T0}, and ψ_0 These parameters are shown in Fig 87 The actual case to be investigated is represented by Fig 88 It is necessary, then, for the reader to establish the correct proportion between the parameters shown in Fig 87 and the parameters used in the actual case shown in Fig 88 in order to enter the charts

To establish these proportions, the following formulas are obtained from the geometric similarity between Figs 87 and 88

$$\alpha_0 = \alpha$$

$$\beta_0 = \beta$$

$$\theta_0 = \theta$$

Also

$$\frac{Z_0}{Z} = \frac{R_0}{R_T}$$

$$\frac{V_{c_0}}{V_{T_0}} = \frac{V_c}{V_T}, \text{ and}$$

$$\psi_0 = \psi$$

The parameters needed for entering the visual-angle charts are A, the absolute difference in heading at collision as related to ψ, and t_0, the time before collision

Since $A = \frac{V_{c_0}}{V_{T_0}}$, $\frac{V_{c_0}}{V_{T_0}} = \frac{V_c}{V_T}$, and $\psi_0 = \psi$, then t_0 is the only unknown

From Figs 87 and 88, $\theta_0 = K_0 t_0$ and $\theta = Kt$, where K or K_0 = rate of turn, in degrees per minute Since $\theta_0 = \theta$, then

$$t_0 = \frac{Kt}{K_0} \tag{37}$$

If V_T is in mph and K (rate of turn) is in degrees per minute,

$$K = \frac{5042\ 03 V_T}{R_T} \tag{38}$$

and

$$\tan \lambda = \frac{0\ 067 V_T^{\ 2}}{R_T} \tag{15}$$

Substituting Equation (15) in Equation (38),

$$K = \frac{75,254\ 18 \tan \lambda}{V_T} \tag{39}$$

Substituting Equation (39) and Equation (37),

$$t_0 = \frac{75,254\ 18 \tan \lambda\ t}{K_0 V_T} \tag{40}$$

In computing the points necessary for drawing the curves, the following values of the parameters were used

K_0 = 360 degrees per minute, R_0 = 2801 13 feet, and V_{T0} = 200 mph

The following values of the independent variables used

ψ_0 = 0° to 360° in 30° intervals

$\frac{V_{c_0}}{V_{T_0}}$ is used instead of V_{c_0}

$\frac{V_{c_0}}{V_{T_0}}$ = 0 2, 0 4, 0 6, 0 8, 1 0, 1 25, 1 67, 2 5, 5 0, ∞

t_0 = 0, 0 1, 0 2, 0 3, 0 4, 0 5, 0 6, 0 7, 0 8, 0 9, 1 0

Since the value K_0 = 360 degrees per minute was held constant, then Equation (40) becomes

$$t_0 = \frac{209\ 2 \tan \lambda\ t}{V_T} \tag{8}$$

Since the value R_0 = 2801 1 feet was held constant, then

$$Z = \frac{Z_0 R_T}{2801\ 1} \tag{16}$$

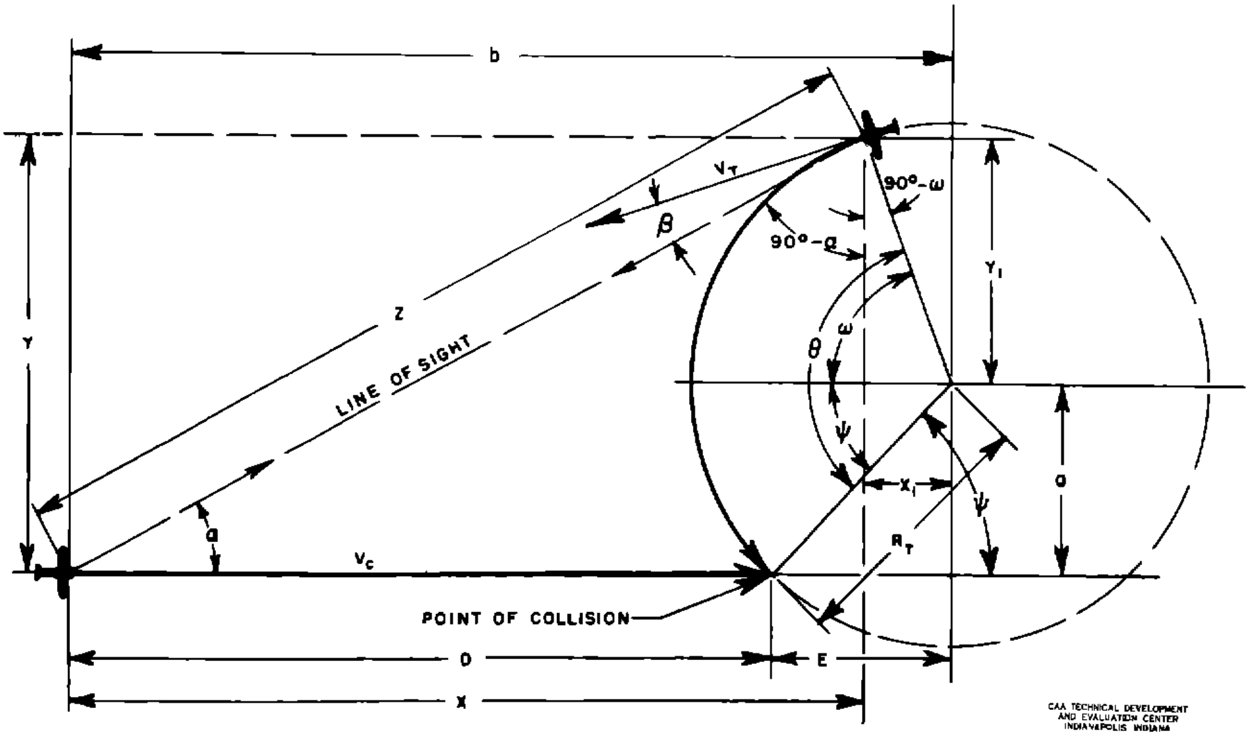
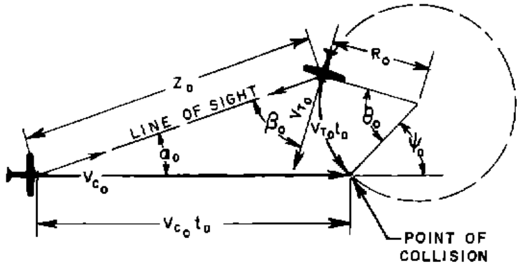


Fig 86 Vector Diagram for Derivation of Formulas for One Airplane Turning Left and One Airplane Flying Straight and Level



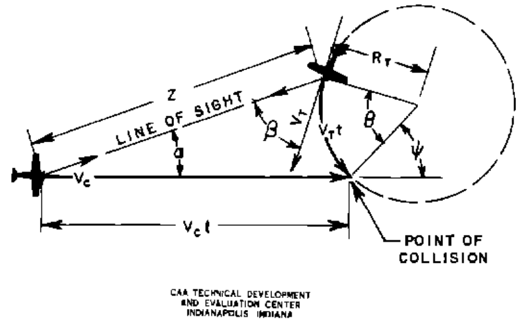


Fig 87 Vector Diagram Showing Similarity to Fig 88 for Derivation of Formulas for One Airplane Turning Left and One Airplane Flying Straight and Level

Fig 88 Vector Diagram Showing Similarity to Fig 87 for Derivation of Formulas for One Airplane Turning Left and One Airplane Flying Straight and Level

DERIVATION OF FORMULAS FOR COLLISION CONDITION D

For this condition, two airplanes are assumed to be on a collision course, both airplanes making a left turn Figure 89 shows the physical significance of the horizontal visual angles and of the distances involved in this condition The horizontal visual angles are measured from straight anead of the pilot at the time of investigation

Locating the center of the larger circle with respect to the point of collision or the origin of the X and Y axis

$$a = R_1 \sin \psi \qquad (41)$$

$$b = R_1 \cos \psi \qquad (42)$$

$$\omega_0 = K_0 t \qquad (28)$$

Where

K_0 = the rate of turn of the airplane turning on the smaller circle, in degrees per minute

t = time of investigation before collision, in minutes

Also

$$\omega_1 = K_1 t - \psi \qquad (25)$$

Where

K_1 = the rate of turn of the airplane turning on the larger circle, in degrees per minute

t = the time of investigation before collision, in minutes

The co-ordinates of the airplane turning on the smaller circle, with respect to the airplane turning on the larger circle at time t, are then given by

$$X_0 = R_0 (1 - \cos \omega_0) \qquad (26)$$

$$Y_0 = - R_0 \sin \omega_0 \qquad (27)$$

And the co-ordinates of the airplane turning on the larger circle are

$X_1 = b - R_1 \cos \omega_1$

When Equation (42) is substituted for b,

$$X_1 = R_1 (\cos \psi - \cos \omega_1) \tag{23}$$

$Y_1 = a - R_1 \sin \omega_1$

When Equation (41) is substituted for a,

$$Y_1 = R_1 (\sin \psi - \sin \omega_1) \tag{24}$$

When these co-ordinates are used, the following is derived

$$\tan \theta = \frac{Y_1 - Y_0}{X_0 - X_1} \tag{29}$$

Substituting in Equations (26), (27), (23), and (24)

$$\theta = \text{arc tan} \frac{R_1 (\sin \psi - \sin \omega_1) + R_0 \sin \omega_0}{R_0 (1 - \cos \omega_0) - R_1 (\cos \psi - \cos \omega_1)} \tag{43}$$

In solving for α, the horizontal visual angle measured from straight ahead of the airplane turning on the smaller circle,

$$\alpha = \omega_0 - \theta - 90° \tag{20}$$

In solving for β, the horizontal visual angle measured from straight ahead of the airplane turning on the larger circle,

$$\beta = \omega_1 - \theta + 90° \tag{21}$$

The distance between airplanes at time t is as follows·

$$Z = \sqrt{(X_0 - X_1)^2 + (Y_1 - Y_0)^2} \tag{22}$$

To construct a minimum number of visual-angle charts to represent the variables involved in this condition, the same law of geometric similarity is applied as was explained in detail in the derivation of formulas for Collision Condition C In this case the similarity between Figs 90 and 91 is used

$$t_0 = \frac{209\ 2\ \tan \lambda\ t}{V_T} \tag{8}$$

Where

$V_T = V_{T_2}$

$\lambda = \lambda_2$

Also

$$Z = \frac{R_2 \, Z_0}{1400\ 56} \tag{30}$$

In computing the points necessary for drawing the curves, the following values of the parameters were used

Held constant K_0 = 360 degrees per minute, R_0 = 1400 56 feet, V_{T_0} = 100 mph

The following values of the independent variables were used

ψ_0 = 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°

$A = \dfrac{V_{T_1}}{V_{T_0}}$ = 0, 0 2, 0 4, 0 6, 0 8, 1 0, 1 25, 1 67, 5 0, ∞

t_0 = 0, 0 1, 0 2, 0 3, 0 4, 0 5, 0 6, 0 7, 0 8, 0 9, 1 0

R/A = 1 0, 2 0, 2 5, 3 0, 3 5, 4 0, 6, 8, 10

Note $R/A = \dfrac{R_1/R_0}{V_{T_1}/V_{T_0}}$

Formulas Needed to Determine Visual Angles and Distances for Two Airplanes on a Collision Course While Flying in the Horizontal Plane and Turning in Opposite Directions (Derivation is Similar to Two Airplanes Turning in Same Direction)

$$\omega_0 = -K_0 t \tag{44}$$

$$\omega_1 = \psi + K_1 t \tag{45}$$

$$\tan\theta = \frac{R_1 (\cos\psi - \cos\theta_1) - R_0 (1 - \cos\omega_0)}{R_1 (\sin\psi - \sin\omega_1) + R_0 \sin\omega_0} \tag{46}$$

$$\alpha = \omega_0 + \theta + 180° \tag{47}$$

$$\beta = \omega_1 + \theta + 180° \tag{48}$$

$$Z = \frac{X}{\sin \theta} \quad (49)$$

$$X = R_1 (\cos \psi - \cos \omega_1) - R_0 (1 - \cos \omega_0) \quad (50)$$

Where

R_1 = Radius of the larger turning circle, in feet

R_0 = Radius of the smaller turning circle, in feet

K_0 = Rate of turn of the airplane on the smaller circle, in degrees per minute

K_1 = Rate of turn of the airplane on the larger circle, in degrees per minute

t = Time of investigation prior to collision, in minutes

α = Visual angle required from the airplane flying on the smaller circle to see the airplane on the larger circle at time t, in degrees

β = Visual angle required from the aircraft flying on the larger circle to see the airplane flying on the smaller circle at time t, in degrees

Z = Distance between the airplanes at time t, in feet

ψ = Difference in heading at collision point as established in Table IV

TABLE IV

RELATIONSHIP BETWEEN ψ AND THE ABSOLUTE DIFFERENCE IN HEADING AT COLLISION POINT FOR TWO AIRPLANES TURNING IN OPPOSITE DIRECTION

Difference in Heading at Collision (degrees)	Condition	Value of ψ in Formulas (degrees)
180		0
90	With the airplane turning on the larger circle on the left of the airplane turning on the smaller circle at collision point	90
0		180
90	With the airplane turning on the larger circle on the right of the airplane turning on the smaller circle at collision point.	270

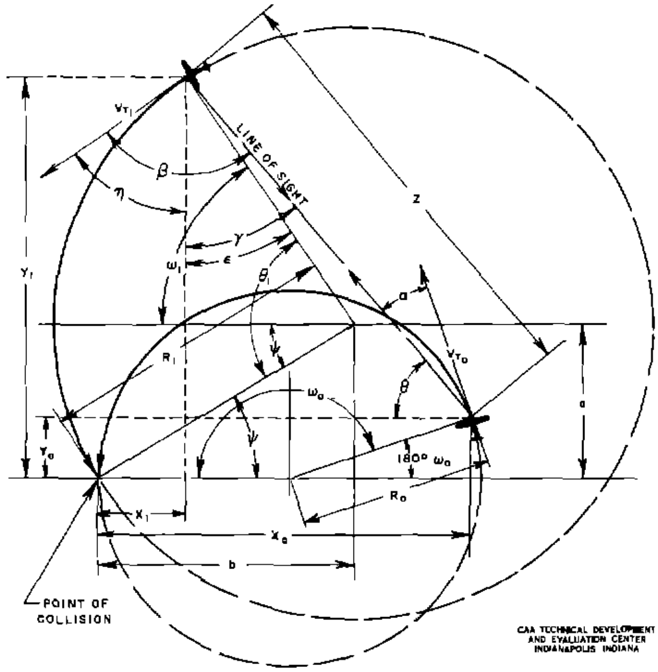


Fig 89 Vector Diagram for Derivation of Formulas for Two Airplanes Turning Left

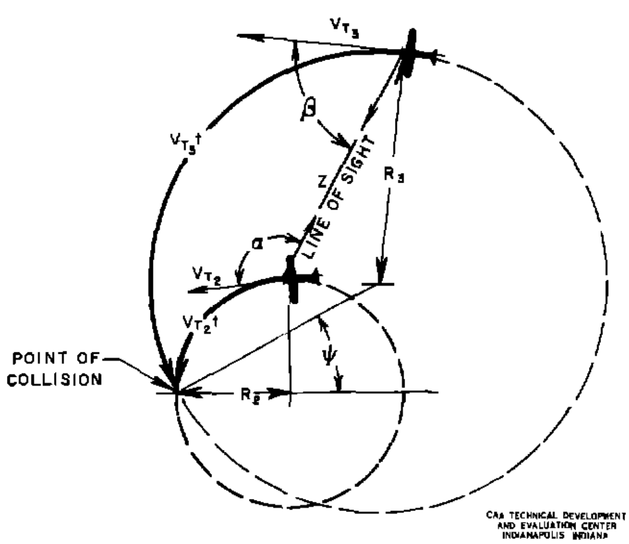


Fig 90 Vector Diagram Showing Similarity to Fig 91 for Derivation of Formulas for Two Airplanes Turning Left

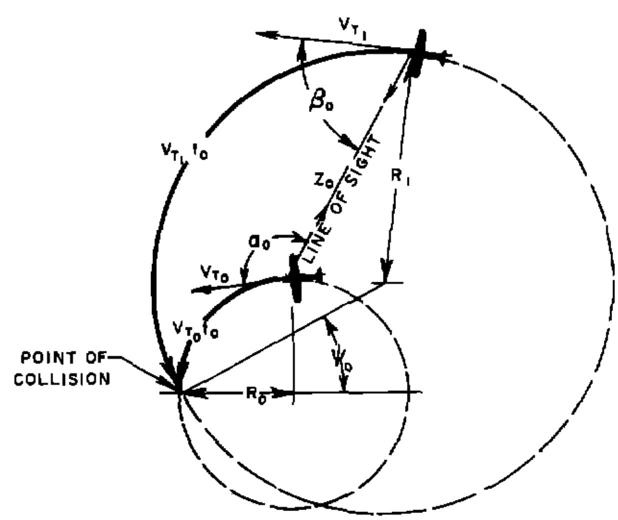


Fig 91 Vector Diagram Showing Similarity to Fig 90 for Derivation of Formulas for Two Airplanes Turning Left

APPENDIX II

FLIGHT-PATH ANALYSIS

The flight paths that are shown in Figs 92 through 108 are actual samples of the typical flight paths of most types of aircraft They were made so that a better understanding of aircraft flight paths in the vicinity of airports would be possible Day and night flights were recorded

Figures 92 through 96 show flight paths that were recorded at Indianapolis, Indiana The Indianapolis Weir Cook Municipal Airport was considered to be the average airport with respect to traffic and terrain conditions

Figures 97 through 101 show flight paths that were recorded at the Birmingham Municipal Airport at Birmingham, Alabama This airport was selected because of its rough terrain immediately surrounding the airport A 20-foot-increment elevation-contour grid is overlayed on the airport Figure 110 shows the mountainous terrain at Birmingham Airport

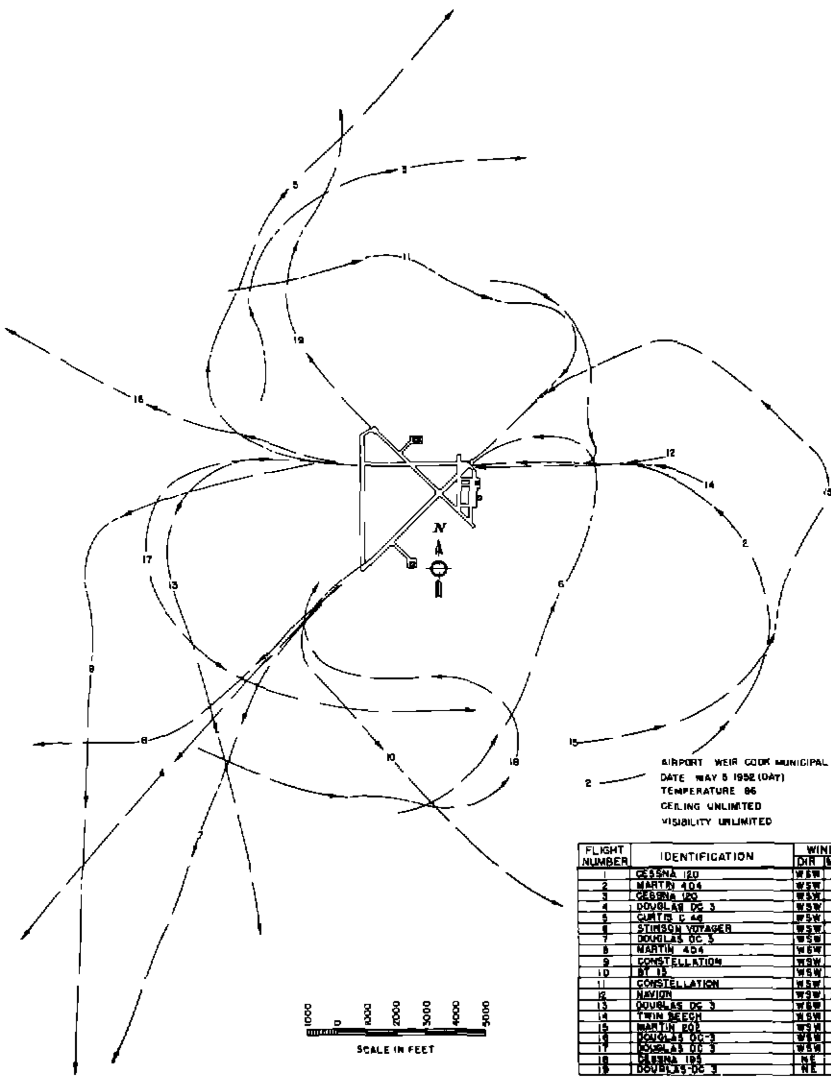
Figures 102 through 108 show flight paths recorded at the Chicago Midway Airport at Chicago, Illinois This airport was selected because of the large number of aircraft that use it

RECORDING PROCEDURE

Three sighting stations were employed to record the aircraft flight paths Each sighting station was equipped with a David White Company Theodolite Model No 6061, one two-way radio, one stop watch, and two personnel to man the station A typical sighting station is shown in Fig 109

The sighting stations were located on each airport as far apart as possible (3000-foot minimum) and as near the formation of an equilateral triangle as terrain and obstructions permitted In all cases, each sighting station was visible from the others to permit azimuth triangulation readings and altitude information The theodolites were leveled and the azimuth scale was zeroed on a point that was visible from all three stations This point in most cases was the control tower on the airport Each station recorded elevation and azimuth locations of another common point in order to obtain further reference for accurately locating the sighting stations

Upon sighting an approaching aircraft, radio contact with the other two stations was made and stop watches were synchronized Azimuth and elevation readings of the aircraft were made at 15-second intervals Later, these points were plotted and the curves were drawn



AIRPORT WEIR COOK MUNICIPAL
DATE MAY 5 1952 (DAY)
TEMPERATURE 86
CEILING UNLIMITED
VISIBILITY UNLIMITED

FLIGHT NUMBER	IDENTIFICATION	WIND DIR	WIND MPH	TIME
1	CESSNA 120	WSW	22	3:00 PM
2	MARTIN 404	WSW	22	3:04
3	CESSNA 120	WSW	22	3:11
4	DOUGLAS DC 3	WSW	22	3:21
5	CURTIS C 46	WSW	22	3:25
6	STINSON VOYAGER	WSW	22	3:30
7	DOUGLAS DC 3	WSW	22	3:38
8	MARTIN 404	WSW	22	4:46
9	CONSTELLATION	WSW	22	[illegible]
10	BT 13	WSW	22	4:58
11	CONSTELLATION	WSW	21	5:03
12	NAVION	WSW	21	5:14
13	DOUGLAS DC 3	WSW	21	5:23
14	TWIN BEECH	WSW	21	5:27
15	MARTIN 202	WSW	21	5:32
16	DOUGLAS DC-3	WSW	21	5:40
17	DOUGLAS DC 3	WSW	21	5:50
18	CESSNA 195	NE	4	7:34
19	DOUGLAS-DC 3	NE	4	7:38

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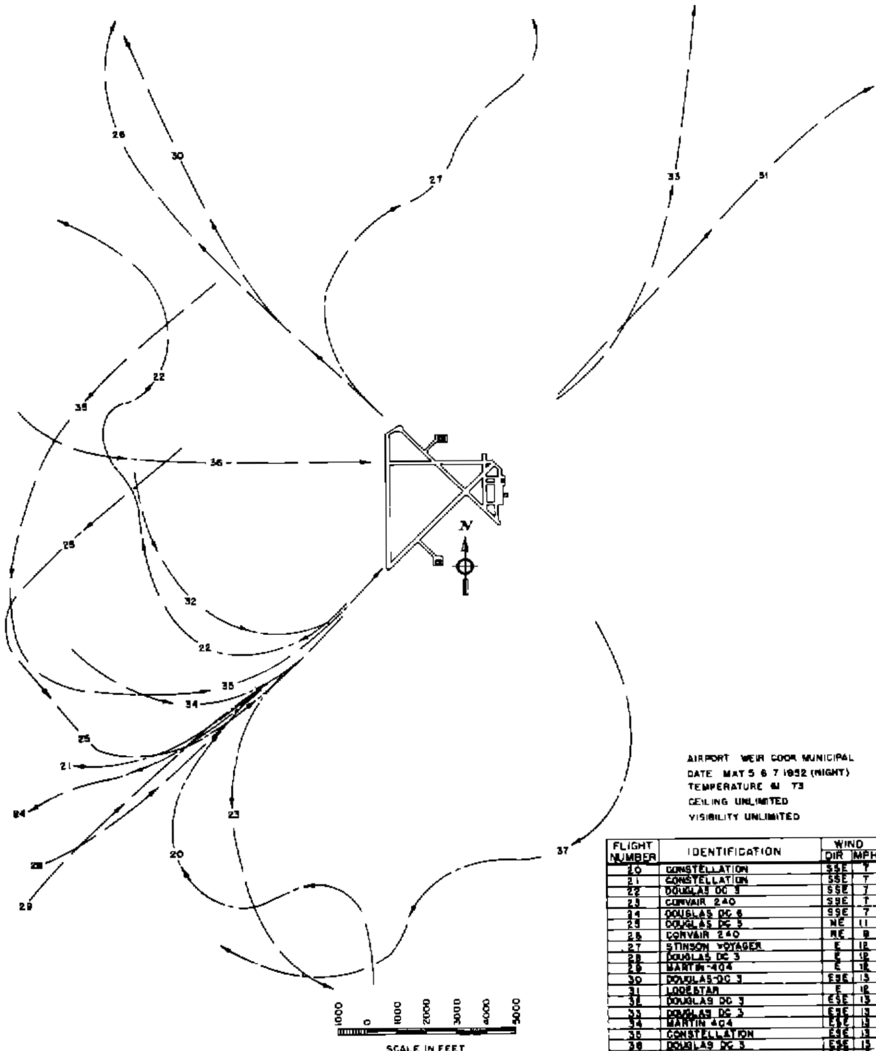
Fig 92 Typical Flight Paths in the Vicinity of Airports



AIRPORT WEIR COOK MUNICIPAL
DATE MAY 5 6 7 1952 (NIGHT)
TEMPERATURE 61 73
CEILING UNLIMITED
VISIBILITY UNLIMITED

FLIGHT NUMBER	IDENTIFICATION	WIND DIR	WIND MPH	TIME
20	CONSTELLATION	SSE	7	7 57PM
21	CONSTELLATION	SSE	7	8 25
22	DOUGLAS DC 3	SSE	7	8 38
23	CONVAIR 240	SSE	7	9 00
24	DOUGLAS DC 6	SSE	7	9 09
25	DOUGLAS DC 3	NE	11	8 27PM
26	CONVAIR 240	NE	9	8 58
27	STINSON VOYAGER	E	12	8 07PM
28	DOUGLAS DC 3	E	12	8 17
29	MARTIN 404	E	12	8 23
30	DOUGLAS DC 3	ESE	13	8 41
31	LODESTAR	E	12	8 57
32	DOUGLAS DC 3	ESE	13	9 04
33	DOUGLAS DC 3	ESE	13	9 34
34	MARTIN 404	ESE	13	9 38
35	CONSTELLATION	ESE	13	9 42
36	DOUGLAS DC 3	ESE	13	9 46
37	MARTIN 404	ESE	13	10 06

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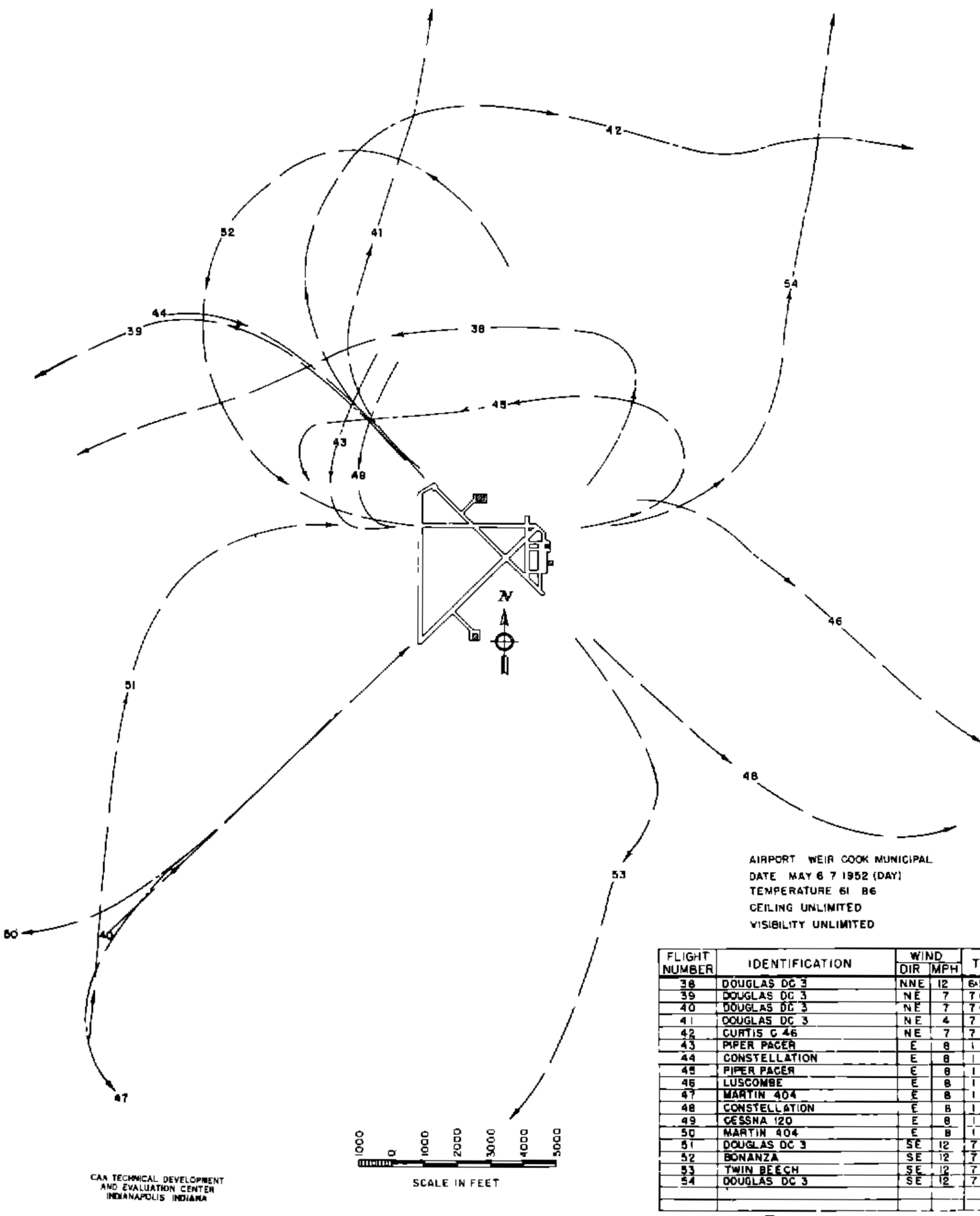
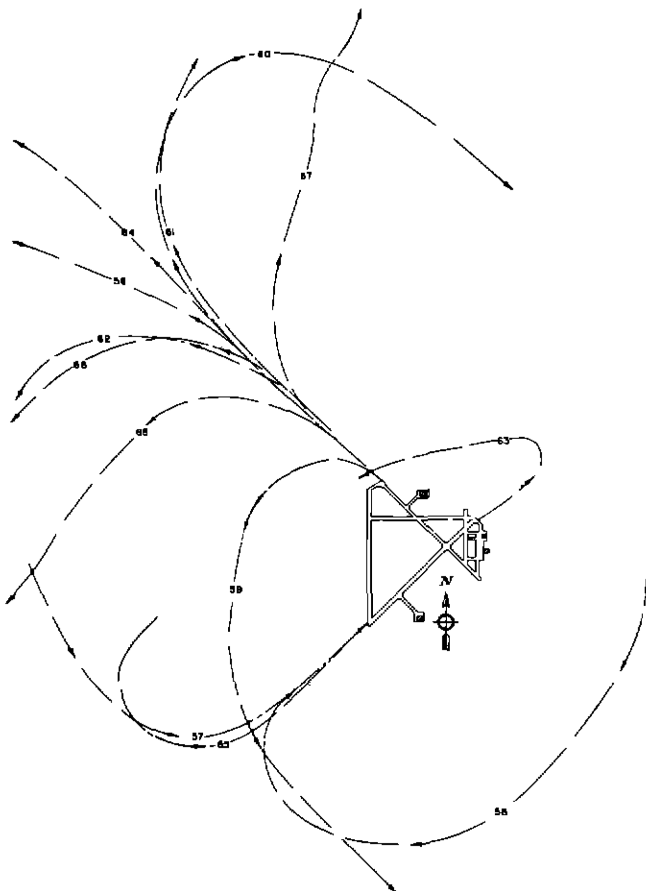
Fig 93 Typical Flight Paths in the Vicinity of Airports



AIRPORT WEIR COOK MUNICIPAL
DATE MAY 6 7 1952 (DAY)
TEMPERATURE 61 86
CEILING UNLIMITED
VISIBILITY UNLIMITED

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
38	DOUGLAS DC 3	NNE	12	6 53 PM
39	DOUGLAS DC 3	NE	7	7 00
40	DOUGLAS DC 3	NE	7	7 04
41	DOUGLAS DC 3	NE	4	7 22
42	CURTIS C 46	NE	7	7 30
43	PIPER PACER	E	8	1 10 PM
44	CONSTELLATION	E	8	1 12
45	PIPER PACER	E	8	1 21
46	LUSCOMBE	E	8	1 25
47	MARTIN 404	E	8	1 32
48	CONSTELLATION	E	8	1 51
49	CESSNA 120	E	8	1 54
50	MARTIN 404	E	8	1 57
51	DOUGLAS DC 3	SE	12	7 13
52	BONANZA	SE	12	7 21
53	TWIN BEECH	SE	12	7 28
54	DOUGLAS DC 3	SE	12	7 40

Fig 94 Typical Flight Paths in the Vicinity of Airports



AIRPORT WEIR COOK MUNICIPAL
DATE MAY 8 1952 (DAY)
TEMPERATURE 60° 62
CEILING 1000 UNLIMITED
VISIBILITY 10 MI. - UNLIMITED

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR.	MPH	
55	MARTIN 404	N	12	2:57 PM
56	DOUGLAS DC 3	NNE	13	3:04
57	CONVAIR 240	NNE	13	3:11
58	MARTIN 404	NNE	13	3:19
59	BONANZA	NNE	13	3:28
60	MARTIN 404	NNE	13	3:31
61	CONVAIR 240	NNE	13	3:35
62	DOUGLAS DC 3	NE	13	6:33
63	TAYLOR CRAFT	NE	13	6:40
64	CONVAIR 240	NE	13	6:47
65	CONSTELLATION	NE	8	6:57
66	DOUGLAS DC 3	NE	8	7:08
67	DOUGLAS DC 3	NE	8	7:35

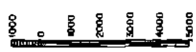


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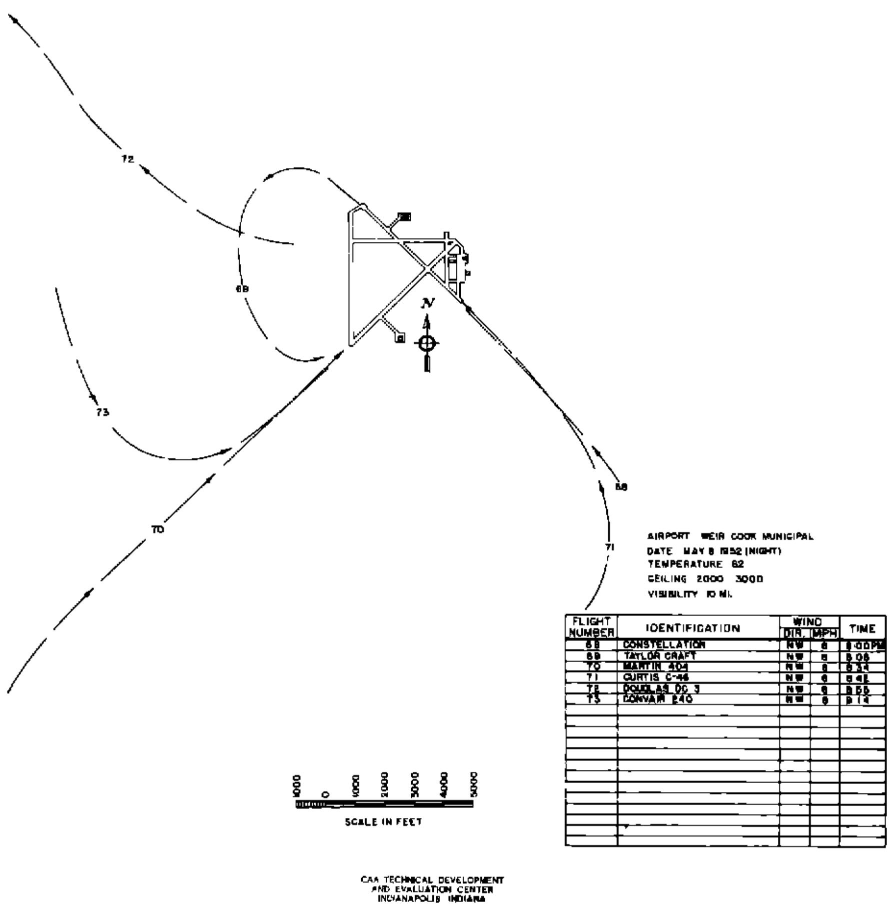
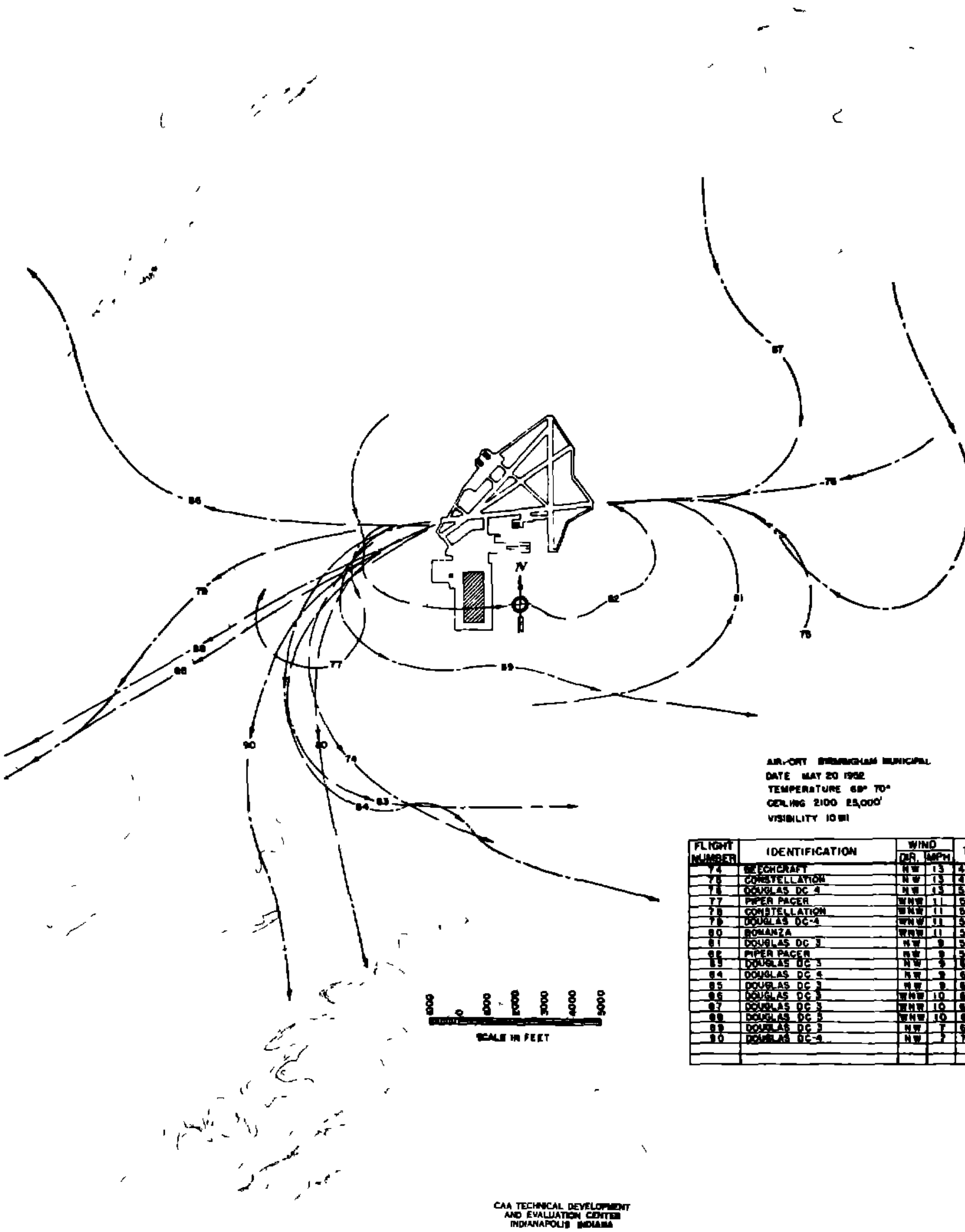
Fig 95 Typical Flight Paths in the Vicinity of Airports



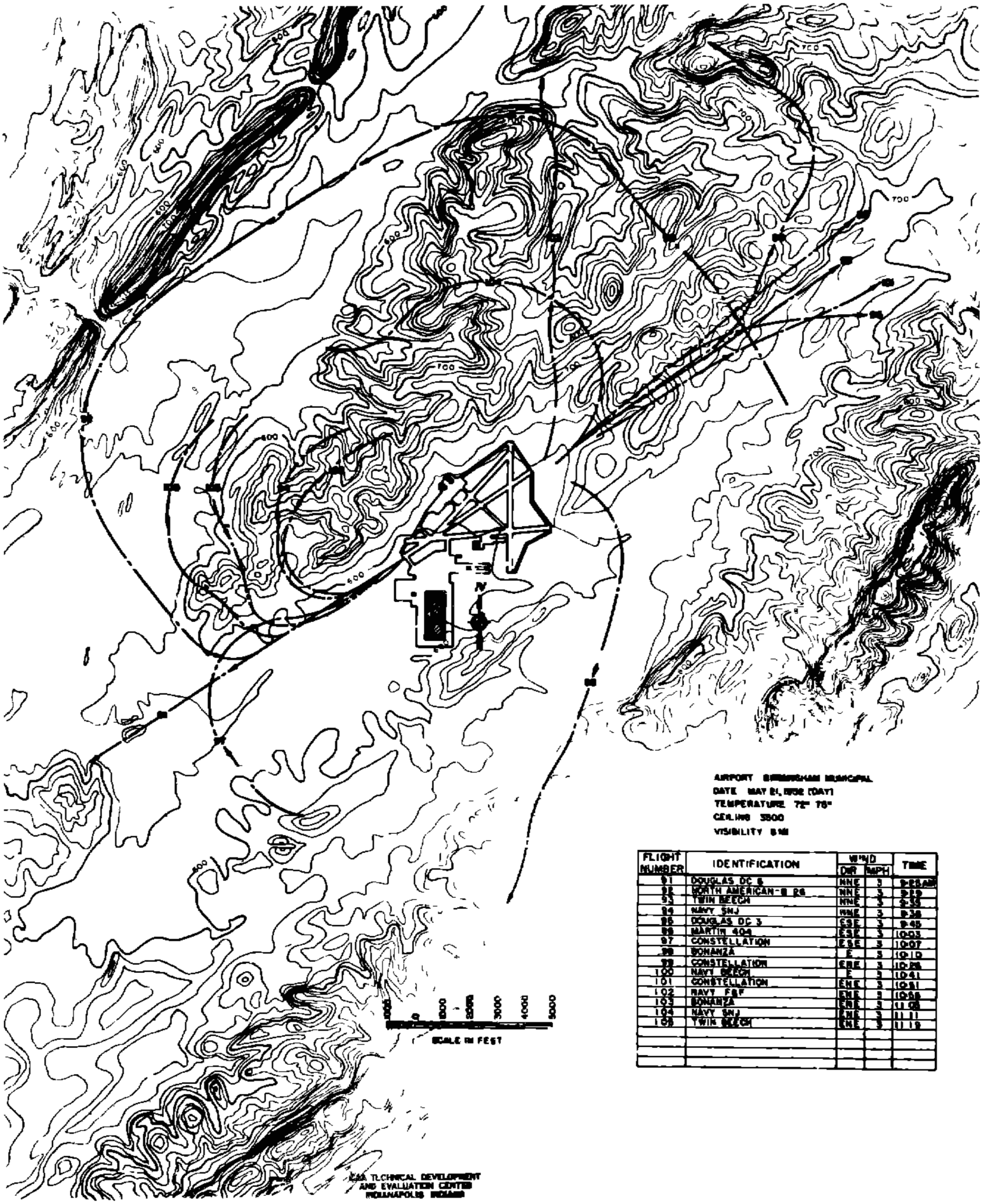
FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR.	MPH	
68	CONSTELLATION	NW	6	8 00PM
69	TAYLOR CRAFT	NW	8	8 08
70	MARTIN 404	NW	6	8 34
71	CURTIS C-46	NW	6	8 42
72	DOUGLAS DC 3	NW	6	8 55
73	CONVAIR 240	NW	6	9 14

Fig 96 Typical Flight Paths in the Vicinity of Airports



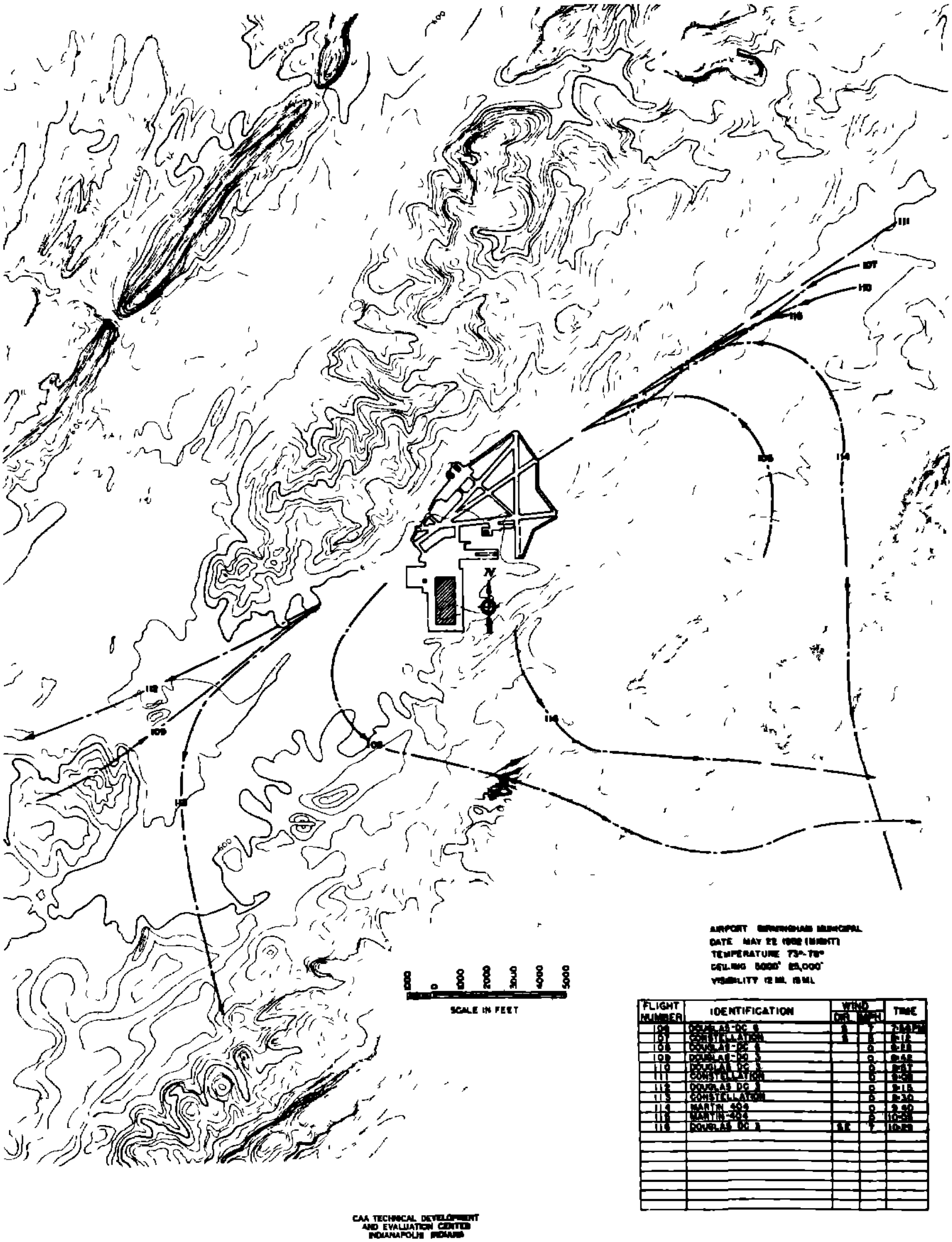
FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR.	MPH	
74	BEECHCRAFT	NW	13	4 54 PM
75	CONSTELLATION	NW	13	4:58
76	DOUGLAS DC 4	NW	13	5 04
77	PIPER PACER	WNW	11	5 09
78	CONSTELLATION	WNW	11	5 19
79	DOUGLAS DC-4	WNW	11	5 23
80	BONANZA	WNW	11	5:34
81	DOUGLAS DC 3	NW	9	5 45
82	PIPER PACER	NW	9	5 48
83	DOUGLAS DC 3	NW	9	6 02
84	DOUGLAS DC 4	NW	9	6 12
85	DOUGLAS DC 3	NW	9	6 16
86	DOUGLAS DC 3	WNW	10	6 38
87	DOUGLAS DC 3	WNW	10	6 41
88	DOUGLAS DC 3	WNW	10	6:45
89	DOUGLAS DC 3	NW	7	6 56
90	DOUGLAS DC-4	NW	7	7 04

Fig 97 Typical Flight Paths in the Vicinity of Airports



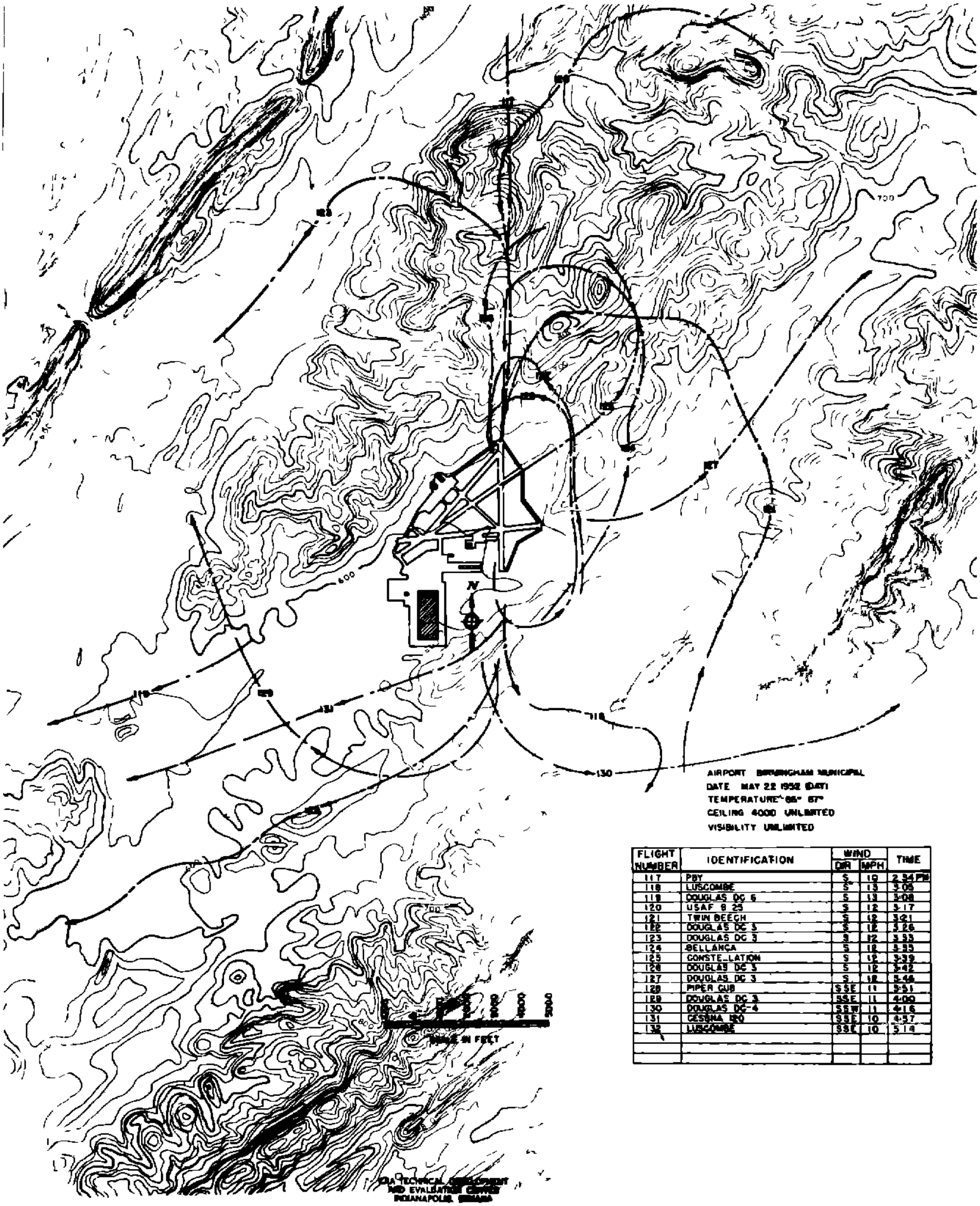
FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
91	DOUGLAS DC 6	NNE	3	9:25AM
92	NORTH AMERICAN-B 26	NNE	3	9:29
93	TWIN BEECH	NNE	3	9:33
94	NAVY SNJ	NNE	3	9:38
95	DOUGLAS DC 3	ESE	3	9:45
96	MARTIN 404	ESE	3	10:03
97	CONSTELLATION	ESE	3	10:07
98	BONANZA	E	3	10:10
99	CONSTELLATION	ENE	3	10:28
100	NAVY BEECH	E	3	10:41
101	CONSTELLATION	ENE	3	10:51
102	NAVY F8F	ENE	3	10:58
103	BONANZA	ENE	3	11:05
104	NAVY SNJ	ENE	3	11:11
105	TWIN BEECH	ENE	3	11:19

Fig 98 Typical Flight Paths in the Vicinity of Airports



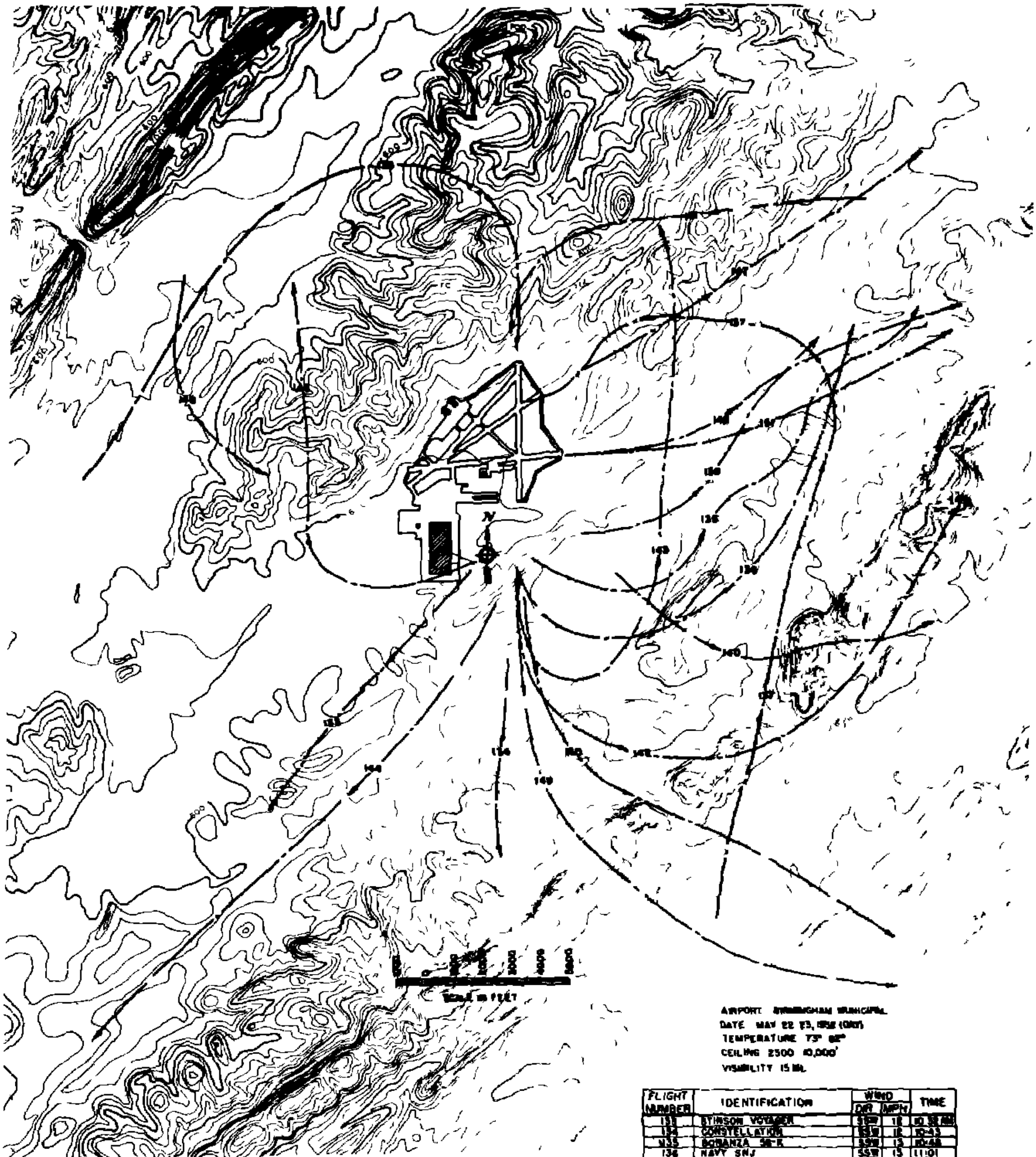
FLIGHT NUMBER	IDENTIFICATION	WIND DIR.	WIND MPH	TIME
106	DOUGLAS-DC 6	S	7	[illegible]
107	CONSTELLATION	S	[illegible]	[illegible]
108	DOUGLAS-DC 6		0	[illegible]
109	DOUGLAS-DC 3		0	[illegible]
110	DOUGLAS DC 3		0	[illegible]
111	CONSTELLATION		0	[illegible]
112	DOUGLAS DC 3		0	9:15
113	CONSTELLATION		0	9:30
114	MARTIN 404		0	9:40
115	MARTIN-404		0	[illegible]
116	DOUGLAS DC 3	[illegible]	7	[illegible]

Fig 99 Typical Flight Paths in the Vicinity of Airports



FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
117	PBY	S	10	2:54 PM
118	LUSCOMBE	S	13	3:05
119	DOUGLAS DC 6	S	13	3:08
120	USAF B 25	S	12	3:17
121	TWIN BEECH	S	12	3:21
122	DOUGLAS DC 3	S	12	3:26
123	DOUGLAS DC 3	S	12	3:33
124	BELLANCA	S	12	3:35
125	CONSTELLATION	S	12	3:39
126	DOUGLAS DC 3	S	12	3:42
127	DOUGLAS DC 3	S	12	3:46
128	PIPER CUB	SSE	11	3:51
129	DOUGLAS DC 3	SSE	11	4:00
130	DOUGLAS DC-4	SSW	11	4:16
131	CESSNA 120	SSE	10	4:57
132	LUSCOMBE	SSE	10	5:14

Fig 100 Typical Flight Paths in the Vicinity of Airports



FLIGHT NUMBER	IDENTIFICATION	WIND DIR	WIND MPH	TIME
133	STINSON VOYAGER	SSW	12	10 38 AM
134	CONSTELLATION	SSW	12	10:43
N35	BONANZA 35-R	SSW	13	10:48
136	NAVY SNJ	SSW	13	11:01
137	DOUGLAS DC 4	SSW	13	11 09
138	CONSTELLATION	SSE	10	11 20
139	BONANZA	SSE	10	11 24
140	CESSNA 120	SSE	10	11 27
141	DOUGLAS DC 3	SSW	10	11 52
142	NAVY [illegible]	SSE	8	9:13 AM
143	BONANZA	SSE	10	9:19
144	DOUGLAS DC 6	SSE	10	9 20
145	BONANZA	SSE	10	9 27
146	MARTIN 404	SSE	10	9:36
147	DOUGLAS DC 3	SSE	10	9 48
148	DOUGLAS DC 3	SSE	8	9 55
149	DOUGLAS DC 6	SSE	8	10:23
150	CONSTELLATION	SSE	8	10 35
151	CONSTELLATION	SSE	10	10 45

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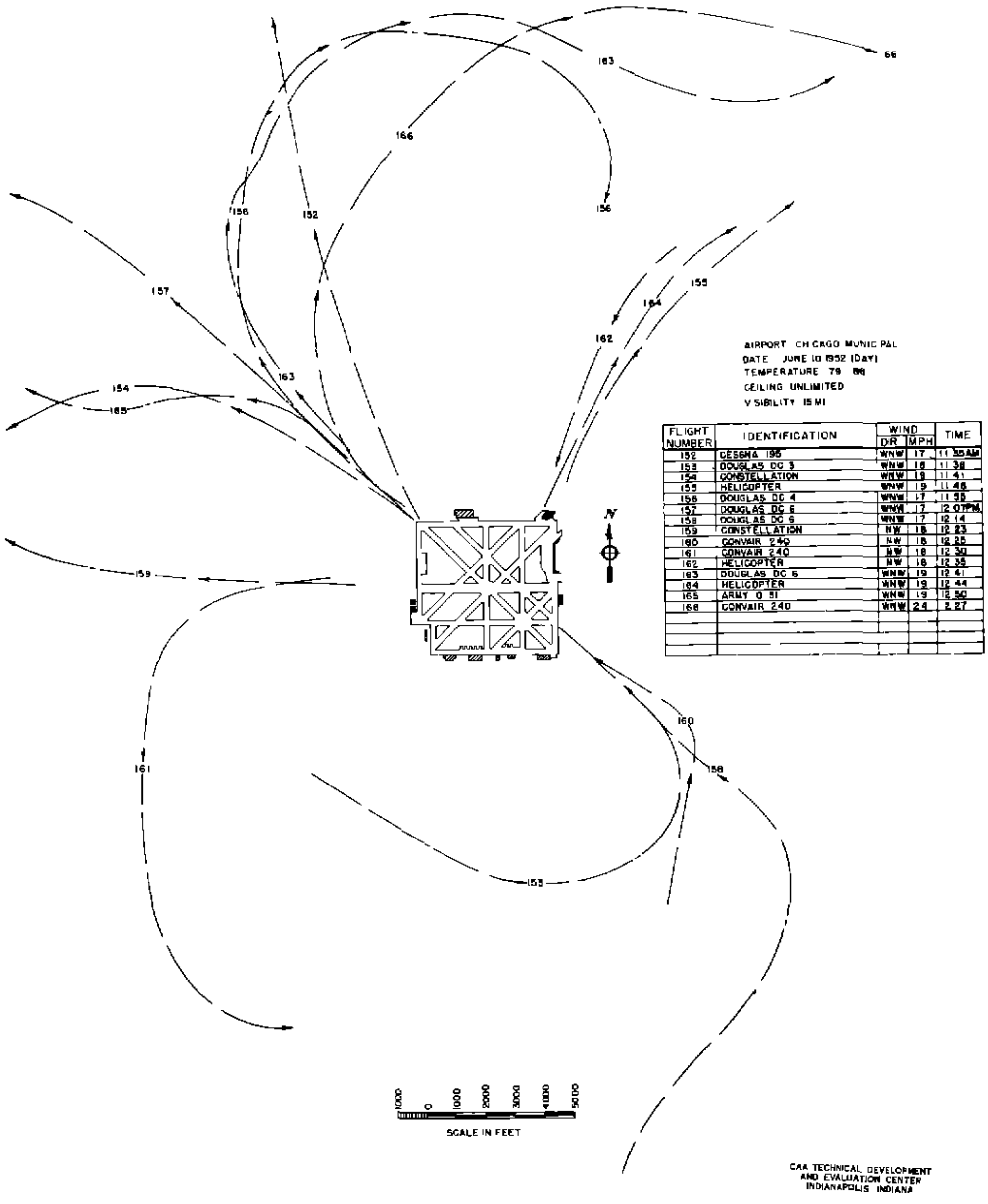
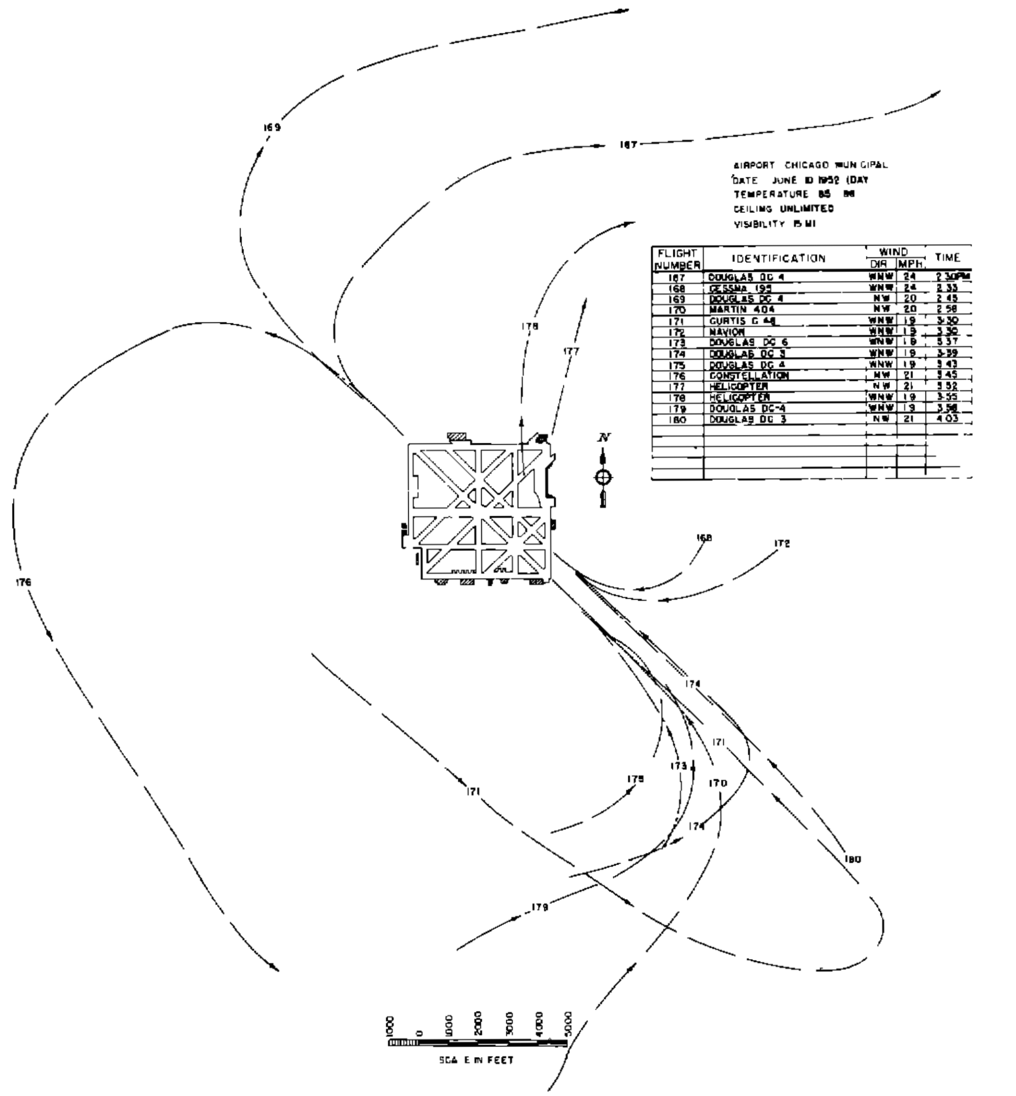
Fig 101 Typical Flight Paths in the Vicinity of Airports



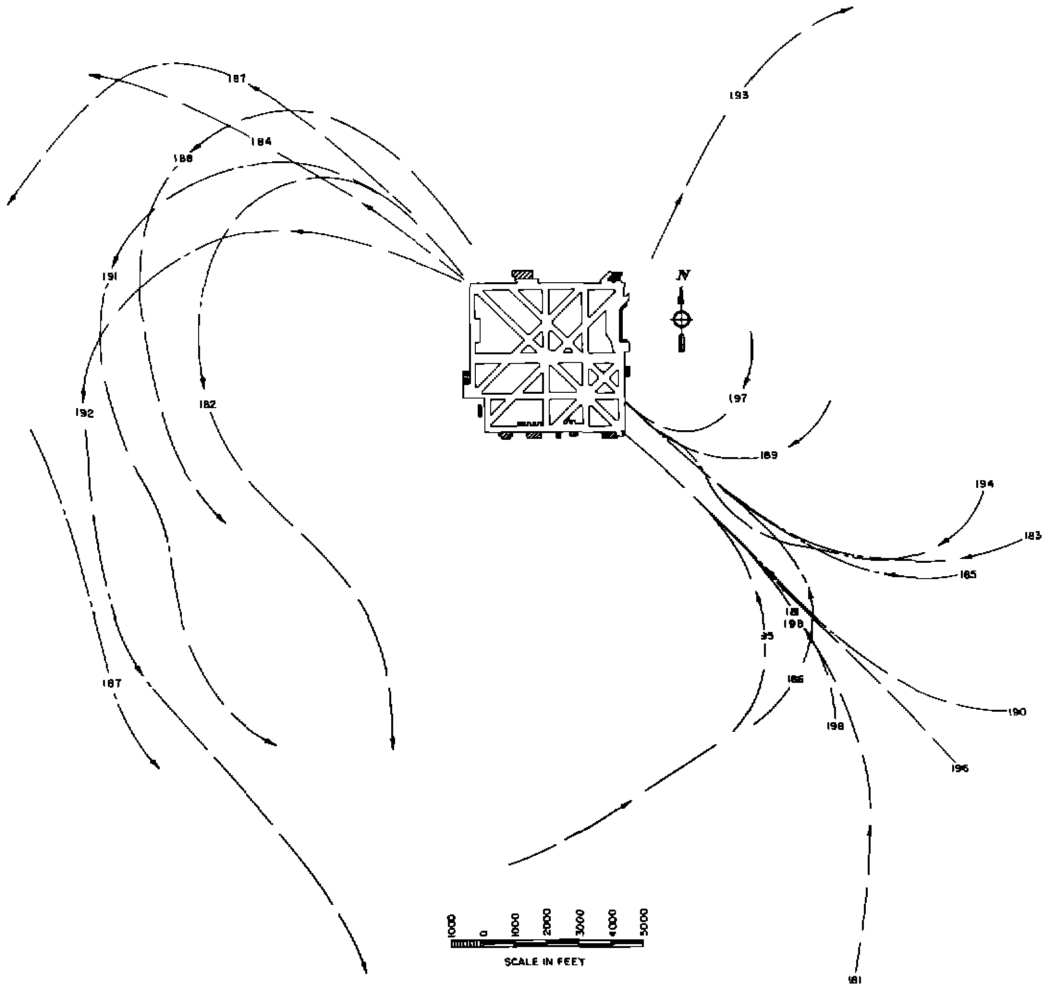
FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
152	CESSNA 195	WNW	17	11 35AM
153	DOUGLAS DC 3	WNW	18	11 38
154	CONSTELLATION	WNW	19	11 41
155	HELICOPTER	WNW	19	11 46
156	DOUGLAS DC 4	WNW	17	11 55
157	DOUGLAS DC 6	WNW	17	12 07PM
158	DOUGLAS DC 6	WNW	17	12 14
159	CONSTELLATION	NW	18	12 23
160	CONVAIR 240	NW	18	12 25
161	CONVAIR 240	NW	18	12 30
162	HELICOPTER	NW	18	12 35
163	DOUGLAS DC 6	WNW	19	12 41
164	HELICOPTER	WNW	19	12 44
165	ARMY O 51	WNW	19	12 50
166	CONVAIR 240	WNW	24	2 27

Fig 102 Typical Flight Paths in the Vicinity of Airports



FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
167	DOUGLAS DC 4	WNW	24	2 30PM
168	CESSNA 195	WNW	24	2 33
169	DOUGLAS DC 4	NW	20	2 45
170	MARTIN 404	NW	20	2 58
171	CURTIS C 46	WNW	19	3 30
172	NAVION	WNW	19	3 30
173	DOUGLAS DC 6	WNW	19	3 37
174	DOUGLAS DC 3	WNW	19	3 39
175	DOUGLAS DC 4	WNW	19	3 43
176	CONSTELLATION	NW	21	3 45
177	HELICOPTER	NW	21	3 52
178	HELICOPTER	WNW	19	3 55
179	DOUGLAS DC-4	WNW	19	3 58
180	DOUGLAS DC 3	NW	21	4 03

Fig 103 Typical Flight Paths in the Vicinity of Airports



AIRPORT CHICAGO MUNICIPAL
DATE JUNE 10 1952 (DAY)
TEMPERATURE 83 85°
CEILING 1800 UNLIMITED
VISIBILITY 7 MI 15 MI

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
181	DOUGLAS DC-6	NW	21	4 07 PM
182	DOUGLAS DC 3	NW	20	4 24
183	LOCKHEED LODESTAR	NW	20	4 27
184	BONANZA	NW	20	4 32
185	DOUGLAS DC-6	NW	20	4 38
186	MARTIN 404	NW	20	4 42
187	DOUGLAS DC 6	NW	20	4 47
188	DOUGLAS DC 3	NW	20	4 55
189	DOUGLAS DC-3	NW	20	4 58
190	DOUGLAS DC 6	NW	20	5 07
191	CONSTELLATION	NW	20	5 10
192	CONVAIR 240	NW	19	5 13
193	HELICOPTER	NW	20	5 16
194	CONVAIR 240	NW	19	5 20
195	CURTIS C 46	NW	19	5 23
196	DOUGLAS DC 6	NW	19	5 26
197	CESSNA 195	NW	18	5 29
198	CURTIS C 46	NW	19	5 32

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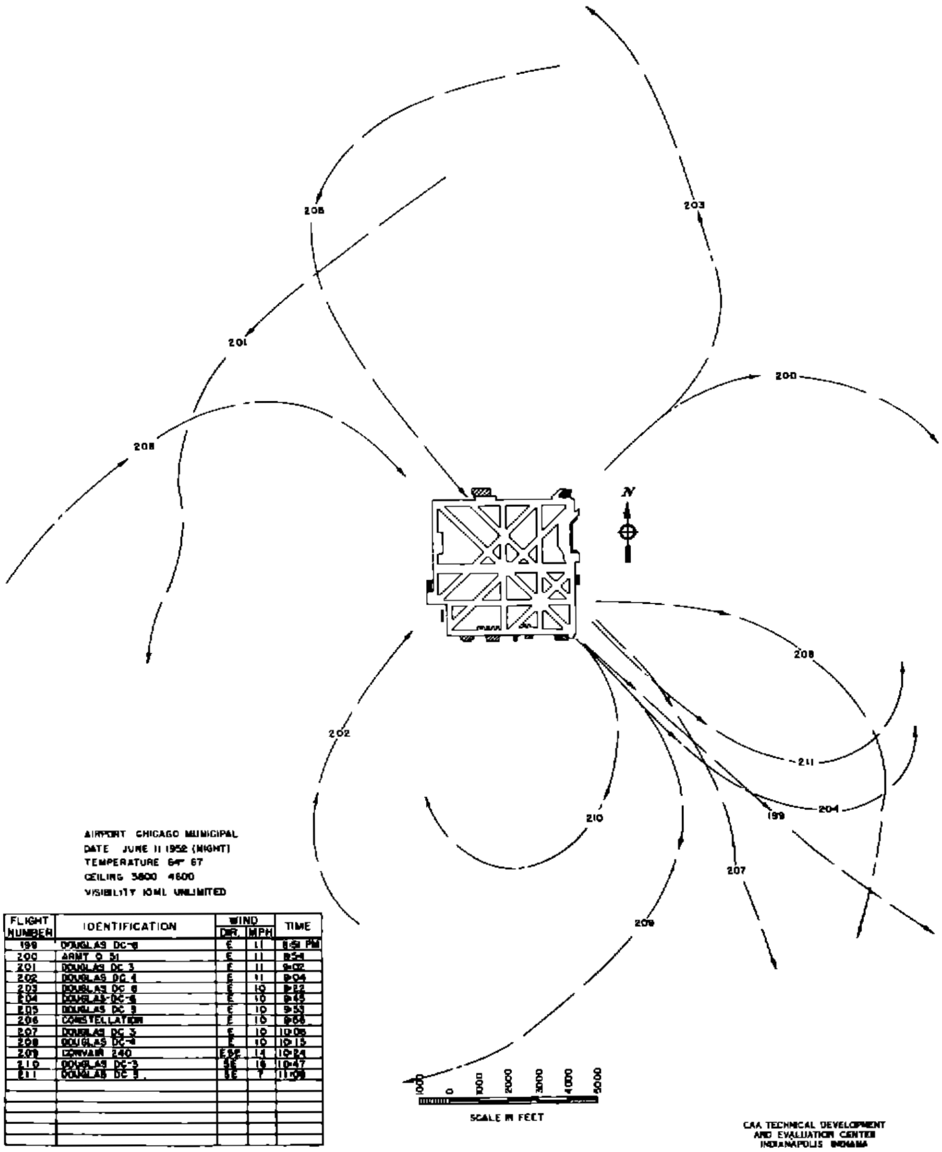
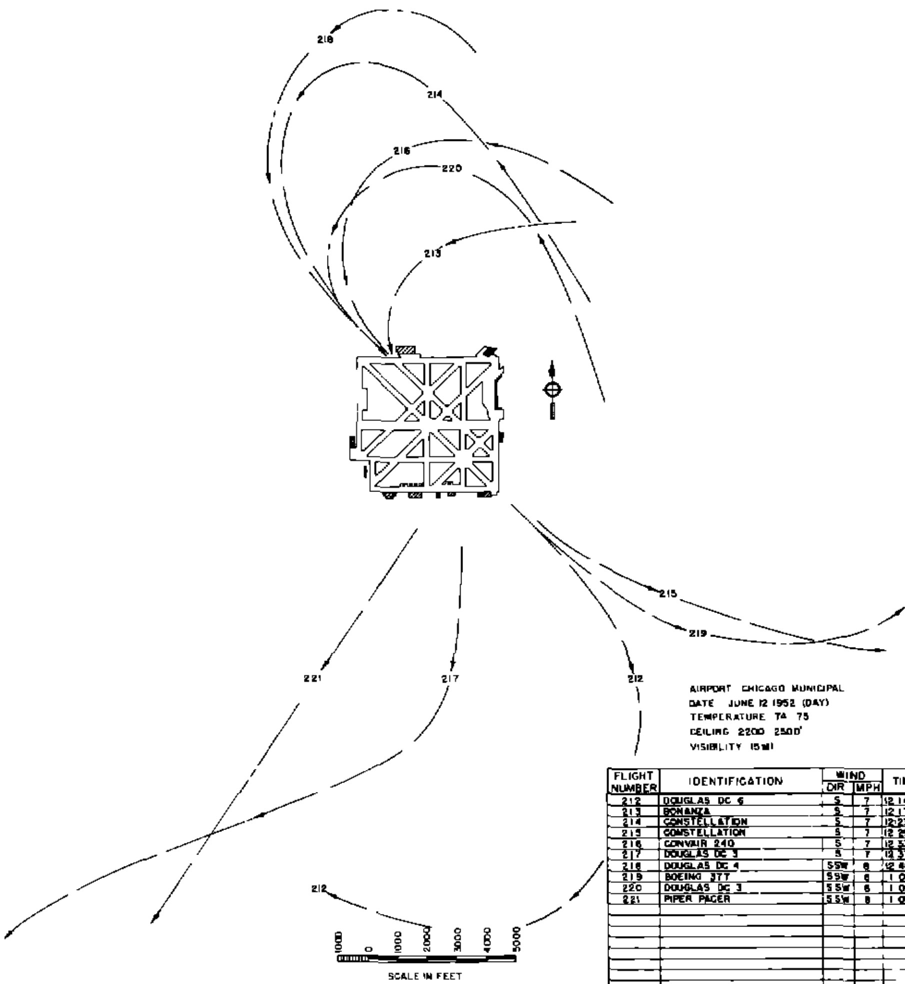
Fig 104 Typical Flight Paths in the Vicinity of Airports



AIRPORT CHICAGO MUNICIPAL
DATE JUNE 11 1952 (NIGHT)
TEMPERATURE 64° 67
CEILING 3800 4600
VISIBILITY 10MI UNLIMITED

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR.	MPH	
199	DOUGLAS DC-6	E	11	8:51 PM
200	ARMY C 51	E	11	8:54
201	DOUGLAS DC 3	E	11	9:02
202	DOUGLAS DC 4	E	11	9:04
203	DOUGLAS DC 6	E	10	9:22
204	DOUGLAS DC-6	E	10	9:45
205	DOUGLAS DC 3	E	10	9:53
206	CONSTELLATION	E	10	9:58
207	DOUGLAS DC 3	E	10	10:06
208	DOUGLAS DC-4	E	10	10:15
209	CONVAIR 240	ESE	14	10:24
210	DOUGLAS DC-3	SE	18	10:47
211	DOUGLAS DC 3	SE	7	11:09

Fig 105 Typical Flight Paths in the Vicinity of Airports



AIRPORT CHICAGO MUNICIPAL
DATE JUNE 12 1952 (DAY)
TEMPERATURE TA 75
CEILING 2200 2500'
VISIBILITY 15 MI

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
212	DOUGLAS DC 6	S	7	12 14 PM
213	BONANZA	S	7	12 17
214	CONSTELLATION	S	7	12 23
215	CONSTELLATION	S	7	12 29
216	CONVAIR 240	S	7	12 33
217	DOUGLAS DC 3	S	7	12 37
218	DOUGLAS DC 4	SSW	8	12 46
219	BOEING 377	SSW	6	1 02
220	DOUGLAS DC 3	SSW	6	1 04
221	PIPER PACER	SSW	8	1 08

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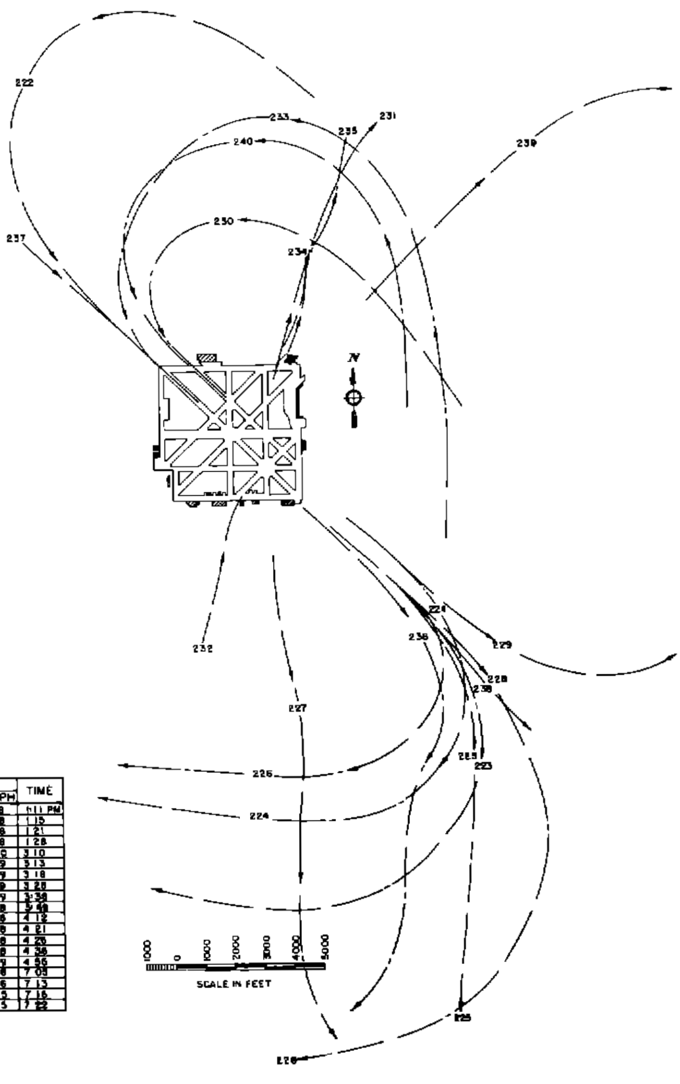
Fig 106 Typical Flight Paths in the Vicinity of Airports



AIRPORT CHICAGO MUNICIPAL
DATE JUNE 12 1952 (DAY)
TEMPERATURE 71° 74°
CEILING 1800' 2200'
VISIBILITY 3MI 15MI

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
222	DOUGLAS DC 6	SE	8	1 11 PM
223	CURTIS C 46	SE	8	1 15
224	DOUGLAS DC 3	SE	8	1 21
225	DOUGLAS-DC-4	SE	8	1 28
226	DOUGLAS-DC 6	ESE	10	3 10
227	MARTIN 404	E	9	3 13
228	DOUGLAS DC 6	E	9	3 18
229	DOUGLAS DC 3	E	9	3 20
230	DOUGLAS DC 3	E	9	3 30
231	HELICOPTER	SE	8	3 40
232	HELICOPTER	SE	8	4 12
233	DOUGLAS-DC 3	SE	8	4 21
234	HELICOPTER	SE	8	4 26
235	HELICOPTER	SE	8	4 36
236	CONSTELLATION	E	9	4 56
237	BOEING 377	E	6	7 05
238	DOUGLAS DC 4	E	6	7 13
239	DOUGLAS DC 6	E	5	7 16
240	DOUGLAS DC 6	E	5	7 22

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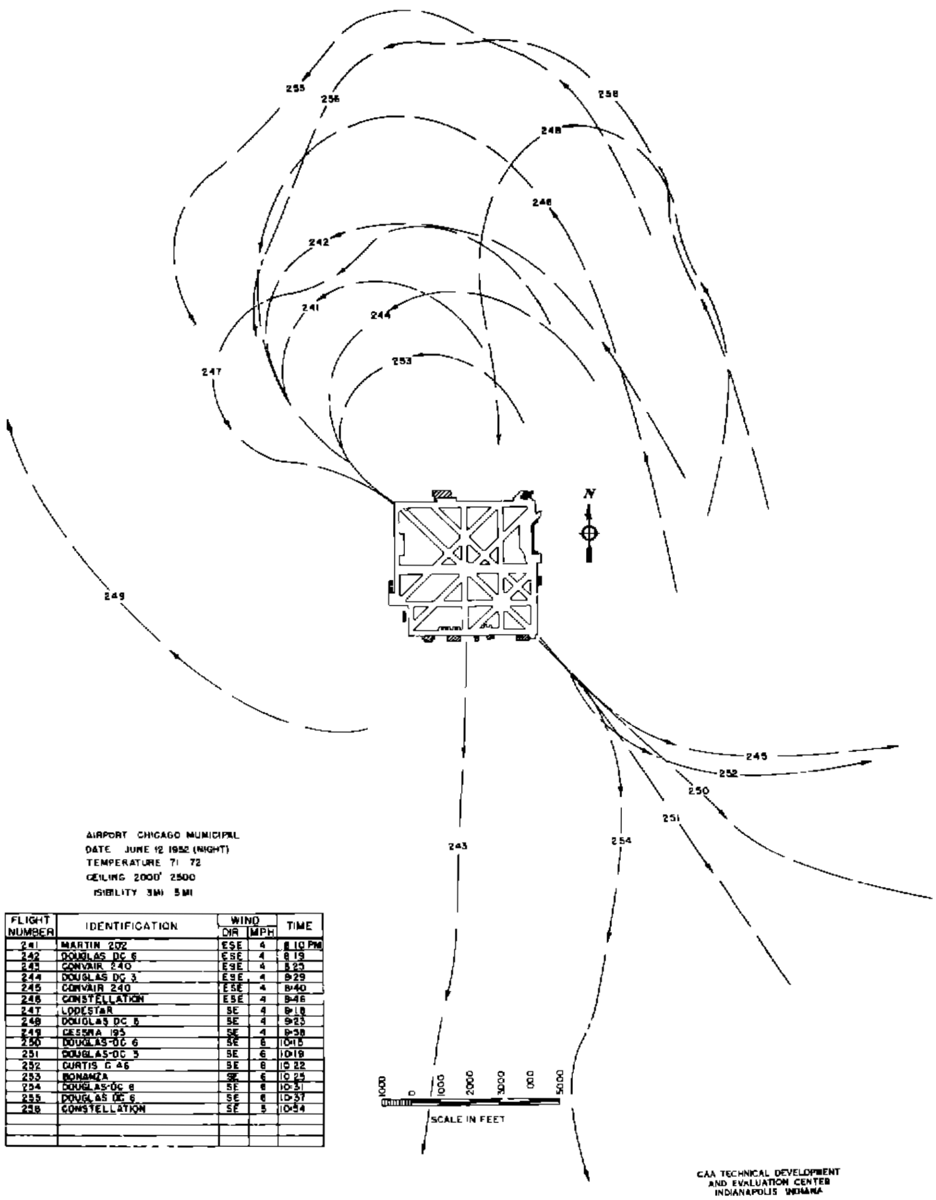
Fig 107 Typical Flight Paths in the Vicinity of Airports



AIRPORT CHICAGO MUNICIPAL
DATE JUNE 12 1952 (NIGHT)
TEMPERATURE 71 72
CEILING 2000' 2500
VISIBILITY 3MI 5MI

FLIGHT NUMBER	IDENTIFICATION	WIND		TIME
		DIR	MPH	
241	MARTIN 202	ESE	4	8 10 PM
242	DOUGLAS DC 6	ESE	4	8 19
243	CONVAIR 240	ESE	4	8 25
244	DOUGLAS DC 3	ESE	4	8 29
245	CONVAIR 240	ESE	4	8 40
246	CONSTELLATION	ESE	4	8 46
247	LODESTAR	SE	4	9 18
248	DOUGLAS DC 6	SE	4	9 23
249	CESSNA 195	SE	4	9 38
250	DOUGLAS-DC 6	SE	6	10 15
251	DOUGLAS-DC 3	SE	6	10 19
252	CURTIS C 46	SE	6	10 22
253	BONANZA	SE	6	10 25
254	DOUGLAS-DC 6	SE	6	10 31
255	DOUGLAS DC 6	SE	6	10 37
256	CONSTELLATION	SE	5	10 54

Fig 108 Typical Flight Paths in the Vicinity of Airports

Fig 109 Typical Flight-Path Recording Station

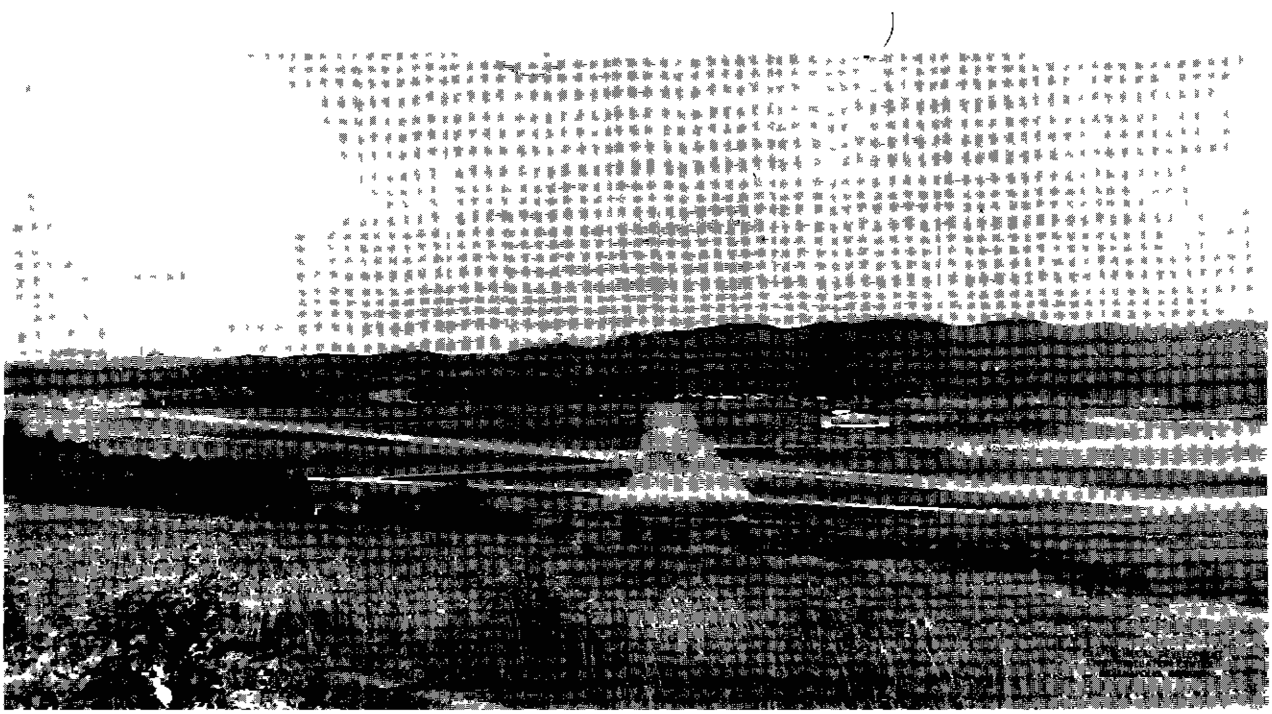


Fig 110 Birmingham Municipal Airport