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A PRELIMINARY INVESTIGATION OF THE APPLICATION OF THE TANGENTIAL APPROACH PRINCIPLE TO AIR TRAFFIC CONTROL

FOR LIMITED DISTRIBUTION

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SUMMARY

This report describes the basic geometry of the tangential approach principle, and indicates how this principle may be applied to the guidance of aircraft without special electronic equipment or instrumentation The study of this approach principle was part of an operational evaluation program on the use of airport surveillance radar as a traffic control aid Included are the following possible applications

1. As an aid to the radar controller in directing a PPI approach, and in providing separation between successive PPI approaches
2. As an aid to the pilot in intercepting and maintaining alignment on a desired omnirange course

Since the study was not carried out to the desired completeness because of other project work, the information contained in this report is presented for possible application by those groups and agencies interested in the control and flight of aircraft

A mathematical analysis of the trajectory of the aircraft under the investigated approach system is included in the appendix.

INTRODUCTION

In early work conducted on the use of radar vectoring techniques as an aid to air traffic control, it became apparent that a traffic controller required considerable experience with a normal radar display in order to supply reliable vectoring information to an aircraft. Using a normal radar display, with a simple overlay of the airport and surrounding facilities, often requires the controller to give his best estimate of the headings required by the aircraft to fly on to the correct approach path If his estimate is in error, additional heading corrections may be necessary in order that the aircraft can complete the approach properly. Since it appears that the use of predetermined equal correction lines on an overlay for the radar indicator may be of aid in supplying more accurate information, this preliminary investigation was conducted on one principle, to determine the effect of these aids to air traffic control

THE TANGENTIAL APPROACH PRINCIPLE

The tangential approach principle is not new, since it has been used in various forms for aircraft control and servo mechanisms In this study, the tangential approach principle was used as a semi-automatic means for aligning an aircraft on a desired course. Various methods may be employed, but all utilize the principle of making the correction angle a function of the displacement angle, as illustrated in Fig. 1

In operation, the function of any approach system is to direct the aircraft toward the desired course and to align the aircraft on such course at or before the time it reaches a specified transition point on the course. Fig. 2 illustrates the corrections required. The transition point normally would be one of the following

1 A point on the final PPI approach course where the pilot takes over for visual landing,
2 a point on the desired course where the pilot changes over to another radio facility or a different system of navigation or
3 an omnirange facility.

Of major importance in the use of this principle is the effect of cross-wind on the flight path of the aircraft The characteristics of the approach system in funneling an aircraft toward a specified transition point also supply a type of automatic correction when the system is operating in a cross-wind condition Fig 3 illustrates an extreme case of an aircraft using a tangential approach with a direct cross-wind component equal to 50 per cent of the aircraft velocity The aircraft drifts toward the downwind side of the course until it reaches a point where its correction angle exactly balances the wind-drift angle plus the displacement angle. The aircraft then proceeds back toward the desired course and ultimately crosses the transition point The disadvantage of this procedure is that when the aircraft approaches the transition point, it is not on the desired course, but is approaching that course at an angle θ, Fig 3 If not compensated for, an extreme cross-wind such as the one indicated in this illustration would make the system unsuitable for approaches under extremely low ceiling and visibility conditions

Determination of Drift

As shown in Fig. 3, the correction system stabilizes when the following condition is reached·

$$\phi - w = \theta \qquad (1)$$

where

ϕ = correction angle
w = wind-drift angle
θ = displacement angle

After the flight path has stabilized on a straight track toward the transition point, the drift angle may be calculated from the existing correction angle and displacement angle

$$\phi - \theta = w \qquad (2)$$

It is then possible to compensate for the cross-wind by changing all the correction angles of the system by an amount equal to the wind-drift angle. This may be accomplished quickly and easily through the use of a rotatable correction scale, as indicated in Fig. 4 This arrangement effectively cancels out the cross-wind component on the final approach course, producing a flight path very close to the path taken under a no-wind condition As a result, the aircraft is lined up on the desired course before it crosses the transition point

Effect of Changing Correction Factor

As shown in Figs 1 and 2, the approach system is designed so that the correction angle is a function of the displacement angle. This relationship is expressed by the formula

$$\phi = K\theta \qquad (3)$$

where

ϕ = correction angle
K = correction factor
θ = displacement angle

Various values of K were tried in this study. Theoretically, any value greater than unity will function to bring the aircraft toward the desired course, but, for practical purposes, values between 2.0 and 5.0 appear most satisfactory in actual operations. It has been found that increasing the correction factor provided more correction for the same amount of displacement and had an effect analogous to narrowing the course. A higher correction factor tends to bring the aircraft to the desired course sooner, thus lengthening the final approach path This effect is apparent in Fig 5

However, the ability of an aircraft to line up on a desired course also depends on the amount of angular heading change required, the turning radius of the aircraft and the space available in which to accomplish the necessary change in heading Unless the aircraft becomes affected by the correction system a sufficient distance from the transition point, it may not be able to accomplish the necessary heading change to get lined up on the desired course before it reaches the transition point In this respect, an increase in the correction factor tends to delay the start of the initial turn, as illustrated by the flight path of aircraft B in Fig. 5B.

Although the base leg of this aircraft was as far out as that of aircraft A, Fig. 5A, the start of the initial turn of aircraft B was delayed to the extent that it finally overshot the desired course. Normally, higher correction factors tend to keep the aircraft closer to the desired course at all times, since a smaller change in the displacement angle produces a larger change in the correction angle. This effect is apparent in comparing Figs. 3 and 5, and also Fig 6. An extremely high correction factor is not desirable If unnecessarily large correction angle changes are started, the aircraft may turn toward, but overshoot, the desired course. As a result, a periodic hunt may develop.

APPLICATION OF THE TANGENTIAL APPROACH TO RADAR OPERATIONS

Using present operational methods, considerable skill is needed by a radar operator to line up an aircraft precisely on a desired track This procedure includes the following basic steps.

1 Operator determines that the aircraft is off course.
2 Operator estimates the lateral error and determines correction angle to be used, taking into consideration the turning radius of the aircraft and the distance available ahead to the point where the aircraft must be lined up with the course.
3. Operator computes the new heading.
4 Operator transmits the new heading to the pilot.

In order to reduce the skill required to direct a PPI approach, as well as to reduce the mental effort, time lag and possibility of human error in going through the various steps of this procedure, attention has been directed toward applying this approach system to the ASR radar scope. The simplest method is to provide a grid or an overlay to the scope, as shown in Fig. 7. Operation of this system is extremely simple. Coming into the range of the scope, the aircraft is first given a heading as necessary to enable it to enter the approach system at a sufficient distance from the transition point so that it will have enough space in which to accomplish the necessary turn to the final approach course. As the radar return crosses any radial line on the grid scale, the operator simply reads to the pilot the magnetic heading which appears at the end of the radial line. This heading furnishes the proper correction angle As the aircraft crosses subsequent radial lines, the new headings are read directly from the scale to the pilot. Since the correction angle decreases as the aircraft approaches the desired course, the aircraft ultimately "spirals" into the desired course, intercepting it at a very shallow angle This latter characteristic greatly reduces the amount of skill required by the operator, since it is no longer necessary for him to anticipate or lead the pilot in making heading changes as required All headings are read directly from the correction scale. Miles from touchdown and corresponding altitudes of the glide path are printed at the ends of the concentric range marks on the overlay and may be read directly to the pilot when the aircraft crosses the various range marks. Although the overlay is the simplest and cheapest method of implementing a tangential approach system in conjunction with a radar scope it has the following disadvantages·

1. Radial lines converge at the transition point, becoming harder to differentiate as the radar return nears the latter point

2 The heading correction scale is fixed, so the system is not readily adaptable for quick changes in landing direction or for wind-drift adjustments.

In order to compensate for these disadvantages, a rotatable cursor assembly, as illustrated in Fig 8, has been designed and tested This assembly overcomes the difficulty of the converging lines by eliminating all lines on the scope face Instead, it uses a pivoted transparent cursor which can be moved by the operator to follow the radar return The heading is read from the correction scale around the circumference of the scope. This correction scale is a circular ring which may be adjusted in azimuth in order to compensate for known cross-wind conditions. The entire assembly may be rotated in order to change operations to a different direction of landing. In addition, the distance from the transition point to the touchdown point may be varied as required

RADAR SIMULATION TESTS

The objective of any PPI approach is to guide the aircraft to a point on the approach course, headed toward the airport and at the proper altitude, from whence the pilot can take over and make a visual approach In order to determine the relative advantages of the tangential radar approach versus the present manual radar approach, a total of 960 approaches were made on a 2/1 radar simulator

The 2/1 radar simulator is a mechanical device with a 17-inch circular scope. The scope face is made of plexiglass and can be covered with translucent overlays marked to represent runways and surrounding terrain for any desired airport See Figs. 9 and 10. The heart of the trainer is a Haydon synchronous motor which powers the movement of the simulated radar return The electric motor is mounted on a swiveling head so that it can be turned to drive the mechanism in any direction A simple cable and pulley system hooks it up with the azimuth control wheel The simulated radar return is a spot of light on the scope face It comes from a small pilot light which is mounted directly over the clock motor and is projected up through a tiny hole in the projector See Fig 11 In operation, the spot of light moves across the scope face at a constant scale speed of 285 mph This speed is approximately double the approach speeds of present commercial aircraft, and accounts for the fact that this madhine is called a 2/1 simulator. The doubled speed rate is advantageous for laboratory studies because it allows operational tests to be made in one-half the usual flight time.

All turns in the simulation tests were conducted at the rate of six degrees per second. Since the flight path was flown at twice the normal approach speed, the six degrees per second turning rate produced a flight path corresponding to the standard rate of three degrees per second at normal approach speed.

On each simulated approach, the run was started with the aircraft on base leg Standard radar phraseologies were used to turn the aircraft on final approach and guide it down the final approach path to the transition point, which was assumed to be a point on final approach, one mile from touchdown

Three factors were measured on each run, as follows·

1. The number of separate heading changes necessary in guiding the aircraft down to the transition point This factor is indicative of the relative communications load required for this operation.
2 Horizontal error (lateral distance from the final approach course) as the aircraft passed the transition point. This factor is indicative of the relative precision of the system Measurements were taken in inches The scale of the scope display was 1.55 inches to the mile.
3. Heading difference (angle between the bearing of the final approach course and the actual heading of the aircraft) as the aircraft passed the transition point This factor indicates the amount of heading change which the pilot would be required to make between the transition point and the touchdown point, assuming that a cross-wind landing gear was not used Measurements were taken in degrees The tangential approach system used in these tests utilized a correction factor of 3 0.

Phase I of the study compared the manual and tangential approach systems under no-wind conditions.

Phase II compared the systems with a wind drift of ten degrees, assuming that the tangential system was not corrected for drift.

Phase III compared the systems with a wind drift of 20 degrees, assuming that the tangential system was not corrected for drift

Phase IV was similar to Phase III, except that the tangential system was corrected to compensate for the 20-degree wind drift

Phase V compared the two systems in making a 270-degree delay pattern from base leg to final approach, under no-wind conditions

Results of these tests are listed in Table I. They are summarized as follows·

Communications

The tangential approaches consistently required more heading changes than the manual approaches throughout the tests. The over-all average was· Manual - 4.02; Tangential - 5.59 changes per run.

Precision

Over the entire range of the tests, the tangential approaches showed smaller lateral errors than the manual approaches. Average errors throughout the tests are shown in Table II.

The errors apply to the mechanical simulator, and are not as large as would be encountered in actual ASR operations, since they do not include the azimuth and range errors which would be present on the radar scope. Although the lateral errors of the corrected tangential runs in Phase IV were somewhat greater than the uncorrected runs in Phase III, the heading differences of the corrected runs were considerably less. It should be realized that PPI approaches with 20-degree drift will be extremely rare except on single runway airports, inasmuch as the chief reason for making an approach on PPI is to land the aircraft into the prevailing wind when such wind is not aligned with the ILS or GCA runway.

Link Simulation Tests

In order to check the validity of the 2/1 simulator tests, 20 simulated PPI approaches were made on a Link trainer Ten of these approaches were manual and ten were tangential. The accuracy of the Link approaches was not as good as the 2/1 simulator approaches because the Link flight paths were much harder to follow. However, the Link tests verified the previous findings, viz , that the tangential approaches consistently had smaller lateral errors than did the manual approaches. One difference brought out in the Link tests was the fact that the manual approach required an average of 7.6 heading changes as against an average of 7.8 for the tangential approach

Other Findings

Tests showed that the tangential approach required considerably less skill than the manual approach In several cases, stenographers with no previous radar training and with only a few minutes instruction were able to direct perfect tangential approaches on the 2/1 simulator Although the tangential approach system includes a large series of correction angles coupled with displacement angles, it is not necessary to use all the corrections to make a successful approach. Corrections may be skipped as necessary in order to direct the flight path in accordance with other considerations In other words, the tangential approach system used in conjunction with a radar scope does not restrict the normal use of the scope in any way, but provides an extra advantage when needed. This feature is especially useful in air traffic control, since one of the most effective methods of providing adequate separation between aircraft is through the use of path-stretching techniques, as illustrated in Fig. 12. The tangential approach system is extremely useful for this purpose, as an aircraft can be kept on an arbitrary heading until sufficient separation has been obtained from other aircraft, at which point a tangential approach can be started instantly, using the headings obtained from the correction scale Using the Navascreen, a variation of this technique, the tangential peel-off has been tried. In this case, a covey of aircraft initially separated by altitude is brought on a base leg into a tangential approach system Using selected corrections, the group is fanned out, then each aircraft is brought in for a successive approach as soon as adequate separation is obtained from the preceding aircraft. Since all heading corrections are obtained automatically from the heading correction scale, the entire procedure is relatively simple to accomplish. It appears that this procedure may have value in military operations.

APPLICATION OF THE TANGENTIAL APPROACH TO OMNIRANGE FLIGHT TECHNIQUES

The initial study of the tangential approach was based on securing guidance from ground-derived (radar) indications However, it soon became apparent that the same guidance information could be obtained by the pilot from air-derived indications in flying the omnirange. When the deviation indicator is calibrated to a course sensitivity of 30 degrees, each dot of deflection from center indicates a displacement angle of approximately 3 degrees, as illustrated in Fig. 13. Knowing the displacement angle at all times, it is possible for the pilot to apply a suitable correction factor and make a tangential approach to the desired course. If a correction angle of 10 degrees per dot is used, the correction factor K in the equation $\phi = K\theta$ is 10/3 or 3.333, which is within the range of the values which tests indicate are satisfactory for use in actual operations. The number 10 has the additional advantage of ease in handling in the quick mental calculations of correction angles

Application of a 10-degree correction for each dot of deflection was first tested on the 2/1 simulator, which established the fact that use of this guidance principle should make practical a 1-minute holding pattern on any omnirange; since, indicator guidance always should be available during the last half of the outer turn to realign the aircraft quickly on the inbound course A simple mock-up was constructed to demonstrate this principle Meanwhile, the idea of basing the correction angle on displacement information received from the deviation indicator was tested on the Link trainer A 30-degree course sensitivity was not available, but the automatic ILS attachment to the Link trainer provided a course sensitivity of 8 degrees. In this case, it was decided to use a correction of 5 degrees for each dot of deflection, which was equivalent to a correction factor of

6 25 for this narrow course The figure of five degrees was chosen for its relative ease of handling in quick mental calculations. Using this system of correcting five degrees for every dot of deflection, a relatively inexperienced instrument pilot then proceeded to fly the automatic ILS course in the Link trainer It was found that the system took most of the work out of finding the course and making corrections to stay on course, as the pilot no longer had to grope for the beam but now had definite, precise limits on which to base his corrections It was found relatively easy to make a 1-minute race track holding pattern at the middle marker and to get aligned on the inbound course immediately at the conclusion of the outer turn Many tests were made by deliberately pulling off the narrow ILS course and quickly lining up on it again, using the system. Later, the 10-degree per dot correction system was tried out in a DC-3 aircraft while flying a 1-minute holding pattern on the Indianapolis terminal omnirange. The system aided in aligning and maintaining the aircraft on the inbound course, and functioned exactly as had been predicted by the simulator tests.

It should be understood that a deflection of, for example, 5 dots does not necessarily mean that the pilot should complete a turn to a correction angle of 50 degrees It merely indicates that the pilot should start a turn toward that heading and continue it only until a different indication is received Thus, the 50-degree correction angle should be thought of only as a maximum limit In many cases the needle will indicate a 4-dot deflection before the turn has proceeded very far, in which case the pilot should realize that a 40-degree correction angle will be the maximum limit to the turn. As the needle passes the 3-, 2- and 1-dot indications, the pilot should ease off the correction angle correspondingly so as to spiral the aircraft precisely into the desired course. The entire correction process is continuous, and the advantage of the system as a new flight technique is the fact that it supplies the pilot with definite maximum limits for his changes in heading This feature minimizes overcorrection and subsequent oscillation of the flight path

As illustrated in Fig 4, it is possible to compensate for a known cross-wind in flying the omnirange by substituting for the desired course the heading which will enable the aircraft to stay on such course. All other corrections are adjusted accordingly For example, in using the 10-degree per dot correction system, assume that the desired course is 360 degrees toward the station, but that a heading of 10 degrees will be required in order to compensate for a known cross-wind from the right In this case the pilot simply substitutes, in all his mental calculations, the heading of 10 degrees for the desired course of 360 degrees. Thus, a 1-dot deflection to the right would indicate a new heading of 20 degrees, two dots 30 degrees, etc.

CONCLUSIONS

1. Simulation tests indicate that use of the tangential approach principle in conjunction with surveillance radar will increase the accuracy of approaches and reduce the amount of skill and concentration required by the controller

2 Simulation and flight tests indicate that use of the tangential approach principle in conjunction with the deviation indicator may simplify omnirange flight procedures and make possible increased accuracy of interception and alignment of aircraft on a desired omnirange course. Additional study and tests by other groups and agencies on the flight techniques required appear to be desirable

3. As a result of this investigation, it is believed desirable to study further the application of tangential approach principle to air traffic control techniques It is planned to include this work in the simulation program on air traffic control and the evaluation of the airport surveillance radar equipment at a later date.

APPENDIX I

MATHEMATICAL ANALYSIS OF THE TRAJECTORY OF THE AIRCRAFT UNDER THE TANGENTIAL APPROACH PRINCIPLE

In Fig 14 the basic geometry of the elements used in this approach principle is shown. The desired course to be followed is illustrated by the line AB. Point B is the location at which the aircraft is to be on the desired course. The aircraft is located at point C with a heading of ϕ with respect to the desired course. At this point, the aircraft is to start the approach to the desired course. This heading angle ϕ is proportional to the displacement angle θ since it is upon this principle the approach system is based. V is the air speed of the aircraft with components V_p and V_θ.

From the geometry of the figure and the relation $\phi = K\theta$, the following equations can be obtained·

$$V_p = \frac{dp}{dt} = V \text{ Cos } (K-1)\ \theta \qquad (1)$$

$$V_\theta = p\ \frac{d\theta}{dt} = V \sin (K-1)\ \theta \qquad (2)$$

Using these two equations, the trajectory of the aircraft can be stated as follows

$$\frac{1}{p}\ \frac{dp}{d\theta} = \cot\ (K-1)\ \theta \qquad (3)$$

This integrates into

$$p = c\ [\ \sin\ (K-1)\ \theta\ ]^{\frac{1}{K-1}} \qquad (4)$$

where c is a constant.

If the starting location of the aircraft is known and a value for K is assigned, the equation of the path can be determined. For example, if K = 2 and p = 10 when θ = 45 degrees, the equation of the approach path will be

$$p = 14.14 \sin\theta \qquad (5)$$

If we change K to 3, as used during part of the investigations, then

$$p = 10 \sqrt{\sin\ 2\theta} \qquad (6)$$

In all cases, we find that the path is tangent to the desired course at point B.

TABLE I

PHASE I

90-degree Approach
No Wind

Total Runs 120 Manual
120 Tangential

Base Leg Miles from Touchdown	MANUAL						TANGENTIAL					
	No. of Changes		Lateral Error		Heading Difference		No. of Changes		Lateral Error		Heading Difference	
	Avg	Max	Avg	Max	Avg.	Max	Avg.	Max.	Avg	Max.	Avg.	Max.
8	3 80	7	0 028	0 11	1.4	5	7.35	11	0 020	0.07	1.1	4
7	4 15	7	0 021	0 06	1 1	4	6.10	8	0.017	0.05	1.1	5
6	3 65	6	0 021	0 05	1 6	5	6 65	8	0.013	0.07	1.7	10
5	3 70	6	0 020	0.05	1.4	5	6.30	7	0.010	0 04	0 6	2
4	3 30	5	0 033	0.15	1.7	5	5.80	8	0.013	0.05	1 2	10
3	2 95	4	0 056	0 25	4 3	15	3.10	8	0.042	0.20	1.9	10

PHASE II

90-degree Approach
10-degree Wind Drift

Total Runs· 120 Manual
120 Tangential Uncorrected

Base Leg Miles from Touchdown	MANUAL						TANGENTIAL UNCORRECTED					
	No of Changes		Lateral Error		Heading Difference		No of Changes		Lateral Error		Heading Difference	
	Avg	Max.	Avg	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.	Avg.	Max.
8	4 75	7	0 027	0 08	11.0	15	5.70	8	0.028	0.10	13.9	20
7	4 75	7	0 029	0.10	12.5	20	5.75	9	0.021	0 05	15.6	20
6	3 80	5	0 015	0 05	11 0	15	5 05	8	0.013	0.05	15.6	20
5	3.50	6	0 021	0.08	10 8	15	5 90	9	0.027	0.10	15.2	22
4	4.05	6	0.034	0 08	10 9	19	5.90	9	0.031	0 10	14.4	20
3	3 90	6	0 041	0.08	11 8	25	8.05	16*	0 033	0.07	14.1	20

* In some runs, a large number of intermediate corrections were issued in order to determine whether any improvements in accuracy would result No appreciable improvement was noted, however

PHASE III

Total Runs
120 Manual
120 Tangential Uncorrected

90-degree Approach
20-degree Wind Drift

Base Leg Miles from Touchdown	MANUAL No. of Changes		Lateral Error		Heading Difference		TANGENTIAL UNCORRECTED No. of Changes		Lateral Error		Heading Difference	
	Avg	Max	Avg.	Max.	Avg	Max	Avg.	Max.	Avg.	Max.	Avg.	Max
8	5.15	8	0.033	0.07	21.0	25	6.70	14*	0.015	0.05	33.5	36
7	4.60	6	0.019	0.05	20.8	25	5.35	9	0.011	0.06	34.1	38
6	3.65	7	0.018	0.08	20.7	25	5.60	8	0.018	0.10	31.1	37
5	3.50	6	0.022	0.06	21.0	28	5.10	8	0.014	0.06	34.2	38
4	3.10	4	0.025	0.05	19.9	23	6.05	20*	0.019	0.10	32.4	36
3	2.95	5	0.046	0.12	22.3	50	4.60	8	0.038	0.10	34.4	50

PHASE IV

Total Runs
120 Manual*
120 Tangential Corrected

90-degree Approach
20-degree Wind Drift

Base Leg Miles from Touchdown	MANUAL No. of Changes		Lateral Error		Heading Difference		TANGENTIAL CORRECTED No. of Changes		Lateral Error		Heading Difference	
	Avg	Max.	Avg.	Max	Avg	Max.	Avg	Max.	Avg.	Max	Avg.	Max.
8	5.15	8	0.033	0.07	21.0	25	6.10	7	0.029	0.06	19.5	25
7	4.60	6	0.019	0.05	20.8	25	5.60	7	0.022	0.06	19.1	27
6	3.65	7	0.018	0.08	20.7	25	5.65	8	0.027	0.07	19.8	26
5	3.50	6	0.022	0.06	21.0	28	6.15	8	0.019	0.06	18.7	23
4	3.10	4	0.025	0.05	19.9	23	4.95	7	0.024	0.06	18.8	24
3	2.95	5	0.046	0.12	22.3	50	4.95	10	0.036	0.09	19.2	25

* - Manual runs used in Phase III are listed for direct comparison.

* In some runs, a large number of intermediate corrections were issued in order to determine whether any improvements in accuracy would result. No appreciable improvement was noted, however

PHASE V

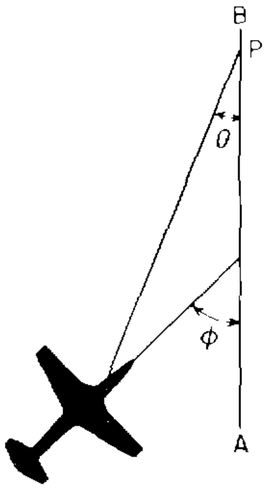
270-degree Delay Pattern
No Wind

Total Runs 60 Manual
60 Tangential

Base Leg Miles from Touchdown	MANUAL						TANGENTIAL					
	No. of Changes		Lateral Error		Heading Difference		No. of Changes		Lateral Error		Heading Difference	
	Avg.	Max.	Avg	Max.	Avg.	Max.	Avg	Max.	Avg.	Max.	Avg.	Max.
8	5.1	6	0.022	0.07	3.1	7	6.6	8	0.027	0.06	2.4	8
7	4.9	6	0.014	0.04	0.8	2	5.4	7	0.023	0.05	2.3	8
6	4.1	5	0.018	0.05	3.5	10	4.4	6	0.016	0.04	1.0	10
5	4.8	7	0.020	0.05	2.5	5	3.8	5	0.011	0.03	0.2	2
4	4.4	6	0.012	0.04	0.6	2	4.5	5	0.020	0.04	3.6	10
3	4.0	5	0.021	0.06	1.2	8	3.6	5	0.016	0.05	2.0	10

TABLE II

Base Leg	MANUAL		TANGENTIAL	
	Scope Error in Inches	Equivalent Error in Feet	Scope Error in Inches	Equivalent Error in Feet
3-4 miles	0.033	112	0.027	97
5-6 miles	0.019	65	0.017	58
7-8 miles	0.024	82	0.021	72



FORMULA

$C = Kd$, IN WHICH $\phi = K\theta$

K (CORRECTION FACTOR) MAY HAVE ANY VALUE GREATER THAN 1.0

LINE A-B = DESIRED COURSE
POINT P = TRANSITION POINT
ANGLE θ - DISPLACEMENT ANGLE
ANGLE φ = CORRECTION ANGLE

FIG I DEFINITIONS

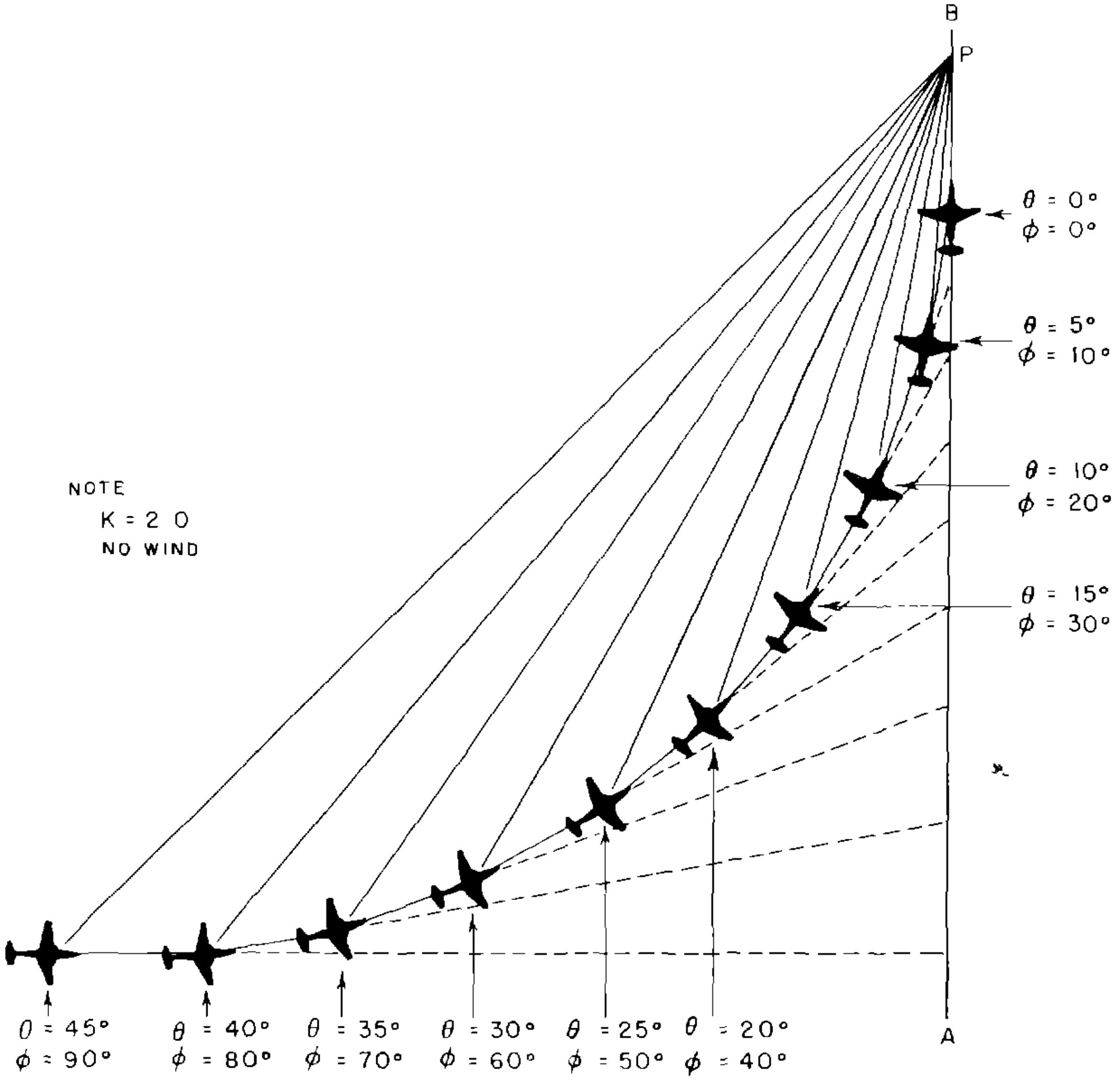
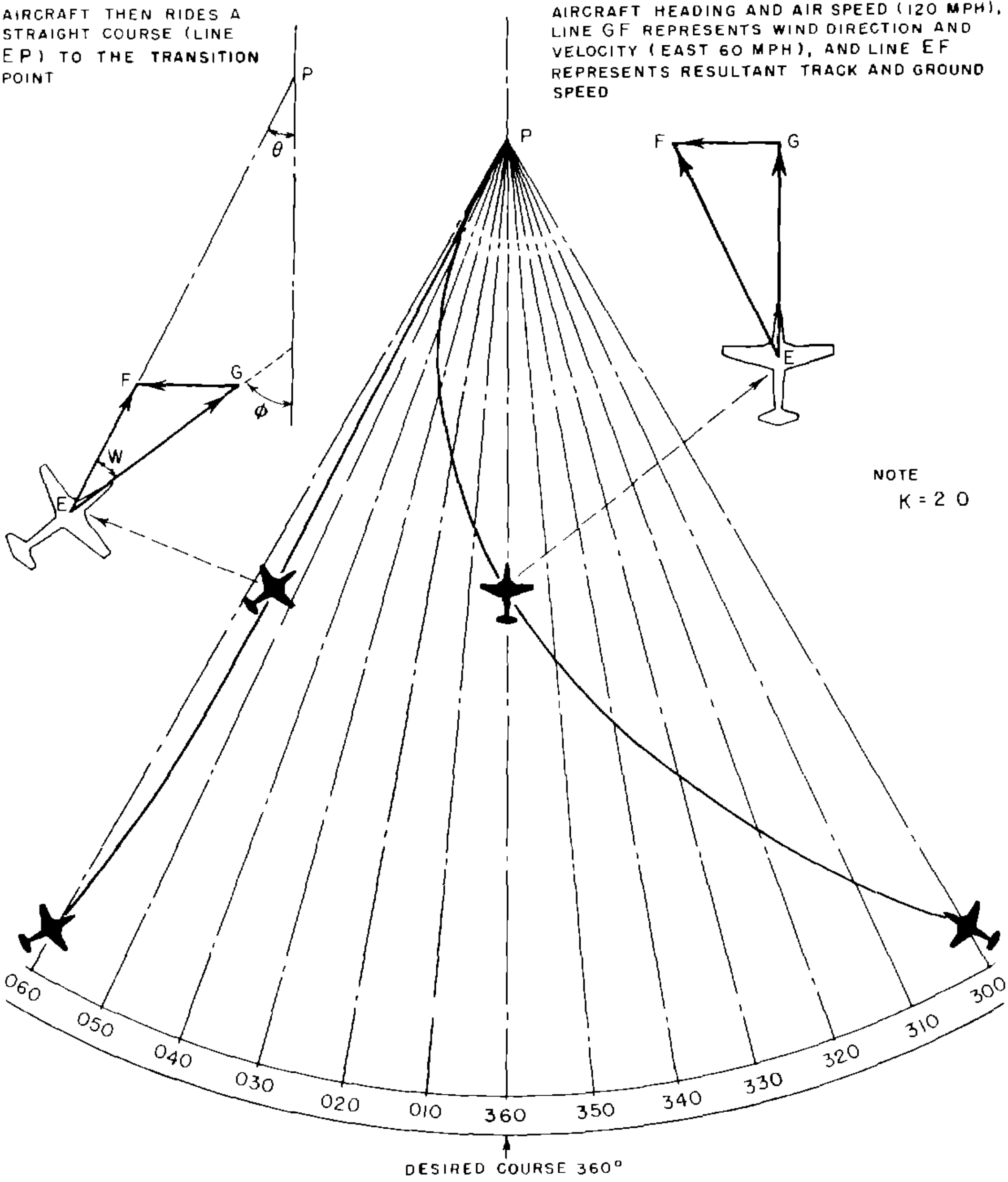


FIG 2 TANGENTIAL APPROACH



CORRECTION SYSTEM STABILIZES WHEN THE ANGLE ϕ (CORRECTION ANGLE) MINUS THE ANGLE W (WIND DRIFT ANGLE) EQUALS THE ANGLE θ (DISPLACEMENT ANGLE)

AIRCRAFT THEN RIDES A STRAIGHT COURSE (LINE EP) TO THE TRANSITION POINT

CROSSWIND COMPONENT DRIFTS AIRCRAFT TOWARD THE DOWNWIND SIDE OF THE COURSE. EVENTUALLY THE AIRCRAFT ASSUMES A CORRECTION ANGLE WHICH BRINGS IT BACK TO THE DESIRED COURSE AT THE TRANSITION POINT

IN WIND TRIANGLES, LINE EG REPRESENTS AIRCRAFT HEADING AND AIR SPEED (120 MPH), LINE GF REPRESENTS WIND DIRECTION AND VELOCITY (EAST 60 MPH), AND LINE EF REPRESENTS RESULTANT TRACK AND GROUND SPEED

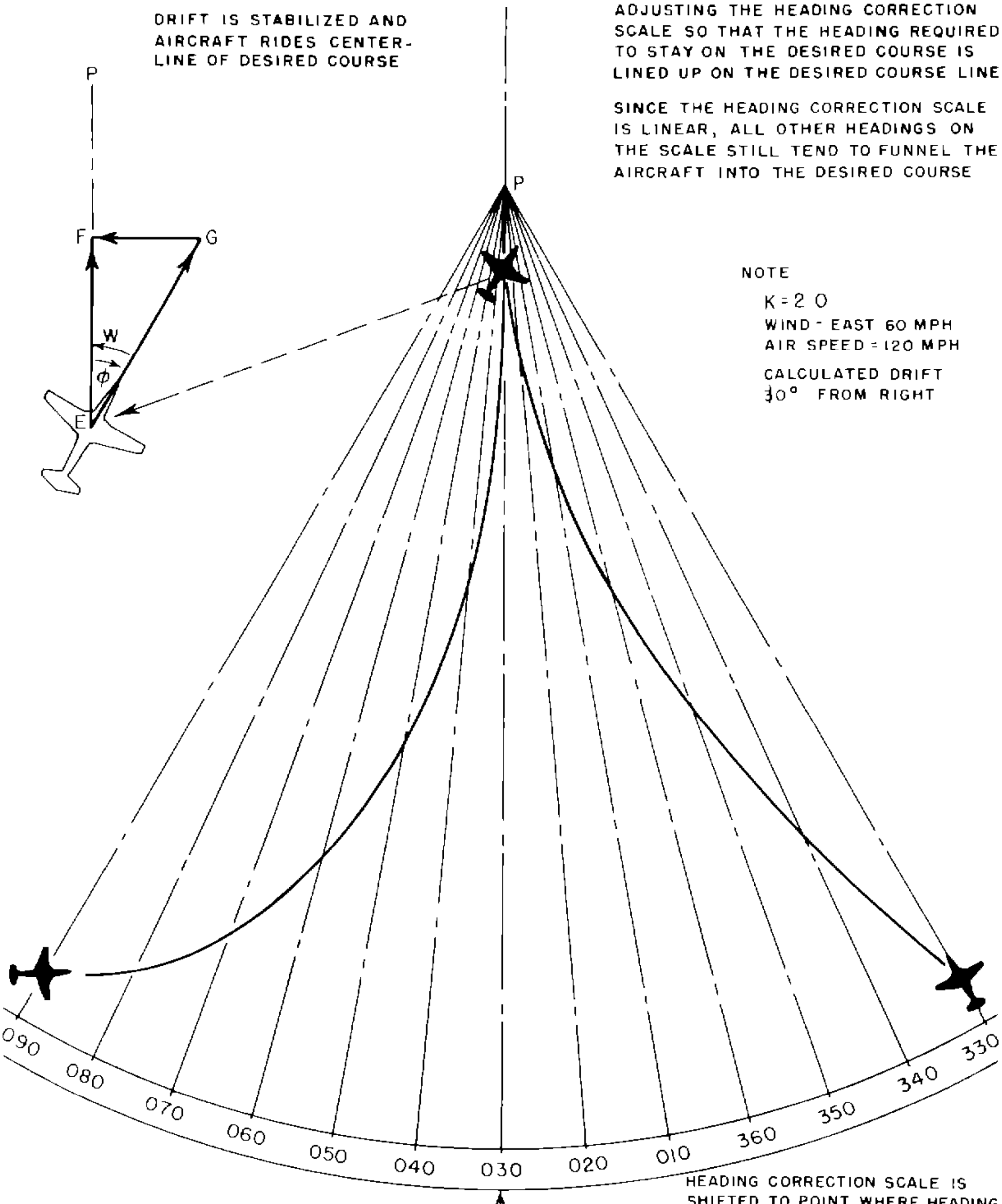
NOTE
K = 2.0

FIG 3 EFFECT OF CROSSWIND

$\phi - W = \theta$

$30° - 30° = 0°$

DRIFT IS STABILIZED AND AIRCRAFT RIDES CENTERLINE OF DESIRED COURSE



IF THE APPROXIMATE DIRECTION AND VELOCITY OF THE WIND IS KNOWN, IT IS POSSIBLE TO CORRECT FOR IT BY ADJUSTING THE HEADING CORRECTION SCALE SO THAT THE HEADING REQUIRED TO STAY ON THE DESIRED COURSE IS LINED UP ON THE DESIRED COURSE LINE

SINCE THE HEADING CORRECTION SCALE IS LINEAR, ALL OTHER HEADINGS ON THE SCALE STILL TEND TO FUNNEL THE AIRCRAFT INTO THE DESIRED COURSE

NOTE

K = 2 0

WIND - EAST 60 MPH

AIR SPEED = 120 MPH

CALCULATED DRIFT 30° FROM RIGHT

DESIRED COURSE 360°

HEADING CORRECTION SCALE IS SHIFTED TO POINT WHERE HEADING OF 030° LINES UP WITH DESIRED COURSE

FIG 4 CORRECTION FOR KNOWN CROSSWIND

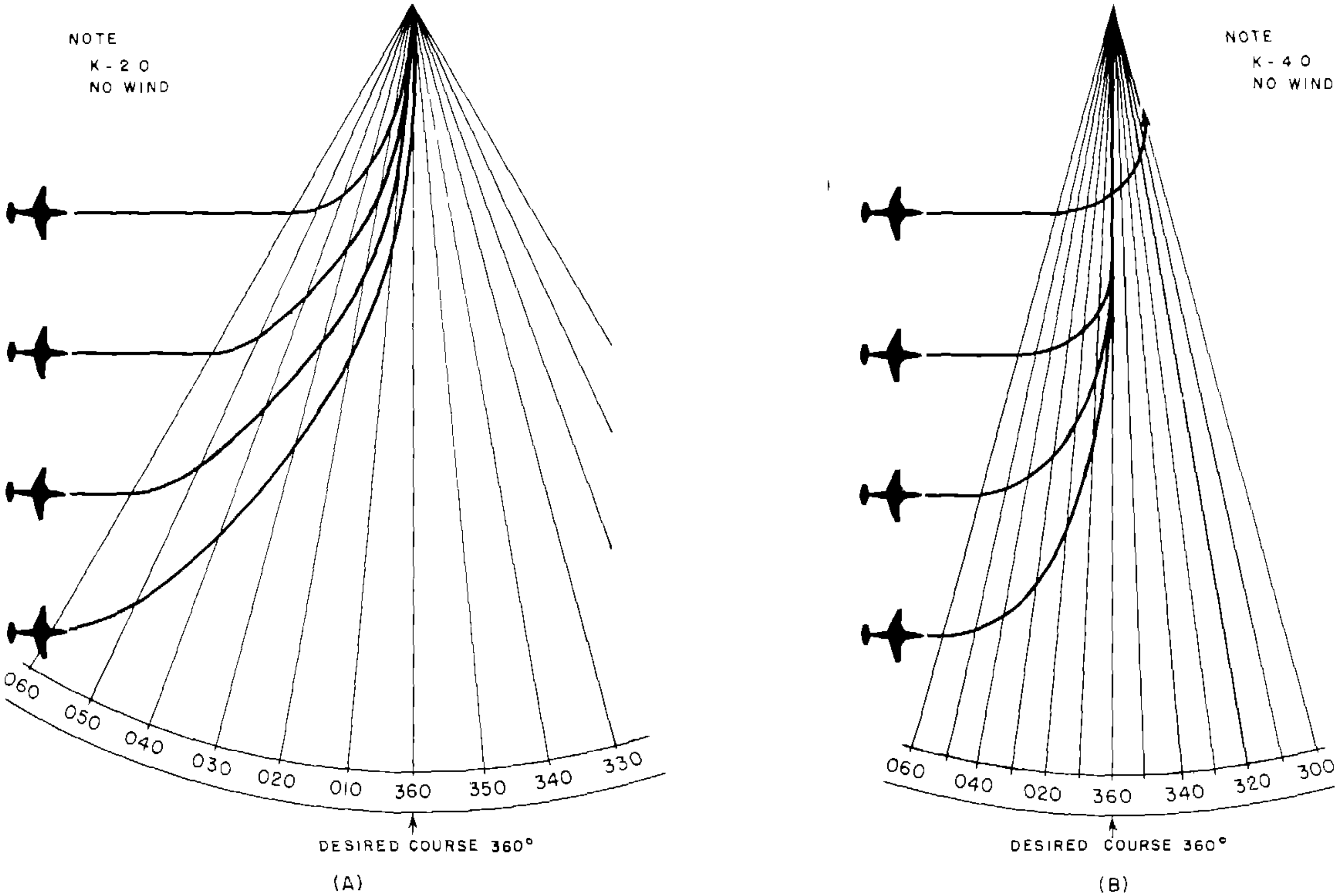


FIG 5 EFFECT OF CHANGING CORRECTION FACTOR

NOTE

K = 4 0

WIND = EAST 60 MPH (LINE GF IN WIND TRIANGLE)

AIR SPEED = 120 MPH (LINE EG IN WIND TRIANGLE)

$\phi - W = \theta$

COMPARE WITH FIG 3 HIGHER CORRECTION FACTOR REDUCES EFFECT OF WIND DRIFT ON FLIGHT PATH, FLIGHT PATH STABILIZES AT A LOWER DISPLACEMENT ANGLE, AND AIRCRAFT RIDES CLOSER TO DESIRED COURSE

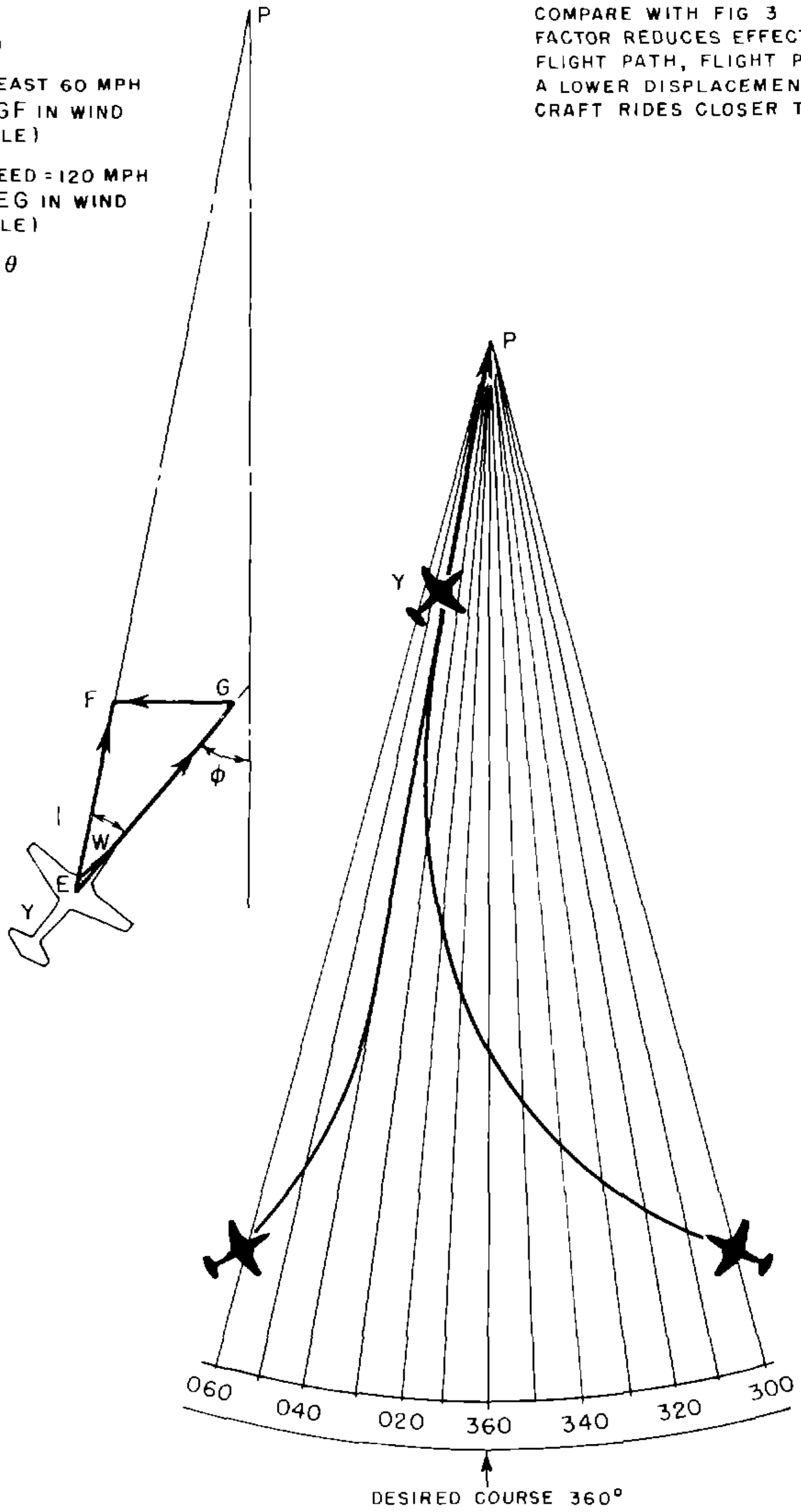
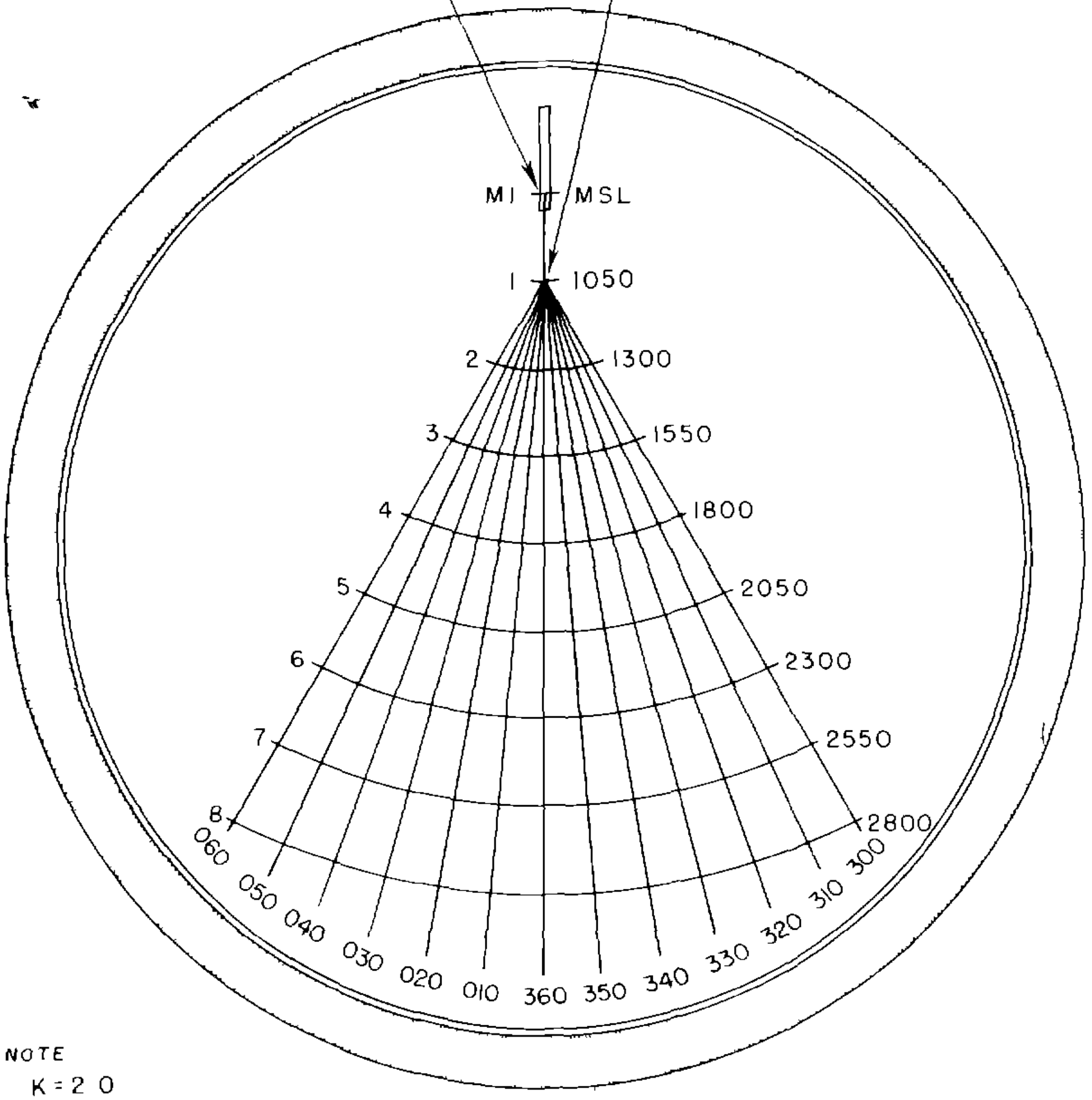


FIG 6 EFFECT OF CROSSWIND

SCOPE DISPLAY DECENTERED SO THAT RUNWAY TOUCHDOWN POINT COINCIDES WITH THIS POINT ON THE OVERLAY

TRANSITION POINT OF TANGENTIAL APPROACH SYSTEM LOCATED ONE MILE FROM TOUCHDOWN POINT ON RUNWAY



NOTE

K = 2 0

THIS OVERLAY IS CALIBRATED FOR A FIELD ELEVATION OF 800 MSL AND A DESCENT RATE OF 250 FEET PER MILE AND IS SUITABLE FOR PPI APPROACHES IN ONE DIRECTION (NORTH) ONLY A DIFFERENT OVERLAY IS USED WHEN THE DIRECTION OF LANDING IS CHANGED IN EACH CASE, THE SCOPE DISPLAY MUST BE READJUSTED TO LINE UP WITH THE OVERLAY IN USE

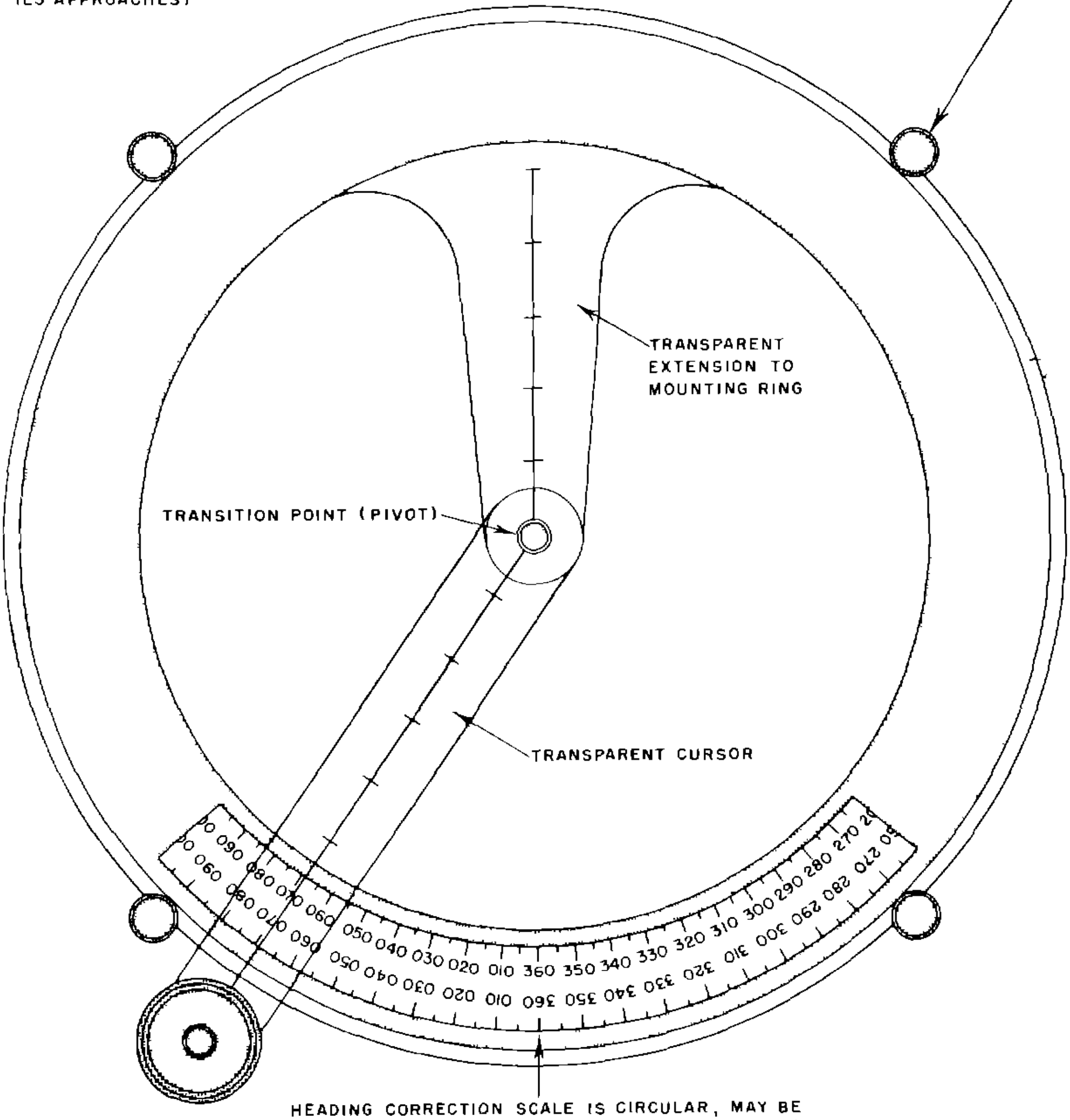
FIG 7 OVERLAY FOR ASR SCOPE

SCOPE DISPLAY DECENTERED TO ALIGN RUNWAY WITH INDEX LINE, DISTANCE TO TRANSITION POINT MAY BE CHANGED AS DESIRED (EXAMPLE WITH TOUCHDOWN POINT 4-5 MILES FROM TRANSITION POINT TANGENTIAL SYSTEM MAY BE USED TO VECTOR AIRCRAFT INTO LOCALIZER COURSE AT OUTER MARKER FOR ILS APPROACHES)

NOTE

ENTIRE ASSEMBLY MAY BE SHIFTED TO PERMIT APPROACHES IN ANY DIRECTION

SETSCREWS LOCK MOUNTING RING AND HEADING CORRECTION SCALE IN POSITION



HEADING CORRECTION SCALE IS CIRCULAR, MAY BE ADJUSTED FOR DRIFT CORRECTIONS (SEE FIGURE 4)

FIG 8 CURSOR ASSEMBLY FOR ASR SCOPE

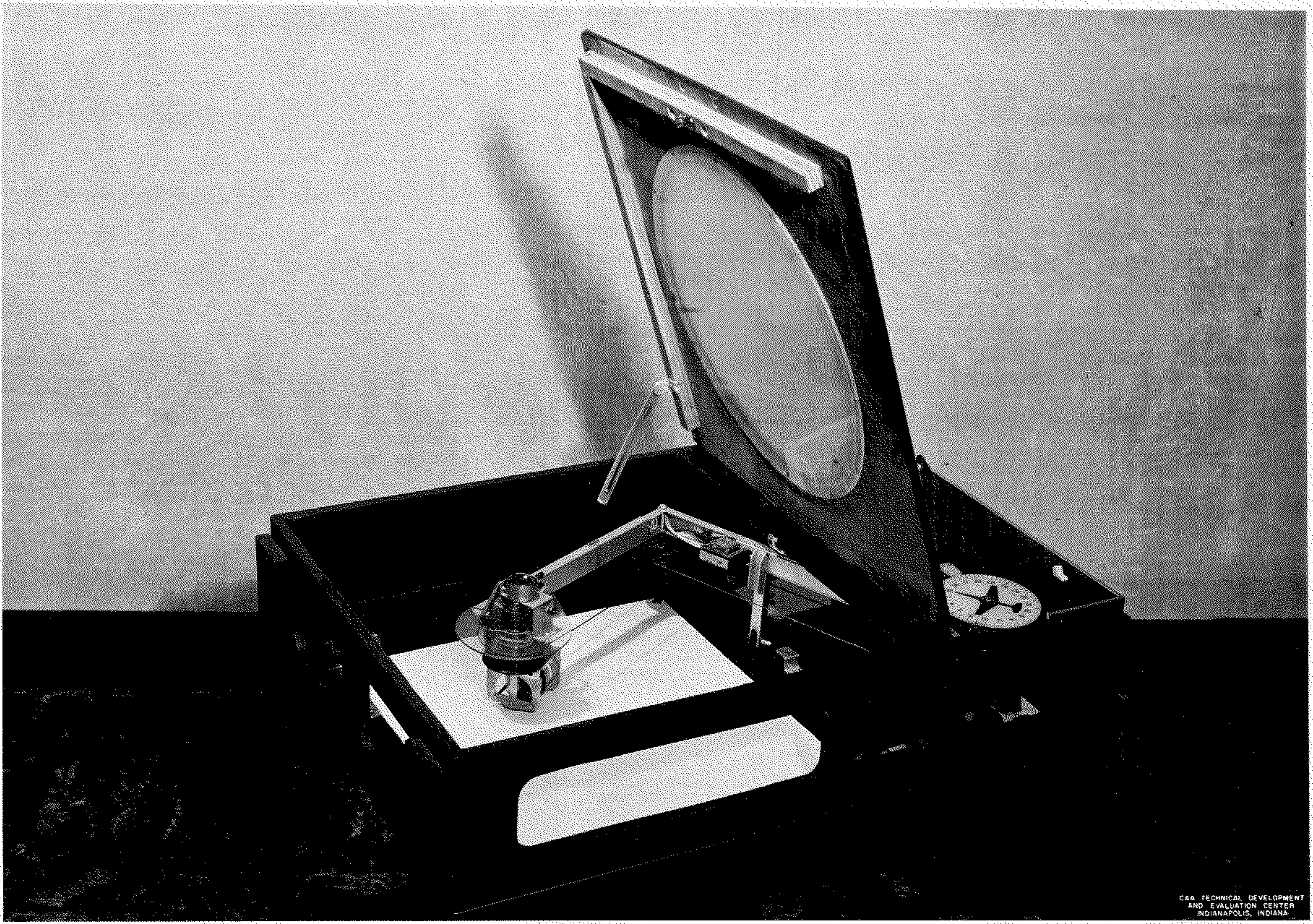


FIG. 9 INTERIOR OF 2/1 SIMULATOR

FIG. 10 2/1 SIMULATOR WITH CURSOR

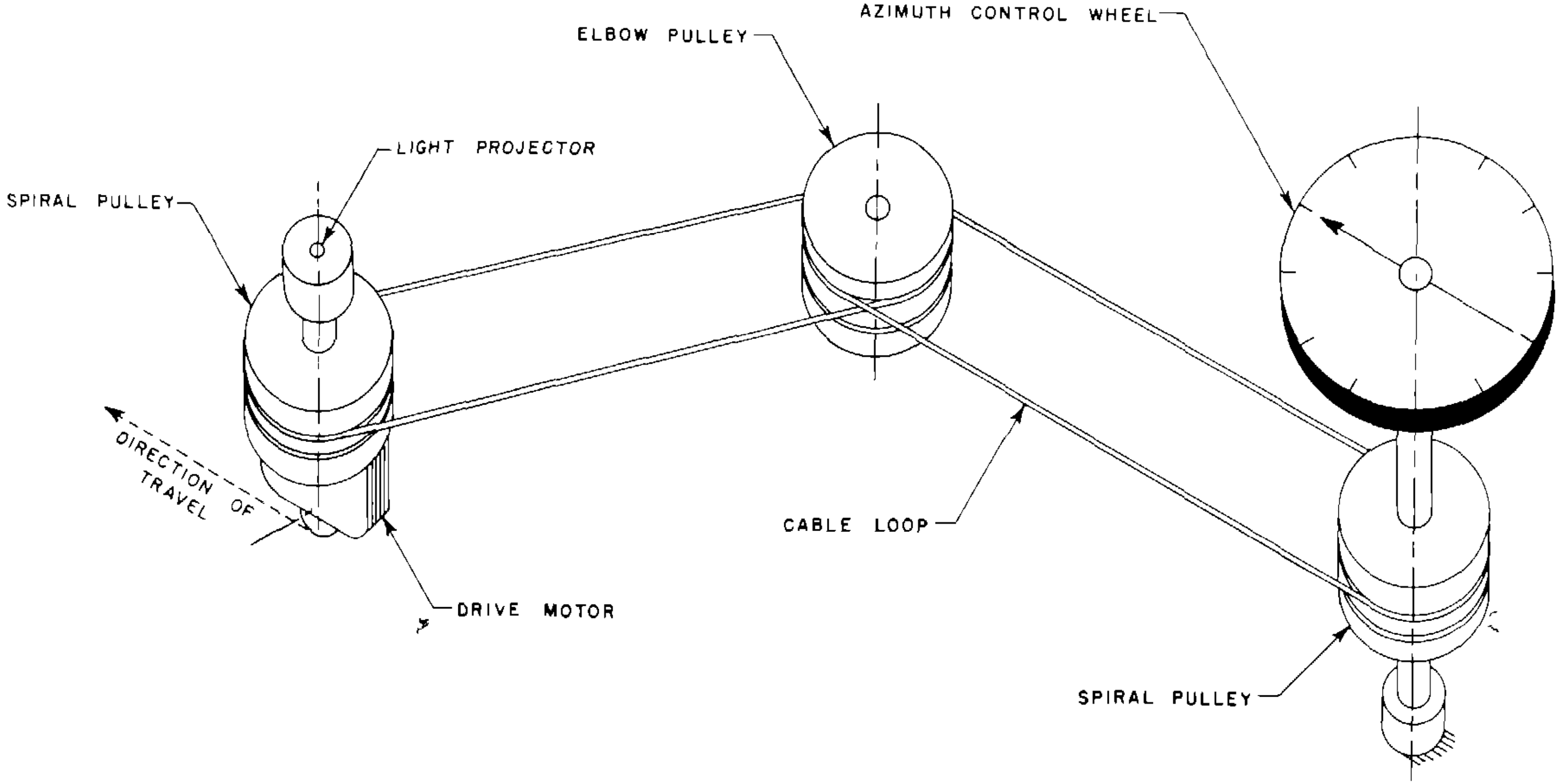
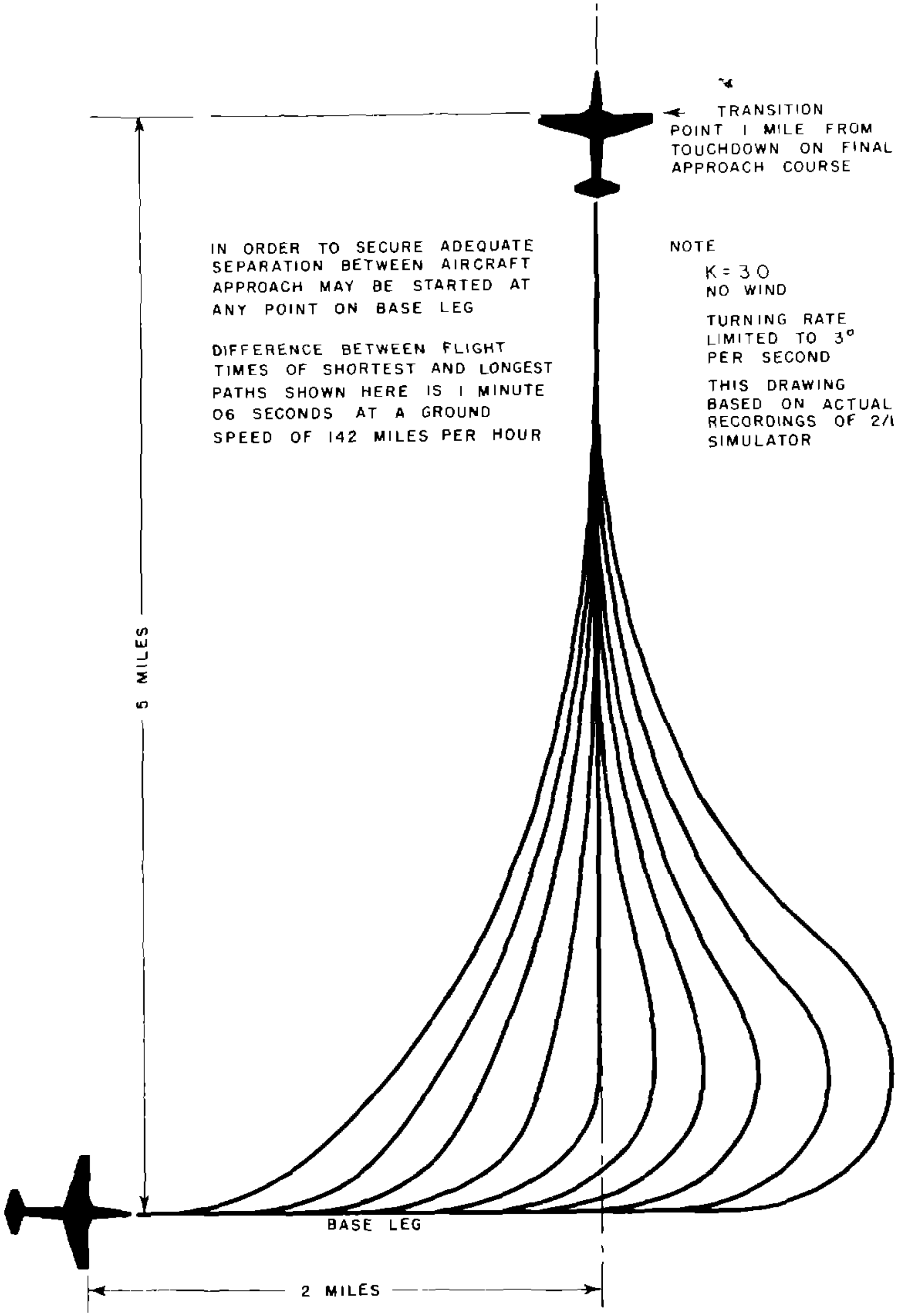


FIG 11 MECHANICAL HOOKUP OF 2/1 SIMULATOR



IN ORDER TO SECURE ADEQUATE SEPARATION BETWEEN AIRCRAFT APPROACH MAY BE STARTED AT ANY POINT ON BASE LEG

DIFFERENCE BETWEEN FLIGHT TIMES OF SHORTEST AND LONGEST PATHS SHOWN HERE IS 1 MINUTE 06 SECONDS AT A GROUND SPEED OF 142 MILES PER HOUR

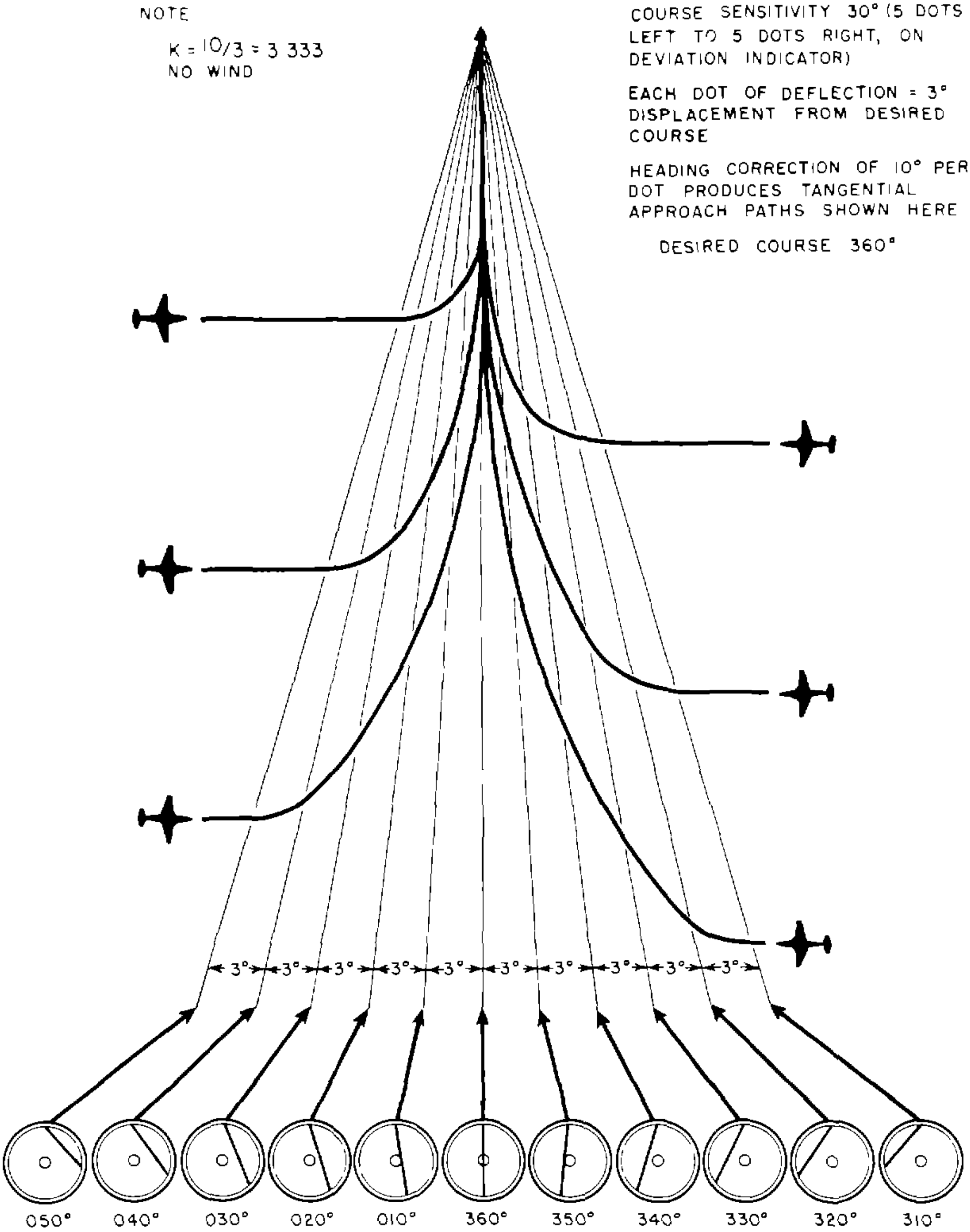
NOTE

K = 30
NO WIND

TURNING RATE LIMITED TO 3° PER SECOND

THIS DRAWING BASED ON ACTUAL RECORDINGS OF 2/1 SIMULATOR

FIG 12 PATH-STRETCHING TECHNIQUES



NOTE

K = 10/3 = 3 333
NO WIND

COURSE SENSITIVITY 30° (5 DOTS LEFT TO 5 DOTS RIGHT, ON DEVIATION INDICATOR)

EACH DOT OF DEFLECTION = 3° DISPLACEMENT FROM DESIRED COURSE

HEADING CORRECTION OF 10° PER DOT PRODUCES TANGENTIAL APPROACH PATHS SHOWN HERE

DESIRED COURSE 360°

ON RECEIPT OF INSTRUMENT INDICATIONS SHOWN ABOVE, PILOT STARTS A TURN TO THE CORRESPONDING GYRO HEADING, CONTINUALLY ADJUSTS HEADING IN ACCORDANCE WITH THIS SYSTEM

FIG 13 TANGENTIAL APPROACH TO OMNIRANGE

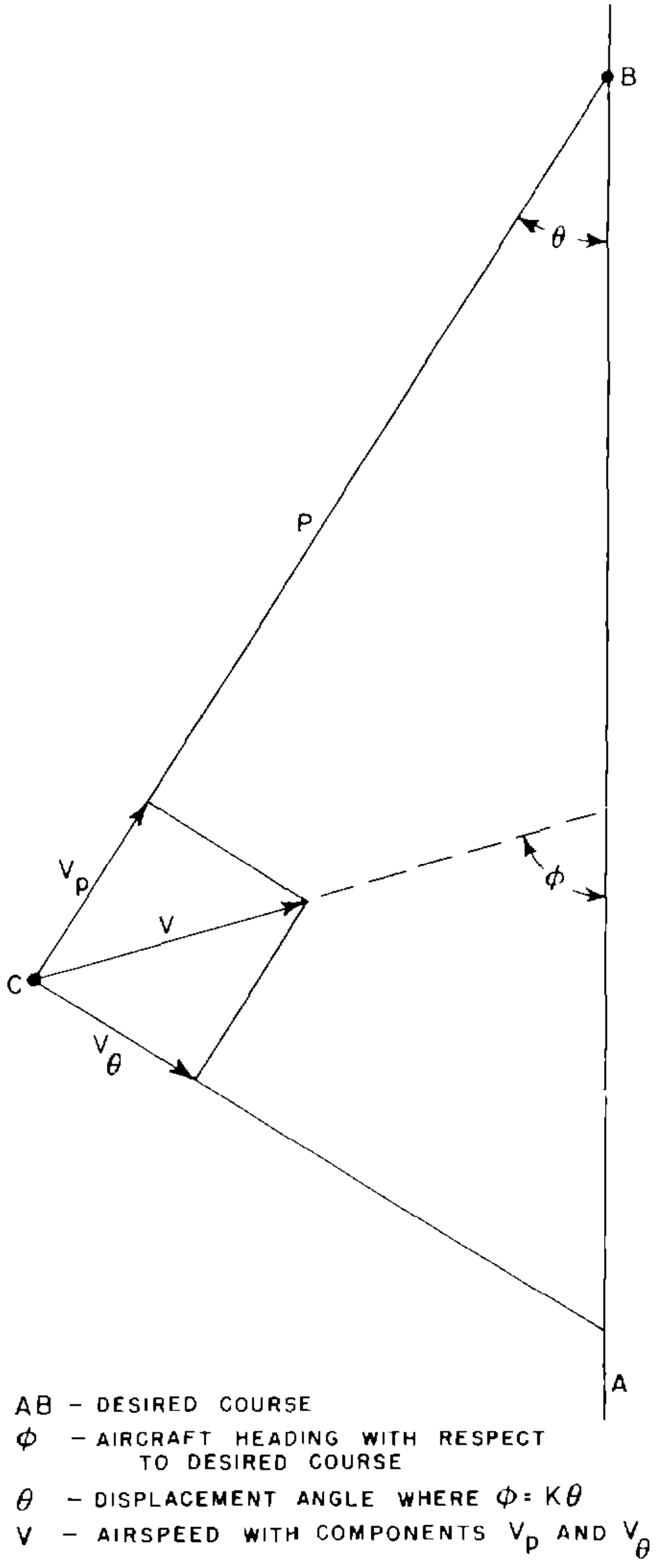


FIG 14 GEOMETRY OF TANGENTIAL APPROACH SYSTEM