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EFFECTS OF VARIOUS ANTENNA ROTATIONAL RATES ON A TYPE ASR-1 RADAR

FOR LIMITED DISTRIBUTION

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SUMMARY

This report describes operational and technical tests conducted to determine the effect of changing antenna rotational rates on Type ASR-1 airport surveillance radars. The operational phase of this program was performed by air traffic control personnel to establish the accuracy and relative work load imposed on the radar operator by approaches made at various rotational speeds. The program included additional tests using two or more aircraft to determine the effect of these varying rates on the ability of a controller to establish and maintain approved radar separation in an airport terminal area. Engineering personnel carried out a technical evaluation in order to ascertain the performance of the equipment at the varying rates.

The antenna rotational rates evaluated in this program ranged from 6 to 28 revolutions per minute (rpm). Two radars were used. An L-band radar located at the Technical Development and Evaluation Center at Weir Cook Airport, Indianapolis, Indiana was used in tests of 6, 9, 12, and 14 rpm. A Type ASR-1 S-band radar located at New York International Airport (Idlewild) was used in tests of 14, 18, 24, and 28 rpm. Measurements for the accuracy tests were compiled from 299 separate plan position indicator (PPI) approaches.

Results of the operational tests indicated that there was no correlation between the radar rotational rate and the approach accuracy over the entire rpm range tested. The accuracy of approaches at all rotational rates averaged well within the tolerance of the radar equipment itself. Summaries of the PPI approach results and of the individual controller accuracies are presented in tabular form. See Tables I and II.

The results also indicated that there was no correlation between the antenna rotational rate and the communications work load. However, it is apparent that there was a considerable increase in mental effort necessary to conduct approaches at rotational rates below 18 rpm. This increase was due to the increased extrapolation, known as "crystal balling," required in visualizing the current position of the aircraft involved. The results obtained from a questionnaire presented to the controllers after each run are tabulated in Table VI.

Technical tests on the Idlewild installation indicated that reducing the Type ASR-1 radar antenna rotational rate progressively from 28 rpm to 14 rpm produced no appreciable improvement in the moving target indicator (MTI) performance.

INTRODUCTION

At certain airport surveillance radar locations, severe ground clutter (which is the ground return, or the reflection from stationary targets) precludes satisfactory tracking and guiding of aircraft by radar through the clutter areas, even with the MTI adjusted for optimum performance. One solution to the problem appeared to be the reduction of the antenna rotational rate, since improved MTI performance was theoretically predicted at lower speeds. To validate the assumption, an evaluation of this technical problem was indicated. As a corollary to the MTI improvement evaluation, it was also necessary to determine what effect lowered antenna speed would have upon the operational use of the Type ASR-1 radar should the expected technical improvement in MTI materialize. At the request of the Administrator of CAA, TDEC assisted the Office of Federal Airways in performing this task. At a meeting held at TDEC on August 28, 1951, a committee was selected to plan the necessary program, to conduct the tests, and to prepare a report containing recommendations. This committee was composed of the following men from the Office of Federal Airways: Robert A. Taylor (Chairman), John A. Apuli, Bernard R. Boymel, and John F. Zwaska; and from the TDEC: Richard C. Borden and Norman R. Smith. This report contains a résumé of the tests and results of the evaluation program, together with conclusions regarding the effects of changing antenna rotational rates.

EVALUATION OBJECTIVES

The evaluation of various antenna rotational rates was made from tests conducted to determine whether reducing the rates would resolve technical and operational problems now associated with radar systems at terminal areas. The evaluation was made to determine:

1. Whether a decrease in rotational rate would improve the MTI performance of the Type ASR-1 radar.
2. The controller work load and degree of mental concentration required at the various rotational rates.
3. The accuracy with which PPI approaches may be conducted at various rotational rates when various aircraft speed types and classes are used.
4. The ability of a controller to establish and maintain approved radar separation between aircraft within a terminal area.

EVALUATION PROCEDURES

Before the accuracy tests were started, the extended runway center lines were surveyed to a point 280 feet from the approach end of each runway. Surveyor's stakes were established at these points to mark the location for the theodolite used in the approach tests. Two-way radio communications were established between the radar controller and the aircraft and also between the radar controller and the theodolite crew.

Personnel requirements for the accuracy runs included two men at the theodolite and two men at the radar control position. At the theodolite, one man performed the duties of tracker while the second man recorded the measurement data and handled the necessary communications. At the radar position, one operator performed the control functions while the other operator recorded the necessary data and co-ordinated the aircraft movements with the control tower. An audio oscillator, or beeper, was connected to the communication transmitter at the radar position; and as the aircraft passed each mile marker on the final approach, the radar operator depressed the beeper control which sounded a high-pitched tone as a signal to the theodolite operator to take a displacement reading. The displacement readings taken at the theodolite position, the record of headings issued, the target quality, and the comments of the operators formed the data for the accuracy tests.

Various speed classes of aircraft were utilized in conducting these tests. At Indianapolis, aircraft types included a Piper Pacer (slow class), several C-46 and DC-3 transports (medium class), and an F9F jet (fast class). At Idlewild, aircraft types included a Stinson (slow class), a twin-engined Beech and a DC-3 (both medium class), and an F84 jet (fast class).

Photographic records of the radar indicator were made at various antenna rotational rates. MTI performance was recorded by making time exposures showing an aircraft flying a box pattern around the airport and through areas where fixed targets produced high clutter density.

Throughout the evaluation all pilots were briefed regarding the necessity of flying only the headings issued by the radar operator, and they were requested to make no attempt to achieve a visual line-up with the runway. Close co-ordination was effected between the radar controller and the associated control tower in all instances. The control tower decisions regarding the granting or withholding of approach clearances were followed rigidly. In order to avoid interference with normal airport traffic, most of the PPI approaches were conducted on a runway other than that being used for take-offs and landings. For this reason most of the approaches were made with an appreciable cross-wind component which increased the radar controller's work load somewhat, since compensation had to be made for wind drift. However, since this complication was encountered throughout the test program, it is believed that it did not appreciably affect the relative accuracy of approaches at any specific antenna rate over those of any other rate tested.

OPERATIONAL EVALUATION

Operational Tests at Indianapolis.

When the L-band radar was used, it was noted early in the evaluation that any change in antenna rotational rate necessitated a realignment of the map overlay. Since the equipment did not have a readily accessible centering adjustment, it was necessary to have aircraft fly automatic instrument landing system (ILS) approaches to the instrument runways and to move the map overlay until it would coincide with the extended runway center line. Visual approaches were made to align the map overlay for those runways not served by an ILS. To insure accuracy of map alignment, the theodolite crew advised the radar controller whenever the aircraft was definitely established on course.

Fig. 1 shows the accuracies obtained for the PPI approaches made at Indianapolis at antenna rotational speeds of 6, 9, 12, and 14 rpm. The one-mile point displacements rated as usable (500 feet) and those rated as excellent (300 feet) are plotted in Fig. 3 and compared with the data taken at Idlewild. Fig. 4 shows typical points at which heading changes were transmitted to the pilot, and Table III lists the maximum and average number of heading changes required at different rotational speeds. During the runs, the locations of fade-outs were either noted or recorded on film and are shown in Fig. 5; a summary is provided in Table IV.

Photographic views of the PPI operating under various conditions, such as antenna rotational rate, gain, aircraft patterns, and different types of aircraft, are reproduced in Figs. 6 to 18.

Operational Tests at Idlewild.

Personnel conducting evaluation tests at Idlewild were advised by Idlewild controllers that the overlay map was accurate on all runways except Runway 22. The Idlewild controllers suggested that, when conducting approaches to Runway 22, the aircraft target should be directed to an imaginary runway center line parallel to and slightly to the right of the extended runway center line as shown on the map overlay. The map overlay inaccuracy for this runway may have contributed to the greater average error shown for the antenna rotational rate of 28 rpm, since several approaches were made to Runway 22 at that rate.

The ground clutter areas on the approaches to Runways 22 and 13 caused the aircraft target to fade out completely at a point two miles from the end of the runway. The targets were not visible again until about one mile from the end of the runway and in some instances were not visible again until they had turned away from the airport and were outbound two or three miles distant.

It is believed that this condition resulted in less accurate approaches to these runways because it was not possible to make any azimuth corrections after the aircraft target had reached a point two miles from the end of the runway.

Although the six-mile range would have provided for greater accuracy of approaches, it was necessary to use the ten-mile range at Idlewild because of the large area of the airport. The final approach courses to Runways 4 and 7 were found to be relatively free of ground clutter areas, and the targets did not disappear for an excessive length of time. The traffic patterns used for radar test approaches at Idlewild are shown in Fig. 26.

The MTI performance proved to be unsatisfactory at all antenna rotational rates evaluated. In numerous instances and as a result of the ground clutter areas northwest, northeast, and south of the airport, a departing aircraft target was not observed by the radar controllers until the aircraft was from one to three miles from the airport. They also noted while guiding aircraft for an approach that targets would suddenly appear on the scope very close to the aircraft under radar control. In most of these cases the controller did not have time to issue traffic information to the aircraft being guided. The locations of the fade-outs during PPI approaches are shown in Fig. 19, and a summary is provided in Table V.

The accuracies obtained on final approach are shown in Fig. 2, and the individual controller accuracies are listed in Table II. These are also compared in Fig. 3 with the displacement obtained on the final approach at the one-mile point. The results of the questionnaire filled out by the controller after each run are listed in Table VI. The measurements taken on the communications work load are recorded in Table III by the method indicated by Fig. 4.

During one phase of the evaluation at Idlewild, a jet fighter was solicited to make PPI approaches. When the pilot contacted the radar controller, he was directed to proceed to the Floyd Bennett Naval Air Station at an altitude of 1,500 feet mean sea level (MSL), 500 feet higher than the normal altitude for other aircraft types. Controller personnel were not able to identify the aircraft target when the pilot reported over the Floyd Bennett Air Station; and numerous attempts (including 360° turns, various headings, and flight over known visual reference points) were made to establish identification. The pilot was directed to climb to 2,500 feet MSL, at which altitude identity was established and the radar controller was able to conduct a satisfactory PPI approach.

In order to determine the ability of a controller to establish and maintain approved radar separation between aircraft within a terminal area, 276 approaches were conducted with four F6F-type aircraft at the Idlewild Airport. These aircraft operated within a speed range of 80 to 190 knots. The speed of a particular aircraft was not known to the radar controller unless the information was requested. The approaches were conducted at radar antenna rotational rates of 28, 24, 18, and 14 rpm. Each aircraft was assigned a holding point. See Fig. 26. One was assigned to Point Able, two to Riis Park Intersection, and one to Long Beach Intersection. As soon as pilots reported that they had reached these points, radar guidance toward the final approach course was initiated to the aircraft in the order in which the reports were received. This was done to place the aircraft on the final approach course to Runway 4. At the same time, approved lateral separation between aircraft was maintained. After the initial run of four aircraft, the two aircraft that were originally assigned to Riis Park were directed outbound on a heading of 180°. After passing the outbound gate, these aircraft were again worked into the final approach course. The other two aircraft always returned to their respective fixes via direct routes and were again considered in the problem. This routing presented a control problem that was constantly changing throughout the test.

It is significant to note that although some control personnel indicated that as many as six aircraft could be guided at one time, all the radar guidance was accomplished over water areas and to a runway that was known to be relatively free of clutter areas. It is believed that this figure is not characteristic, if applied to the whole terminal area at Idlewild Airport, because of the large clutter zones existing over the land areas around the airport.

Photographs taken of the viewing screen of the radar operating under various conditions are reproduced in Figs. 20 to 25.

TECHNICAL EVALUATION

The engineering phase of the Type ASR-1 radar antenna rotational rate evaluation consisted of two separate parts. The first of these involved modification of the antenna drive system to provide reduced rotational speeds, and the second involved an engineering evaluation of the radar performance at reduced rates of antenna scan.

Equipment Modifications.

The Type ASR-1 radar antenna is driven by a 220-volt, 60-cycle per second (cps), single-phase, 3/4-horsepower (hp) motor. One limitation imposed upon the modification was that the radar, being a commissioned facility, could not be disabled for any appreciable length of time. A study of the electrical and mechanical changes required to replace the existing motor with either a lower speed ac motor or with a variable speed dc motor revealed that such a major change would not only result in a two- to six-month delay of the evaluation program but would also necessitate decommissioning the radar for two or three days. Furthermore, any failure of the modified antenna drive installation would require further disablement of the radar until such time as the trouble could be remedied or until the original drive system could be reinstalled. In view of this, some alternative method was sought which would not conflict with the operational demands upon the radar. It was suggested by the manufacturer that the motor be operated at reduced frequency and reduced voltage in order to achieve variable speed within certain limits. In order to ascertain that such a mode of operation would not damage the motor and to assure that satisfactory torque and horsepower could be maintained at reduced speeds, preliminary tests were conducted by TDEC engineers at Oklahoma City, using the Type ASR-1 radar installed at the CAA Aeronautical Center.

The tests indicated that such a procedure was completely satisfactory at speeds down to approximately 13 rpm. In order to provide a variable frequency source of power, a 220-volt gasoline generator was employed. It was decided that this technique was practical; and in preparation for the evaluation program, TDEC engineers were sent to Idlewild to perform a similar modification of the Type ASR-1 radar located at that airport. Design of this type of antenna drive motor is such that operation at antenna speeds below 12 rpm can result in connection of the starting winding of the motor, which is controlled by a centrifugal switch. In this case, if power is still applied, the starting winding will burn out almost instantly. In order to insure that this would not happen, two sets of line fuses were installed. When operating from the normal service of 220 volts at 60 cps, 50-ampere (amp) fuses were inserted in the line; however, when operating from the gasoline generator, these were replaced through relay control by 5-amp fuses. The circuit employed to provide variable speed is shown as Fig. 27. This arrangement required starting of the motor from the commercial power source to prevent failure of the 5-amp fuses. Since the speed-versus-voltage curve characteristic of the engine generator was not linear, it was necessary to use a Variac variable transformer to provide the proper proportional voltage at the reduced frequencies. In conducting the subsequent evaluation tests, the traffic controller was provided with a remote control switch by which he could select either the normal 28-rpm antenna scan (in which case the drive motor was fed by its normal supply) or any pre-set rotational speed from 14 to 28 rpm (in which case the drive motor was fed from the engine generator supply). Transfer under load was possible with this arrangement so that target comparisons could be made at the two different rates on two successive scans.

In the case of those tests performed using the TDEC L-band radar at rotational speeds ranging from 6 to 14 rpm, no extensive modifications were required. The antenna scanning system of the L-band radar uses a dc motor controlled in speed through an amplidyne generator. Normally, the control field of the amplidyne is fed from the output of a control amplifier the input of which is determined by the error voltage from the rotor of a selsyn control transformer. This selsyn is normally driven by a variable speed slewing motor. The PPI indicator follows the antenna through a separate servo control system. Considerable difficulty was experienced in proper operation of the PPI yoke follow-up system at the higher rotational speeds inasmuch as the gearing and the yoke drive motor employed were originally designed for lower speeds. Angular errors thus introduced were considerably decreased by modifying the antenna drive system so that the antenna was slaved to the indicator rather than to the slewing motor.

Scope.

Paralleling the evaluation of surveillance radar with respect to the accuracy of PPI-controlled approaches at reduced antenna scan rates, an overall evaluation of radar performance at the lower scanning rates was made. It has been shown theoretically that MTI operation, particularly over areas of heavy ground clutter, can be improved by lowering the rate of antenna rotation. The effectiveness of MTI operation is decreased as the ratio between the amplitude of return from stationary targets and the amplitude of return from the desired moving target increases. This is due to the fact that returns from stationary targets, when compared on a pulse-to-pulse basis, contain fluctuating components much the same as those normally obtained from moving targets. In general, the amplitude of these fluctuations increases with the amplitude of the reflection from the stationary target; and when these fluctuations become comparable in amplitude to the fluctuations normally expected from the moving target on a pulse-to-pulse basis, it is no longer possible to distinguish between the two. An inherent MTI factor, which tends to favor the moving target in this respect, is the repetitive nature of the moving target's return (phase shift) compared to the random fluctuations and phase shifts characteristic of stationary reflections. This line of reasoning indicates that the greater the number of reflections obtained per scan per target the more efficient will be the MTI system in differentiating between stationary and moving targets. The ability of an MTI system to perform this differentiation is generally defined in terms of subclutter visibility, which is the decibel (db) ratio of the amplitude of the stationary target return to the amplitude of the moving target return at which ratio moving targets are just discernible when flying over clutter. This ratio increases, although not linearly, with an increasing number of hits per scan. According to information contained in the manufacturer's instruction book, the subclutter visibility of the Type ASR-1 radar is approximately 15 db at a scan rate of 28 rpm. So many variables are involved in performing such a calculation that it is virtually impossible to determine statistically how effective any given increase in the number of hits will be in improving MTI presentations at any specific radar site or in any particular areas relative to that radar site. Direct examination of the controller's display at different antenna scan rates appears to be the most effective method of determining the degree of improvement. In addition to examining the effect of reduced scanning rates on subclutter visibility, the effect on radar coverage in the absence of MTI was also examined with respect to maximum range, operation through precipitation, and general appearance of the display.

Subclutter Visibility.

There is no evidence to indicate that any appreciable improvement in target return was affected through reduction of the scan rate from 28 to 14 rpm. Analysis of the compiled data reveals no correlation whatsoever between the number of fade-outs and the antenna scan rate. In some cases, the number of fade-outs per approach was greater at the lower rates of scan than at the maximum rate of 28 rpm. Tables VII, VIII, and IX illustrate this point.

Table VII is a tabulation of fade-outs at various antenna rotational rates for all of the approaches made over Location 13 on Runway 7, which location may be identified in Fig. 19. Table VIII is a similar tabulation for Location 20 on Runway 4. Table IX tabulates the same data for all approaches and includes all of the fade-outs recorded at Locations 2, 3, 9, 12, 13, 14, 19, and 20.

In an effort to obtain evidence that the theoretically predicted improvement was actually attained, aircraft were guided by radar through areas of particularly heavy clutter and the target quality was examined at different scan rates. Two different techniques were employed in making these observations. In some cases, the aircraft was guided over the same track several times with a change in scanning rate performed between successive runs. In other cases, the antenna scanning rate was changed between successive scans in an effort to compare the relative quality of the radar signal. In neither case was there a perceptible difference in the quality of the target as displayed on the indicator. Scope photographs of a predetermined box pattern flown at different scan rates also fail to reveal any significant difference in the reliability of target returns. Some of these photographs are reproduced in Figs. 21 to 25.

Failure to substantiate the theoretically predicted improvement is quite possibly due to the number of variables of unknown magnitude which were present and which could well obscure any relatively small improvement in subclutter visibility. Included among these variables are: antenna pattern, aircraft altitude, wind velocity, faithfulness in following identical tracks, and radial velocity of the aircraft. An extensive examination of these variables for the purpose of either eliminating or controlling them was beyond the scope of this program. However, a computation of ground approach speeds required to produce the first radar blind speed was made for each of the four runways employed. The resulting curves are shown in Fig. 28. Examination of these curves shows that by necessity the large majority of approaches had to be made at speeds approximating the first radial blind speed at which speeds the slope of the radial speed-versus-response curve is greatest. This condition, no doubt, contributed a great deal to the inconsistency of the data obtained.

Maximum Range.

In order to check the maximum range capability of the ASR-1 radar at different antenna scan rates, a particular permanent echo at a distance of approximately 15 miles was selected. With the antenna scanning rate at 14 rpm, the receiver gain was reduced until the echo signal was just barely perceptible on the display. The scanning rate was then increased to 28 rpm and the signal strength again observed. There was no apparent change in the appearance of the target at the two different scan rates. The same procedure was then carried out in reverse order with the same result. It was concluded that no appreciable increase in maximum range coverage was achieved through reduction of the scanning rate from 28 to 14 rpm.

Precipitation.

A number of aircraft targets were examined while they were flying through heavy precipitation areas. Comparisons were made of the signal returns under these conditions at both 28- and 14-rpm scanning rates. They were also made on both a track-to-track and a scan-to-scan basis of antenna rotational rate changes. These observations indicated that there was no improved target-to-precipitation ratio at the lower scan rates.

General Display Appearance.

No marked differences other than the following were observed in the general appearance of the PPI display at the different scan rates.

1. The persistence relative to the scan period appeared reduced at the lower scan rates, indicating that any improvement due to increased bombardment of the cathode-ray tube (CRT) phosphor at the lower scan rates was more than outweighed by the decay characteristic of the CRT phosphor.

2. With MTI in operation, there was less tendency for the arcs representing moving targets to split up at the lower scanning rates. This is in accordance with theory, but the improvement in this respect is not considered of major importance inasmuch as there was considerable breaking up of the targets even at the lower scanning rates.

CONCLUSIONS

Operational.

1. PPI approaches can be conducted with an accuracy within the tolerance of the radar equipment itself throughout the range of antenna rotational rates tested (6 to 28 rpm). Within this range, there is no apparent relationship between the antenna rotational rate and the final approach accuracy at the one-mile point.

2. With present-day aircraft, including jet fighters, there is very little difference in the amount of controller concentration required in conducting approaches at rotational rates of 28 rpm down to 18 rpm; however, an increasing amount of concentration becomes necessary as the rotational rate is reduced below 18 rpm. This extra mental effort is caused by the increasing amount of extrapolation required at the lower rotational rates. Controller reactions indicate that at 18 rpm radar position information is being received as fast as the controller can make use of it. While operating at rotational rates progressively lower than 18 rpm, the controller becomes more and more conscious of the fact that he is waiting for the sweep to get around to the target again; in other words, he believes that he is not receiving radar position information as fast as he would like to have it.

3. In conducting PPI approaches there is no relationship between antenna rotational rate and communications work load. No appreciable difference exists in the number of heading changes required to conduct approaches at the various rotational rates tested.

Technical.

1. Reduction of the antenna scan rate from 28 rpm down to and including 14 rpm, all other variables remaining unchanged, did not result in any operationally observable improvement in subclutter visibility.

2. As a result of reducing the antenna scan rate to 14 rpm, there was no appreciable improvement in any other performance characteristic of the radar.

RECOMMENDATIONS

1. Other means for improving subclutter visibility besides increasing "bits-per-scan" should be thoroughly explored. These methods should include more careful siting and antenna pattern control plus improvement in the internal stabilities of the MTI system.

2. In the presence of any gains obtained by the methods listed, the possibility of additional gains through a reduction of antenna rotational rate should be re-examined.

3. In drawing up specifications for future airport surveillance radar equipment, other performance factors should not be restricted by the former requirement of a high rotational rate. If performance can be improved or if

mechanical reliability can be increased through use of a lower antenna rotational rate, serious consideration should be given to a decrease in rotational rate to a minimum of 18 rpm.

TABLE I

PPI APPROACH SUMMARY

Airport	Radar Antenna (rpm)	Number of Approaches	Displacement At 1 Mile From Runway Maximum (feet)	Average (feet)
Indianapolis	6	15	819	255
	9	59	1557	299
	12	56	765	161
	14	53	1117	238
Idlewild	14	24	649	238
	18	29	552	230
	24	24	721	266
	28	39	774	264

TABLE II

INDIVIDUAL CONTROLLER ACCURACY
PPI APPROACHES

Controller	Average Displacement in Feet at 1-Mile Point							
	Indianapolis Airport Antenna (rpm)				Idlewild Airport Antenna (rpm)			
	6	9	12	14	14	18	24	28
A		230	169	181	124	44		146
B	217	310	199	289		239	267	140
C	296	189	111	133		306	227	270
D		490	142	270		212	201	239
E					270	352	502	413
F					383	223	135	313
G		325		254				
H			232					
I			204					
J			61					
Average	255	299	161	238	238	230	266	264

Previous radar experience of controllers:

A, C = 60 PPI approaches.
B, D, E, F, J = Several hundred PPI approaches.
G, H, I = No previous experience.

TABLE III

HEADING CHANGES

Radar	rpm	Number of Heading Changes	
		Maximum	Average
Indianapolis	6	7	4.5
	9	9	4.9
	12	7	4.0
	14	8	4.4
Idlewild	14	8	4.7
	18	7	4.3
	24	7	3.9
	28	7	5.0

TABLE IV

INDIANAPOLIS RADAR TESTS
SUMMARY OF FADE-OUTS

*Location No.	Antenna Rate (rpm)	No. of Fade-Outs
1	12	2
1	14	3
1	14	2
1	14	2
1	14	6
1	14	6
1	14	1
1	14	1
1	14	4
1	14	2
2	14	2
2	14	5
2	14	3
3	14	1
3	14	7
4	9	2
4	9	3
4	9	2
4	9	1
4	12	2
4	12	3
4	14	4
4	14	9
4	14	8
4	14	5
4	14	3
4	14	4
4	14	3
4	14	7
4	14	6
4	14	3
4	14	1
4	14	2
4	14	2
4	14	7
5	9	6
5	12	2
5	12	4
5	14	1
6	9	2
6	9	1
6	9	2
6	9	1
6	9	2
6	9	3
6	9	3
6	9	1
6	9	2
6	9	3
6	9	1
6	12	6
6	12	5
6	12	3
6	12	7
6	12	6
6	12	3
6	12	7
6	12	3
6	12	3
6	12	3
6	12	1
6	12	2
6	14	5
7	9	2
7	9	5
7	12	2
7	12	2
8	12	1
9	12	7
9	12	8
9	12	1
9	12	2
9	12	1
9	12	3
9	12	3
9	12	3
9	12	2
9	12	6
9	12	2
9	12	6
9	12	2
9	12	4
10	9	2
11	9	2
11	9	2
11	9	2
11	9	11
11	9	2
11	9	4
11	9	3
11	9	2
11	14	1
11	14	1
11	14	2
12	9	2
12	9	1
12	9	1
12	9	1
12	14	3
12	14	2
12	14	2
12	14	2
12	14	4
12	14	2
12	14	2
12	14	2
13	9	1
14	6	1
14	9	1
15	6	1
15	9	6
15	9	5

* See Fig. 5

TABLE V

IDLEWILD RADAR TESTS
SUMMARY OF FADE-OUTS

*Location Number	Antenna Rate (rpm)	Fade-Outs
1	28	4
1	28	Lost completely at 2 miles
1	28	Lost completely at 2 miles
1	28	Lost completely at 1 1/2 miles
1	28	Lost completely at 1 1/2 miles
2	28	1
2	28	1
2	28	2
3	28	2
3	28	1
4	28	1
5	28	1
6	28	1
7	28	Target invisible on downwind leg until 3 miles north
7	28	Target invisible on downwind leg until 3 miles north
8	28	Lost completely at 1 1/4 miles
8	28	Lost completely at 1 1/2 miles
8	28	Lost completely at 1 3/4 miles
8	28	Lost completely at 1 1/2 miles
8	28	Lost completely at 2 miles
8	28	Lost completely at 2 miles
8	28	Lost completely at 2 miles
8	28	3
9	28	4
10	28	3
10	28	4
11	28	2
11	28	2
11	28	2
11	28	2
12	14	1
13	14	3
13	14	3
13	14	1

* See Fig. 6.

TABLE V (Continued)

IDLEWILD RADAR TESTS
SUMMARY OF FADE-OUTS

*Location Number	Antenna Rate (rpm)	Fade-Outs
13	14	3
13	18	2
13	18	1
13	18	2
13	18	1
13	18	1
13	18	2
13	24	2
13	28	1
13	28	2
13	28	2
13	28	1
14	18	2
14	14	1
15	14	3
15	14	1
16	28	2
16	28	2
16	28	1
16	18	3
16	18	1
16	18	1
16	18	1
16	18	1
16	18	1
16	18	1
16	14	2
16	14	3
17	18	4
17	14	2
17	28	5
18	24	4
19	14	1
19	14	2

*See Fig. 6.

TABLE V (Continued)

IDLEWILD RADAR TESTS
SUMMARY OF FADE-OUTS

*Location Number	Antenna Rate (rpm)	Fade-Outs
19	24	1
19	14	1
20	14	3
20	14	1
20	14	1
20	14	1
20	24	1
20	24	3
20	24	Very weak target
21	14	1
21	24	2
21	28	3
22	14	Target invisible on downwind leg until 3 miles south
22	14	Impossible to identify until 2 1/2 miles south
23	18	2
23	24	1
23	24	1
23	24	1
23	24	1
23	24	3
23	24	3
23	24	2
23	24	1
23	24	1
23	24	1
23	24	2
23	24	4
23	24	2
23	24	1
23	24	4
23	24	1
24	24	4
24	28	1
25	24	1

*See Fig. 6.

TABLE VI

QUESTIONNAIRE SUMMARY AIRPORT SURVEILLANCE RADAR ROTATION RATES

Questions Asked	Ans.	Number Replies For Various Antenna Rates							
		Indianapolis				Idlewild			
		6	9	12	14	14	18	24	28
1. In your opinion, was the radar equipment operating in a satisfactory manner?	Yes		3	7	4	5	5	4	5
	No	2	3	1	2				3
2. Was it necessary to make numerous adjustments in gain control while making an approach?	Yes								3
	No	2	5	7	6	5	5	4	5
3. In your opinion, was the MTI presentation adequate for the control of terminal area traffic?	Yes	1	3	5	4	2	4	2	3
	No	1	3	3	2	3	1	2	5
4. Did the target disappear for an excessive length of time during turns?	Yes		2	6	2			1	1
	No	2	4	1	4	5	5	3	7
5. Was it difficult to judge when to start the turn-on to final approach?	Yes	2	6	3	2	1	1	1	1
	No			5	4	4	4	3	7
6. If you found that you overshot or undershot the turn-ons for considerable distance, to which of the following reasons do you attribute this error?									
a. Slow pilot reaction.				1	1				
b. Controller's tendency to wait for one more look before making decision to turn.		2	2	1	1	1			
c. Loss of target at the critical point.			3	5	2		1	1	1
d. Controller's tendency to crystal ball the actual position of the aircraft.		1	2	1	1	1			

TABLE VI (Continued)

QUESTIONNAIRE SUMMARY AIRPORT SURVEILLANCE RADAR ROTATION RATES

Questions Asked	Ans.	Number Replies Indianapolis 6	 9	 12	 14	 Idlewild 14	 18	 24	 28
e. Misjudgment of the amount of wind drift during turn.		2	2	1	3	1	3	1	2
7. Did you feel that the turn-on was sufficiently accurate for a PPI approach?	Yes		4	8	6	4	5	4	8
	No	2	2			1			
8. Did you experience any difficulty in correcting for wind drift?	Yes	2	5		3	1		1	1
	No		1	8	3	4	5	3	7
9. Do you feel that you were able to conduct satisfactory approaches at this antenna rpm?	Yes		3	7	6	3	4	4	6
	No	2	3			2	1		2
10. Did you experience any difficulty in maintaining radar separation between two aircraft in the terminal area on the same or converging courses?	Yes			1		4		2	1
	No	1		1	1	2	6	4	7
11. Did you experience any difficulty ascertaining whether or not you had radar separation between the aircraft being guided and other aircraft in the terminal area on converging courses?	Yes		1	2	1	4		3	2
	No	1	1	3	3	1	5	3	8
12. How many inbound aircraft do you think it would be possible to control by radar (i.e., maintaining radar separation and providing radar navigation)?		3	1 2 2	3 2	3 3	3 2 6 3	3 4 4 6 4	2 1 2 4 3 6 4	2 3 3 4 1 3 4 4 6

TABLE VI (Continued)

QUESTIONNAIRE SUMMARY AIRPORT SURVEILLANCE RADAR ROTATION RATES

Questions Asked	Ans.	Number Replies							
		Indianapolis				Idlewild			
		6	9	12	14	14	18	24	28
13. Did you experience any difficulty in identifying the aircraft target?	Yes	1	1		1	2		1	2
	No	1	5	8	5	7	8	7	10
14. Did this antenna rotational speed require more or less concentration on your part than required with the ASR-1 when performing a similar type operation?	More	2	6	6	5	8	5	4	
	Less	-	-	-	-	-	-	-	-
	Same					1	4	4	11

The following questions were answered at the completion of the evaluation, using CPS-5, and again following ASR-1 evaluation tests.

	Replies	
	Indianapolis	Idlewild
15. What is the lowest rotational rate used that you consider would permit an average controller to perform adequately all radar-controlled functions (PPI approach radar guidance, maintaining three miles separation in the terminal area and on the final approach, and identification of target) without undue guesswork or excessive concentration?	None	14 rpm
	None	18 rpm
	14 rpm	18 rpm
	14 rpm	18 rpm
		18 rpm
		18 rpm
		18 rpm
		24 rpm
		28 rpm
16. Do you think it will be difficult to train new personnel, using the lowest rotational rate as specified in Question 15?	Yes	No
	Yes	No
	Yes	No
	No	No
		No
		No
		No
		No
		No

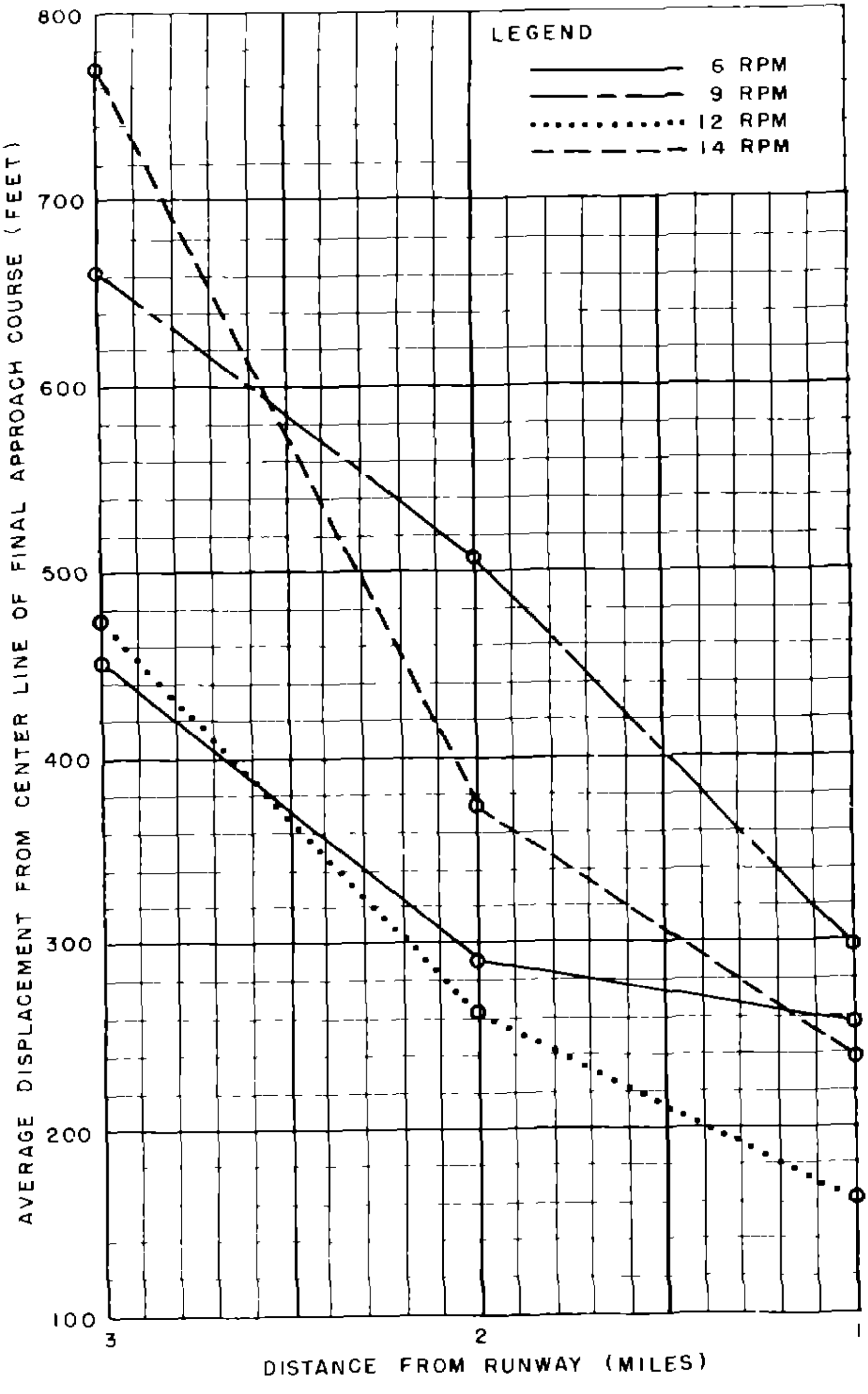


FIG 1 FINAL APPROACH ACCURACY, INDIANAPOLIS PPI APPROACHES

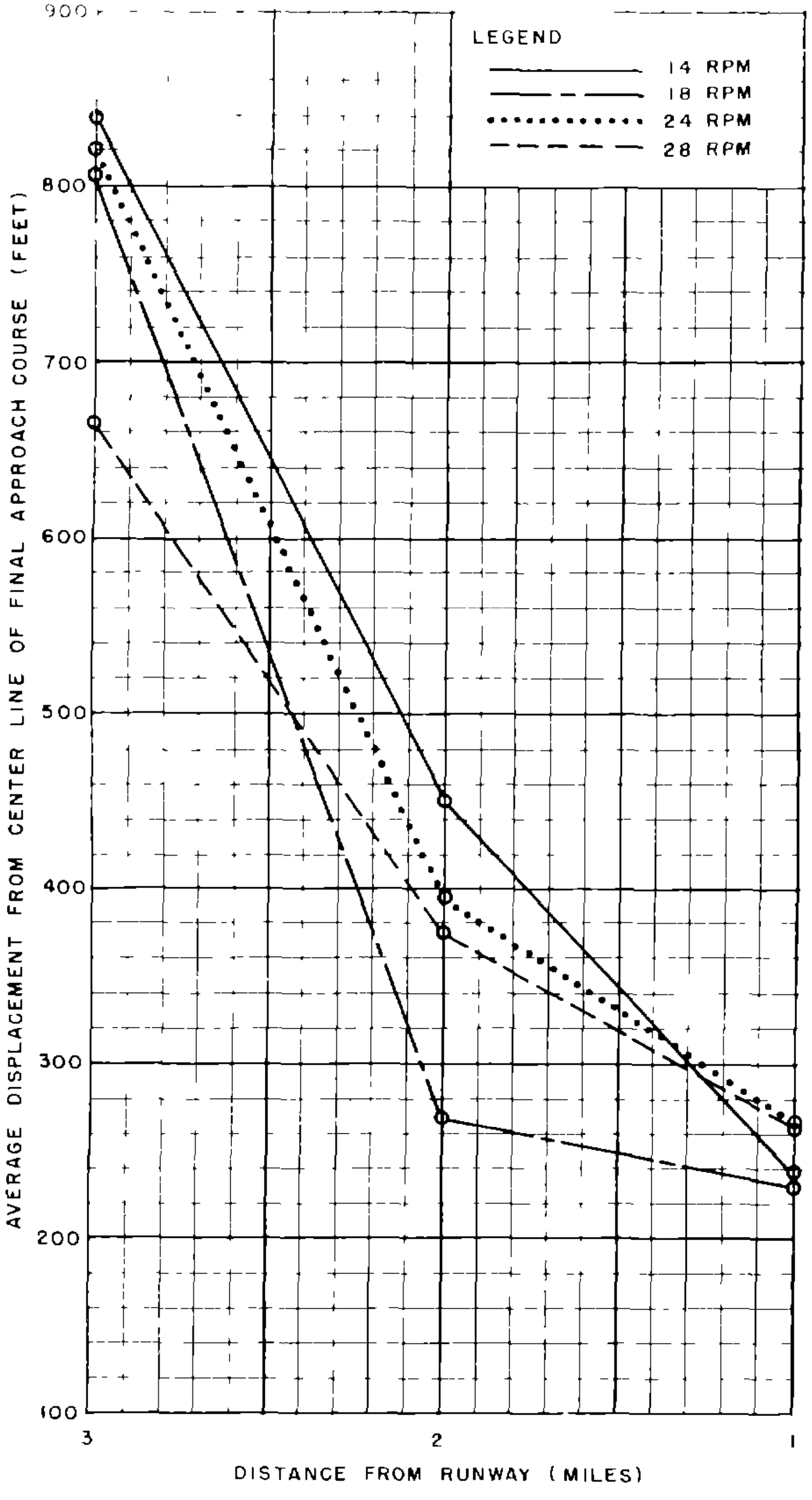


FIG 2 FINAL APPROACH ACCURACY, IDLEWILD PPI ACCROACHES

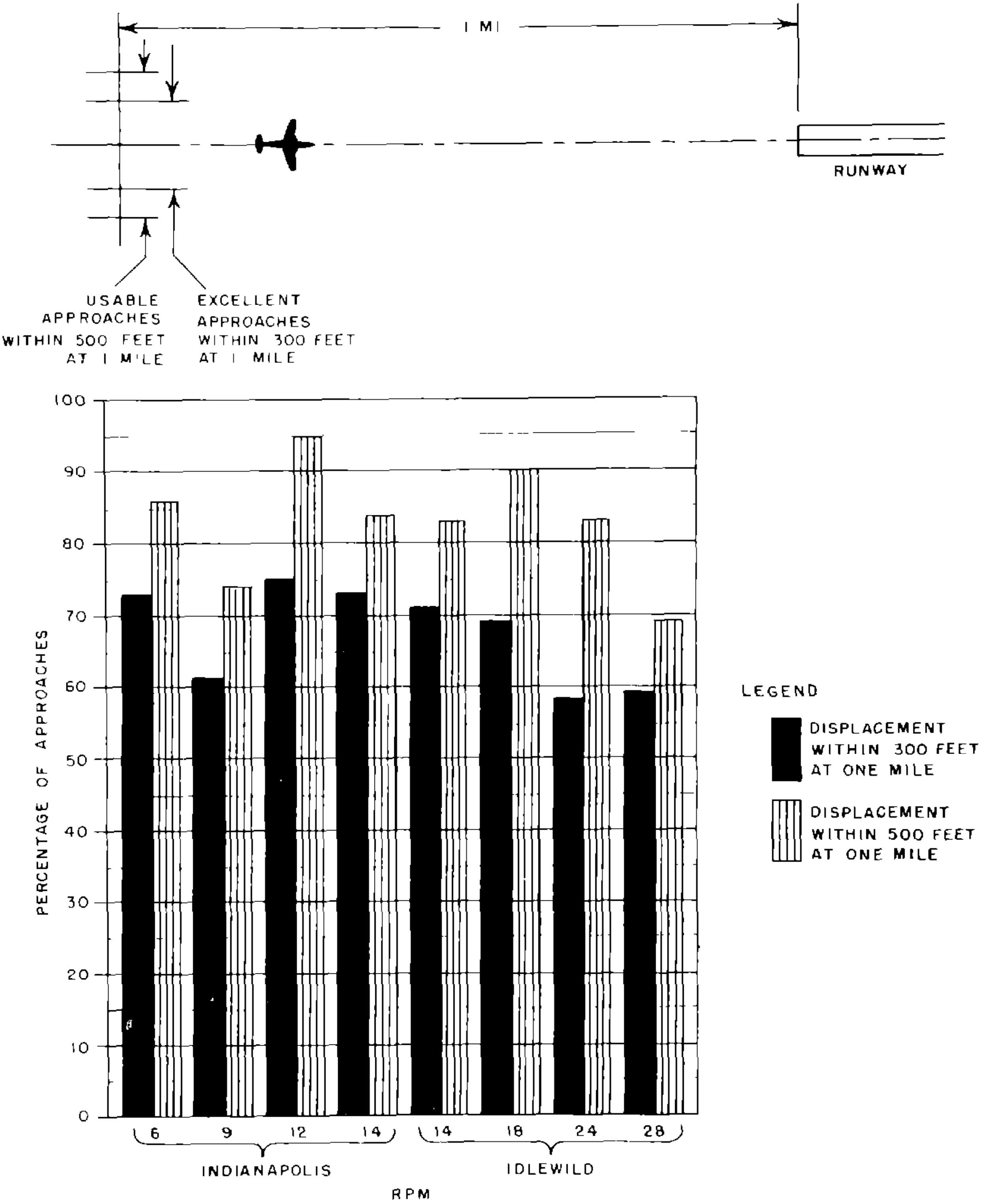


FIG 3 DISPLACEMENT AT ONE-MILE POINT

DURING EACH APPROACH, AN OBSERVER RECORDED THE NUMBER OF HEADING CHANGES WHICH WERE REQUIRED TO TURN THE AIRCRAFT FROM BASE LEG TO FINAL APPROACH AND GUIDE THE AIRCRAFT DOWN THE FINAL APPROACH PATH TO A POINT ONE MILE FROM THE END OF THE RUNWAY THIS DATA APPEARS IN TABLE III

ARROWS INDICATE POINTS AT WHICH HEADING CHANGES WERE TRANSMITTED TO THE PILOT IN THIS TYPICAL PPI APPROACH

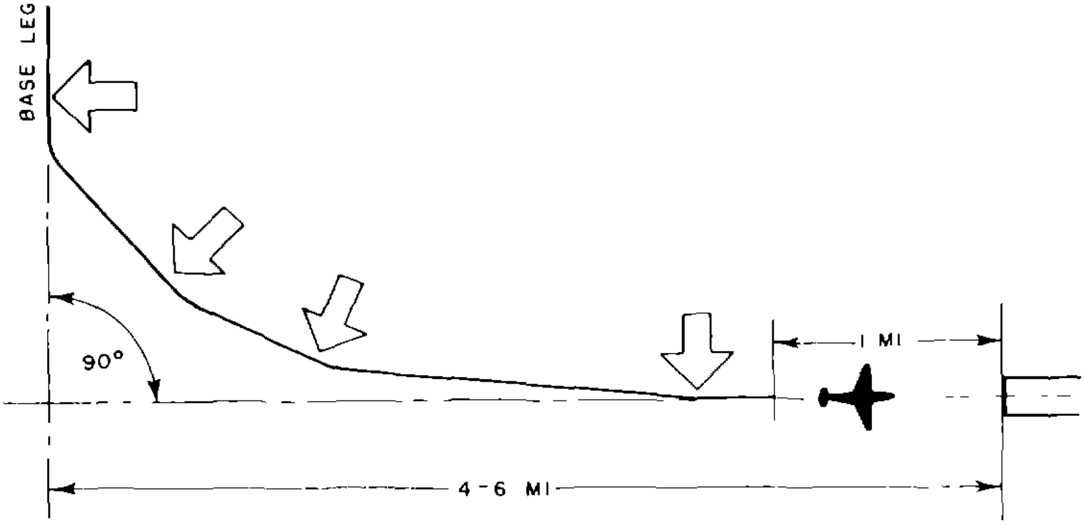
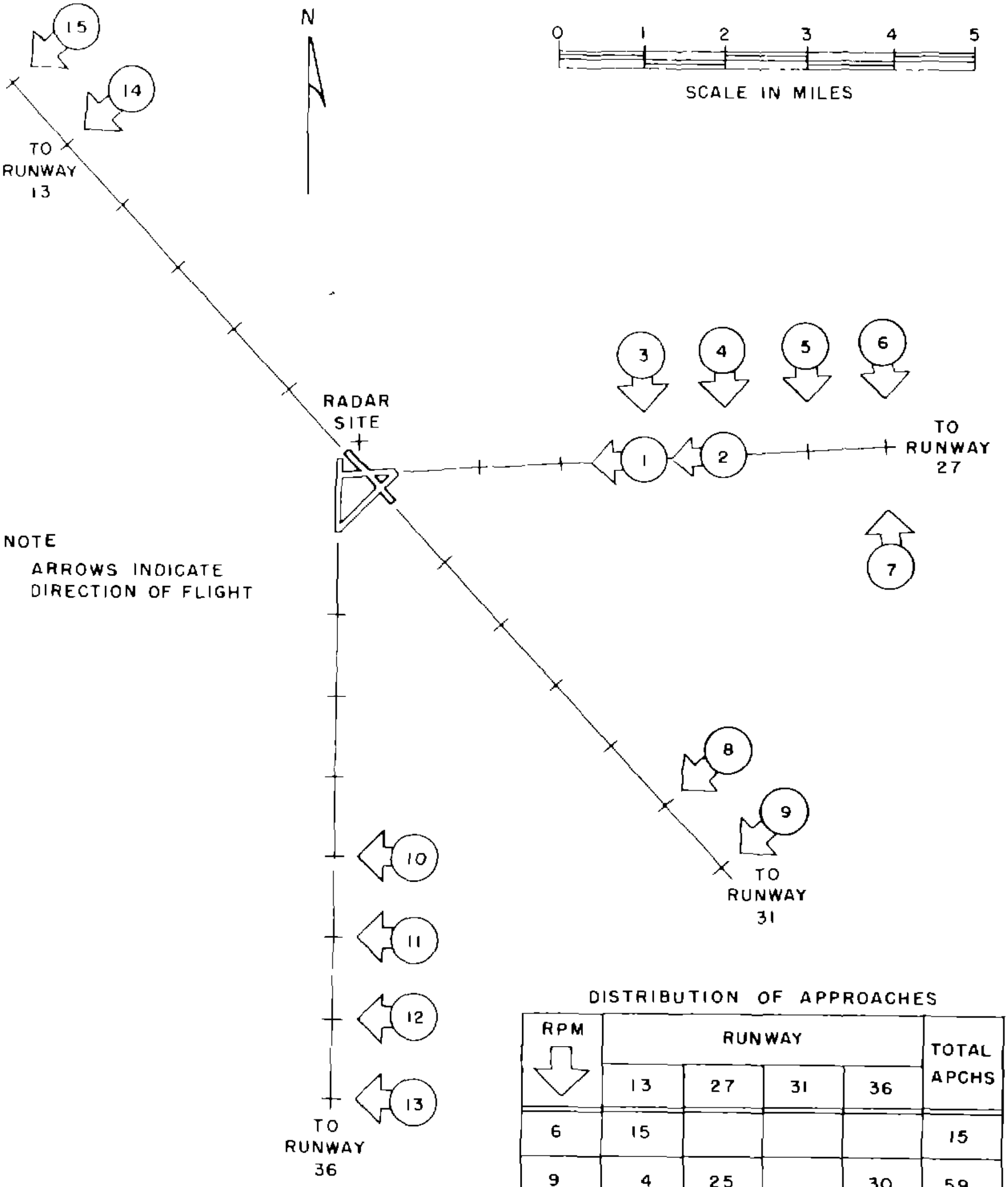


FIG 4 MEASUREMENTS OF COMMUNICATIONS WORK LOAD



NOTE

ARROWS INDICATE DIRECTION OF FLIGHT

DISTRIBUTION OF APPROACHES

RPM	RUNWAY				TOTAL APCHS
	13	27	31	36	
6	15				15
9	4	25		30	59
12	3	35	18		56
14		18		35	53
TOTAL	22	78	18	65	183

FIG 5 LOCATION OF FADE-OUTS DURING PPI APPROACHES, INDIANAPOLIS

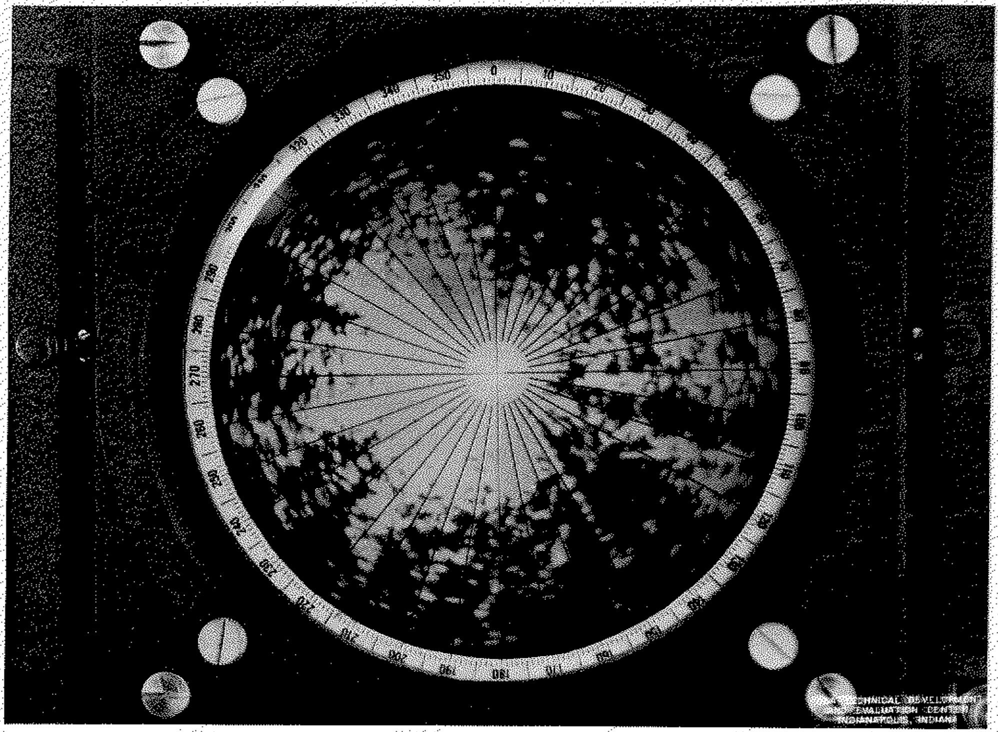


FIG. 6 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 10-MILE RANGE, ANTENNA ROTATIONAL RATE 12 RPM, NORMAL GAIN.

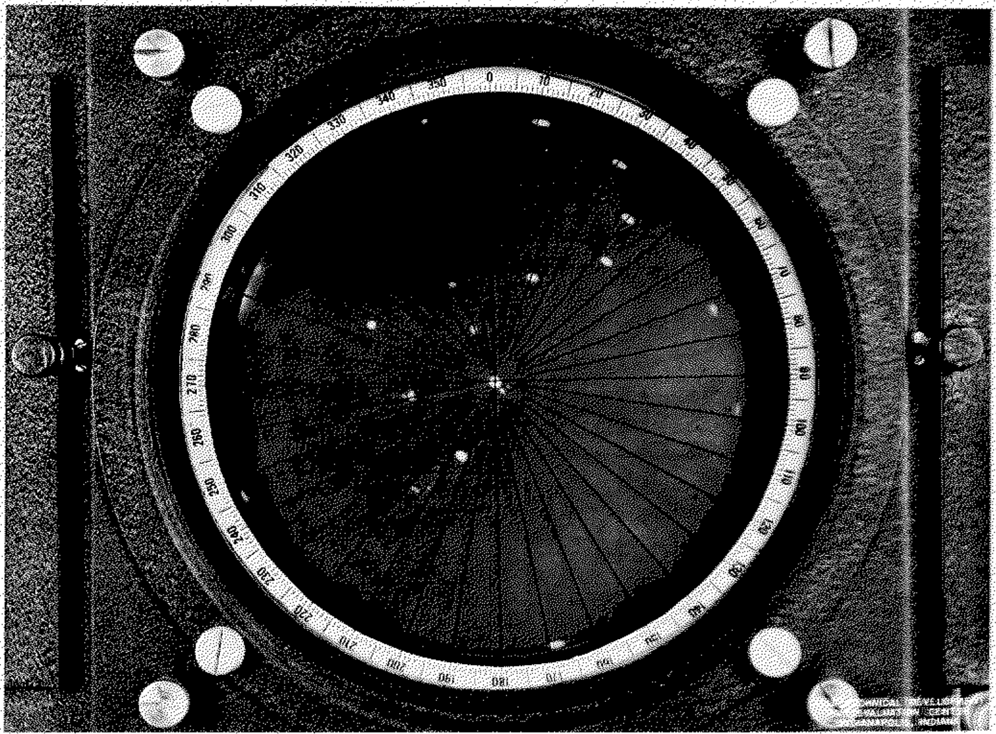
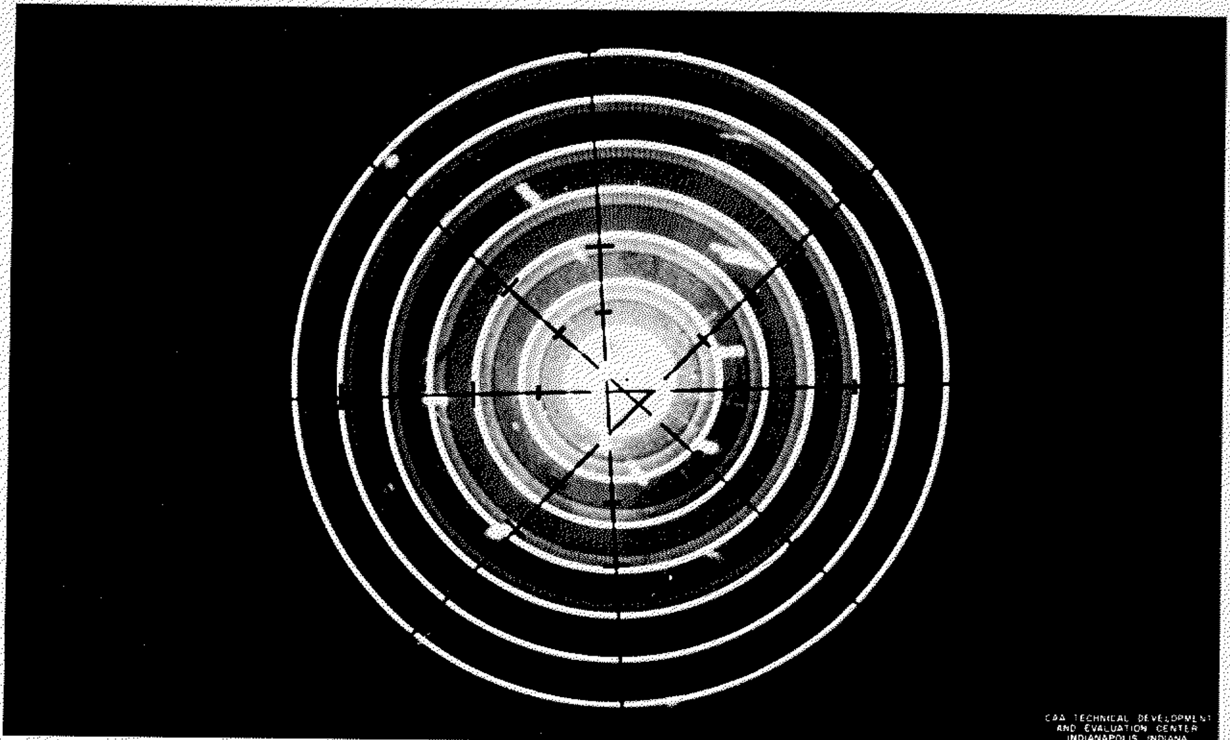


FIG. 7 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 10-MILE RANGE, ANTENNA ROTATIONAL RATE 12 RPM WITH MTI.



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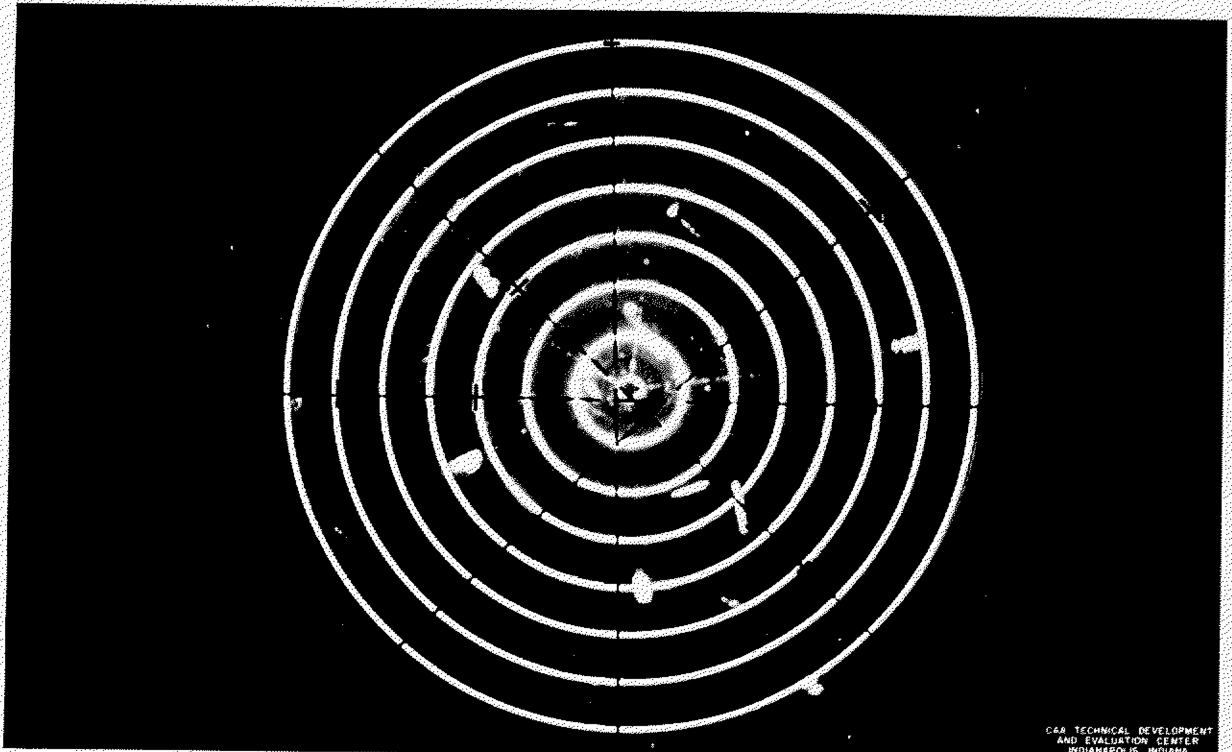
ANTENNA ROTATIONAL RATE 9 RPM



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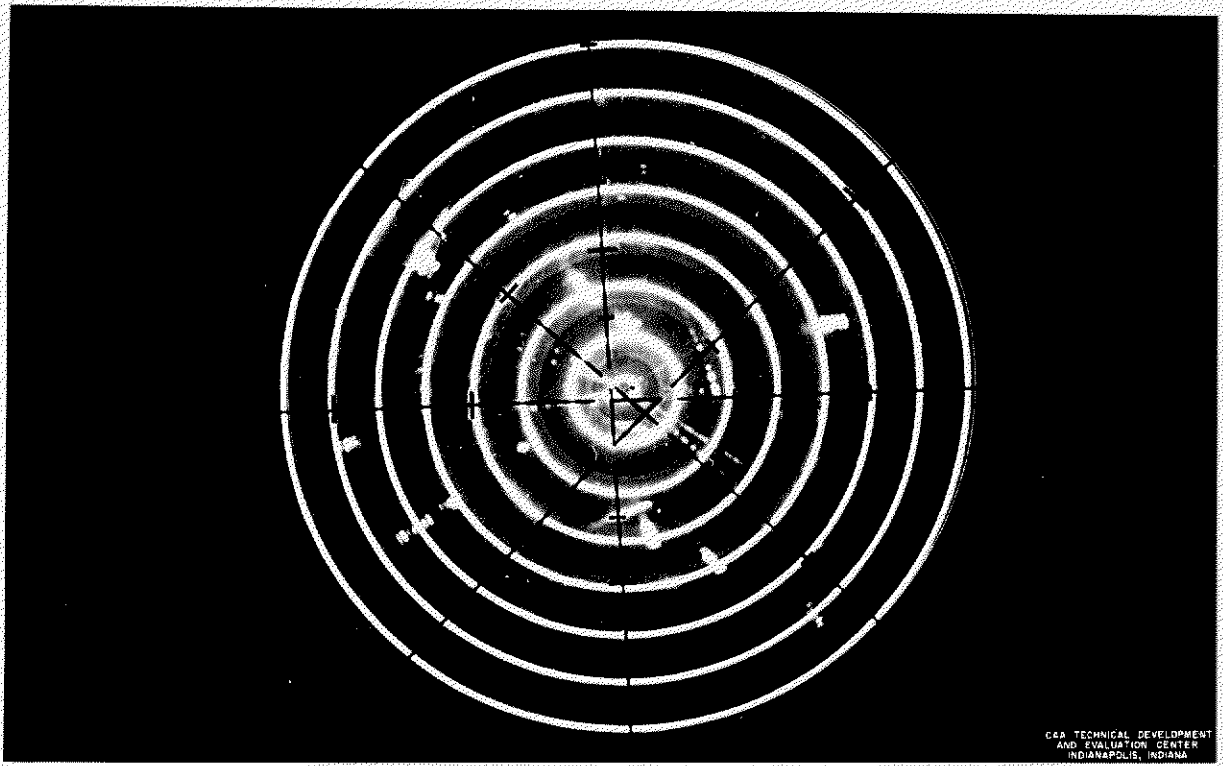
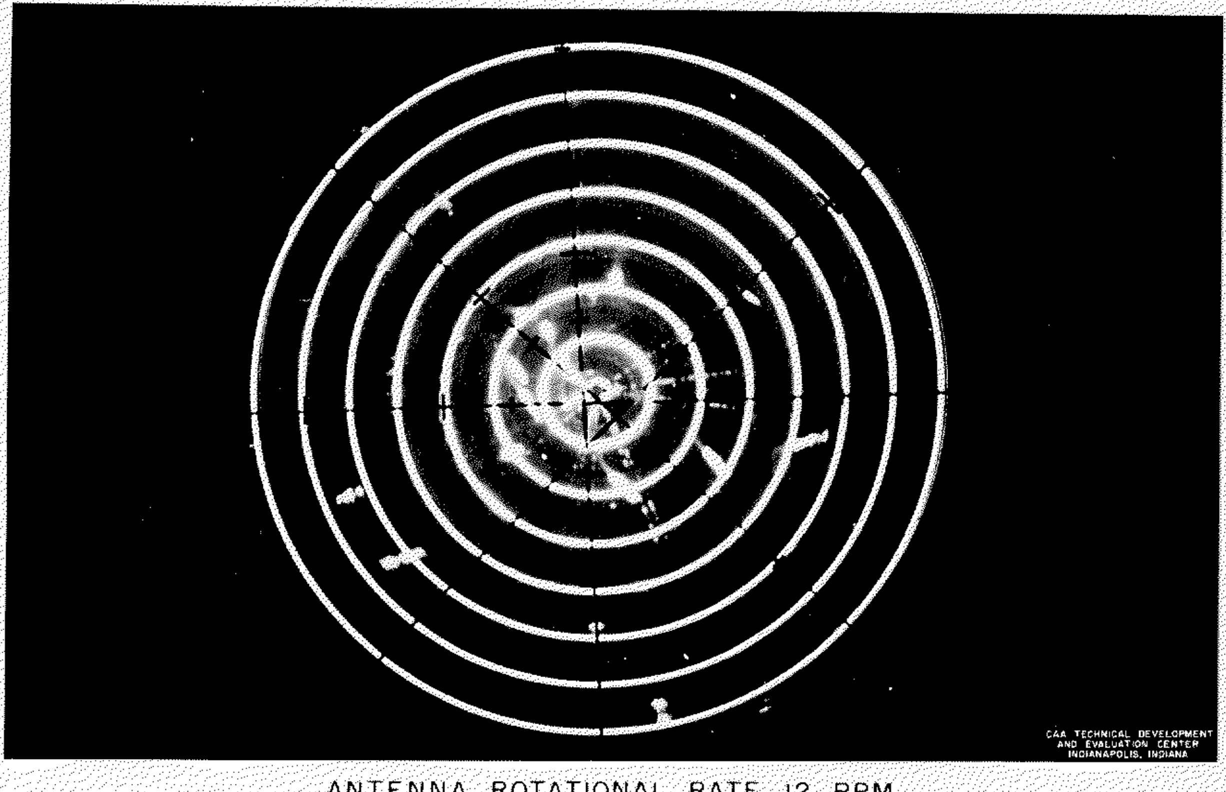
ANTENNA ROTATIONAL RATE 14 RPM

FIG. 8 CAA EXPERIMENTAL L-BAND RADAR DISPLAYS, 35-MILE RANGE, PICTURES TAKEN 20 SECONDS APART.



ANTENNA ROTATIONAL RATE 6 RPM



ANTENNA ROTATIONAL RATE 12 RPM

FIG. 9 CAA EXPERIMENTAL L-BAND RADAR DISPLAYS, 35-MILE RANGE, PICTURES TAKEN 1 MINUTE APART.

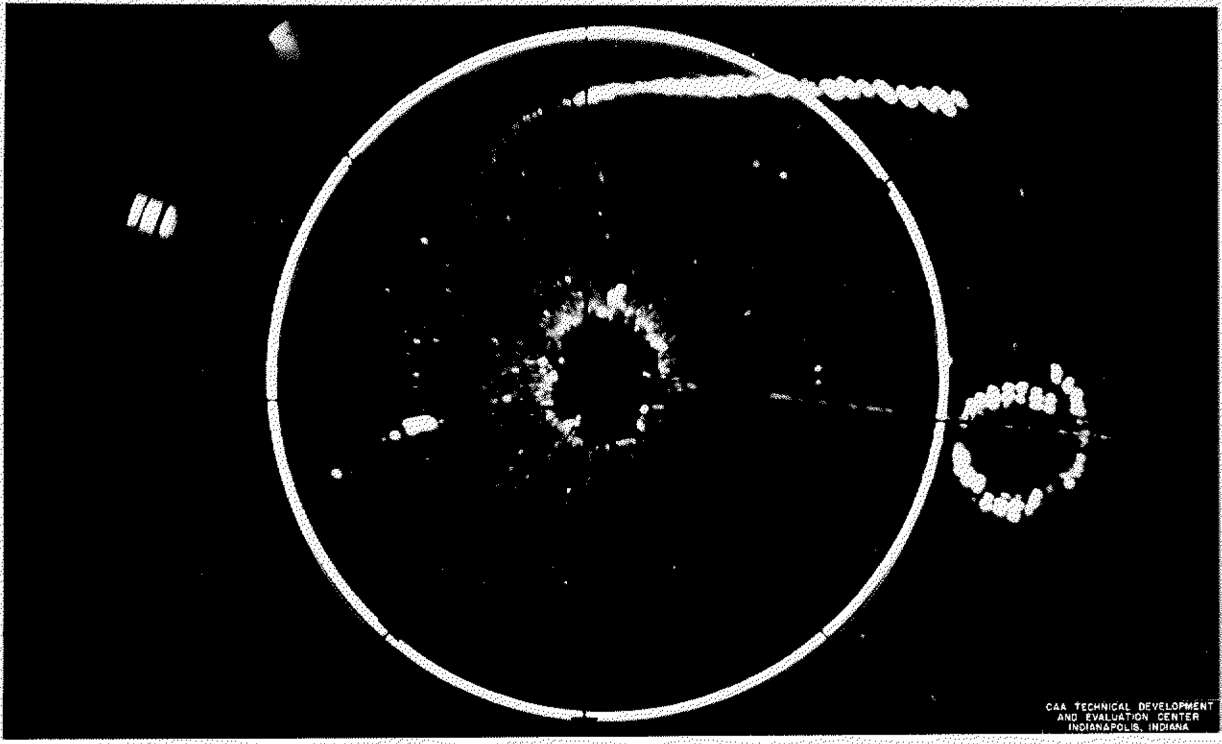


FIG. 10 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 14 RPM, DC-3 AIRCRAFT MAKING A RIGHT 360-DEGREE TURN, AIRSPEED 170 MPH.

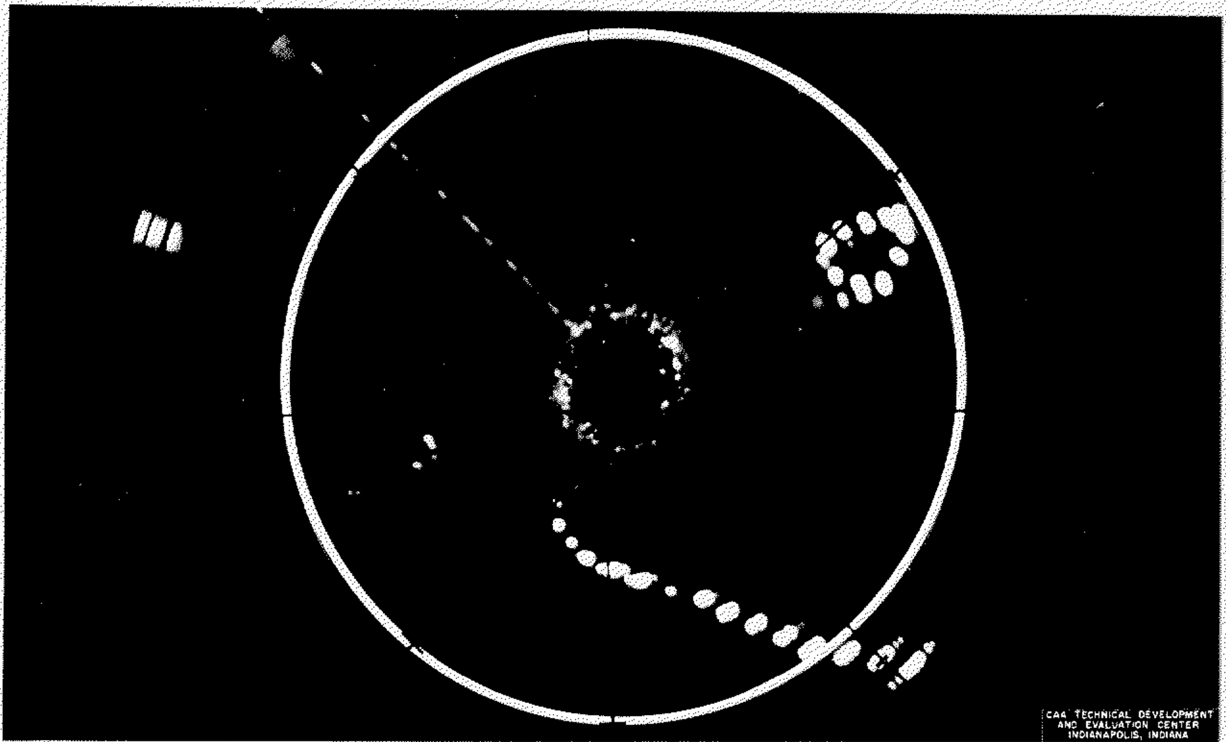


FIG. 11 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 9 RPM, DC-3 AIRCRAFT MAKING A LEFT 360-DEGREE TURN, AIRSPEED 170 MPH.

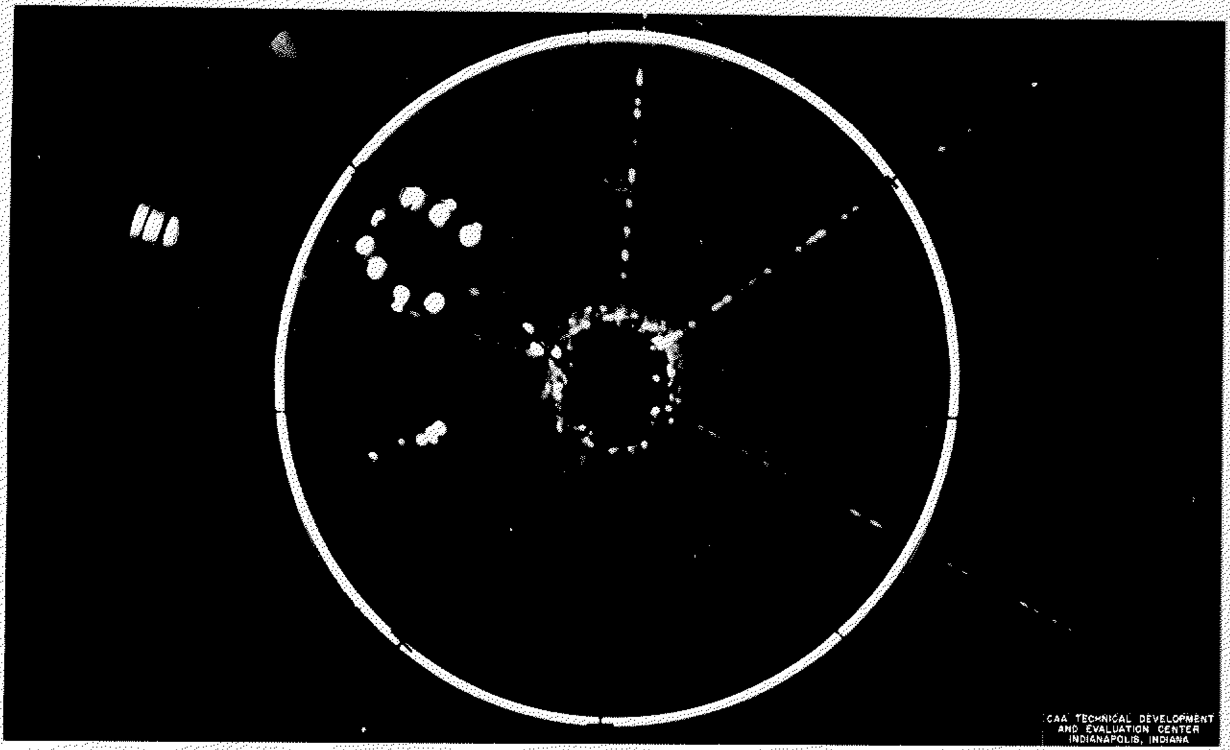


FIG. 12 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 6 RPM, DC-3 AIRCRAFT MAKING A RIGHT 360-DEGREE TURN, AIRSPEED 170 MPH.

FIG. 13 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 14 RPM, DC-3 AIRCRAFT MAKING A RIGHT 360-DEGREE TURN, AIRSPEED 120 MPH.

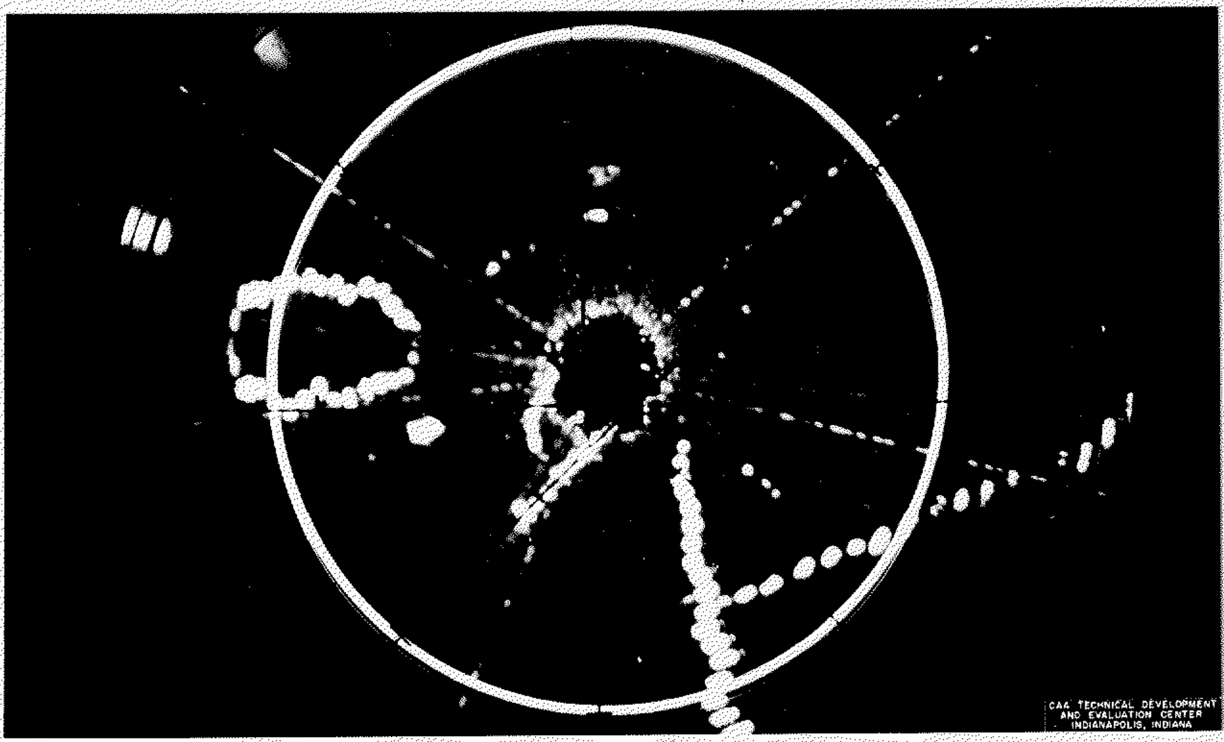


FIG. 14 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 12 RPM, DC-3 AIRCRAFT MAKING A RIGHT 360-DEGREE TURN, AIRSPEED 120 MPH.
NOTE TARGET DISPLACEMENT RESULTING FROM ERRATIC SERVO.

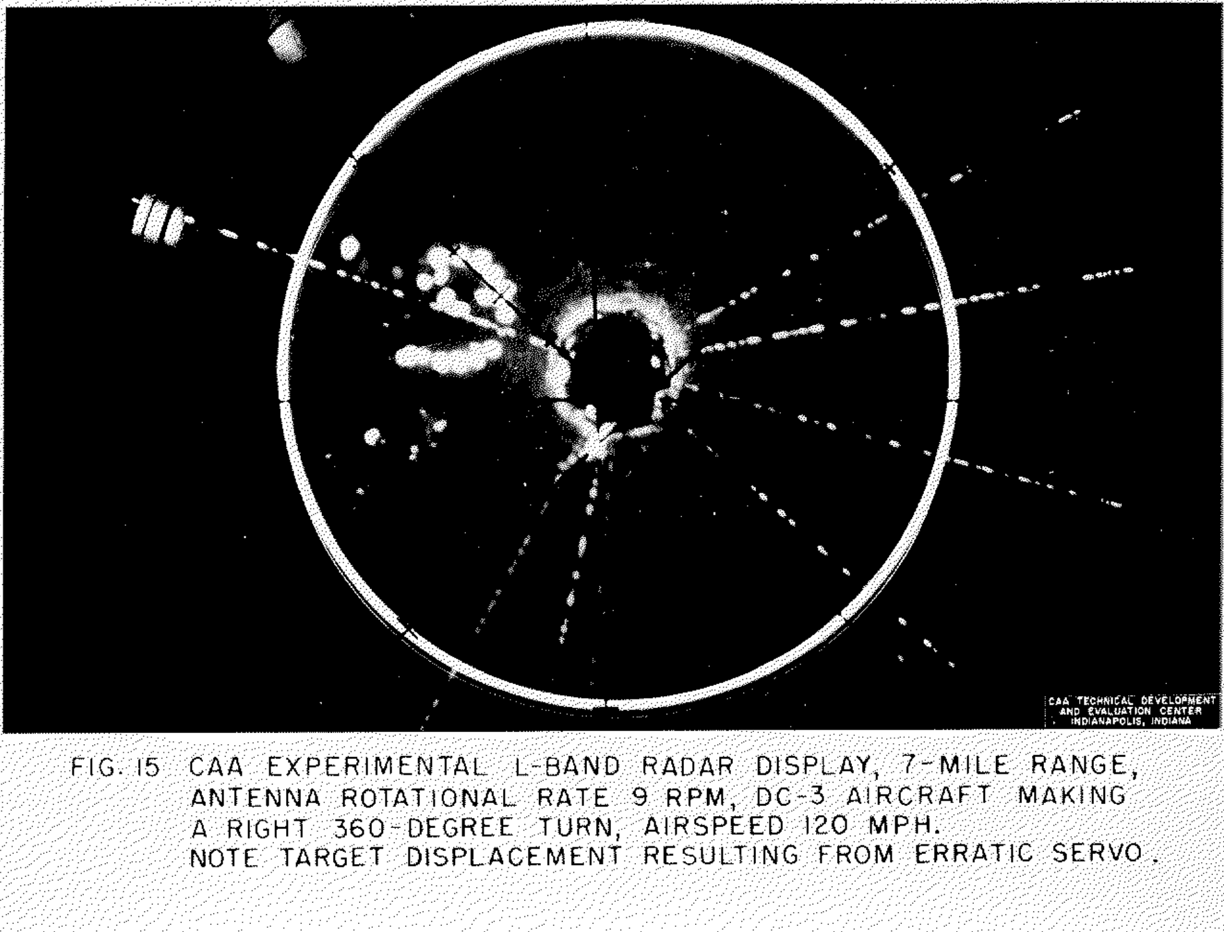


FIG. 15 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, ANTENNA ROTATIONAL RATE 9 RPM, DC-3 AIRCRAFT MAKING A RIGHT 360-DEGREE TURN, AIRSPEED 120 MPH.
NOTE TARGET DISPLACEMENT RESULTING FROM ERRATIC SERVO.

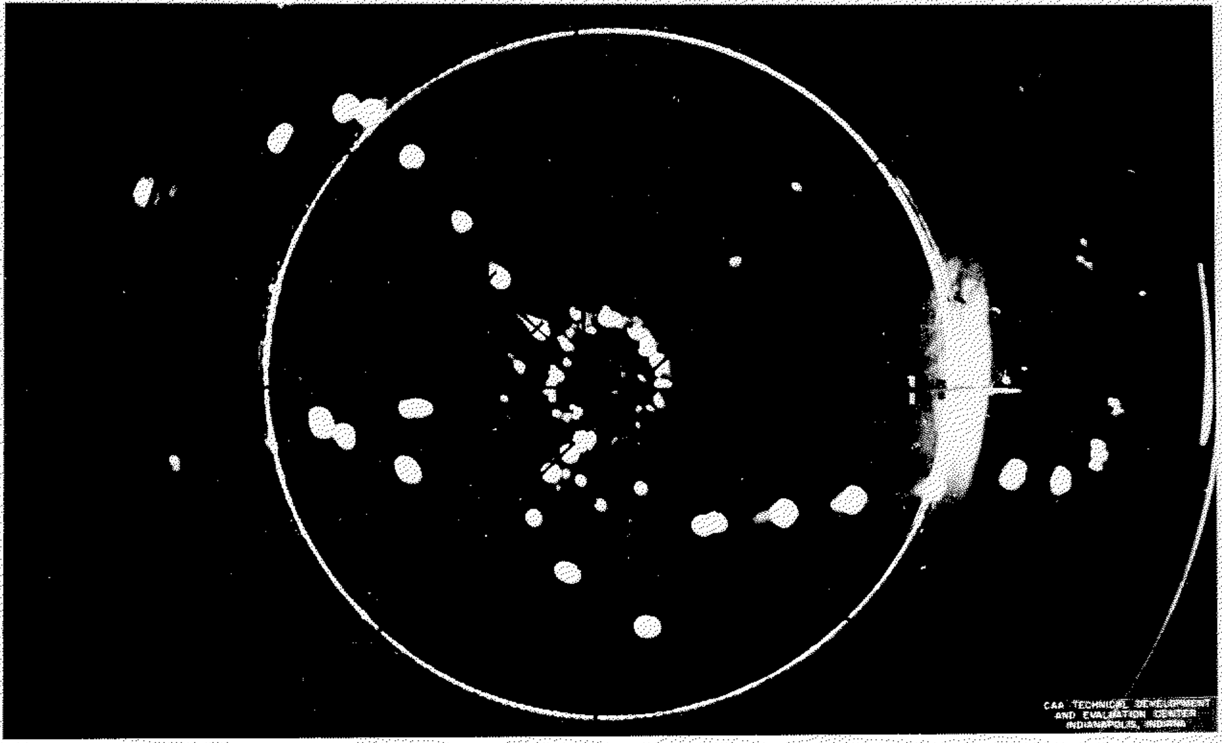


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FIG. 16 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 10-MILE RANGE, 2 JET AIRCRAFT IN WEIR COOK MUNICIPAL AIRPORT TRAFFIC PATTERN.

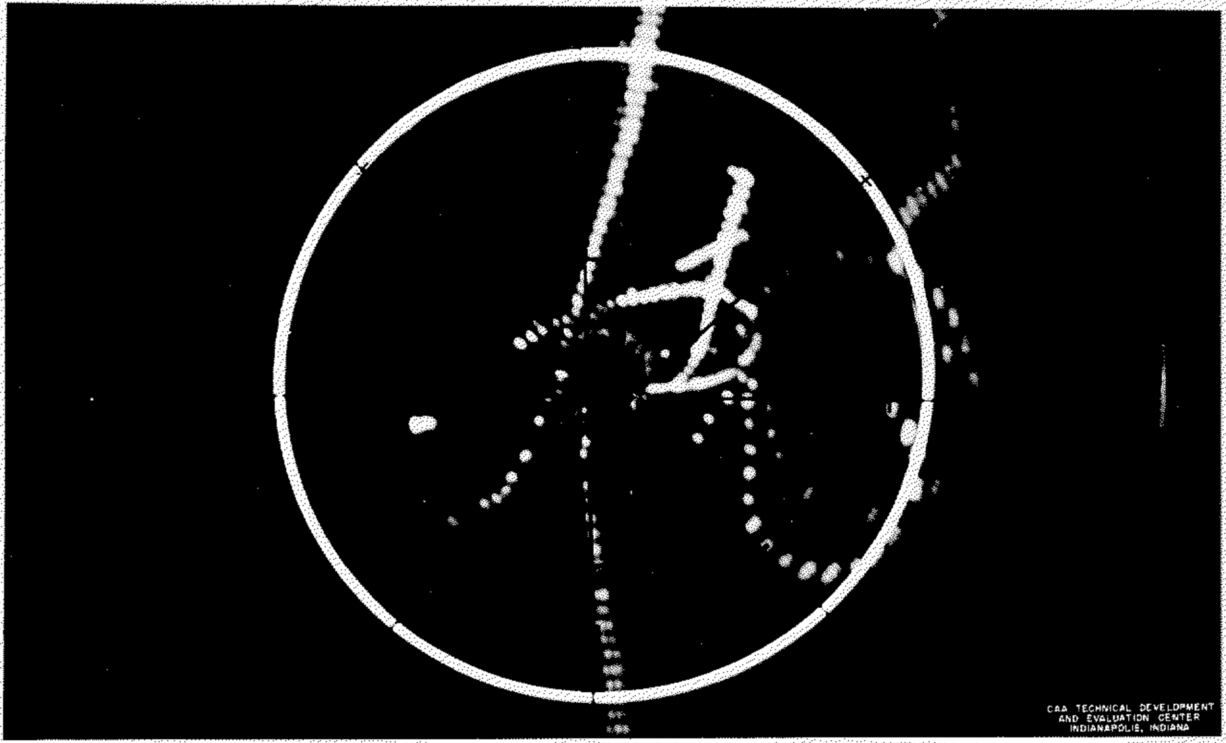

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FIG. 17 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 7-MILE RANGE, JET AIRCRAFT MAKING A 360-DEGREE TURN IN EAST SECTOR, ALTITUDE 3000 FEET, AIRSPEED 180 MPH.

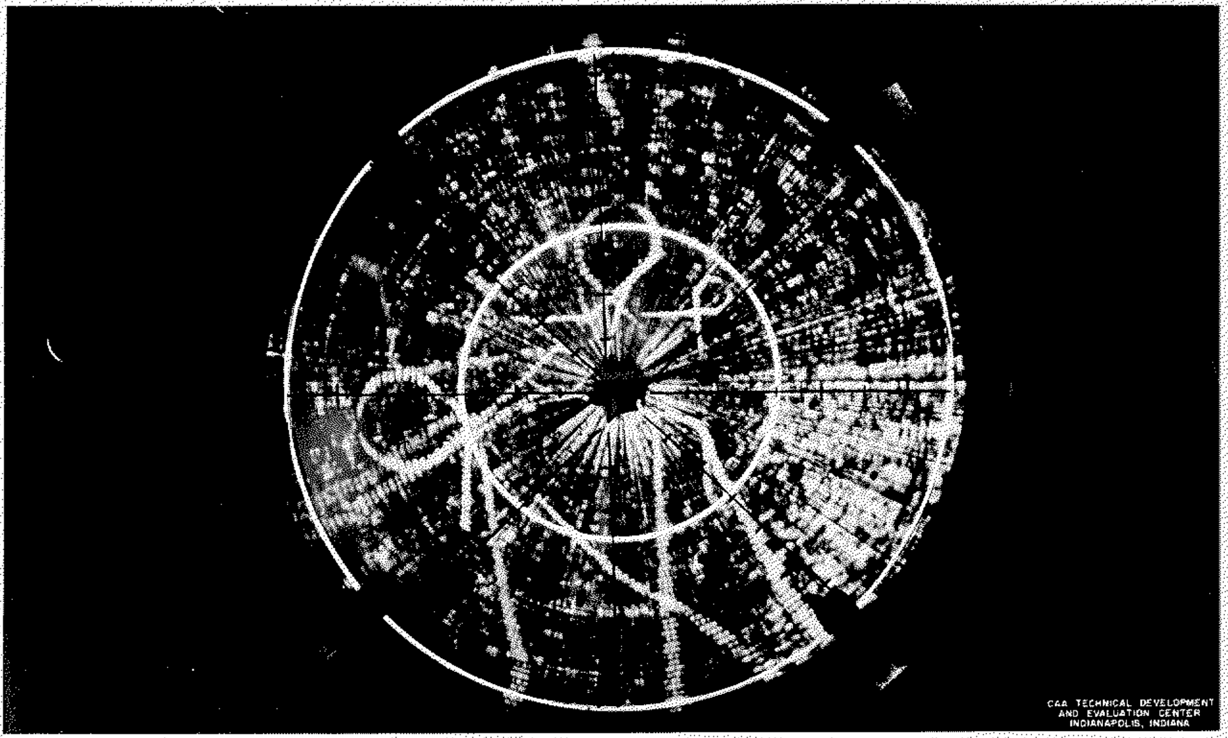
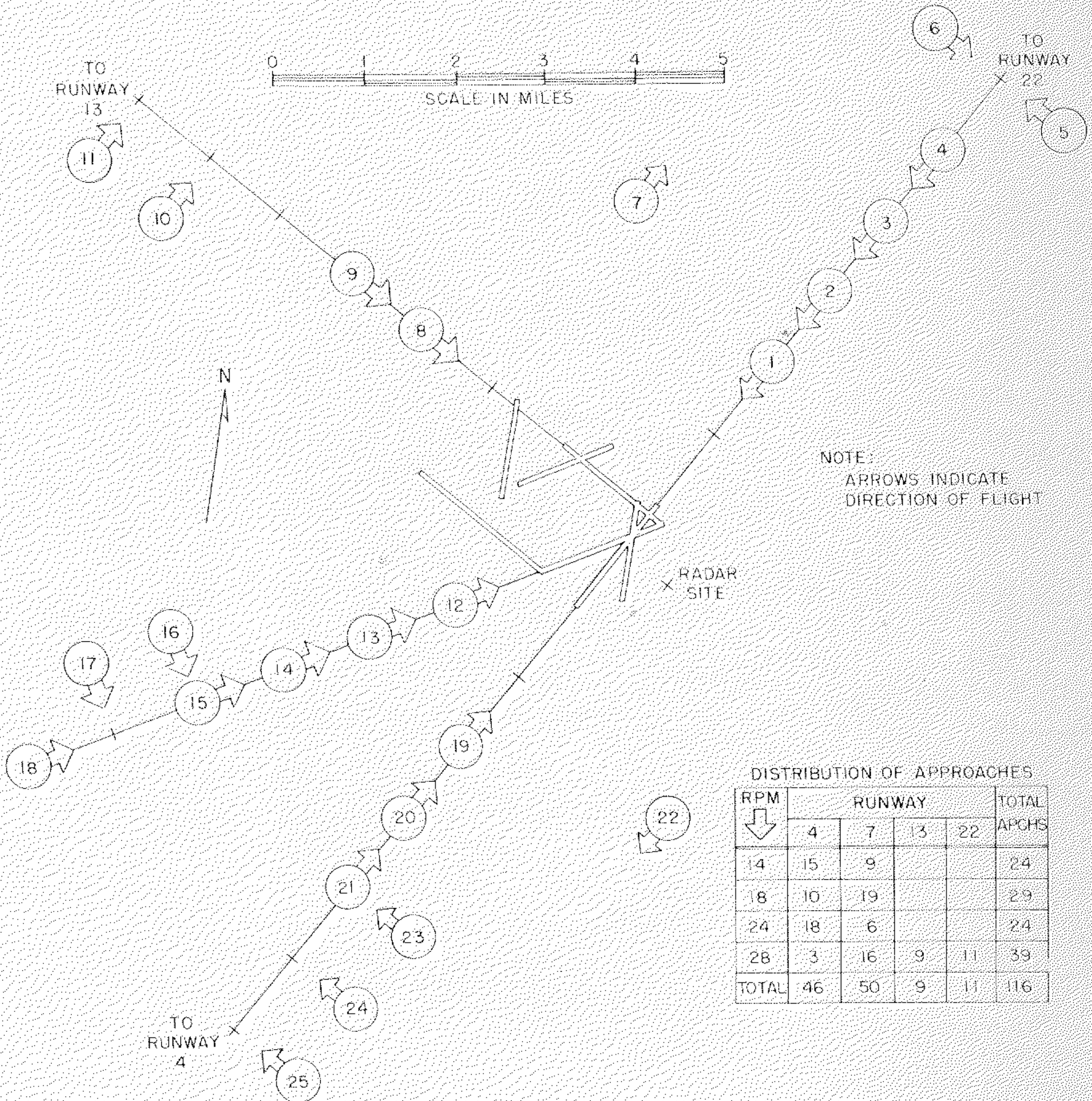


FIG. 18 CAA EXPERIMENTAL L-BAND RADAR DISPLAY, 10-MILE RANGE, PIPER PACER MAKING 270-DEGREE TURNS NORTHWEST, NORTHEAST, AND SOUTHEAST OF THE AIRPORT; C-46 MAKING 270-DEGREE TURNS NORTH AND WEST OF THE AIRPORT.



DISTRIBUTION OF APPROACHES

RPM ⇩	RUNWAY 4	RUNWAY 7	RUNWAY 13	RUNWAY 22	TOTAL APCHS
14	15	9			24
18	10	19			29
24	18	6			24
28	3	16	9	11	39
TOTAL	46	50	9	11	116

FIG. 19 LOCATION OF FADE-OUTS DURING PPI APPROACHES, IDLEWILD

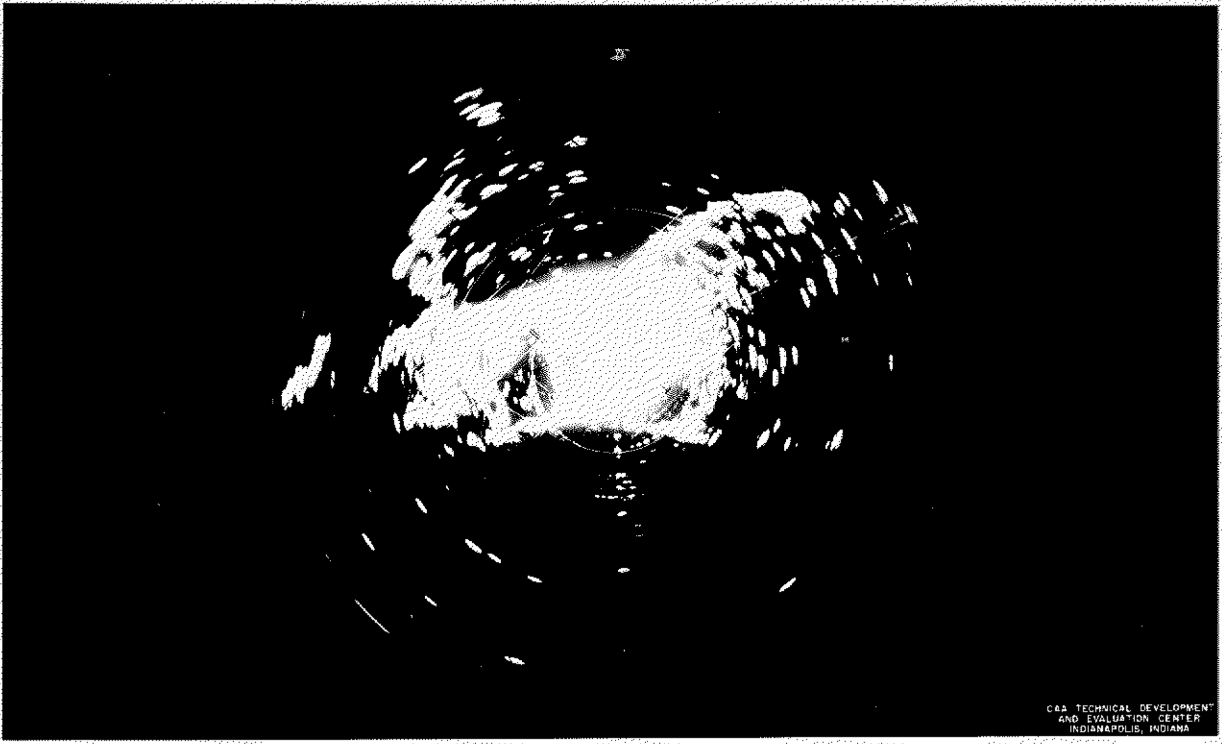

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FIG. 20 TYPE ASR-1 RADAR DISPLAY, 20-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 28 RPM,
NORMAL GAIN, CLUTTER AREA.

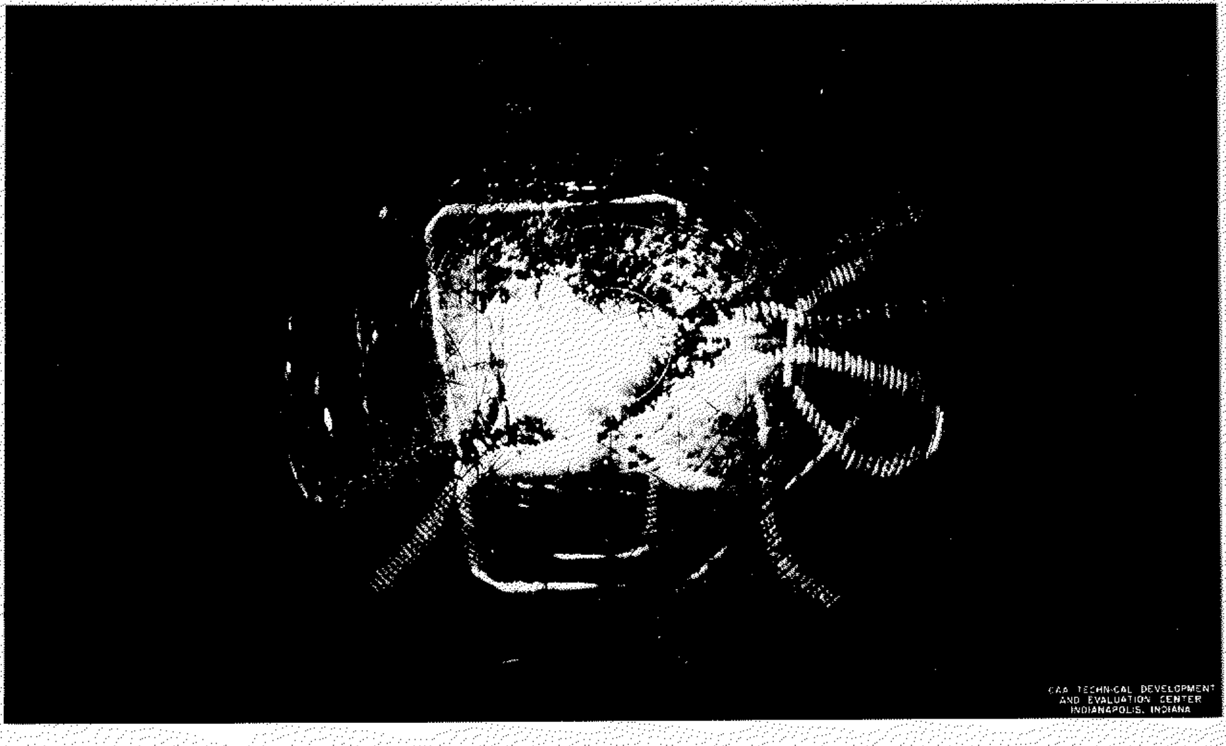
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FIG. 21 TYPE ASR-1 RADAR DISPLAY, 10-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 14 RPM WITH MTI,
DC-3 AIRCRAFT FLYING A BOX PATTERN,
AIRSPEED 150 MPH, ALTITUDE 2000 FEET.

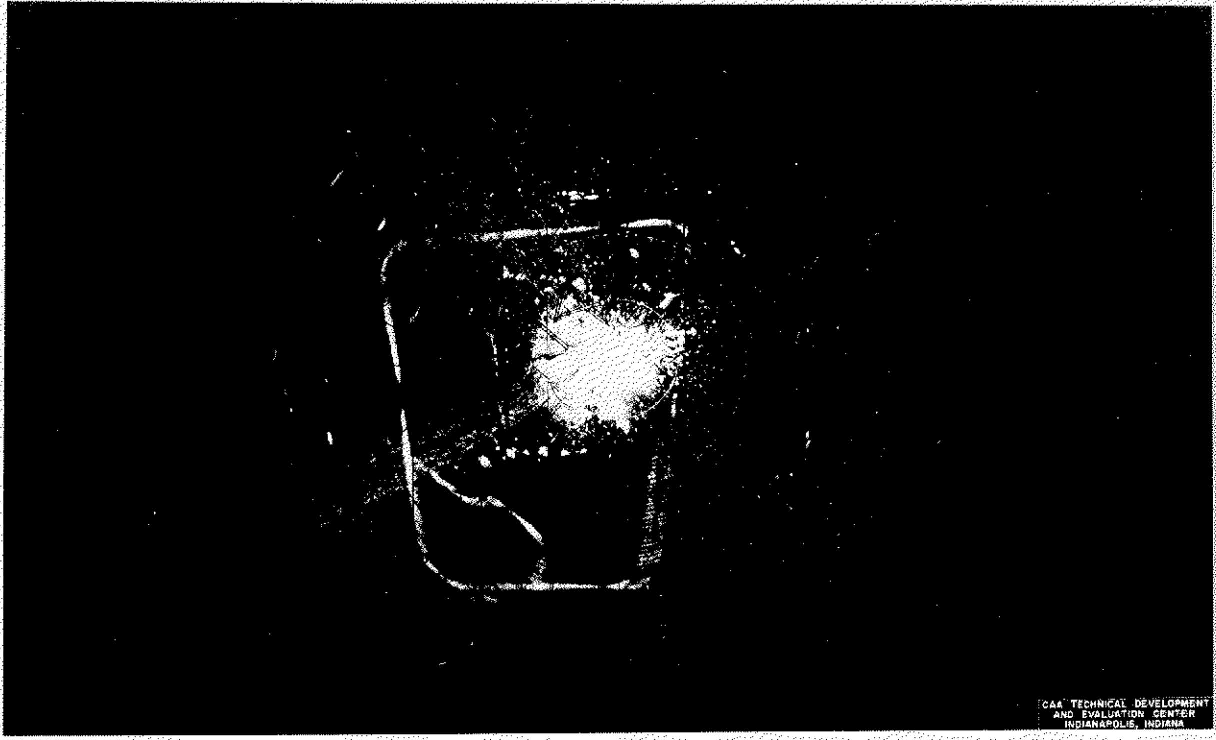

FIG. 22 TYPE ASR-1 RADAR DISPLAY, 10-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 18 RPM WITH MTI,
DC-3 AIRCRAFT FLYING A BOX PATTERN,
AIRSPEED 150 MPH, ALTITUDE 2000 FEET,
HEAVY RADAR INTERFERENCE.

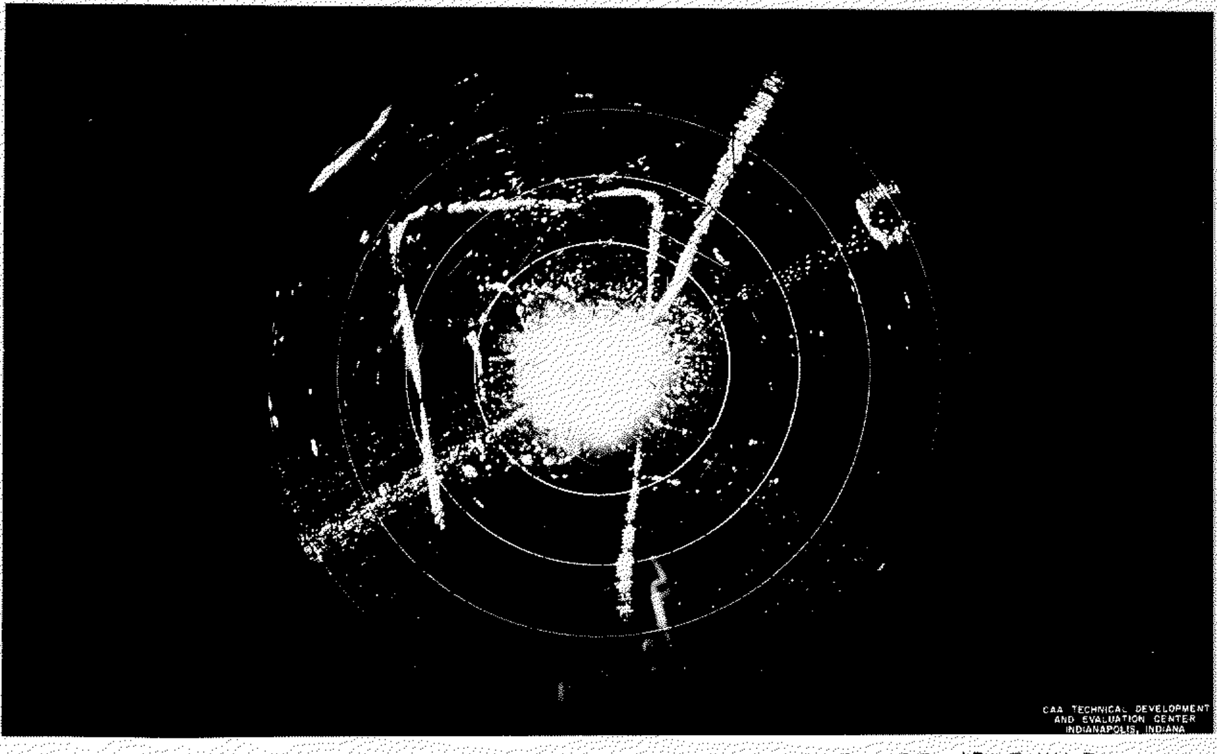

FIG. 23 TYPE ASR-1 RADAR DISPLAY, 10-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 24 RPM WITH MTI,
DC-3 AIRCRAFT FLYING A BOX PATTERN,
AIRSPEED 150 MPH, ALTITUDE 2000 FEET.

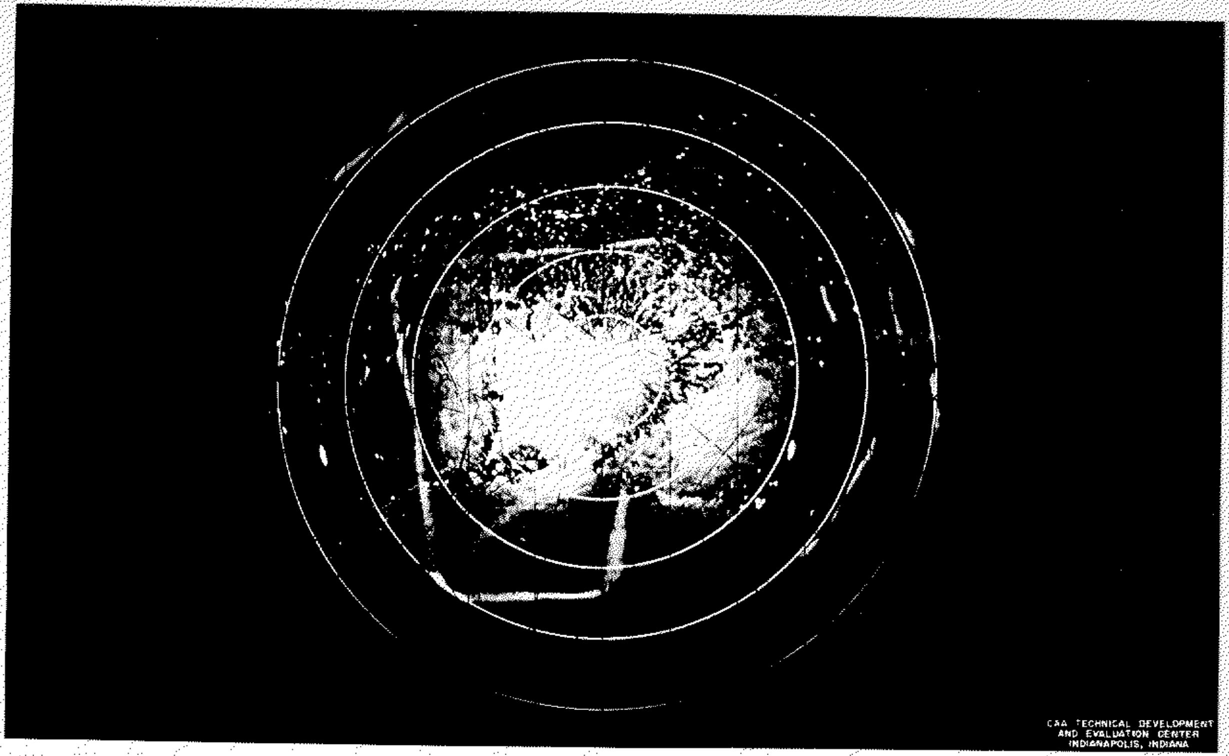

FIG. 24 TYPE ASR-1 RADAR DISPLAY, 10-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 28 RPM WITH MTI,
DC-3 AIRCRAFT FLYING A BOX PATTERN,
AIRSPEED 150 MPH, ALTITUDE 2000 FEET.

FIG. 25 TYPE ASR-1 RADAR DISPLAY, 10-MILE RANGE, IDLEWILD,
ANTENNA ROTATIONAL RATE 24 RPM WITH MTI,
NAVY JRB FLYING BOX PATTERN ON DIAGONAL HEADINGS,
AIRSPEED 126 MPH, ALTITUDE 2500 FEET;
STINSON 105 FLYING BOX PATTERN ON CARDINAL HEADINGS,
AIRSPEED 90 MPH, ALTITUDE 2500 FEET.
NOTE FADE-OUT AREAS NORTHEAST.

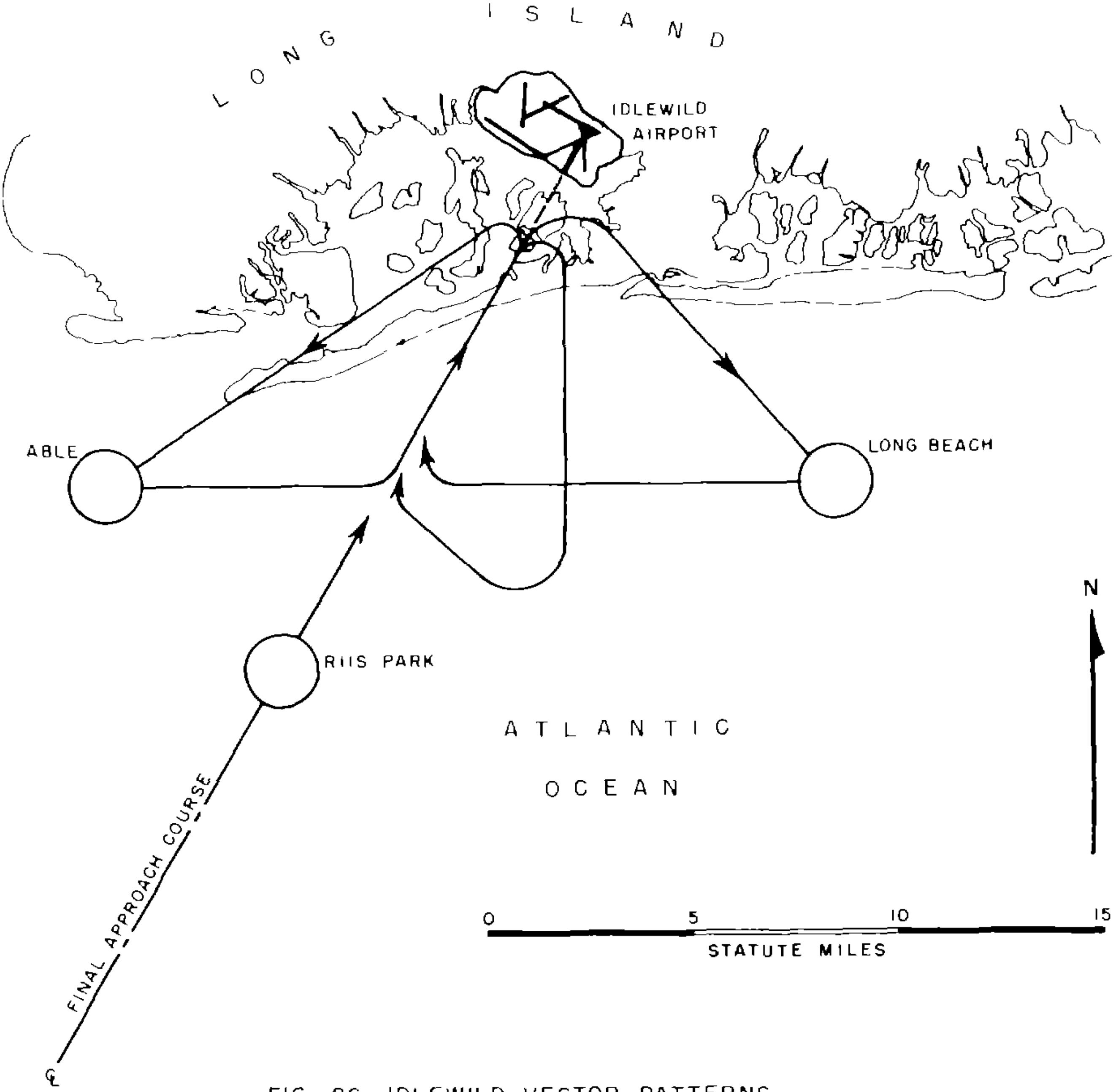

FIG 26 IDLEWILD VECTOR PATTERNS

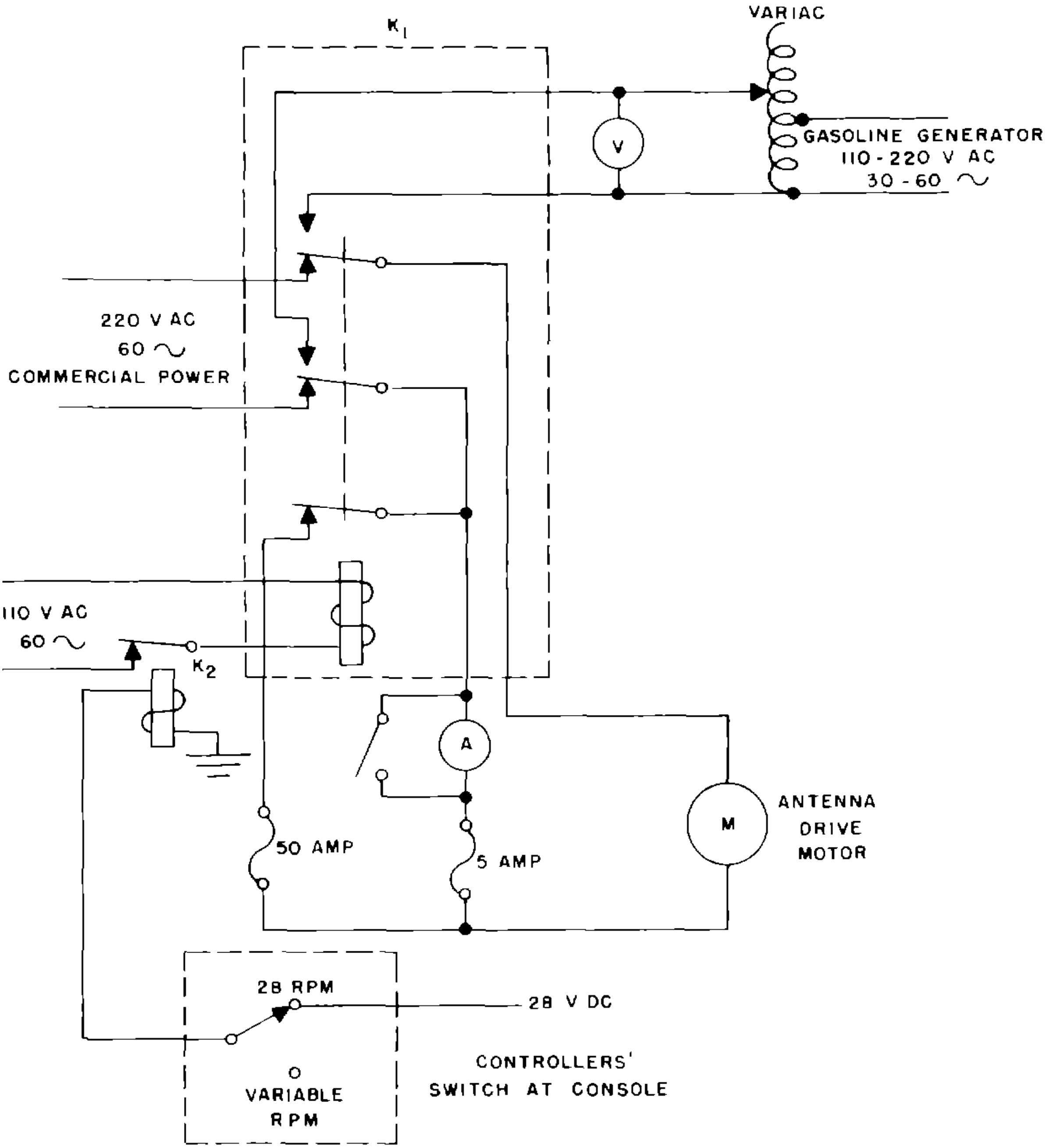

FIG 27 VARIABLE SPEED CONTROL OF TYPE ASR-1 RADAR ANTENNA

[illegible]

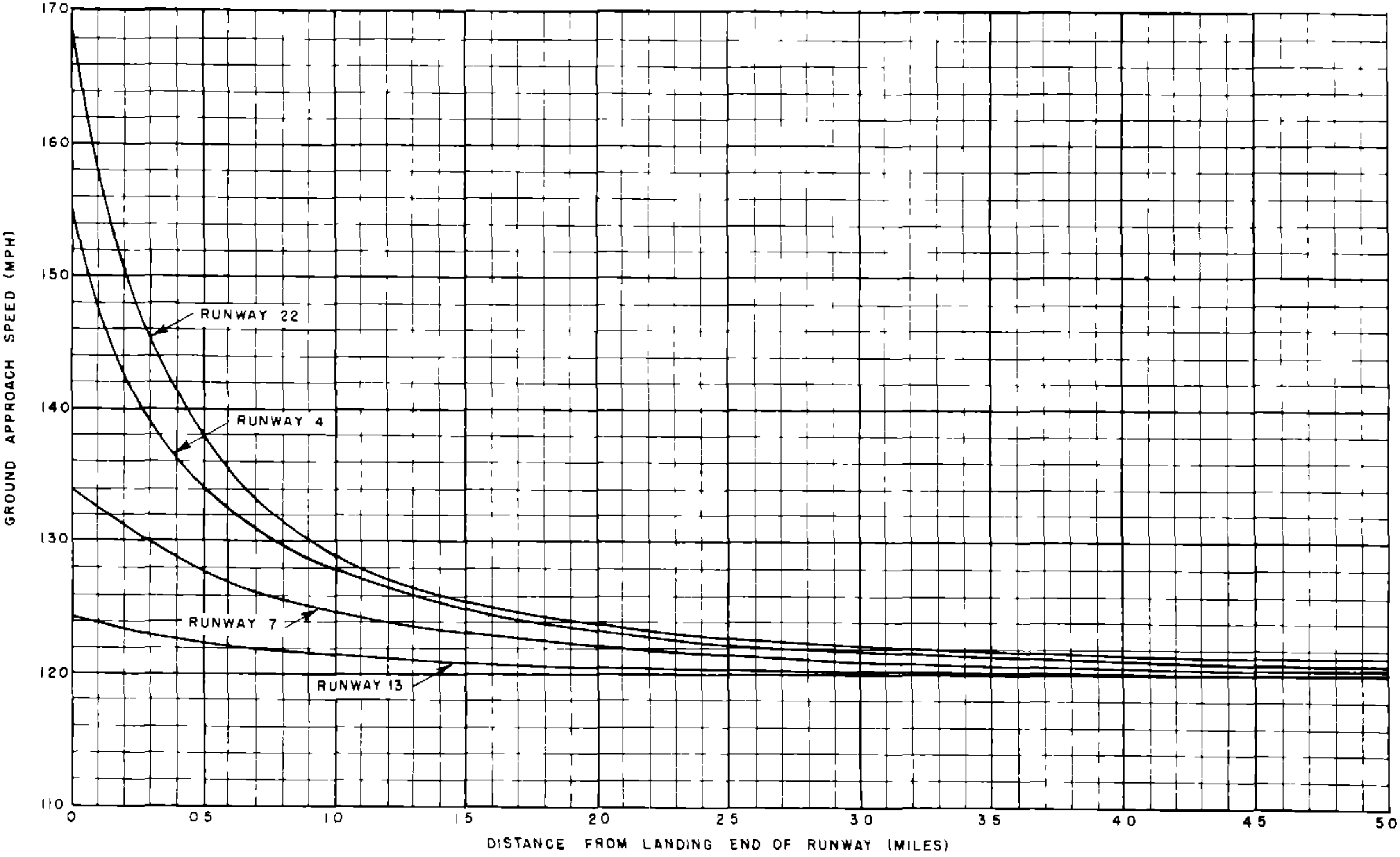

FIG 28 GROUND APPROACH SPEED VERSUS DISTANCE TO LANDING END OF RUNWAY REQUIRED TO PRODUCE FIRST RADIAL BLIND SPEED (120 MPH), IDLEWILD