INTERIM REPORT

SIMULATION TEST OF THE ARCATA, CALIFORNIA, DIAMOND RUNWAY CENTERLINE

PROJECT NO. 430-301-05X

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(RD-69-35)

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SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

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ABSTRACT

The guidance value of the Arcata diamond runway centerline paint markings was tested by comparison with the U. S. standard centerline markings in the Dalto/P-3 visual simulation facility. Twenty experienced pilots participated in the testing. Results generally favored the U. S. standard centerline consisting of a 3-foot-wide interrupted stripe with 120-foot painted length and 80-foot gaps, as opposed to the 10-foot maximum width diamonds with 75-foot length and spacing. The only exception was that the diamonds were seen farther away prior to touchdown, a result that is attributed to the one-third larger total painted area.

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INTRODUCTION

Purpose

The purpose of this test was to determine if the diamond runway centerline marking system provides superior guidance to that of the U. S. standard runway centerline marking under simulated Categories II and IIIA visibilities.

Background

The diamond pattern runway marking system has been installed at Arcata Airport, California, for a number of years. Advocates of this marking system have proposed that the diamond pattern provides superior guidance to that of the U. S. standard system and that it should be considered for adoption as a standard.

The diamond marking system consists of elongated, diamond-shaped paint markings along the runway centerline, together with touchdown zone distance markings installed as shown in Figure 1. The present test was confined to the centerline.

Runway centerline markings are used on all runways, and runway centerline lighting is required for Category II operations. Visual guidance along the runway centerline is particularly important to pilots for exercise of directional control during landing and takeoff operations. Centerline guidance becomes more important as visibility is decreased and aircraft speeds increase. Consequently, since higher approach speeds are being flown in lower visibilities of Category II operations, efforts are underway to improve visual guidance along the runway centerline.

Under most daytime low-visibility conditions, semiflush runway centerline lighting provides greater visual range for guidance than painted markings. Nevertheless, there still is need for effective runway centerline markings. This need is most apparent in bright daylight fog with a low brightness contrast. With reduced contrast, the effectiveness of lights is greatly reduced. The relatively large area of white painted marking, particularly when seen against the contrasting background of a black runway, makes the marking easier to see. For this reason, it is anticipated that painted runway markings will continue to be part of the standards required for projects supported under the Federal-Aid Airport Program and required for instrument operations.

Description of Centerline Marking Systems: The present U. S. standard runway centerline marking is a broken line with 120-foot painted stripes and 80-foot gaps or spaces. Minimum stripe width is 1 foot for

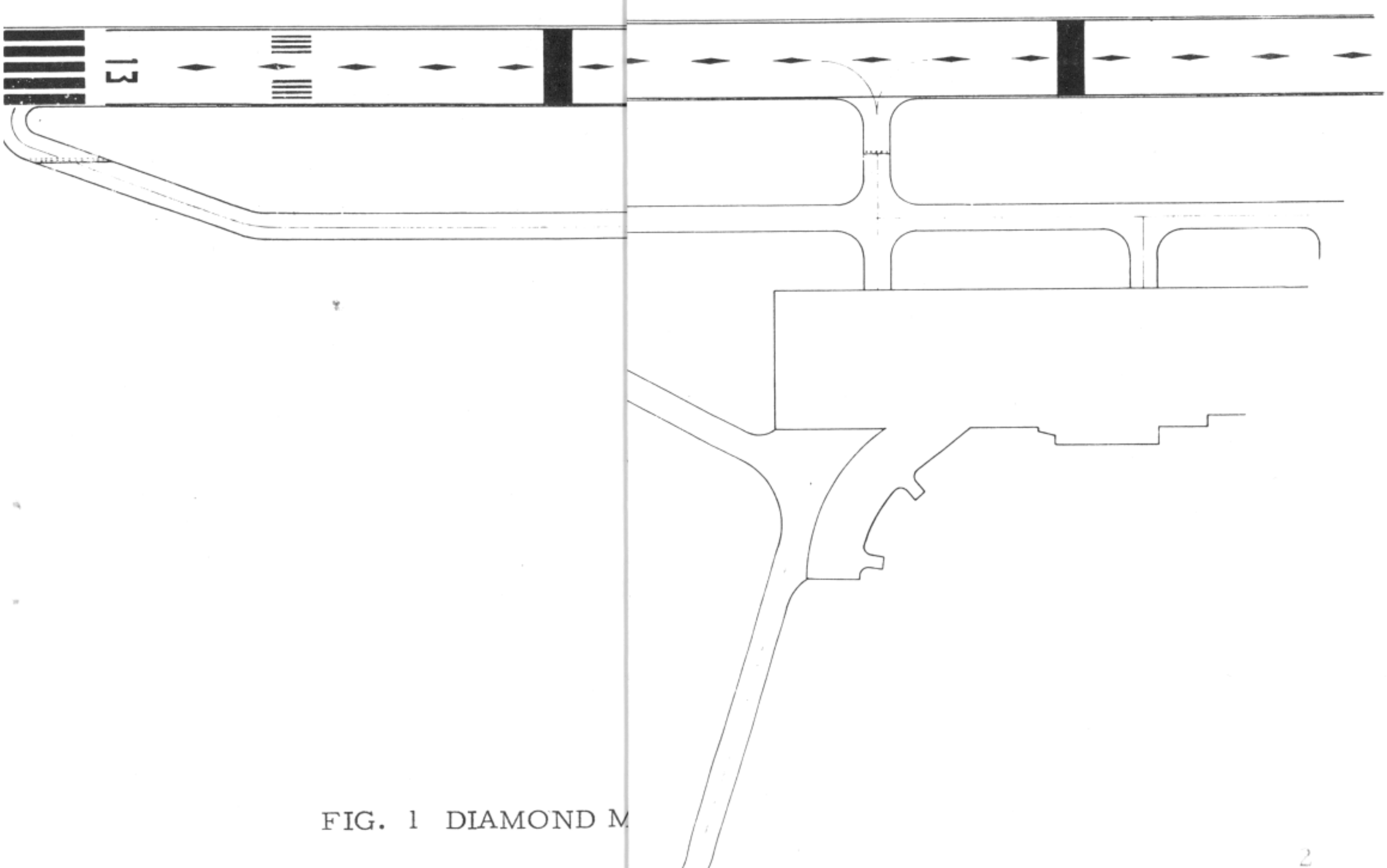

FIG. 1 DIAMOND M

basic (VFR) runways and 3 feet for instrument and all-weather runways.[1] Maximum allowable widths are not spelled out so clearly. It is, however, the usual practice to conform to the indicated standard of 3 feet as a maximum for width of centerline runway marks at major airports.

The dimensions of the diamonds are: length, 75 feet; maximum width, 10 feet; and gap or spacing, 75 feet (see Figure 2). For 1,000 feet of marked centerline, this gives a total of 2,624 square feet of paint versus the 1,800 square feet of paint in a simular distance of the standard interrupted stripe.

If the standard interrupted stripe centerline mark were widened to 4 to 5 feet, it would comprise, from the eye position of a pilot whose plane was on the runway, more of a squared trapezoid than a stripe. For example, at a 360-foot distance, a 5- by 120-foot stripe, seen from a 15-foot eye elevation, is about equally as wide as long. If boldness were due simply to number of square feet of paint, the standard 120-foot stripe would have to be widened to 4 feet 4-1/2 inches to attain equal boldness compared to the 75- by 10-foot diamond. If stripe length were reduced to 75 feet, paralleling the diamond length, width would have to be increased to 5 feet to produce equal paint footage. Such a 5-foot stripe would, from a 360-foot distance and a 15-foot height, become almost a short transverse dash. Of course, from the same reasoning, the diamond is foreshortened and appears wider than it is long when viewed at such a distance down the runway. Here, it might be argued that the points line up along the runway centerline, preserving fine-grain directional guidance.

Description of Model Runways for Test: Two moving belts were prepared for use in the Dalto/P-3 visual simulation facility. Each belt served as a model runway, with approach lights, passing before a television camera to produce the signals projected on a screen in front of the pilot subject. The diamond centerline was installed on the first half of one model 10,000-foot runway with the U. S. standard centerline markings completing the remainder of the runway. The second model runway had the patterns reversed, the U. S. standard at the approach end and the diamond centerline installed on the second half. The simulated runway edge lights were removed for the paint-marking test.

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[1] FAA Advisory Circular AC 150/5340-1A, 6/30/66, "Marking of Serviceable Runways and Taxiways."

CENTERLINE MARKER

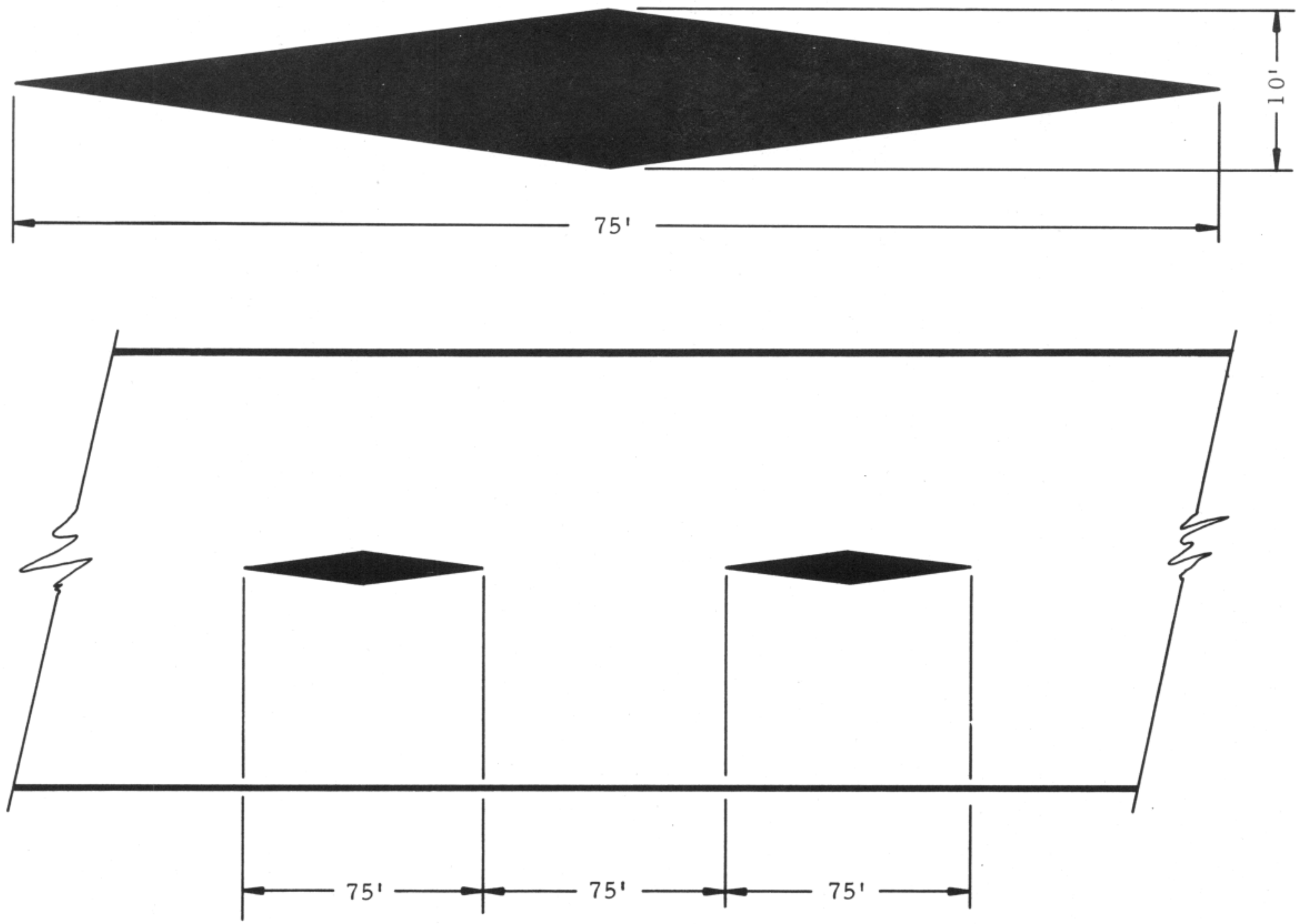

FIG. 2 DIMENSIONS OF DIAMONDS

The ICAO pattern A touchdown zone markings were used for the 3,000-foot touchdown zones (approach ends) on both runway models (see Figure 3, pattern A). The far ends of both runways retained the 4-3-2-1 U. S. standard touchdown zone stripes (ICAO pattern B) that had been installed for previous tests. (See Figure 3, pattern B.)

Since the intention of the test was to direct the attention of each subject pilot to the guidance value of the centerline markings, a special provision was made to delete a portion of the usual runway edge markings. These are 3-foot white stripes running the length of the standard runway defining the left and right edges, and a pilot receives a great deal of longitudinal guidance from these edge marks. To focus attention on the centerlines, the edge marks were removed in the 5,000-foot center section of each runway (see Figure 4). Hence, the first 3,000 feet at the approach end was marked with the ICAO pattern A touchdown zone with edge stripes; the next 5,000 feet of runway bore only centerline marks (2,500 feet of each test pattern); and the final 2,000 feet carried the U. S. standard touchdown zone and runway edge markings.

Description of Flight Simulation Environment: The simulation environment consisted of the Curtiss-Wright P-3 flight duplicator and the Dalto visual simulation system attachment. The flight duplicator provided a single pilot cockpit environment with standard flight instruments and controls.[2] As explained under "Subject Instructions" (see Appendix), the simulator was set up to simulate either a split-axis or an automatic approach and landing system for ILS approaches to the runway. In the split-axis configuration, the pilot had control of pitch attitude and power application. The speed was locked at 130 knots at lift-off and remained at 130 knots for the approach and touchdown. Nosewheel/rudder steering was provided on specified runs. The remaining runs were locked on the runway centerline or offset to one side as further described in subsequent paragraphs. Outputs from the simulator controlled the action of the visual simulation system.

The visual simulation system provided a visual scene of the runway and paint-marking configuration plus the standard approach lighting system as it would appear under low-visibility, day fog conditions. The picture was generated by a closed circuit television camera viewing a

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[2] Details of the flight duplicator may be found in Report No. RD-66-37, "A Configuration Design Concept for Distance Coded Marking of Category II and IIIA Runways."

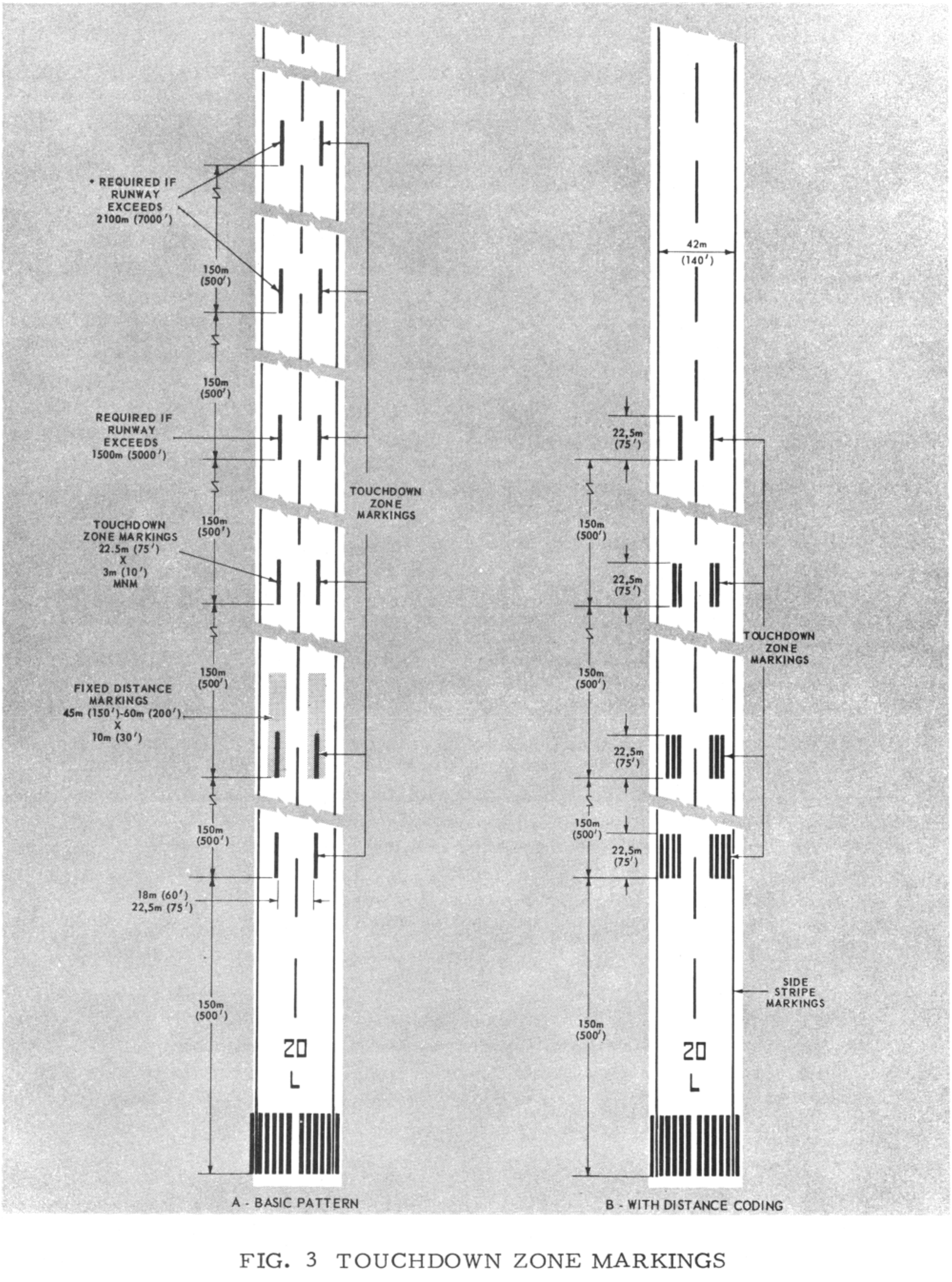

FIG. 3 TOUCHDOWN ZONE MARKINGS

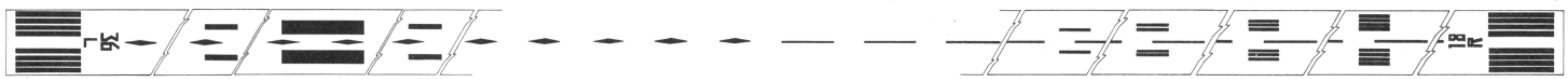

FIG. 4 MODEL RUNWAY TEST PATTERN

model runway system with the resulting visual scene projected on a large screen in front of the pilot's cockpit.

The 300:1 scale model runway and approach lighting system was installed on an endless moving neoprene belt. The speed of the belt was controlled proportionally to the ground speed as computed by the simulator.

Visual range conditions for Category II (approximately 1,200 feet) and Category IIIA (approximately 700 feet) under bright day fog conditions were simulated by the use of fluorescent lights and appropriate light shields installed over the moving belt at the camera end of the model runway enclosure. The visual range on final approach was, of necessity, increased approximately 50 percent over the on-ground visual range due to the approach path angle and the inability to further control the lighting. Brightness levels for the day fog conditions were set up and maintained at $.42 \pm .03$ footlamberts on the projected paint markings and $.25 \pm .03$ footlamberts on the background or runway adjacent to the paint marking. The overall result was a quite realistic bright field, with no ground texture, and a reasonably realistic attenuation of visibility of the paint markings with distance.

Design of the Tests: On the general topic of pattern and dimensions of centerline markings, there are many specific questions that might be asked. The purpose, however, was to evaluate a particular variant, the diamond pattern. Hence, only two of the multitude of possible sizes, shapes, and spacings of centerline markings had to be examined, the standard and the proposal. Each had to be tested for several features--guidance prior to touchdown while on final approach, landing rollout guidance, and guidance during takeoff roll. If no marked advantage of the diamond pattern turned up in any one of these guidance phases, it would be reasonable to cut off further inquiry on a diamond centerline. On the other hand, if a substantial preference for the diamond pattern were to turn up in the results, one would be left with a question in mind as to whether the larger area versus the pattern shape of the diamonds might be the controlling feature. Obviously, if the key feature were painted area, it would be simpler and cheaper to widen existing centerline stripes than to change over to diamonds. But, before going on to such matters, the question had to be, "Is there a preference for the diamond pattern?"

To establish the presence or absence of a preference for the diamond pattern, a questionnaire was developed with a total of 12 items. Four of these asked which pattern was better for landing guidance prior to touchdown, referring to runway direction information, aid in aligning the aircraft, farthest seeing distance, and overall quality of guidance.

Two questions related to the rollout phase of landing and asked the preference for recovery of runway centerline after displaced touchdown and guidance to remain on the centerline. Two questions were concerned with the takeoff roll and asked about alignment guidance and overall takeoff roll guidance. The last four questions were general, inquiring about possible marked disadvantages, shape preferences, dimensions of marks, and need for further tests. (The subject instructions and questionnaire will be found in the Appendix.)

Landing touchdowns, each followed by rollout and stop near the end of the runway, followed in turn by repositioning for takeoff, were controlled to show the two model runways from left, right, and center of the runway centerline axis. In addition, the pilot was given control of the nosewheel/rudder steering on certain takeoffs so that he gained experience in maneuvering to and across the runway centerline.

After completion of these various approaches, the subject was asked to observe the centerline markings while sitting in the cockpit under controlled slow speed, on-ground conditions and, in addition, under controlled low-altitude passes over the runway. Finally, the subject was asked to watch the television picture from the model runways on a TV monitor that provided a sharper picture than the large screen projection system.

After all of this systematic exposure of the subject pilot to the alternatives, he was asked to fill out the questionnaire. The preference responses obtained on that questionnaire became the primary data.

Twenty pilots participated as subjects in the testing. Ten were exposed to the 700-foot visual range and 10 were exposed to the 1,200-foot visual range. All of the 10 participating in the lower visibility tests were drawn from the FAA, NAFEC, Flight Operations Branch, and should be considered highly experienced and thoroughly qualified in low-weather operations. The 10 pilots participating in the 1,200-foot visual range tests consisted of 4 from the FAA, Flight Inspection District Office, 2 from the United States Air Force, both qualified as airline copilots, 3 from the NAFEC, Flight Operations Branch, and 1 from FAA, Flight Standards Service.

DISCUSSION

Results

In the questionnaire there were 10 basic questions requiring a comparison and statement of preference between the two centerline patterns.

Inspection of the responses summarized in Table I reveals that there were no marked differences between the two visibility ranges. Those few questions showing a wide majority preferring one pattern or the other duplicated the preference for both 700- and 1,200- foot visibilities. Because of this similarity in trends, it will be simpler to discuss the pilots' preferences using the total column.

With all 20 subject pilots considered together, the preferences on all questions except two were in favor of the U. S. standard centerline. There are six questions, numbers 4, 5, 6, 7, 8, and 10, on which the choices are divided evenly or very nearly so. Attention should be directed, then, to the remaining questions, those on which the subjects produced a consensus view.

On question 1 (Landing, prior to touchdown: For seeing the runway direction (runway direction guidance) I prefer the: Diamond ℄; Stripe ℄), 11 preferred the stripe and 6 the diamonds. Question 2 (Landing, prior to touchdown: For aid in correcting the aircraft alignment with the runway, I prefer the: Diamond ℄; Stripe ℄) produced 12 for the stripes and only 5 for the diamonds. Question 3 is discussed below. Beyond number 3, the only question showing a consensus of judgment was number 9 (General Questions: Did either pattern have any marked disadvantage such as jolting visual interruptions? Yes; No). Seven said "yes," the diamond pattern had one or more disadvantages; one said "yes," the stripe pattern had one or more disadvantages. Like questions 1 and 2, then, question 9 favors the U. S. standard pattern.

Question 3 (Landing, prior to touchdown: I believe the pattern that can be seen from farthest away is the: Diamond; Stripe) represents the divergent consensus. Apart from it, no query raised a strong vote in favor of the diamond centerline. Question 3 asked which pattern could be seen the farthest away prior to touchdown, and all eight of the lowest visibility pilots expressing a choice said the diamonds could be seen farthest. In the 1,200-foot visual range condition, a 2 to 1 majority, 6 to 3, voted for the diamond. Hence, question 3 produced 14 votes for the visual range of the diamond versus only 3 votes for the stripes.

There seems a ready explanation as to why the diamond centerline was seen farther away on approach. There is, in fact, about one-third more painted area in the diamond centerline. In low contrast, bright day fog, it is the large painted area of runway marks that makes them stand out and provide guidance. Therefore, we must assume that the pilots were correct in saying the diamonds could be seen at greater approach range, while keeping in mind that the pilots rated the stripes superior or equal on every other question.

TABLE I

PREFERENCES FOR THE DIAMOND VS. STRIPE CENTERLINE

	700' RVR			1200' RVR			Total		
	Di.	St.	=	Di.	St.	=	Di.	St.	=
Approach									
Q1 (RW Direction)	2	5	3	4	6	0	6	11	3
Q2 (AC Alignment)	2	5	3	3	7	0	5	12	3
Q3 (See Farthest)	8	0	2	6	3	1	14	3	3
Q4 (Overall Quality)	4	5	1	5	3	2	9	8	3
Roll-out									
Q5 (To recover ℄)	3	4	3	4	5	1	7	9	4
Q6 (Overall Guidance)	3	5	2	5	4	1	8	9	3
Take-off									
Q7 (Better Alignment)	2	4	4	4	4	2	6	8	6
Q8 (Overall Guidance)	3	5	2	5	5	0	8	10	2
General									
Q9 (Marked Disadvantages)	4	1	5	3	0	7	7	1	12
Q10 (Shape Preference)	2	4	2	4	5	1	6	9	3
Q11 (Dimensions)	Comments				--			--	
Q12 (More Tests)	Comments				--			--	

The subjects were asked to rate the strength of their preference over scale range from 1 to 10--"favor slightly" to "favor strongly." The strength of preference statements varied widely with different questions. Also, the pilots preferring the diamond centerline on any given question tended to state a slightly stronger strength of preference than did the pilots preferring the U. S. standard centerline. Between questions, the range was from a low mean strength of 1 unit (favor slightly) on question 3 to a high mean strength of 5-1/2 units (a middle strength) on question 5. Most questions produced mean strength of preference in the 3- to 4-unit area, about halfway from slight to medium as a preference. Between centerlines, the superior strength of preference for those choosing the diamonds was mild as well, about 1 unit on the average, although consistent for 8 of the 10 preference questions.

None of the mean preference scores was very strong, and no readily interpretable pattern appeared in these scores.

Cost Considerations: A complete cost analysis for each of the centerline patterns under test was not requested in the initiation of the present test program. Disregarding cost, it was requested that the guidance value of the diamond pattern be assessed. Taking note of the test results, with an indication that the diamonds provide a bold directional signal that can be seen farther away than the standard dashes, a preliminary cost estimate was made.

The manager of a major international airport was requested to estimate time and cost involved in painting a runway with the diamond pattern versus the standard pattern. The information obtained pointed to a major penalty in using the diamond pattern at a busy airport. Runway closing for repainting was estimated at 7 hours for the diamond pattern and 1 hour for the standard pattern for a runway 7,000 feet in length. The direct cost estimate for the diamond pattern was $900 versus $300 for the standard pattern.

CONCLUSIONS

Based on flight simulator examination leading to comparisons and statements of preference of 20 experienced pilots and a cost analysis for painting the diamond and standard pattern, it is concluded that:

1. When conditions are such that both are visible, the U. S. standard runway centerline marking, consisting of a long interrupted stripe, provides adequate and superior guidance information compared to the diamond pattern centerline under simulated Category II and Category IIIA visibilities.

2. Due to the larger painted area, the diamond pattern centerline can be seen farther away on approach.

3. The complex shape of the diamond pattern would involve considerable additional time and money to paint and repaint runways, as compared to the standard pattern.

RECOMMENDATIONS

Based on the preference of pilots for the U. S. standard centerline marking and the time and cost factors involved in applying the diamond pattern, it is recommended that:

1. The present U. S. standard for runway centerline marking not be changed to employ diamond-shaped markings.

APPENDIX

SUBJECT INSTRUCTIONS AND QUESTIONNAIRE

Runway Centerline Marking Test

A diamond runway marking configuration (Figure 1 of report) has been installed at Arcata, California. Advocates of this marking pattern report that guidance is superior to that provided by the U. S. standard configuration.

The first test in this series compares the diamond centerline with the U. S. standard centerline.

After several simulated takeoffs, approaches, and landings with rollout, together with other observations of the two configurations, we want you to give us your opinion on them. Obviously, it would be better to measure aircraft performance with both markings, but present resources make it necessary to carry out this comparison "subjectively." Still, there is reason to believe that you, as an experienced pilot, after seeing both patterns in a series of simulated runs, can give a valid opinion.

As you may recall, the U. S. standard for the so-called all-weather runways, or ILS runways, requires a centerline stripe of 120 feet in length and a minimum of 3 feet in width with 80-foot spacing. The Arcata diamond is 75 feet in length by 10 feet in width with a spacing of 75 feet.

We have two runways set up on separate belts with the diamond centerline installed on the first half of one runway and the standard centerline from the midpoint to the end of the runway. The second runway has the patterns reversed. In addition, we have removed the runway edge marking in the center portion of the runway (between the touchdown zones) for test purposes to eliminate distraction from other cues.

The data session will require six takeoffs, approaches, and landings on each of the two runway configurations.

The simulator will be set up to simulate both a split-axis and an automatic approach and landing system with an equal number of approaches on each. You will control only the elevator for pitch attitude for the split-axis approaches. The experimenter will brief you on the auto approach and landing setup. The runs will be varied to keep you aligned with the centerline, offset to right and left, and, on certain runs, you will be given control of the nosewheel/rudder steering on the takeoff and landing roll to enable you to maneuver across the runway centerline.

The simulated visual range of the paint-marking pattern will be 700/1,200 feet.

Please think of yourself as a pilot observing landing-roll, or takeoff with particular attention to the runway centerline marking. If the view is from an aircraft that is displaced from the correct runway alignment, try to estimate the ease of making corrections using the markings for guidance.

After completion of these approaches, you will be asked to observe the centerline markings while sitting in the cockpit under controlled speed, on-ground, conditions. Also, you will be asked to observe the patterns on the TV monitor since the monitor provides a sharper picture more representative of a clear day condition.

After this series of runs, we will ask you to fill out the attached questionnaire. So that you will know what you will be asked, please read the questions now.

Before we start the data runs, we will give you a few approaches for familiarization with the simulator and the procedures.

QUESTIONNAIRE

Runway Centerline Marking Test

Directions: Runway marking provides some guidance for alignment with the runway and for touchdown, as well as for rollout and for takeoff. Since there may be some differences in the utility of the guidance provided by the two different patterns in the present test for these flight phases, the questions following are grouped under the headings: Landing, prior to touchdown; Landing, rollout; and Takeoff roll. Spaces are provided for you to check-mark your answers. At the end, your comments would be much appreciated.

Landing, prior to touchdown

1. For seeing the runway direction (runway direction guidance) I prefer the:

Diamond ℄ ________

Stripe ℄ ________

Please indicate the degree or strength of your preference, as appropriate for each question, by placing a checkmark on the scale:

1 ________ 5 ________ 10
Favor Slightly — Favor — Favor Strongly

Comments:

2. For aid in correcting the aircraft alignment with the runway, I prefer the:

Diamond ℄ ________

Stripe ℄ ________

Strength of preference: 1 ________ 5 ________ 10
Favor Slightly — Favor — Favor Strongly

Comments:

3. I believe the pattern that can be seen from farthest away is the:

Diamond ________

Stripe ________

Comments:

4. I prefer the overall quality of guidance (prior to touchdown) of the:

Diamond ℄ ________

Stripe ℄ ________

Strength of preference: 1 ________ 5 ________ 10
Favor Slightly — Favor — Favor Strongly

Comments:

Landing, rollout

5. For recovery of the centerline if displaced upon touchdown, I estimate that less effort will be required with the:

Diamond ℄ ________ Strength of preference: 1 ________ 5 ________ 10

Stripe ℄ ________

1	5	10
Slightly Better	Better	Much Better

Comments:

6. For overall guidance helping the pilot to stay on the runway centerline while rolling out, I prefer:

Diamond ℄ ________ Strength of preference: 1 ________ 5 ________ 10

Stripe ℄ ________

1	5	10
Favor Slightly	Favor	Favor Strongly

Comments:

Takeoff roll

7. During the takeoff roll, which pattern provides better alignment guidance?

Diamond ℄ ________ Strength of preference: 1 ________ 5 ________ 10

Stripe ℄ ________

1	5	10
Slightly Better	Better	Much Better

Comments:

8. Overall, for takeoff roll guidance, I prefer the:

Diamond ℄ ________ Strength of preference: 1 ________ 5 ________ 10

Stripe ℄ ________

1	5	10
Slightly Better	Better	Much Better

Comments:

General Questions

9. Did either pattern have any marked disadvantage such as jolting visual interruptions?

Yes ________ No ________

If "Yes," please explain:

10. Do you feel that the shape of markings of one pattern provides better guidance than the other?

Yes ________ No ________

If "Yes," which pattern do you prefer:

Diamond ℄ ________ Strength of preference: 1________5__________10

1	5	10
Favor Slightly	Favor	Favor Strongly

Stripe ℄ ________

Comments:

11. Would you recommend changing the dimensions or make other changes for centerline marking? Yes ______ No ______

If "Yes," please indicate your preference for changes to:

	Length	Width	Spacing
Diamond ℄	____________________	____________________	______________
Stripe ℄	____________________	____________________	______________
Other ℄	____________________	____________________	______________

Comments:

12. Do you feel that further testing or evaluation should be made? Yes___ No___
Please explain:

My comments about this comparison are (use reverse if more space is required):

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