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Project No. 430-008-01R

ANALYSIS OF RUNWAY MARKING CONFIGURATIONS FOR BRIGHT DAYLIGHT CONTACT FOG OPERATIONS

NOVEMBER 1964

FEDERAL AVIATION AGENCY

Systems Research & Development Service

Atlantic City, New Jersey

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ABSTRACT

Four experiments were conducted to determine the feasibility of utilizing runway marking to provide guidance for visual transition for landing and for monitoring of runway distance to go. The experiments were done in a visual landing simulator modified to present the field and brightness contrast relationships characteristic of a bright daylight contact fog with a visual range of approximately 1,200 feet. The results suggest that it is feasible to provide visual support under the specified visibility conditions with patterns compatible with the standard narrow gauge touchdown lighting configuration. In addition, it appears possible that these systems can be designed without marking elements in the critical centerline wear area of the landing zone and in "double ended" versions providing distance to go information. Future work will attempt to extend the distance indicating code to a configuration adequate for 12,000 feet, as well as for the 7,000-foot runway used in these experiments.

INTRODUCTION

It has been suggested that under conditions of low brightness contrast such as are obtained with a bright daylight contact fog, runway markings are easier to see than touchdown zone lights. The relatively large areas represented by elements of a marking configuration appear to function as the dominant cues when field brightness is high and when the contrast between runway signal lights and field brightness is low. At least, informal pilot reports of low visibility daytime landing experiences point in this direction.

This report describes a series of experiments designed to develop criteria for a runway marking configuration that would satisfy the following objectives:

1. Provide guidance for visual transition for landing under Category II day-fog conditions.

2. Be compatible, although not necessarily identical, with narrow gauge touchdown lighting configurations.

3. Reduce the need to maintain paint in critical wear areas as much as possible.

4. Provide runway distance information on take-off as well as landing.

Experiment I in the series is concerned with the feasibility of visual landing under Category II (1,200-foot RVR) day-fog conditions with a runway marking pattern that eliminates the centerline in the touchdown zone. Experiment II compares an experimental narrow gauge configuration with an International Civil Aviation Organization (ICAO) narrow gauge pattern that incorporates a boldly marked aiming point. In Experiment III two versions of a double-ended 3:2:1 marking pattern, differing primarily in longitudinal spacing of elements, are examined and compared for effectiveness in providing distance information on take-off as well as landing. Both of these configurations employ a mid-point stripe that divides the 7,000-foot simulated runway into two 3,500-foot sections. Finally, in Experiment IV the wide-spaced version of these two 3:2:1 patterns is compared with a bidirectional ICAO configuration, both incorporating the mid-stripe. Again the analysis is directed toward determining effectiveness in guiding take-off as well as landing operations.

All of the experiments were conducted in a flight simulator with a Dalto belt type visual attachment modified to provide a 1,200-foot visual range with runway marking elements as the defining targets in an atmosphere representative of a bright daylight contact fog. (For details of this modification, see Appendix A.)

EXPERIMENT I

Centerline (C) vs. Split-Centerline (S) Narrow Gauge Patterns

If runway markings are to be used to support visual transition for landing under low visibility day-fog conditions, the compatibility of the configuration with lighting patterns employed for the same purpose becomes an important issue. An obvious response to this requirement is simply to represent the same general pattern in a marking configuration, as has been done with the "Narrow Gauge Centerline" pattern shown in Figure 1. At the same time, the special problem of durability under heavy use mitigates against the use of runway markings where frequent damage from tire marks is likely. One such location, of course, is the runway centerline. Even though centerline lighting is thought to be an essential feature of runway lighting, including the landing zone, it is conceivable that no material degradation of guidance would be experienced if the centerline marking were deleted in the landing zone. With this deletion, however, it was felt that some longitudinal strengthening of lateral elements of the pattern might be required to compensate for the alignment information lost without the centerline. The "Split-Centerline" configuration (Figure 1) used in this experiment represents such an attempt to strengthen lateral elements. The centerline has been replaced by stripes that tie together successive pairs of the inner barrettes of the narrow gauge array.

A laboratory study in 1947 and a field test in 1951 at the School of Aviation Medicine (References 3 and 4) resulted in a recommendation that chevrons in a distance coded arrangement be adopted by the U. S. Air Force. Since these patterns would be incompatible with contemporary standards for displaced threshold marking and underrun marking, and would require application of paint in critical wear areas, they are not being considered in the present experimental program.* The main

*A separate point of interest in the 1947 study was a simple method of simulating a runway viewed through fog represented by a ground glass screen. The apparatus did not permit the observer to perform control responses, however, and was limited to measurement of symbol recognition distance as represented by the visual acuity required to resolve and recognize the symbol through the screen. The description of the fog screen suggests that light scattering effects were achieved, but there seemed to have been no attempt to relate screen density to fog transmissivity, or to scale density as a function of angle of regard.

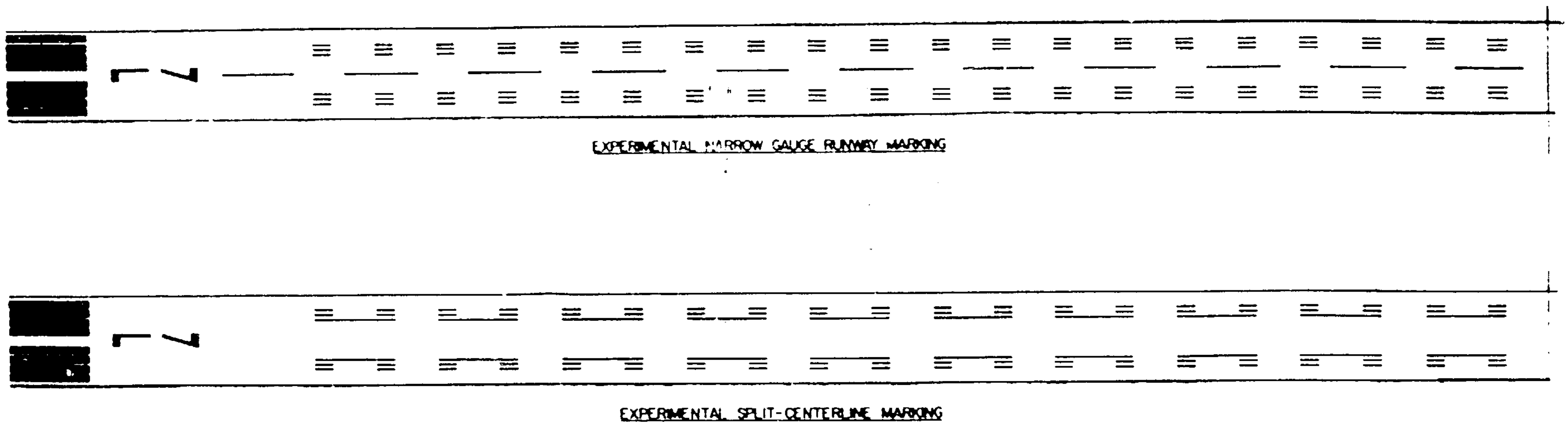

Figure 1. EXPERIMENTAL NARROW GAUGE AND SPLIT-CENTERLINE MARKING SYSTEMS

purpose of the experiment was to determine whether the split-centerline treatment resulted in any important degradation of the guidance qualities of the narrow gauge configuration.

Experimental Method

The plan of the experiment is illustrated in Table I. The statistical model is the "t" test based on difference scores, a technique of repeated measures on the same subjects in which each subject forms his own control (Reference 5). The analysis will show whether a significant gain or loss in level of performance has occurred as a result of the experimental treatment.

The flight procedure used in the experiment is essentially the same as that used in preceding experiments in the visual aids program (References 6-12). Through controlled manipulation of the simulator flight environment, rotational displacements are introduced on each axis of flight in the segment of the flight path where the visual system is supposed to provide guidance information, and the pilot's ability to recognize these displacements and to control visually the rate at which they are corrected is analyzed. In this landing zone marking problem, the displacements introduced were in roll, pitch-attitude, and heading, with respect to line-of-flight. Details of the procedure are described in Appendix B.

The underlying assumption in this approach is that the pilot is performing a compensatory tracking task in which the comparison stimulus is the visual recall of the appearance of the scene when the landing is being performed correctly. The pilot must remember how things appear when the flight is proceeding satisfactorily, and interpret the ongoing visual scene accordingly. Degradation in performance will appear in a reduction in the frequency with which predetermined criterion levels are achieved.* The differences between the experimental patterns will be functions of the relative clarity and reliability with which cues indicating orientation in space and rate of change in orientation in space are provided.

Subjects

Five NAFEC project pilots participated as subjects in the experiment. All pilots were active project pilots, multi-engine and instrument rated, and several were jet qualified. The pilots were qualified by the experimenter in the P-3 and Dalto Visual Simulation Complex before starting data runs. The average check out time for a pilot was about one hour, and the criterion of proficiency was judged by

*See "Data Recorded," p. 7

TABLE I

Experimental Design, Experiment I

Experimental Configurations

S - Split-Centerline Narrow Gauge
C - Centerline Narrow Gauge

Displacement Variables

Heading - Aircraft is displaced on heading axis at time of visual transition, with respect to the line of flight and runway heading.

Roll - Aircraft is displaced on roll axis at time of visual transition to runway lighting and marking.

Attitude - Aircraft is displaced on pitch axis at time of visual transition to runway lighting and marking.

Number of Trials

Maneuver	Pattern C	Pattern S	Total
H	6	6	12
R	6	6	12
A	6	6	12
	18	18	36

Schedule

Session	Variable	No. Trials	Pattern Sequence		Record Preference
1	H	6	CCC	SSS	√
2	R	6	SSS	CCC	√
3	A	6	CCC	SSS	√
4	A	6	SSS	CCC	√
5	R	6	CCC	SSS	√
6	H	6	SSS	CCC	√

the experimenter (who was a pilot and a rated flight simulator instructor) with the concurrence of the pilot subject.

Data Recorded

The following data were recorded by the experimenter by observing the pilot's actions and the visual scene presented, and, where feasible, by Brush Recorder:

1. Displacement Recognition. After exposure to the displacement, the pilot initiates a control response in the appropriate direction.

2. Rate of Correction. Pilot completes the appropriate control response prior to the criterion points (runway threshold and point of touchdown).

3. Flare Path. Pilot rounds out glide path so that velocity vector is reduced to a normal rate of descent at touchdown.

4. Longitudinal Positioning at Touchdown. Pilot touches down within a defined space (the first, second, or third 1,000-foot sector of the landing zone), or a minimum distance from the aiming point (usually 1,000 feet from the runway threshold).

5. Lateral Positioning at Touchdown. Pilot touches down within a defined space (inside the narrow gauge marking pattern), or a minimum distance from centerline.

Pilot Performance

There is no evidence of any significant degradation of performance attributable to the treatment of the centerline in these narrow gauge marking configurations. As a matter of fact, the only differences of sufficient magnitude to warrant the performance of a statistical analysis favor the split-centerline technique (see Table II), and of these only one (completion of corrective maneuver before crossing threshold) produced a difference approaching statistical significance. It is difficult to see why the split-centerline pattern might be more effective in controlling rate of response, unless the larger spatial intervals represented by the center lane of the touchdown zone, and the longer inner barrettes, offer visual angles more adequate in providing rate information in the early phase of the landing maneuver. The rate of change would be greater over a portion of the approach path with these larger visual angles and thus more effective in cueing rate of closure than the smaller angles

TABLE II

Summary of Performance Results, Experiment I

Centerline vs. Split-Centerline Narrow Gauge Patterns

Criterion Measure	Centerline (C)	Split Centerline (S)	t*	p
Displacement Recognition**				
Heading (H)	6.0	6.0	-	-
Roll (R)	5.8	5.8	-	-
Attitude (A)	6.0	6.0	-	-
Rate of Correction***				
Before threshold (H+R+A)	7.4	10.0	2.203	.10 - .05
Before touchdown (H+R+A)	16.0	16.2	-	-
Flare Path (F)***	9.6	10.8	1.395	.30 - .20
Positioning at Touchdown***				
Lateral (L)	****			
Mean distance from centerline	31.0	27.6	.91	.50 - .40
Frequency within barrettes	6.2	7.6	.965	.40 - .30
Longitudinal (P)				
Frequency within middle 1,000-foot sector	9.2	10.6	1.28	.30 - .20
Mean distance from threshold	1278.8	1281.4	.031	.90

* "t" test.
** Each pilot had 6 opportunities under each condition.
*** Each pilot had 18 opportunities under each condition.
**** Scores on this variable are average lateral displacement from runway center.

subtended by the centerline plus narrow gauge array at the same distances from touchdown. In view of the overall lack of performance discrimination between these patterns, however, it is felt that not too much emphasis should be placed on this point as far as implications for operational employment are concerned.

Pilot Questionnaire Responses

Pilots participating in the experiment did not seem disturbed by the unorthodox "split-centerline" treatment (Tables III and IV). As far as pilot preferences are concerned, it would appear that either pattern would be reasonably well accepted. It should be noted, however, that none of the pilots reported having had previous experience with runway marking under critical day visibility conditions. All of the pilots felt that a test was required to validate their judgment, but participation in the test did not materially affect their acceptance of either pattern, unless it might be said that their responses are not quite as confident as they were before. They were a little more conscious of missing or confusing features in each pattern after they had flown with it in the Category II day-fog simulation (Table IV).

TABLE III

Pre-Test Questionnaire Responses: Centerline (C) vs. Split Centerline (S)

	C	S	p
1. Configuration preference (for Category II day-fog)	3	2	1.00*
	Yes	No	
2. Disturbing or confusing features in S?	1	4	.18**
3. Disturbing or confusing features in C?	2	3	.50**
4. Test required?	5	0	.03**
5. Previous experience with marking under critical day visibilities?	0	5	.03**
6. Familiar with narrow gauge runway lighting?	2	3	.50**

*Two-tailed binomial test. (A two-tailed test is used when there is no reason to anticipate that the difference will be in a particular direction. See Reference 13, pp. 36-42)

**One-tailed binomial test. (A one-tailed test is used when there is reason to anticipate that the difference will be in a particular direction.)

TABLE IV

Post-Test Questionnaire Responses: Centerline (C) vs. Split Centerline (S)

		C	S	p
1.	Pattern with most adequate guidance?	2	3	.50*
		Yes	No	
2.	Confusing features in S?	2	3	.50*
	Confusing features in C?	3	2	.50*
3.	Helpful features missing in S?	2	3	.50*
	Helpful features missing in C?	2	3	.50*
		C	S	
4.	Pattern most helpful in touchdown and roll out?	2	3	.50*
		Yes	No	
5.	Size and spacing adequate in C?	5	0	.03*
	Size and spacing adequate in S?	5	0	.03*
	Number of stripes in C?	5	0	.03*
	Number of stripes in S?	5	0	.03*

*One-tailed binomial test.

As usual, the quality of flight simulation was accepted as fair to good (Table V). The visual simulation was more highly regarded, being judged as good to excellent. This reaction is particularly interesting in that the use of the Dalto to simulate a day-fog condition has never been attempted before and represents something of a first in the techniques employed in the visual aids program.

TABLE V

Pilot Ratings of Quality of Simulation, Experiment I

	Excellent	Good	Fair	Poor
Flight (P-3A)	0	3	2	0
Visual (Dalto)	1	4	0	0

Discussion

The results of this experiment suggest that it is possible to utilize a landing zone marking system for visual landings under bright daylight contact fog conditions. There was no evidence that modifying the narrow gauge pattern in such a way as to eliminate the centerline marking in the landing area degraded pilot performance. Both treatments—centerline and split-centerline—appeared acceptable to the pilots participating in the test.

Whether centerline marking is essential in the landing area under conditions other than those simulated here remains to be determined. The same conclusions may not apply to night operations, for example, especially where landing lights are being used. A decision suitable for one visibility condition may not be suitable for another, and both the known factors regarding guidance elements essential under each condition, and the relative expectancy of each condition, must be taken into account. Further, the absence of the centerline and the emboldenment of the inner barrettes as in the split-centerline configuration could induce lateral displacements of operational importance. Also, this study has considered only landing operations. Absence of the centerline marking could be very annoying to a pilot on a low visibility take-off roll.

Generalization from the results of the experiment, therefore, ought to be limited to the operational and marking pattern characteristics directly represented, and should be restrained until flight experience with the experimental configuration is obtained.

EXPERIMENT II

Experimental (C) vs. ICAO (I) Narrow Gauge Patterns

In recent years the ICAO Visual Aids Panel has produced a marking pattern following the narrow gauge lighting principle, but expressing the principle in a single row of bold stripes spaced longitudinally at 500-foot intervals with a larger pair of stripes 1,000 feet from the threshold to define an aiming point (Figure 2). Since this configuration is an ICAO standard, it is important to determine whether any significant gain or loss in guidance value is to be expected if it is to be used in the Category II day-fog condition instead of a pattern based on the U. S. Standard Touchdown Zone Lighting Configuration. The contribution of the aiming point to the usefulness of the system is also a matter of interest.

The ICAO pattern as adapted for this study has 75-foot by 10-foot stripes spaced at 500-foot intervals on a 60-foot gauge. The aiming point is defined by expanding the 1,000-foot stripe to a broad panel 150 feet long by 25 feet wide. The experimental narrow gauge pattern used for comparison employs three stripe barrettes 30 feet long and 3 feet wide on 100-foot centers longitudinally as in Experiment I. The stripes are separated laterally by 5-foot intervals within barrettes and the barrettes are, as usual, in a 60-foot gauge. Both configurations use the U. S. standard instrument runway edge, centerline, and threshold marking.

Experimental Method

The plan of the experiment is illustrated in Table VI. The statistical model, flight procedure, equipment, and data recorded were the same as Experiment I (see Appendixes A and B for details). The ten subjects were all active NAFEC project pilots, multi-engine and instrument rated. Several were jet qualified. Each pilot flew a series of 6 sessions, with 6 approaches per session, making a total of 36 approaches per pilot, or 360 for the experiment.

Pilot Performance

The only difference between the experimental narrow gauge and the ICAO patterns approaching statistical significance is in precision of longitudinal positioning at touchdown. The pilots were better able to comply with the instruction to attempt to land in the middle 1,000-foot sector of the landing zone (last line, Table VII) with the ICAO configuration. Since this pattern has an aiming point indicator at 1,000 feet and the experimental

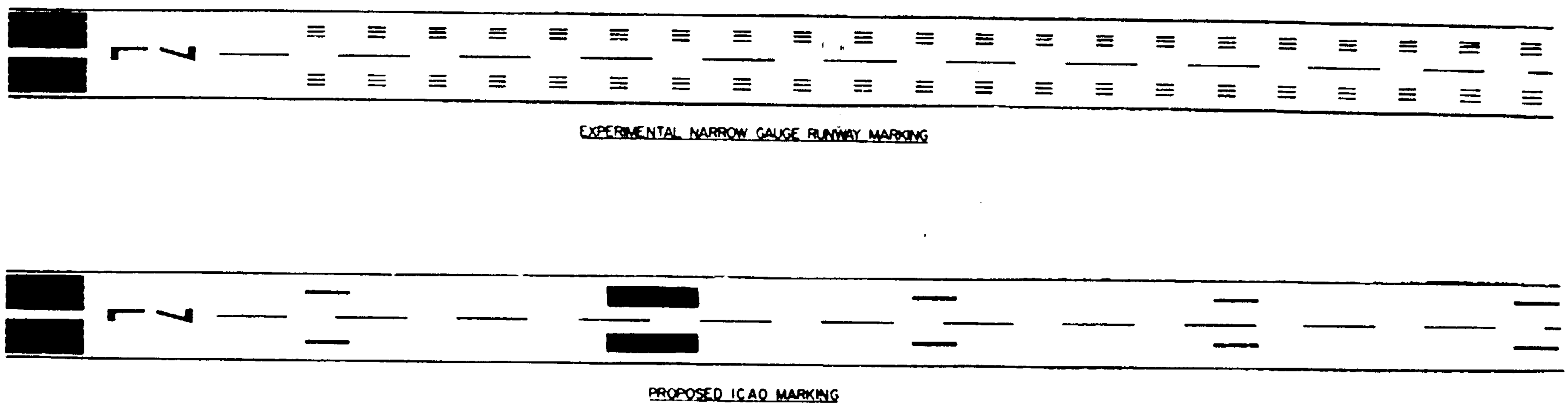

Figure 2. EXPERIMENTAL NARROW GAUGE AND ICAO MARKING SYSTEMS

TABLE VI

Experimental Design, Experiment II

Configurations or Patterns

C - Experimental Centerline Narrow Gauge
I - ICAO Narrow Gauge With Aiming Point

Displacement Variables

Heading - Aircraft is displaced on heading axis at time of visual transition, with respect to the line of flight and runway heading.
Roll - Aircraft is displaced on roll axis at time of visual transition to runway lighting and marking.
Attitude - Aircraft is displaced on pitch axis at time of visual transition to runway lighting and marking.

Number of Trials

Maneuver	Pattern C	Pattern I	Total
H	6	6	12
R	6	6	12
A	6	6	12
	18	18	36

Schedule

Session	Variable	No. Trials	Pattern Sequence		Record Preference
1	H	6	CCC	III	√
2	R	6	III	CCC	√
3	A	6	CCC	III	√
4	A	6	III	CCC	√
5	R	6	CCC	III	√
6	H	6	III	CCC	√

TABLE VII

Summary of Performance Results, Experiment II

Criterion Measure	Mean: Narrow Gauge (C)	Mean: ICAO (I)	"t" ratio	d.f.	p
Recognition*					
Heading Displacements (H)	6.0	6.0	-	-	-
Roll Displacements (R)	6.0	6.0	-	-	-
Attitude Displacements (A)	6.0	6.0	-	-	-
Rate of Correction**					
Retrim before threshold (H+R+A)	1.1	1.4	.758	9	.50 - .40
Retrim before touchdown (H+R+A)	16.3	16.4	-	-	-
Flare Path (F)**	9.0	10.3	1.150	9	.40 - .30
Positioning at Touchdown					
Lateral (L)					
Average Deviation***	22.0	22.7	.359	9	.80 - .70
Frequency to Criterion**	12.7	13.2	.832	9	.50 - .40
Longitudinal (P)					
Distance from Threshold****	1294	1389	1.15	9	.30 - .20
Frequency to Criterion**	11.4	13.1	2.00	9	.10 - .05

* Based on 6 opportunities under each condition.
** Based on 18 opportunities under each condition.
*** Lateral displacement in feet from centerline.
**** Absolute distance in feet from threshold.

narrow gauge does not, this result is not at all surprising. Both simulator and operational tests have shown that visual control of point of touchdown can be facilitated by coding the marking or lighting pattern to define the preferred or desired landing position (References 2, 8, 9, and 10).*

Although none of the other performance criteria produced significant differences, it may be noted that the trend on all measures having to do with maneuver execution favors the ICAO configuration (Table VII).

Pilot Questionnaire Responses

One point that stands out dramatically in the judgmental responses of the participating pilots is the growth and importance of the aiming point in determining their views after they had been systematically exposed to the configurations under conditions in which they had to depend on the visual guidance received from the patterns to perform their task. In pre-test questionnaire responses (Table VIII), the experimental narrow gauge was the pattern of choice for Category II day-fog operations by 7 of the 10 pilots, and continuity of pattern was given as the primary reason. By the end of the third experimental session (18 runs), however, and for the balance of the test, the pilots' selections moved toward the ICAO configuration (Table IX). An analysis of the reasons given for their choices at this point revealed that the availability of the aiming point was the main reason for choosing the ICAO pattern and that lack of such guidance was the main factor for rejecting the experimental narrow gauge (Table X, Questions 1 and 4). When asked directly what features they missed in the narrow gauge (Table X, Question 3), all of the pilots mentioned an aiming point, or distance to go information. When asked whether the aiming point in the pattern was helpful (Question 5), all but one said "yes," and when asked if this point should be identified in all configurations (Question 6), all said "yes." The criticism of the ICAO pattern (Question 2) seemed concentrated on two points: (1) a desire for more continuous marking, and (2) a desire for more complete distance to go information, such as might be obtained with a "3:2:1" configuration (see, for example, Reference 9).

*In an additional effort to validate this point, the variance ratio of Pattern C with respect to Pattern I in mean touchdown distance from threshold was examined (see Table XII). Based on 10 subjects, the ratios seemed to go in the wrong direction: "I" has the greater variability. A review of individual scores, however, shows Subject 2 to be entirely out of line with the rest of the pilots (touchdown on Pattern I was 1,000 feet farther down the runway than the maximum displacement of any other pilot). With Subject 2 removed, the variance ratio is in the expected direction: $F = 2.062$. For 8 d.f., however, this F is of marginal significance.

TABLE VIII

Pre-Test Questionnaire, Experiment II

Question	Response	Primary Reason for Choice	Primary Reason for Rejection	Probability of Smaller Frequency
1. Which configuration most acceptable for Category II fog?	7 C 3 I	Continuity of Pattern. Aiming point/distance information.	Lack of aiming point. Lack of continuity.	.172 **
2. With which runway marking systems have you had critical daytime low visibility experience?	2 "NAFEC" 1 Standard 1 3:2:1 6 None	NA	NA	NA ***
3. Familiar with narrow gauge lighting systems?	10 Yes 0 No	NA	NA	NA ***
4. Test required to validate your opinions?	10 Yes 0 No	NA	NA	NA ***

*Binomial test.
**One-tailed.
***No statistical estimate is given because the question is not directly concerned with the differences in experimental conditions.

TABLE IX

Configuration Preferences as Expressed Periodically During the Experiment

Session	Frequency of Choice C	Frequency of Choice I	Prediction	Probability of Smaller Frequency
Pre-Test	7	3	C > I	.172*
1	6	4	C = I	.74**
2	5	5	C = I	.99**
3	4	6	C < I	.377*
4	3	7	C < I	.172*
5	5	5	C < I	.623*
6	4	6	C < I	.377*
Post-Test	4	6	C < I	.377*

*One-tailed binomial.
**Two-tailed binomial.

It seems quite obvious that pilots desire aiming point, and preferably distance to go information, regardless of whether it has been demonstrated that such information affects objective measures of performance.

Both visual and flight simulation conditions were moderately, if not enthusiastically, received (Table XI). Since the modification to achieve a day-fog condition was experimental in itself, the degree of acceptance was encouraging.

Discussion

In this comparison of experimental narrow gauge and ICAO standard touchdown zone marking configurations, the most distinctive feature of either configuration and the one that most measurably influenced both pilot performance and opinion was the identification of an aiming point. It seems apparent that future runway marking systems should include this feature in the form of a distance coded treatment that could also yield both aiming point and distance information. Previous work has pointed in this direction (References 2, 8, 9, and 10), and subsequent studies in this program will explore it further.

TABLE X

Post-Test Questionnaire, Experiment II

Question	Response	Primary Reason for Choice	Primary Reason for Rejection	Probability of Smaller Frequency
1. Which configuration is most acceptable for a Category II fog?	4 C	Continuity; compatibility with touchdown zone lighting.	Insufficient guidance.	.377*
	6 I	Aiming point; distance to go.	Insufficient distance information	
2. Are there any missing features in Pattern I?	6 Yes	Want more markings.	-	.377*
	4 No	Want 3:2:1	-	
3. Are there any missing features in Pattern C?	10 Yes	Want aiming or reference point and distance to go information	-	.001*
	0 No	-	-	
4. Which pattern provided most adequate guidance in landing?	5 I **	Aiming point.	-	.500*
	4 C	Better continuity and directional guidance.	-	
5. Was an aiming point in the pattern helpful?	9 Yes	Aids in controlling glide path and presenting undershoots and over-shoots.	-	.011*
	1 No	-	Once runway is sighted all features are used for landing.	
6. Should aiming point be identified in all configurations?	10 Yes	(see answers to Question 5)	-	.001*
	0 No		-	

* Single tailed binomial
** Only 9 subjects responded.

TABLE XI

Pilot Ratings of Quality of Simulation, Experiment II

	Excellent	Good	Fair	Poor
Flight (P-3A)*	2	3	2	2
Visual (Dalto)**	1	4	1	2

*No response from 1 Subject.
**No response from 2 Subjects.

TABLE XII

Positioning at Touchdown
Average Displacement* With Respect to Reference Point
Experiment II

Subject	Longitudinal** C	Longitudinal** I	Lateral*** C	Lateral*** I
1	1,677	1,494	34	32
2	1,917	2,536	14	16
3	1,356	1,301	13	18
4	1,100	1,165	21	23
5	1,302	1,216	22	19
6	796	813	20	15
7	598	935	29	18
8	1,194	1,522	17	22
9	1,210	1,320	18	21
10	1,789	1,588	32	43
Σ	12,939	13,890	220	227
M	1,293.9	1,389.0	22.0	22.7
σ^2	174,540.3	223,824.0	$F = 1.283$, $p > .25$	
σ^2 Without S_2	142,432.6	69,079.8	$F = 2.062$, $p > .10, < .25$	

* In feet.
** Reference point is runway threshold.
*** Reference point is runway centerline.

EXPERIMENT III

Wide Spaced (A) vs. Close Spaced (B) Distance Coded (3:2:1) Narrow Gauge Systems

One configuration that could yield runway distance as well as aiming point information is the 3:2:1 pattern investigated in a study of the feasibility of a completely distance coded runway lighting system (Reference 8). The result of this study for lighting applications was sufficiently positive to warrant consideration of the same concept for marking applications. Besides, essentially the same concept has been employed for many years in the U. S. National Standard Marking System for All-Weather Runways (Figure 3). It is an idea with which most pilots are familiar.

If such a concept is to be employed for runway marking, however, it becomes important to determine whether the distribution of marking elements need be of the same density as the lights in a narrow gauge 3:2:1 lighting array. It is possible that a more distributed pattern with larger marking elements might be as effective as the denser pattern with relatively small marks. Maintenance obviously would be easier. And there is some precedent for it in the finding that aside from the issue of the aiming point, the ICAO pattern with its bold stripes and 500-foot longitudinal spacing interval seemed to serve the pilot equally as well as the more closely spaced narrow gauge configuration.

In this experiment, therefore, a bidirectional 3:2:1 marking pattern (i.e., a 3:2:1/1:2:3 array) in the same spacing and size module as the narrow gauge marking pattern, with barrettes 30 feet long by 3 feet wide on 100-foot centers longitudinally, and a 60-foot gauge, is compared with the 3:2:1 coding system in an adaptation of the present All-Weather Runway Marking System (Figure 4). This adaptation retains 75 by 6 foot stripes placed 5 feet apart laterally with a gauge of 50 feet. By repeating the lateral elements at 500-foot intervals on the longitudinal dimension, the full length of the system is extended from 2, 000 to 3, 000 feet. In this test, both systems have a prominent cross stripe at the runway half-way point, a practice followed in the U. S. Air Force for many years.

Experimental Method

The experiment was conducted in the Dalto Visual Landing Simulator modified to represent a daytime bright contact fog condition with a marking element visual range of 1, 200 feet (see Appendix A). The plan of the experiment is illustrated in Table XIII. The statistical model is the "t"

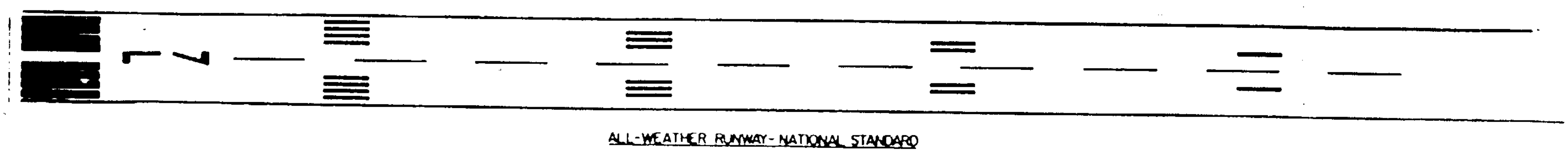

Figure 3. U. S. NATIONAL STANDARD FOR ALL-WEATHER RUNWAY MARKING

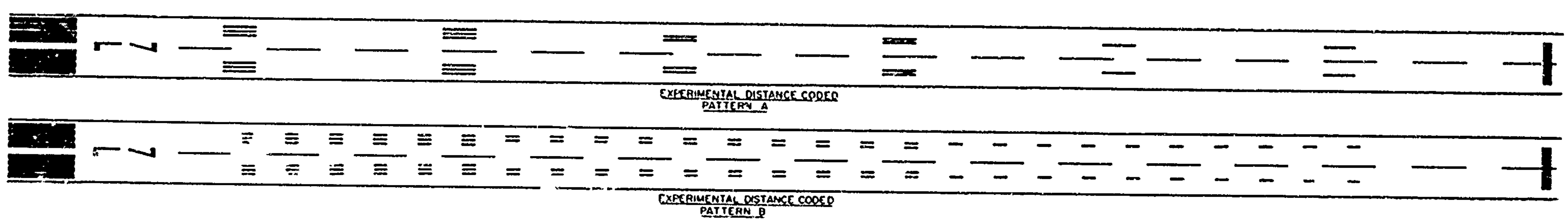

Figure 4. DISTANCE CODED RUNWAY MARKING PATTERNS

TABLE XIII

Experimental Design, Experiment III

Configurations or Patterns

A - 500-foot interval 3:2:1/1:2:3, modified U. S. All-Weather System.
B - 100-foot interval 3:2:1/1:2:3, modified narrow gauge system.

Displacement Variables

Heading	- Aircraft is displaced on heading axis at time of visual transition to runway lighting and marking with respect to the line of flight and runway heading.
Roll	- Aircraft is displaced on roll axis at time of visual transition to runway lighting and marking.
Attitude	- Aircraft is displaced on pitch axis at time of visual transition to runway lighting and marking.
Break-Ground Sector	- On take-off run acceleration is controlled so that take-off velocity is reached in the pre-selected runway sector.

Number of Trials

Maneuver	Pattern A	Pattern B	Total
R	6	6	12
H	6	6	12
A	6	6	12
	18	18	36

Schedule

Session	Landing Displacement	Break-Ground Sector*	Order	
1	R	Randomized	A* A* A	B* B* B
2	H	"	B* B* B	A* A* A
3	A	"	A* A* A	B* B* B
4	A	"	B* B* B	A* A* A
5	H	"	A* A* A	B* B* B
6	R	"	B* B* B	A* A* A

*Acceleration was controlled and point of take-off recorded on first and second runs of each pattern in each session.

test based on difference scores. Both landing and take-off performances were analyzed.

The flight procedure used in the landing phase of this experiment is essentially the same as that used in Experiments I and II.

In the take-off phase of the experiment, the pilots were advised that they should break ground at 120 knots. The experimenter then controlled the rate of acceleration of the P-3 Flight Duplicator in such a manner that the prescribed take-off velocity was reached in the 1,000-foot marking sector preselected in the experimental program as the take-off zone for that run. The subject-pilot reported the sector he thought he was in, based on the code utilized in the runway marking system (1,000 feet remaining, 2,000 feet remaining, or 3,000 feet remaining), when he broke ground. In the data analysis the criterion measure is the frequency of correspondence of the pilot's judgment and the experimenter's judgment as to the sector in which take-off actually occurred. Additional details of the procedure are presented in Appendix B.

A total of 6 NAFEC project pilots and 4 "casual" pilots served as subjects. All of the project pilots were multi-engine and instrument rated. The casual pilots all had military multi-engine experience but were not currently employed as active pilots. The pilots were qualified by the experimenter in the P-3 and Dalto Visual Simulation Complex before starting data runs. Each pilot flew a series of 6 sessions, with 6 approaches per session, making a total of 36 approaches, or 360 approaches for the experiment.

Pilot Performance

Rate information seems to be provided more effectively by the pattern providing the larger visual angles. This relationship was noted in the first experiment in this series with respect to rate of displacement correction, and a tendency for relatively closely spaced landing zone lighting arrays to cause the pilot to judge himself high and dive for the ground has been observed in both simulator and operational test work (References 2 and 8). In the present experiment, the relationship appears primarily in rate of closure, or flare path, performance. There are more short landings (first 1,000-foot sector) with the closely spaced 3:2:1 (Pattern B), and the mean touchdown point for this pattern is closer to the threshold (Table XIV). The same implication can be drawn from the relatively higher number of occasions in which pilots working with Pattern B "flew into the ground." The closely spaced array gives an impression of excessive altitude, and there is a tendency to increase the

TABLE XIV

Summary of Performance Results, Experiment III

Wide Spaced vs. Close Spaced Distance Coded Marking Patterns

Criterion Measure	Wide Spaced Mean (A)	Close Spaced Mean (B)	"t"	p
a. Displacement Recognition				
Heading (H)*	6.0	6.0	X	X
Roll (R)*	6.0	6.0	X	X
Attitude (A)*	5.6	5.7	.953	.40 - .30
H+R+A**	17.6	17.7	X	X
Rate of Correction				
b. Before Threshold (H+R+A)**	1.1	1.1	X	X
c. Before Touchdown (H+R+A)**	16.3	15.8**	.881	.50 - .40
d. Flare Path (Rate of Closure)				
Good**	9.6	7.6	2.07	.10 - .05
High**	3.5	3.9	.379	.80 - .70
Low (Flew into Ground)**	4.9	6.5	1.959	.10 - .05
Lateral Positioning at Touchdown				
e. Frequency within Center Lane (H+R+A)**	6.8	7.1	.161	.90 - .80
Longitudinal Positioning at Touchdown				
f. Within Criterion Zone (H+R+A)**	10.6	10.1	.563	.60 - .50
g. Long Landing (H+R+A)**	3.0	2.1	1.151	.30 - .20
h. Short Landings (H+R+A)**	4.4	5.8	1.843	.10 - .05
i. Absolute Distance from Threshold (in feet)H+R+A	1,552.9	1,294.1	2.400	.05 - .02
j. Recognition of Take-Off Sector***	7.0	8.4	2.426	.05 - .02

*Based on 6 opportunities under each condition.

**Based on 18 opportunities under each condition.

***Based on 12 opportunities under each condition.

Note: The "t" test utilized in these analyses is based directly on difference scores (See Reference 5). Spaces marked "X" indicate that the differences were so small that an analysis was not warranted.

rate of closure in order to recover the glide path and shorten the apparent distance to go for touchdown.

A difference in favor of the closely spaced 3:2:1 pattern appears in the relative frequency with which the pilot's visual judgment corresponds to the programmed point of take-off (Table XIV). The advantage of the closely spaced pattern in this respect probably is related to the pilot's subjective feeling that it provides better continuity of guidance (Table XV) and can be more quickly and easily interpreted.

Pilot Questionnaire Responses

One thing that stands out dramatically in all expressions of pilot opinion is that the pilots want distance coding, particularly for marginal visibility operations. After being briefed on the problem, but before flying it, they expressed this feeling (Table XV), and it appears just as strongly in their post-test responses (Table XVII). They want it, furthermore, not only for landing, but also as an aid for the take-off run, although they are not quite so unanimous in this respect. The reasons for these feelings are obvious, as the summary given in Table XVII indicates. Under marginal visibility conditions the pilot needs all the information regarding his situation that he can get, especially from extra-cockpit sources functioning independently of the aircraft's sensing systems.

The same results have been obtained from all experiments on runway lighting in which the pilot was required to depend on the ground based visual display in the performance of his task (References 2, 6, and 10).

Preferences are not strongly differentiated between the two patterns considered in this experiment, except that there is some tendency to prefer the more closely spaced array because of its greater degree of continuity (Table XVII). This feature may have helped in the utilization of this system for distance remaining information on the take-off run where the vehicle is accelerating rather than slowing down. Although in the landing phase the performance data show some advantage for the widely spaced pattern, pilot preferences are evenly split through the experiment. There is a slight shift toward Pattern A (compare Tables XV and XVI), but it is hardly significant.

The flight simulation was moderately well accepted (Table XVIII), but the visual simulation was regarded as quite good. This observation is again gratifying in view of the experimental modification of the Dalto to represent a daytime bright contact fog.

TABLE XV

Pre-Test Questionnaire Responses, Experiment III

Question	Frequency of Choice		Arguments	p*
Preference for configuration for 1,200 feet RVR? **	A	3	Information spotty, discontinuous.	.58
	B	6	Has distance coding with continuity.	
Both patterns are distance coded. Do you expect this to be useful?	Yes	10	Improves information for deceleration.	.001
	No	0		

*Two-tailed binomial.
**One pilot failed to respond.

TABLE XVI

Pilot Preference for Configuration as Expressed at the End of Each Experimental Session

Session	Frequency of Choice A	Frequency of Choice B	Prediction	Probability of Smaller Frequency
Pre-Test*	3	6	A = B	.58**
[illegible]	5	5	A > B	.623
2	6	4	A > B	.377
3	5	5	A > B	.623
4	5	5	A > B	.623
5	5	5	A > B	.623
6	5	5	A > B	.623
Post-Test	4	6	A > B	.377

*One pilot failed to respond.
**Two-tailed binomial.

TABLE XVII

Post-Test Questionnaire Responses, Experiment III

Question	Frequency of Choice		Arguments	p*
Which pattern provided most adequate guidance?	A	4	Simpler, but lacks continuity.	.754
	B	6	More continuity, quicker to interpret, though somewhat cluttered. Some liked both patterns.	
Which pattern n ost adequate for touchdown and ground roll-out?	A	4		.754
	B	6		
Was distance coding helpful?	Yes	10	Proviues readily obtainable information on location and distance remaining on both landing and take-off.	.002
	No	0		
Desirable to have distance coding in all configurations for Category II marking?	Yes	9**	Under marginal conditions pilot needs all the help he can get.	.004
	No	0		
Are markings on take-off end useful?	Yes	8	Runway remaining information essential for decision to abort.	.110
	No	2	Power and acceleration are determining factors, not runway remaining.	

Adequacy of size and spacing of marking?	Size A	Size B	Spacing A	Spacing B
Just right	7	4	3	3
Too large	0	0	4	0
Too small	1	4	2	4

*Two-tailed binomial.
**One pilot failed to respond.

TABLE XVIII

Pilot Ratings of Quality of Simulation, Experiment III

	Excellent	Good	Fair	Poor
Flight (P-3A)	3	3	3	1
Visual (Dalto)*	3	6	0	0

*One pilot did not respond.

Discussion

In this experiment the utility of two interpretations of the 3:2:1 distance coded runway marking concept under Category II daylight fog conditions was compared. The configurations differed primarily in longitudinal spacing (500-foot versus 100-foot intervals) and in the size of the individual marking elements. Effectiveness in providing both landing and take-off guidance was considered.

The results suggest that there is no strong reason to prefer one pattern or the other except that the widely spaced pattern functions a little more effectively in visual control of the landing maneuver, at least with respect to optimal flare path, or rate of closure, and longitudinal positioning at touchdown. There is less tendency to fly into the ground or land short with the widely spaced array.

In the take-off run, however, the pilots seem better able to utilize the closely spaced array for judgment of runway distance remaining, probably because it offers better continuity of information under a rapidly changing condition.

Pilot preferences are on the whole evenly split between the patterns. They are not split, however, on the desirability of distance coding, both for landing and take-off operations. Pilots want the kind of distance to go, or distance remaining, information represented by the 3:2:1 marking concept.

EXPERIMENT IV

Wide Spaced Distance Coded (3:2:1) Marking System (A) vs. ICAO Narrow Gauge System (I)

In Experiments II and III it was established that the pilots' strong desire for runway distance to go information could be accommodated in a simulated day-fog condition by either a 3:2:1 distance coded (modified U. S. All-Weather) marking system or the ICAO pattern characterized primarily by a prominent aiming point. Feasibility of providing take-off or roll-out distance remaining information was determined only for a bidirectional 3:2:1/1:2:3 array, however. The ability of the ICAO pattern to serve both as a landing aid and a take-off monitoring aid was not explored. Experiment IV is designed to fill this gap in the current series of runway marking studies by comparing the bidirectional 3:2:1 and ICAO configurations in both landing and take-off modes of operation.

For purposes of direct comparison the two patterns are presented side by side in Figure 5. As touchdown zone configurations they should be viewed, of course, from the threshold end of the runway. Viewed from the opposite direction (in the drawing, from the mid-point, both patterns can be interpreted as take-off distance remaining displays. The full 7,000-foot runway is marked by a 3,000-foot landing zone configuration at each end, with a mid-stripe at the 3,500-foot half-way point. In order to limit the essential difference between patterns to a method of identifying reference points, the wide spaced 3:2:1 (modified U. S. All-Weather) configuration has been selected to represent the distance coding concept. Both configurations have a standard 500-foot longitudinal interval between marking elements.

As in Experiments I-III, the problem was run in the Dalto Visual Landing Simulator modified to represent a daytime bright contact fog condition with a marking element slant visual range of 1,200 feet. Both landing and take-off performances were analyzed.

Experimental Method

The plan of the experiment is illustrated in Table XIX. The statistical model again is the "t" test based on difference scores. The flight procedure used in the landing phase of the experiment is the same as that used in Experiments I-III. In the take-off phase of the experiment, the procedure was very similar to that followed in Experiment III, except that the simulator was pre-positioned at the end of the runway for a take-off run from a static start at the beginning of each trial, and the pilot and observer both reported the distance remaining at the time of take-off to

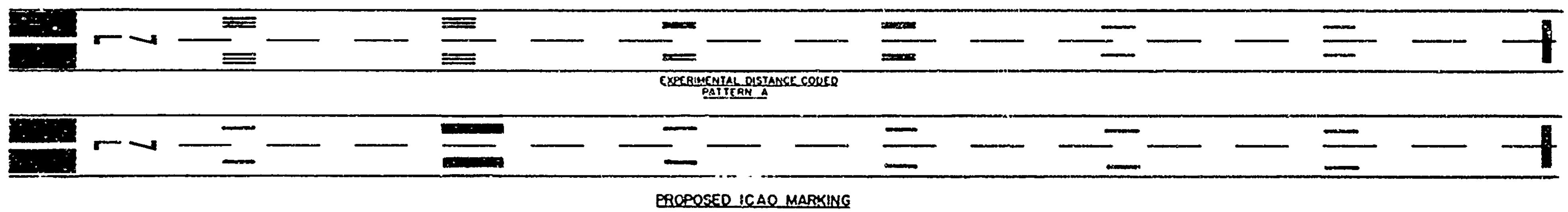

Figure 5. Wide Spaced 3:2:1 vs. ICAO Marking Patterns

TABLE XIX

Experimental Design, Experiment IV

Configurations or Patterns

A - 500-foot interval 3:2:1/1:2: 3, modified U. S. All-Weather System.
I - ICAO narrow gauge with aiming point.

Displacement Variables

Heading	- Aircraft is displaced on heading axis at time of visual transition to runway lighting and marking with respect to the line of flight and runway heading.
Roll	- Aircraft is displaced on roll axis at time of visual transition to runway lighting and marking.
Attitude	- Aircraft is displaced on pitch axis at time of visual transition to runway lighting and marking.
Break-Ground Sector	- On take-off run acceleration is controlled so that take-off velocity is reached in the pre-selected runway sector.

Number of Trials

Maneuver	Pattern A	Pattern I	Total
R	8	8	16
H	8	8	16
A	8	8	16
	24	24	48

Schedule

Session	Landing Displacement	Break-Ground Sector	Order*	
1	R	Randomized	AAAA	I I I I
2	H	"	I I I I	AAAA
3	A	"	AAAA	I I I I
4	A	"	I I I I	AAAA
5	H	"	AAAA	I I I I
6	R	"	I I I I	AAAA

*Take-off was initiated from full stop, pre-positioned by the experimenter at the head of the runway at the beginning of each trial. There was, therefore, the same number of take-off and landing runs.

the nearest 100 feet. As in Experiment III, the experimenter was aided in judging the pilot's actual take-off position by coded distance markers outside the subject's field of view. Performance was scored both as frequency of correspondence of the subject's estimate with the experimenter's observation (± 200 feet), and the absolute difference in estimated and programmed distance remaining. The ± 200-foot tolerance in pilot report and observer score was thought to be a reasonable rule-of-thumb error of estimate for distance judgments in this situation.

The experimenter controlled the point of breaking ground by holding the take-off roll below 120 knots until the segment of the runway prescribed by the experimental program was being approached. At this point control of the rate of acceleration was relinquished and the pilot allowed to reach take-off velocity. Arrival at the take-off sector and speed was indicated by the command, "Rotate." That the experimenter was reasonably successful in distributing points of take-off with respect to runway distance remaining, and that this distribution was identical for the two experimental configurations, is illustrated in Figure 6. Details of this procedure are found in Appendix B.

A total of 10 pilots served as subjects in the experiment. Eight of these were NAFEC project pilots, multi-engine and instrument rated. The two casual pilots were both ex-military with multi-engine experience, but not on active flying status. Each pilot made 24 landings and take-offs on each configuration for a total of 48 runs per pilot and a grand total of 480 runs for the experiment.

Performance Results

Landing. Overall, there seem to be very few differences between the ICAO and wide spaced 3:2:1 patterns in measures of landing performance. It is obvious that neither pattern presented difficulty in recognizing the direction of displacement (Table XXa). The patterns do discriminate in the efficiency with which they facilitate the execution of the corrective maneuver, however. In this respect the wide spaced 3:2:1 pattern is more effective, evidently because pilots find it easier to track attitude rotations with this configuration (Table XXc). On the other hand, control of the rate of closure (flare path) was not affected (Table XXd), and in several categories associated with positioning at touchdown the results appear ambiguous. In lateral alignment, for example, the advantage appears to be with the 3:2:1 pattern on heading displacements, but with the ICAO pattern on attitude displacements. In longitudinal positioning the experimenter scored the 3:2:1 runs short (first 1,000-foot sector of touchdown zone) more often (Table XXi), but the recorded measures of absolute distance from threshold place the mean touchdown point within

TABLE XX

Summary of Performance Results, Experiment IV

ICAO vs. Wide Spaced Distance Coded Marking Pattern for Landing and Take-Off Guidance

Criterion Measure	Wide Spaced Distance Coded Mean (A)	ICAO Mean (I)	"t"	p
a. Displacement Recognition				
H+R+A**	24	24	-	-
Heading (H)*	8	8	-	-
Roll (R)*	8	8	-	-
Attitude (A)*	8	8	-	-
Rate of Correction				
b. Before Threshold				
H+R+A**	1.5	.7	1.634	.20 - .10
Heading (H)*	1.2	.5	1.371	.30 - .20
Roll (R)*	.2	.1	-	-
Attitude (A)*	.1	.1	-	-
c. Before Touchdown				
H+R+A**	21.3	19.3	1.961	.10 - .05
Heading (H)*	6.7	6.0	.990	.40 - .30
Roll (R)*	7.3	7.0	.688	.60 - .50
Attitude (A)*	7.3	6.3	2.133	.10 - .05
d. Flare Path (Rate of Closure)				
Good**	11.9	10.7	1.227	.30 - .20
High**	5.1	5.2	.181	.90 - .80
Low (Flew into Ground)**	7.0	8.1	1.170	.30 - .20
Lateral Positioning at Touchdown				
e. Frequency within Center Lane				
H+R+A**	11.4	9.9	1.250	.30 - .20
Heading (H)*	3.5	2.1	1.867	.10 - .05
Roll (R)*	3.6	3.0	1.071	.40 - .30
Attitude (A)*	4.3	4.8	2.333	.05 - .02
f. Average Deviation from Center Line				
H+R+A**	18.0	17.1	.608	.60 - .50
Heading (H)*	20.0	20.0	-	-
Roll (R)*	20.0	18.0	.576	.60 - .50
Attitude (A)*	14.0	14.0	-	-

Summary of Performance Results, Experiment IV (Continued)

Criterion Measure	Wide Spaced Distance Coded Mean (A)	ICAO Mean (I)	"t"	p
Longitudinal Positioning at Touchdown				
g. Within Criterion Zone				
H+R+A**	15.6	14.2	1.273	.30 - .20
Heading (H)*	4.8	4.1	.875	.50 - .40
Roll (R)*	4.7	4.3	.702	.50 - .40
Attitude (A)*	6.1	5.8	.548	.60 - .50
h. Long Landing (3rd 1,000 ft.)				
H+R+A**	1.5	.9	.732	.50 - .40
i. Short Landing (1st 1,000 ft.)				
H+R+A**	8.9	6.9	2.151	.10 - .05
j. Absolute Distance from Threshold (in feet)				
H+R+A**	1,315	1,193	2.434	.05 - .02
Heading (H)*	1,190	1,100	1.561	.20 - .10
Roll (R)*	1,265	1,164	1.154	.30 - .20
Attitude (A)*	1,491	1,332	2.519	.05 - .02
k. Recognition of Take-Off Sector				
Frequency of Correspondence***	16.7	17.0	.200	.90 - .80
Absolute Differences****	204	207	.686	.60 - .50

*Based on 8 opportunities under each condition.

**Based on 24 opportunities under each condition.

***Based on 24 opportunities under each condition. Score is frequency of correspondence of pilot's judgment with observer's, ± 200 feet.

****Based on mean differences between observer's estimates and pilot's estimates of distance remaining.

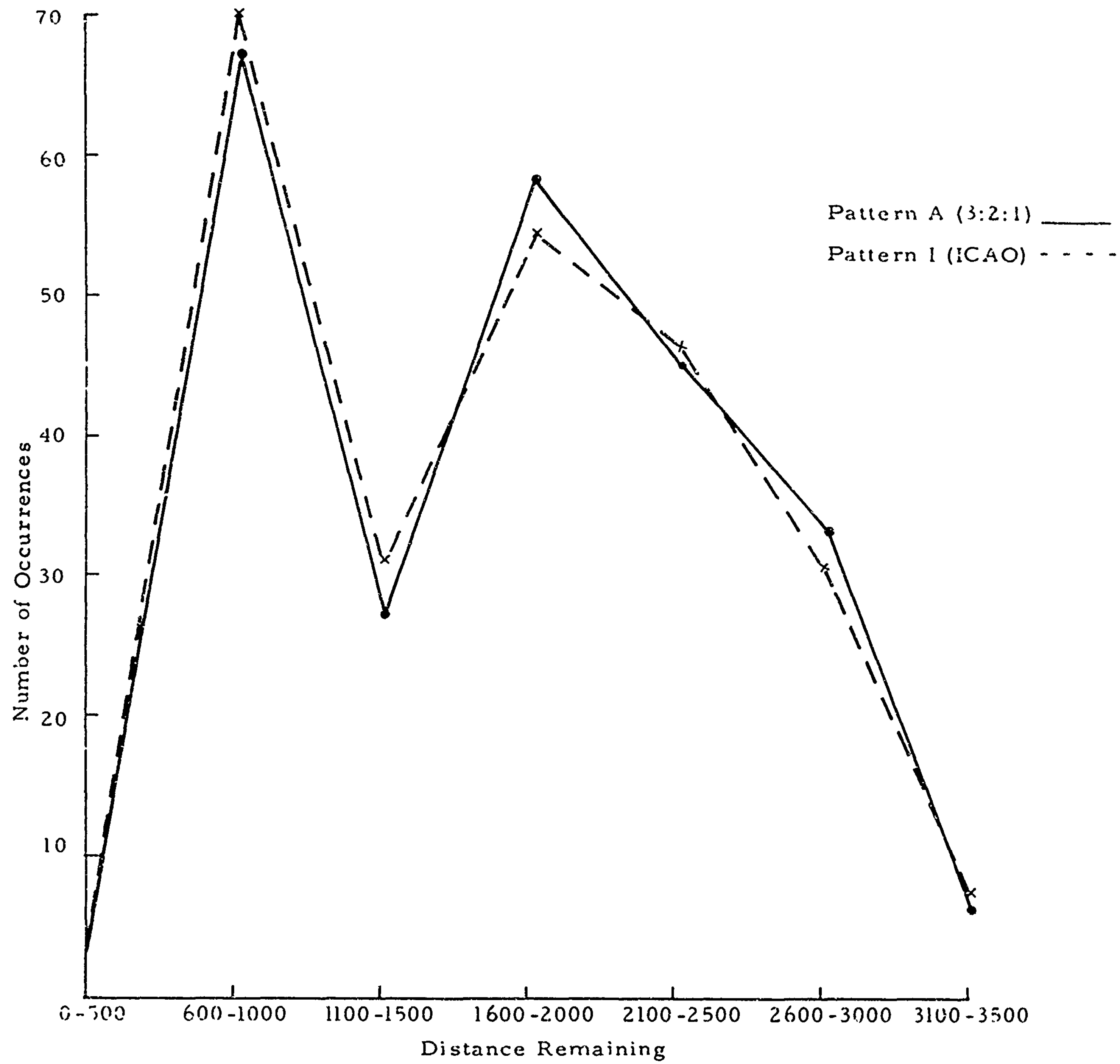

Figure 6. DISTRIBUTION OF TAKE-OFFS WITH RESPECT TO RUNWAY DISTANCE REMAINING

the criterion zone and indicate the trend toward longer landings with the 3:2:1 pattern to be significant (Table XXj). Since the observer judgments on other measures are also in this direction, it would appear best to accept the short landing result as an artifact—a product of experimental error. In Experiment III, the wide spaced 3:2:1 produced the largest absolute distance from touchdown score (Table XIVi) and was lowest in frequency of short landings of the two configurations under consideration (Table XIVh). It would appear that the prominent aiming point on the ICAO pattern would influence touchdown position, particularly attitude displacements requiring re-establishment of the flight path, and the results do show a tendency to land closer to threshold with this configuration (Table XXj).

Take-Off. Neither of the measures of effectiveness in providing distance remaining information suggests any difference in the accuracy of guidance provided by the two configurations (Table XXk). The accuracy measures are based on average differences between observer's and pilot's judgments, however, without respect to sign, or direction. When the difference scores are plotted with respect to direction (Figure 7), it can be seen that there is a definite difference between the configurations in constant error. On the 3:2:1 configuration, the subjects' estimates tend to be higher than the experimenter's—they overestimate the distance remaining. On the ICAO pattern, the pilots tend to underestimate—the actual distance remaining is greater than they realize.

If it were necessary to choose, the more comfortable operational decision, obviously, would be to accept the condition where pilots underestimate rather than overestimate the distance remaining. In view of the overlap in accuracy scores, it is doubtful, however, that the differences between the configurations are either statistically or operationally significant.

Approach Light Detection Latency. Although it was not one of the primary purposes of this experiment, an opportunity was taken to further examine a factor in the approach lighting installation that had produced interesting results in another program, especially since it was felt that this factor could be manipulated without prejudicing the outcome of the landing task. In an experiment on the guidance value of sequence flashing lights under Category II operating conditions, it was found that these lights definitely do increase the distance at which the approach lighting system is visually acquired (Reference 12). Since the experiment was run under conditions simulating night time visibilities, however, it was felt that the generality of the finding could be increased significantly if the same results were obtained under day time restricted visibility conditions. The achievement in the P-3/Dalto facility of an effective simulation of a bright daylight contact fog condition made this possible. The first half of Experiment IV, therefore, was run without strobes (subjects 1-5), the

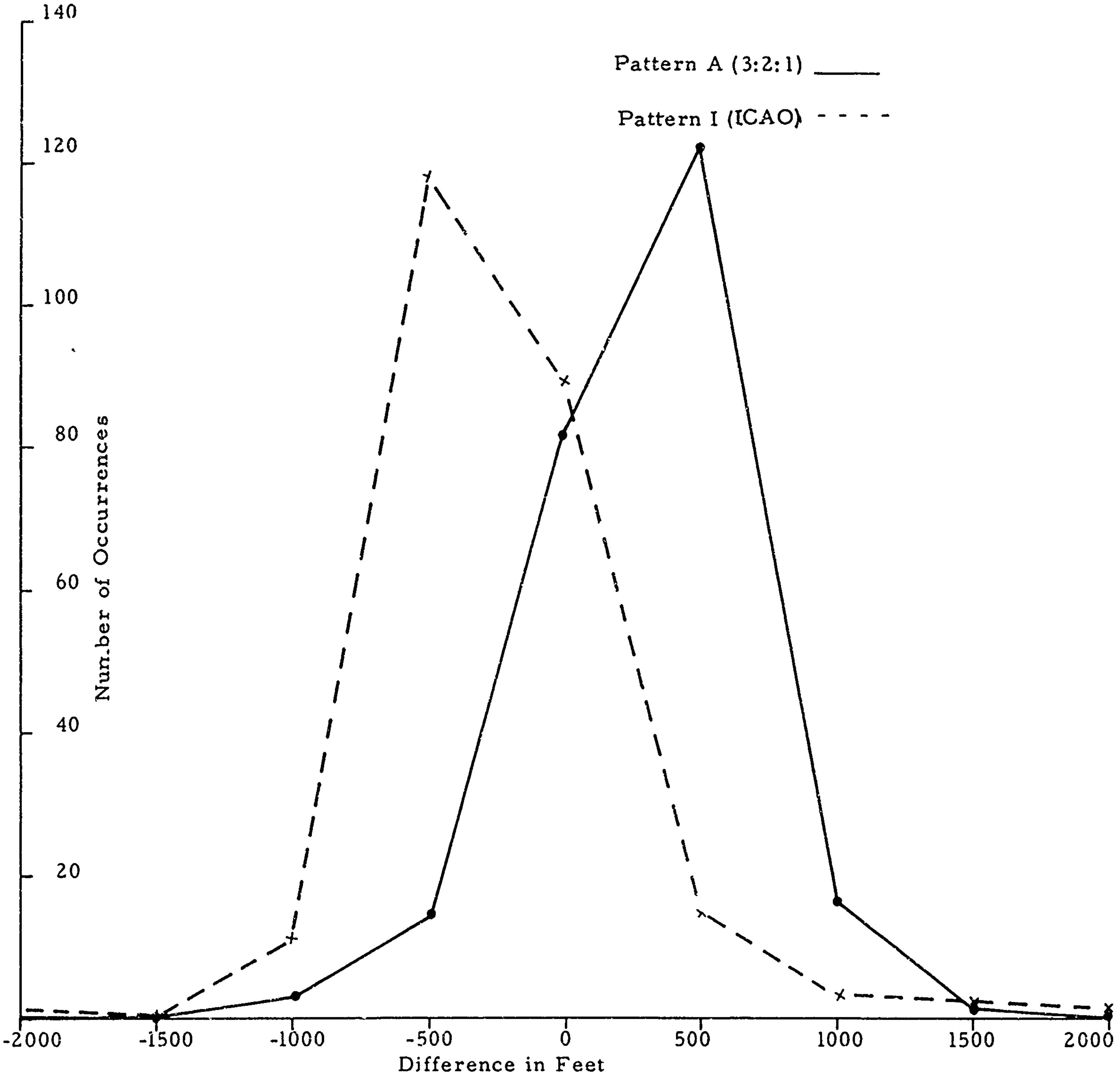

Figure 7. DISTRIBUTION OF DIFFERENCES IN TAKE-OFF DISTANCE REMAINING ESTIMATES, SHOWING CONSTANT ERRORS

second half (6-10) with strobes. Both groups were provided with the Basic Center Row and Crossbar Pattern of steady burning lights (Reference 12). Each group was made up of four project pilots and one casual (ex-military). The measure taken was latency in seconds between the point at which the experimenter detected the approach lighting system, the "intrinsic detection response," and the point at which the subject-pilot detected the system, the "search detection response." Results based on 48 runs for each subject are shown in Table XXI. Since the "t" test (Reference 1) produced a probability level between .05 and .02, it can be stated with confidence that the difference is more than random. The advantage in detection range for strobe lights extends to a simulated bright daylight contact fog condition as well as a simulated Category II night landing condition.*

It is interesting to note that the configuration mean latencies for the daytime condition are about twice as large as those obtained in the night time condition (night means are also presented in Table XXI for purposes of comparison). Also, the gain in detection range offered by the sequence flashing lights is larger under the night time condition (44% vs. 29%). The strobes have their greatest effect in a dark night fog.

Questionnaire Results

As a group the pilots expressed a strong desire for distance coding of the runway marking configuration, although they seemed to feel a little more strongly about it in connection with landing operations than with take-off operations (Tables XXII and XXIII). As a comparison of Tables XXII and XXIII will show, this interest in distance coding was sustained throughout the experiment. For landing zone marking, however, there was no preference between the two test configurations, either before (Table XXII), during (Table XXIV), or after Table (XXIII) the experimental flight sessions. On the other hand, experience with attempts to judge distance remaining at take-off produced a preference for Pattern A (the 3:2:1 or distance coded arrangement).

On both take-off and landing, a mark frequently noticed and favorably commented upon, was the runway mid-stripe (see Table XXIII, Questions 1, 2, 5, 7, 8, and 9, and Appendix C). Since the test runway was only

*Absolute detection ranges are not considered or compared in this analysis because it is realized that the inability to simulate accurately the high brightness levels of the operational environment probably would not produce response thresholds directly comparable with those observed in real life.

TABLE XXI

Approach Light Detection Latency

Without Strobes		With Strobes		
Subject	Latency (sec.)	Subject	Latency (sec.)	Reduction in Latency
1	4.2	6	4.8	
2	6.4	7	6.9	
3	6.7	8	2.6	
4	4.9	9	3.5	
5	5.9	10	2.3	
Σ	28.1	Σ	20.1	
M_{day}	5.6		4.0	29%
M_{night}*	3.2		1.8	44%

$t = 2.349$
for 8 df (n-2), $p = .05 - .02$

*Experiment III, Reference 12

TABLE XXII

Pre-Test Questionnaire Responses, Experiment IV

Question	Frequency of Choice		Arguments	p
1. Preferences for configuration for 1,200-foot RVR?	A	5	Distance is more readily figured—more specific.	
	I	4	Simpler. Solid 1,000-foot marker more distinctive.	.500*
2. Is distance coding or aiming point marking a useful arrangement (for landing)?	Yes	8	For braking, thrust reversing, etc., provided it is simple and unambiguous.	
	No	2	Little value in 1,200-foot RVR. Touch-down distance of 1,000 feet only desirable under certain circumstances.	.055*
3. Would distance coded paint marking be useful for take-off?	Yes	8	For acceleration checks. 500-foot intervals too close. Should be 1,000. Use with arresting gear.	
	No	2	Not needed if indication of take-off power is good. Too difficult to interpret or use in cross checks in instrument weather.	.055*

*One-tailed probability.

TABLE XXIII

Post-Test Questionnaire Responses, Experiment IV

Question	Frequency of Choice		Arguments	p
1. Which pattern provided most guidance for approach and landing?	A	5	Provides distance to go information; better roll guidance; distance information is available even when aiming point not in view.	.623*
	I	5	Simpler to interpret. Prominent aiming point; bolder signal; 3 unmistakable reference points; threshold, aiming point and mid-stripe.	
2. Most effective in providing touchdown distance beyond threshold?	A	5	In both configurations, mid-stripe was most positive identifying feature. Easier to tell exact runway location.	.623*
	I	5	Easy interpretation in 1,000's.	
3. Was distance coding helpful in landing?	Yes	6	If touchdown or braking distance is critical.	.377*
	No	4	Why not use numbers? Have to count off unless familiar with pattern. After "break out" not much attention paid to touchdown point.	
4. Desirable to have distance coding in all configurations for Category II landing?	Yes	9	Very critical with high performance aircraft and on short field. Needed for acceleration checks, abort decision, reverse thrust decision, brake application, and tail hook application.	.011*
	No	1	Really need only a few unmistakable check points.	

* One-tailed binomial test.

Post-Test Questionnaire Responses, Experiment IV (Continued)

Question	Frequency of Choice		Arguments	p
5. Aiming point in "I" useful in landing?	Yes	9	More so than second set of "3 stripes." Most useful reference points are threshold aiming point and mid-stripe.	
	No	1		.011*
6. Did you find the half-way mid-stripe?	Yes	9	(One subject missed)	.002*
	No	0		
7. Would mid-stripe be useful in other conditions?	Yes	9	Most positive identifying work on the runway for both take-off and roll-out	
	No	0		.002*
8. Opposite end touchdown zone markings useful on take-off?	Yes	7	When long take-off is required. Mainly after crossing mid-stripe. On short runways. For judging "no-go" distance.	.172*
	No	3	Requires learning two systems. Should be off before seeing the marking.	
9. Most effective for distance to go information for take-off?	A	7	Mid-stripe most useful in both patterns. (No response from one subject)	.090*
	I	2		
10a. What would you add to the configurations?			Numerals for distance; bold touchdown point in "A"; color coding; more complete distance coding; turn stripes so perpendicular to centerline.	
b. What would you remove?			500-foot marks; P-3 simulator.	

Post-Test Questionnaire Responses, Experiment IV (Continued)

11. Adequacy of size and spacing of the paint pattern.

Size	A	I	A	I
		Spacing		
Just right	9	9	7	6
Too large	0	0	0	0
Too small	1	0**	3	3**

**One subject did not respond to this question.

12. Adequacy of size and spacing of paint stripes

Just right	8	6	7	6
Too many	2	0	0	1
Too few	0	2**	1**	1**

**Two subjects did not respond.

13. Quality of simulation?

	Excellent	Good	Fair	Poor
Flight	2	5	3	0
Visual	6	1	3	0

TABLE XXIV

Configuration Preferences as Expressed Periodically During the Experiment

Session	Frequency of Choice		Prediction	Probability of Smaller Frequency
	A	I		
Pre-Test*	5	4	A > I	.500**
1	6	4	A > I	.377**
2	6	4	A > I	.377**
3	4	6	A > I	.377**
4	6	4	A > I	.377**
5	6	4	A > I	.377**
6	5	5	A > I	.623**
Post-Test	5	5	A > I	.623**

*One subject failed to respond.
**One-tailed binomial.

7,000 feet long, the mid-stripe divided it into two 3,500-foot sections, with the result that with the ICAO pattern, as well as the 3:2:1 pattern, the full length of the runway is coded (threshold, aiming point, termination of narrow gauge marking, mid-stripe, beginning of narrow gauge, aiming point, and opposite end threshold marking). In a 12,000-foot runway, however, both touchdown zone marking patterns would leave a considerable information gap (approximately 3,000 feet) between the mid-point and the termination of the landing zone marking, without additional coding.*

When asked what they would add to improve the test patterns, pilots mentioned such things as numerals for distance to go, orienting stripes laterally instead of longitudinally, and more complete distance coding (Table XXIII, 10). They would delete the 500-foot marks in the 3:2:1 pattern. One subject suggested deleting the P-3 Flight Duplicator! On the whole, size and spacing of paint stripes seemed adequate (Table XXIII, 11 and 12).

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*This problem has been approached in a coded lighting scheme for a 12,000-foot runway (Reference 9), although the measures taken thus far deal only with recognition of position on the runway at landing. Future experiments will explore the feasibility of this scheme for marking for distance to go on take-off, as well as roll-out.

As before, the quality of visual simulation was rated higher than the quality of flight simulation, although both were reasonably well accepted.

Discussion

In Experiment IV, the ICAO narrow gauge and the wide spaced 3:2:1 touchdown zone lighting systems were compared in both landing and take-off modes of operation—i.e., with respect to the ability of these configurations to provide both touchdown position and take-off distance to go, as well as other elements of landing information. Although the participating pilots reiterated their interest in both categories of guidance, only limited differences were found between the experimental patterns in either pilot performance or acceptance. The wide spaced 3:2:1 configuration was associated with more precise control of landing operations, but pilot preferences were evenly divided between patterns. On the other hand, there was some indication that the pilots preferred the 3:2:1 array for take-off guidance, although their performance in estimating distance remaining was not affected by pattern. An interesting effect in constant error did appear: when using the ICAO configuration, pilots tended to underestimate the distance remaining; when using the 3:2:1 pattern they tended to overestimate. From an operational point of view, it would be safer to utilize the system associated with underestimates of distance remaining, but the differences are too small to use as the sole basis for judgment.

An important factor throughout turned out to be the mid-point stripe. Even though only the touchdown zones had been coded, the mid-point marking on the 7,000-foot runway resulted in an almost completely coded runway. Pilot comments on this feature were frequent and favorable. It is quite possible, however, that on a 12,000-foot runway some of the significance of this mark would be lost without additional marking to fill in space between the end of the touchdown zone and the mid-point. More work on this direction needs to be done.

The extra study of approach light detection range with and without the operation of sequence flashing lights confirmed the results obtained in an experiment in a night landing simulation in which positive gain in detection range was achieved with the use of strobe lights.

DISCUSSION

The experiments discussed in this report are part of an experimental program for the development of a runway marking design concept for Category II day-fog operations. In this program the following questions are being considered:

1. Using a pattern of marks compatible with the narrow gauge touchdown zone lighting system, will runway marking provide sufficient guidance for visual transition under Category II bright daylight contact fog conditions?

2. Can the centerline be deleted from the marking system in the landing zone in order to reduce the paint maintenance problem?

3. Will the ICAO simplified narrow gauge pattern with aiming point support operations under the test conditions, and what does the marking of the aiming point contribute to its guidance value?

4. Is it feasible to provide both touchdown distance to go and take-off distance remaining information with a distance coded marking system, and, if so, what is the optimal size and spacing of the elements of this system?

5. Will a system such as the ICAO narrow gauge with aiming point configuration provide both touchdown position and take-off distance to go information, as well as the more completely coded 3:2:1 array?

6. In a longer runway than that used in these experiments (the test runway was 7,000 feet), will it be possible to code the entire length of the runway with marking symbols that are compatible with the runway lighting system?

7. How can the integrity of a coded runway marking system be maintained while accommodating special purpose marking such as arresting gear cable location, displaced thresholds, differential coding of high speed and low speed exits, etc. ?

From the first experiment to the last, the pilots have had very little difficulty accomplishing visual transition for landing with the aid of runway marking under the test conditions. The answer to Question 1, therefore, is "yes." In the arrangement of marking elements, all configurations utilized in the series are compatible with narrow gauge lighting, although in the use of distance coding devices the marking patterns add elements not present in the standard touchdown zone lighting system, and it was found possible to delete the centerline marking in the landing zone area without degrading landing performance. In the configuration without centerline we did, of course, strengthen the lateral elements of the pattern to form a "split-centerline" configuration (see Figure 1); we did not simply delete the centerline without compensation.

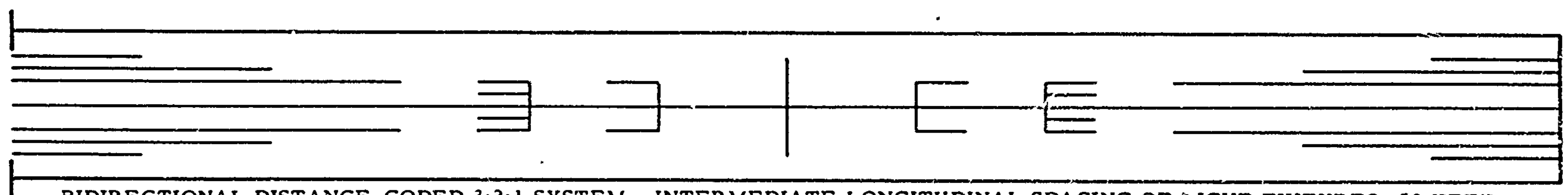
When the ICAO configuration was compared with an experimental narrow gauge system (see Figure 2), it was found that the ICAO simplified narrow gauge performed at least equally well in all guidance categories and, specifically, was more effective in controlling longitudinal positioning at touchdown, obviously because of its aiming point. Question 3 was affirmatively answered, therefore, and the role of aiming point partially explained. The term "partially explained" is used because, although it is obvious that one purpose of this device is to control longitudinal positioning at touchdown, pilot reaction to it indicated an interest in distance coding for which provision of an aiming point may be only a partial answer.

In approaching Question 4, it was recalled that in an earlier experiment concerned with the feasibility of a completely symbolic method of distance coding a 12,000-foot runway (Reference 9), pilots could acquire a practical working familiarity with a double-ended 3:2:1 pattern, coupled with figures to code the interval between landing zones. Although the performance measures used in this early experiment were limited to pilot reports of location over the runway on visual break-out, it was felt that it would be desirable to explore the concept for runway marking in the present program. The idea of symbolic coding was thought to be more attractive than numerical coding because simulator observations showed the numerals to be difficult to read during a process of rapid acceleration or deceleration, and it is not feasible to express numerals with in-set lighting arrays.

If the 3:2:1 system is to be developed to meet the Category II day-fog marking requirement, however, an immediate question is the size and spacing of elements. The present U. S. All-Weather Runway Marking System utilizes a 4:3:2:1 arrangement with longitudinal spacing of 500 feet between elements (see Figure 3), whereas the pattern reflecting the modulus of spacing used in narrow gauge lighting is 100 feet. Experiment III explored this problem. The results suggest that longitudinal spacing is not a critical issue, although pilot performance was more precise on landing operations with the wide spaced 3:2:1 (500-foot longitudinal separation), and more accurate judgments of distance remaining on take-off runs were made with the close spaced 3:2:1 (100-foot longitudinal separation). On the whole, the closely spaced 3:2:1 provides better continuity. Particularly with the addition of runway mid-point marking, the double-ended 3:2:1 arrangement appeared quite effective in providing both landing guidance and distance remaining information.

Comparison of the wide spaced version of the 3:2:1 pattern with the ICAO configuration (Question 4), also with mid-stripe added, showed no particular advantage for either configuration, although the 3:2:1 seemed to offer slightly better guidance in controlling the rate of execution of attitude displacements and longitudinal positioning at touch-down, and there was a tendency to overestimate distance remaining on take-off. With the ICAO pattern, distance remaining estimates tended to be less than the actual distance remaining—a safer tendency, at least if there has to be error. On the 7,000-foot runway used in the simulator, however, addition of the mid-stripe resulted in a completely coded runway with either configuration.

The problem of the longer (say 12,000-foot) runway remains and will be examined in the work to follow (Question 6). Consideration will be given to four main avenues of approach: (1) a marking adaptation of the Experimental Symbolic Distance Indicating Code (Figure 8), which was investigated previously for application to runway lighting (Reference 9); (2) a complete system of painted numerals; (3) a combination of 3:2:1 or ICAO landing zone configurations with numerals in the center roll-out or acceleration area; and (4) a color coded centerline system. Future work will also investigate means for incorporating arresting gear marking, exit marking, displaced threshold marking, and other special purpose effects without degrading the guidance value of the basic runway marking system (Question 7).



BIDIRECTIONAL DISTANCE-CODED 3:2:1 SYSTEM. INTERMEDIATE LONGITUDINAL SPACING OF LIGHT FIXTURES, 50 FEET. AREA BETWEEN LANDING ZONES SYMBOLICALLY CODED 2000 FEET AND 1000 FEET BEFORE AND AFTER MIDPOINT OF RUNWAY. 2000 FOOT CODE BEFORE AND AFTER MIDPOINT IS U-SHAPED, WITH TWO LIGHT ROWS 200 FEET IN LENGTH. LIGHT FIXTURES SPACED AT 50-FOOT INTERVALS LONGITUDINALLY. GAUGE OF U IS 60 FEET, FIXTURES SPACED AT 10-FOOT INTERVALS. 1000-FOOT U SYMBOL BEFORE AND AFTER MIDPOINT HAS SAME DIMENSIONS BUT ONLY SINGLE ROWS OF LIGHT. MIDPOINT OF RUNWAY DENOTED BY A LATERAL ROW OF LIGHTS 100 FEET IN WIDTH; FIXTURES SPACED AT 10-FOOT INTERVALS.

Figure 8. EXPERIMENTAL SYMBOLIC DISTANCE INDICATING CODE

SUMMARY AND CONCLUSIONS

In a series of four experiments, the feasibility of utilizing runway paint marking systems to support visual transition for landing and to provide take-off distance remaining information was investigated in a simulated Category II day-fog condition. Category II visibilities were represented by a bright screen, low signal to ground brightness ratio produced by a modification of the Dalto Visual Attachment in which fluorescent lamps were added to the ultraviolet lamps in the standard Dalto cabinet. Screen brightness and signal brightness were adjusted to produce a realistic appearing attenuation of paint marking conspicuity such that the farthest marking element was just noticeable at a visual range of 1,200 feet. A total of 35 NAFEC operational and casual pilots participated in the program.

The experimental results may be summarized as follows:

1. Runway markings provide sufficient guidance for both landing and take-off operations in a Category II bright daylight contact fog.

2. Runway centerline markings were not needed in the first 3,000 feet of the runway for landing operations.

3. Pilots could learn to obtain distance information from distance coding in touchdown zone markings without degradation of other elements of guidance.

4. A significant feature of the runway marking scheme was the mid-point stripe, particularly on the 7,000-foot runway available for the simulator test.

5. Longitudinal spacing of elements was not critical, although wide spaced elements seemed to be most effective for landing, while close spaced elements were more effective for judgment of distance to go on take-off.

Before the program is completed, principles of distance coding suitable for longer runways and the compatibility of special purpose marking and runway marking must be investigated.

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APPENDIX A

Equipment

The simulation equipment for these experiments consisted of the Curtiss-Wright P-3 Flight Simulator and the Dalto Moving Belt Visual Attachment.

P-3 Simulator. The Curtiss-Wright P-3A Flight Duplicator provides the pilot with a simplified cockpit (single pilot) environment having standard flight instruments, flight controls and navigation aids (Figure 9). The dynamic flight and response characteristics simulated by the P-3 approximate those of a 25,000-pound, twin-engine class aircraft. The inputs to the simulator (movements of flight controls, engine controls, etc.) reflect changes in the analogue computers and associated electromechanical devices which, in turn, transform and transmit, to the cockpit, appropriate instrument readings and control forces.

The outputs of the simulator—altitude, heading, airspeed, etc.—control the actions of the Dalto Visual Simulator Attachment.

Dalto Visual Simulator Attachment. The visual attachment provides a visual stimulus representative of such cues as are perceived by the pilot in a visual landing situation under low ceiling, low visibility conditions. The components of the attachment are:

1. Main Dalto unit.
2. Television projector.
3. Projection screen.
4. Interconnecting compatibility unit.
5. Experimenter's console.

The main Dalto unit houses an endless, moving neoprene belt, television camera, and a translucent filter screen (Figure 10). A model runway and approach lighting system, scaled 300 to 1, is portrayed on the endless belt. The model is representative of 3,000 feet of approach lights and 7,000 feet of runway. The belt is servo-driven at a speed proportional to the ground speed of the simulator.

The simulated runway and approach lighting system is achieved by the placement of fluorescent paint "lights" on the belt in the desired pattern. Overhead ultraviolet lamps activate the fluorescent "lights." Sequenced flashing (strobe) lights in the approach lighting system are simulated by the use of miniature bulbs controlled "off" or "on" by the

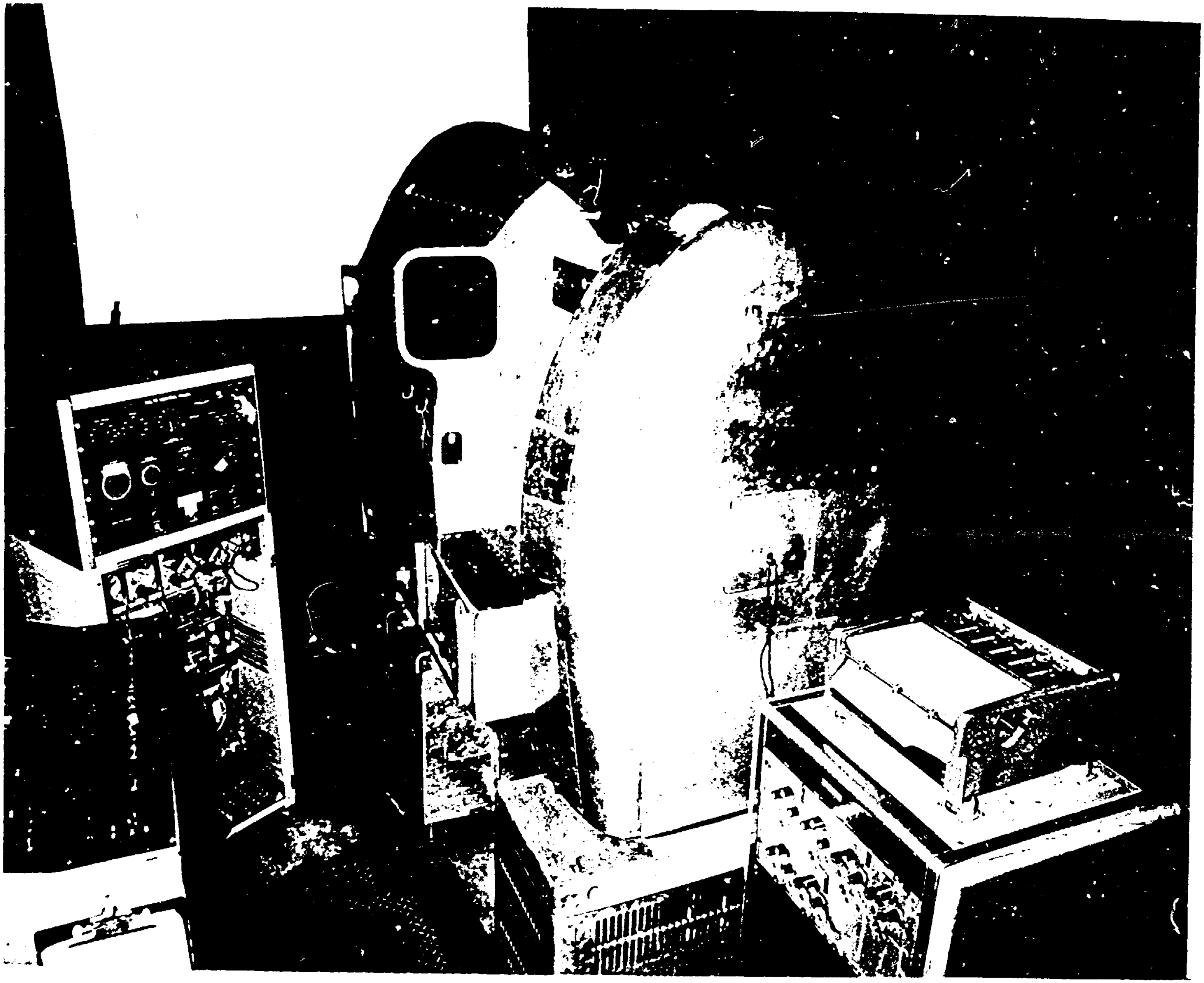

Figure 9. P-3 COCKPIT AND EXPERIMENTER'S CONSOLES

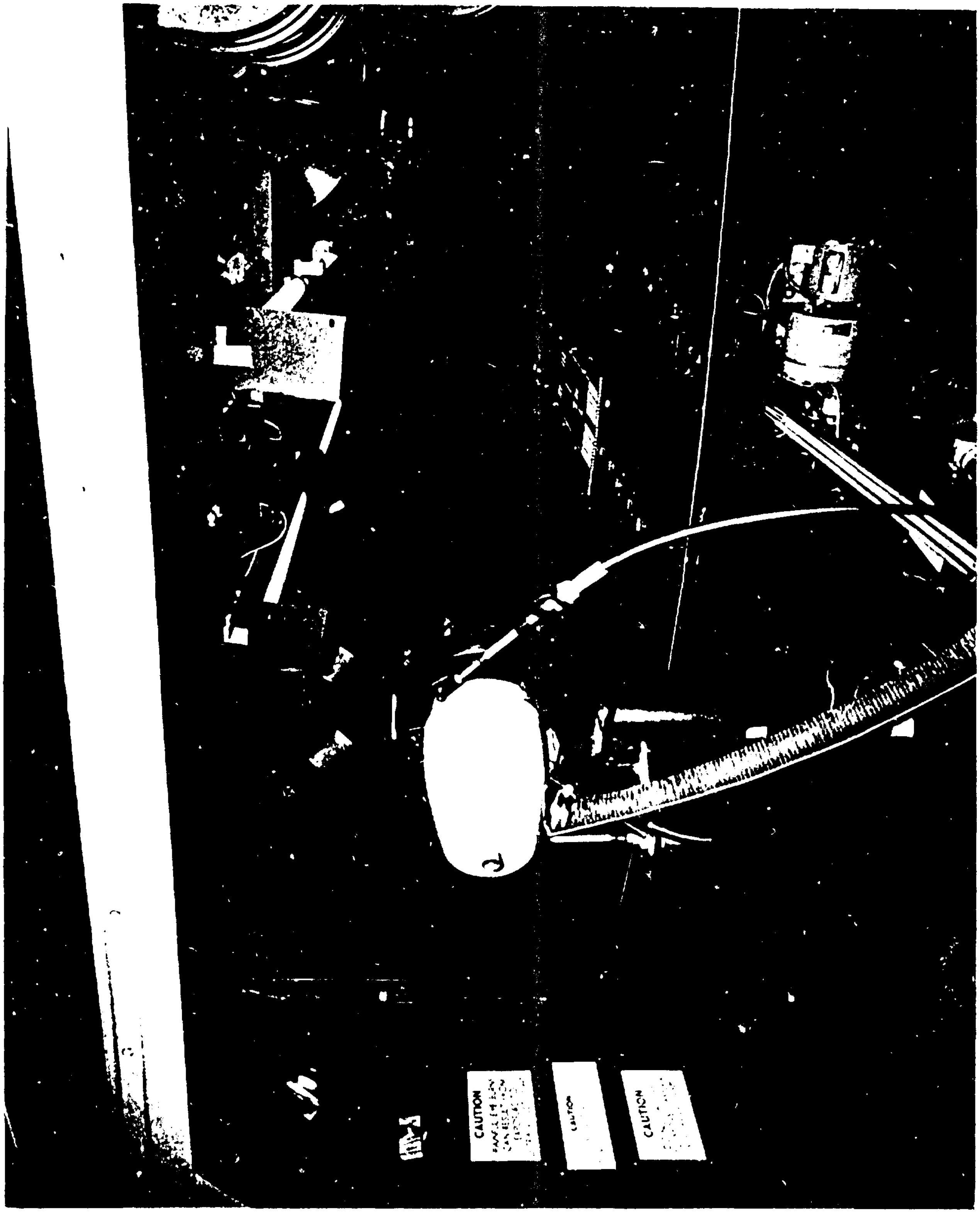

Figure 10. DALTO VISUAL SIMULATOR CABINET, CAMERA AND MODEL RUNWAY

experimenter. The miniature bulbs are placed in the center of each 14-foot bar of lights, spaced 100 feet longitudinally, commencing 200 feet from threshold and extending the length of the 3,000-foot system. The lights are synchronized to discharge or flash in sequence with a complete cycle of the system occurring twice each second—appearing as a ball of light moving toward the runway threshold. Although the extremely high intensity of condenser discharge lights cannot be achieved with this equipment, the light levels simulated are well above the steady burning lights.

A television camera views the model approach lights and runway system, and this unprogrammed scene or presentation is projected on to a 9 foot by 12 foot screen located approximately 14 feet from the pilot's eye position. The camera moves in 5° of freedom—pitch, roll, heading, transverse, and vertical—and its actions are initiated and are synchronous with the movement of the simulator flight instruments and control system through a compatibility unit which matches the outputs of the simulator to the visual attachment. The camera, viewing the moving belt, provides the pilot with the illusion of relative motion towards the approach lights and runway as they would appear during the low visibility approach.

A translucent screen can be moved electrically by the experimenter fore and aft over the simulated runway to increase or decrease the visual range, which is variable from 300 to 2,600 feet. The screen was not used in these experiments because the modification in simulator cabinet illumination (see below) to produce a day-fog condition resulted in a natural attenuation of the visual scene at 1,200 feet.

The experimenter's console contains the main power switches and controls for starting a flight as well as the controls for setting the desired visual range, ceiling height, and the television projection system. Ceiling height is obtained by cutting in the camera video at a pre-set altitude, adjustable by the experimenter in 50-foot increments from zero to 400 feet. The projected lighting condition can be selected as dawn or night by varying the brightness-contrast relationship in the television circuitry.

Modification of Dalto to Simulate Category II Day-Fog Condition. A bright contact day-fog condition was simulated by placing two fluorescent lights overhead at the camera end of the main DALTO enclosure together with appropriate light shields. This was in addition to the ultraviolet lights of the standard installation. The result of this combination was a realistic bright field with no ground texture and an appropriate attenuation of visibility of runway marking with distance (Figure 11).

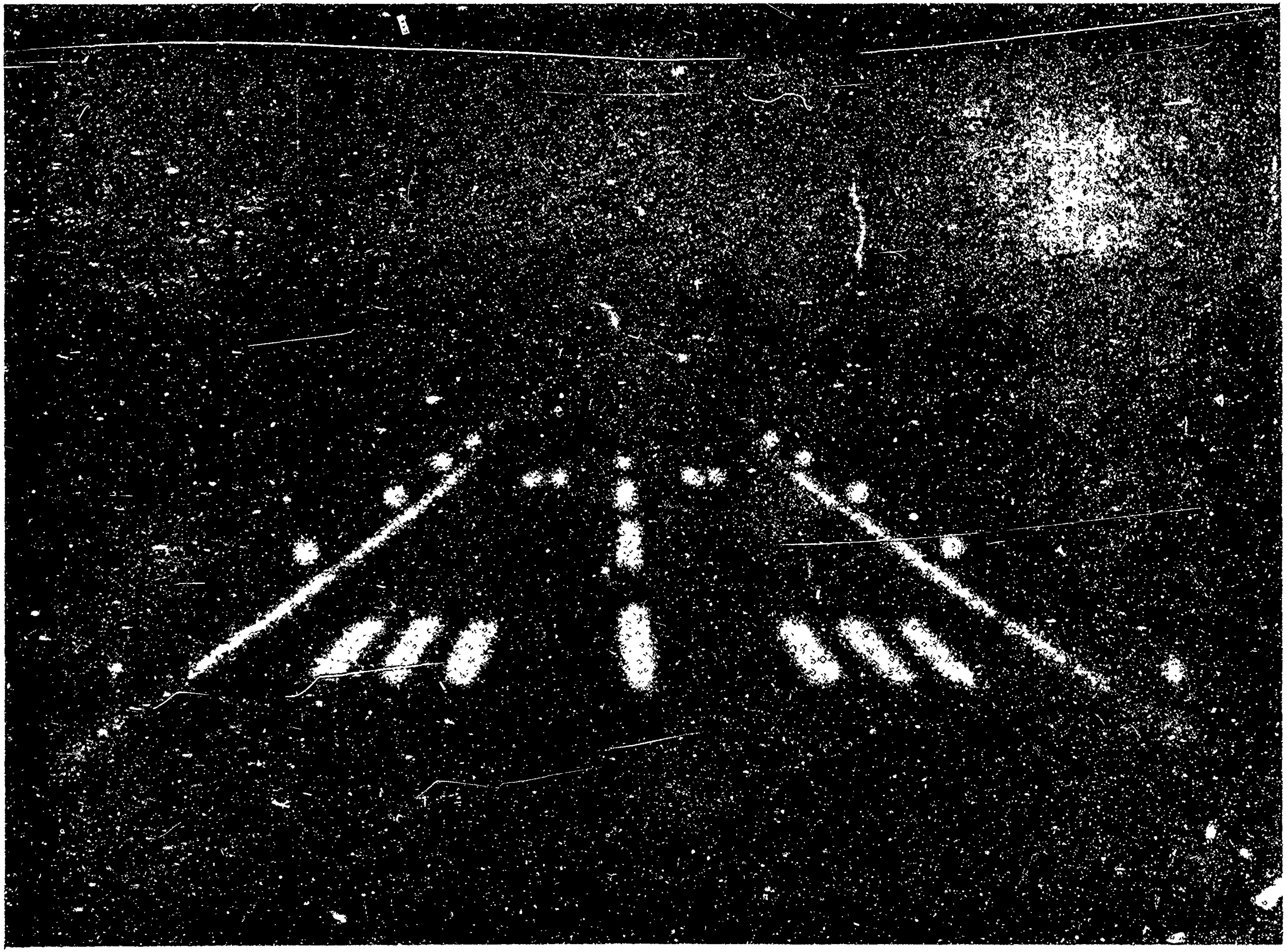

Figure 11. VIEW OF RUNWAY AS SEEN BY THE SUBJECT PILOT

A Spectra Brightness Spotmeter Model #UB 1/2, calibrated daily, was used to ensure consistent brightness levels for the day-fog conditions. The paint marking pattern projected on the screen was set and maintained at .50 ± .03 foot lamberts and the background or runway adjacent to the paint marking stripes was set and maintained at .25 ± .03 foot lamberts.

For these experiments, paint markings were represented by pieces of white commercial tape cut to proper size and backed with adhesive for convenience in changing configurations. The standard technique, where permanence is desired, is to paint the markings directly on the belt.

The pilot views the visual scene through a clear area in the windshield representative of an arc made by a windshield wiper. The remainder of the windshield area is opaque, thus restricting the pilot from seeing additional cues from the edges of the screen. The additional cues of buildings, terrain, horizon, etc., were not simulated for these low visibility conditions.

Recording Equipment and Data Recorded. A 6-channel Brush Recorder (Model RD 2361) activated prior to reaching an altitude of 300 feet, and operating at a speed of 10 mm/sec., was used to record information described in Appendix B.

APPENDIX B

Experimental Procedures

Prior to starting the experiment the pilots were briefed on the purpose of the study. They were told that research was being directed toward the development of runway paint marking patterns suitable for Category II day-fog conditions. They were shown diagrams of the test configurations and a pre-test questionnaire was completed.

The pilots were told that they would fly Instrument Landing System (ILS) approaches, with a localizer course of 360°, for landing on Runway 36. The pilot would fly the simulator to 1,500 feet of altitude, maintaining a heading of 360°, at which time the experimenter would activate the radio aids and manually position the flight approximately one mile beyond the outer marker (OM). The OM was located approximately 5.2 miles from the runway threshold and the middle marker (MM) .6 miles from threshold.

In order to obtain supplemental data for a recently completed study on approach lighting, the pilots participating in Experiment IV also were asked to activate an event marker button mounted on the control wheel to indicate their first point of contact with the approach lights. The experimenter also independently activated an event marker for the same purpose.

Transition from instrument to visual flight occurred after passing the MM, usually about 180 feet of altitude, and the remainder of the approach was completed visually with a slant range runway marking element visibility of 1,200 feet. After touchdown and landing roll-out, the pilot took off, and the flight was manually repositioned by the experimenter at 1,500 feet of altitude for another approach. Each approach and landing required about 8 minutes, and 3 to 5 minutes were required to change to the next marking pattern.

The subjects were told that on all approaches the experimenter would inject a variable into the flight simulator that would effect a displacement about an axis of flight (see Example of Subject Briefing). They were not told when or what displacement would be introduced, only that they were expected to execute the appropriate corrective maneuver with reference to the visual cues presented that would result in optimal alignment and attitude for landing.

Take-off procedures differed for Experiments III and IV since the paint marking patterns were installed on each end of the runway. (The pattern was repeated on each end of the runway to determine the pilot's ability to utilize the coded distance features in judging distance remaining at the take-off point.) Experiment III required the pilot to report the runway distance remaining at take-off in 1,000-foot sectors with reference to the coded segment, i.e., 1,000 feet remaining; 2,000 feet remaining; or 3,000 feet remaining. The experimenter advised the pilot when to apply power after touchdown and also controlled the rate of acceleration on the take-off run in such a manner that the prescribed take-off velocity was reached in the 1,000-foot sector pre-selected in the experimental program as the take-off zone for that particular run. The experimenter, who was well acquainted with the coded patterns, also judged the take-off sector in the same manner.

Experiment IV required the pilot to report the distance remaining at the time of take-off as accurately as possible. (In most cases, the pilots judged the distance in hundreds of feet.) The experimenter, with the aid of coded markers unseen by the pilot, also judged the distance remaining in hundreds of feet. After landing and roll-out the flight was repositioned to the approach end of the runway to obtain better control of point of breaking ground in the pre-selected take-off sector. Acceleration was controlled as in Experiment III and in addition the command, "Rotate," was given by the experimenter at approximately 120 knots in the pre-selected sector.

Example of Pilot Subject Briefing

"The project is a study of pilot visual guidance needs for all-weather take-off and landing. This experiment is concerned with runway paint marking patterns for Category II (1,200 feet visual range) day-fog conditions.

"A survey of pilot reports (J. F. Kennedy International Airport) has indicated that under critical daylight fog conditions, pilots have experienced difficulty in seeing flush lighting patterns, but report that runway paint markings are more readily visible. This phase of the experiment will compare two proposed experimental paint patterns.

"One configuration is basically the U. S. Standard All-Weather System modified by extending it to 3,000 feet as you notice from the drawing; the spacing and dimensions are given. This will be called Pattern A. The other configuration, Pattern I, is the ICAO Pattern which is distance coded to some extent, with an aiming point 1,000 feet from the threshold. You will be asked to make a series of take-offs, ILS approaches, and landings on the two experimental runway marking patterns utilizing a standard approach lighting system. Each of the six sessions will require eight approaches, four on each of the marking patterns. A visual range of 1,200 feet will be used with simulated day-fog conditions. The approach lights and strobes should come into your visual range at about 200 feet. We ask that you press the event button installed on the control wheel on two occasions during the final approach: when you first notice the approach lights, and second, when you transfer from instruments to visual reference. On each approach try to go visual as soon as possible.

"As you have noticed from the drawing, the two configurations under study are coded for distance references. When taking off, we would like you to call out your longitudinal position to determine how much runway distance you have left. All take-off speeds will be at 120 knots, and you will be given the command, "Rotate," when you have reached take-off speed. After you have made your ILS approach and landing, we would like you to call out your touchdown position longitudinally. Then, when the signal is given, advance your power and start your take-off.

"On some approaches you may notice that a minor correction in heading, roll, or attitude (pitch) may be necessary. Your task, on instruments and when visual, is to make the corrections that will place the aircraft in an optimal attitude and position for landing. Please try to land as near the middle of the runway as practicable, also try to land in the second thousand-foot area.

"Before starting the experiment we would like you to complete the Pre-Test Questionnaire. After each session you will be asked to express your preference for either one of the two patterns, together with any additional opinions or remarks. When you have completed the six sessions you will be asked to complete a final questionnaire."

Rotational Displacement Methodology

The displacement variables introduced were Heading (H), Roll (R), and Pitch Attitude (A). All variable displacements were moderate displacements from the flight path since it would be expected normally that the pilot would abort the approach in the case of large displacement at the close range and low altitude.

Heading (H). A 90° crosswind of 15 knots was gradually introduced into the simulator complex as the pilot passed the OM on his ILS approach to Runway 36. The pilot, while flying instruments, became aware of the wind drift by noting the ILS localizer needle and heading indicator, and applied an appropriate drift correction of about 7^{o} to 8^{o}. Wind direction was varied from left to right. After the pilot transitioned from instrument to visual flight and had the runway touchdown zone marking pattern in view, the wind was withdrawn, with the effect of a wind sheer at low altitude. The pilot was then required to effect a heading correction by reference to visual cues only in order to maintain proper line of flight with the runway for final approach, touchdown and landing roll-out.

Roll (R). When the pilot had completed his transition from instrument to visual flight on his ILS approach and had the runway marking pattern in view, a moderate rough air condition was introduced into the simulator and was withdrawn immediately. This, in effect, caused a small but noticeable rotation about the longitudinal axis (8^{o} to 12^{o}), represented by wing down or roll condition in the visual scene. The pilot, by observing visual cues from the runway touchdown zone marking configuration, was required to apply roll correction in the proper direction in order to continue his approach path and attain a wing level condition.

Pitch Attitude (A). As the aircraft passed the OM on the ILS approach, a "wing-icing" condition was introduced into the simulator. To maintain the appropriate rate of descent for the ILS glide path, increased power and/or pitch (nose-up) attitude was required. After the pilot had completed his transition from instrument to visual flight and had the landing zone marking pattern in view, the icing condition was withdrawn. The pilot, by observing the visual scene, was required to decrease power and/or make an attitude change (nose down) in order to maintain or re-establish a flight path which would result in a normal or satisfactory final approach, flare and touchdown position.

Data Recorded

The following data were recorded by the experimenter by observing the pilot's actions and the visual scene presented:

1. Displacement Recognition. After exposure to the displacement, the pilot initiates a control response in the appropriate direction.

2. Rate of Correction. Pilot completes the appropriate control response prior to the criterion points (runway threshold and point of touchdown).

3. Flare Path. Pilot rounds out glide path so that velocity vector is reduced to a normal rate of descent at touchdown.

4. Longitudinal Positioning at Touchdown. Pilot touches down within a defined space (the first, second or third 1,000-foot sector of the landing zone).

5. Lateral Positioning at Touchdown. Pilot touches down within a defined space (inside the touchdown zone lighting system, a minimum distance from centerline, or outside, left or right, of touchdown zone lights).

6. Runway Distance Remaining on Take-Off. Experiments III and IV. Experimenter and pilot report independent judgment of distance remaining based on use of coded paint marking patterns.

7. Approach Light Detection. Experiment IV Only. Event marker activated when approach lights first came into view. (Experimenter and pilots each activated marker independently to supplement detection data for a recent study on approach lighting.)

In addition, a 6-channel Brush Recorder (Model RD2361) activated prior to reaching an altitude of 300 feet, and operating at a speed of 10 mm/sec., was used to record the following:

Channel 1. Displacement from the ILS Localizer, ± 20 mm. representing 1.25° displacement from localizer centerline (1 dot deflection on the pilot's ILS indicator).

Channel 2. (a) Displacement from the ILS Glide Slope, ± 20 mm. representing $\pm .5^{\circ}$ displacement from glide slope (2 dots deflection on the pilot's ILS indicator); (b) Flag Drop (FD), a record of glide slope intercept on the runway, 1,000 feet from threshold.

Channel 3. Altitude, 40 mm. representing 200 to 0 feet.

Channel 4. Recorded automatically: (a) passing the middle marker; (b) the threshold; (c) the 1,000-foot runway mark; (d) the moment of touchdown; (e) *distance markers on the last half of the runway; and (f) *take-off position.

Channel 5. Recorded: (a) pilots indicated air speed of the simulator (40 mm. representing 100 to 160 knots); (b) **pilots' event

*Items (e) and (f) recorded for Experiments III and IV; however, recorded take-off data were not reliable and therefore not used in the analysis.

**Experiment IV only.

marker, activated by the pilot by a switch on his control wheel, indicating when he first saw the approach lights and again when actually going visual to make his final approach and landing; (d) *experimenter's event marker, activated when, in the opinion of the experimenter, the pilot had completed the maneuver correction.

Channel 6. Event marker, operated by the experimenter to indicate (a) when the displacement variable was taken off; (b) when the approach lights first appeared on the screen; (c) when the 1,000-foot roll bar came into view; and (d) when the threshold of the runway appeared visually on the screen.

*Experiment IV only.

APPENDIX C

Digest of Pilot Comments During Experimental Sessions

	Configuration A (Wide Spaced 3:2:1)	Configuration I (ICAO)
Subject #1 Session #1	Pilot feels 2, 500-foot point is most helpful on A.	Pilot feels 2, 500-foot point is a must on pattern I.
2	Gives pilot more information with striped coding.	Pilot likes aiming point. The mid-point is outstanding; pilot would like numerals.
3	Prefers A, but like to see less markings.	The 1, 000-foot aiming point and 3, 500-foot mid-point is what makes it flyable. This configuration would work nicely with heads up (wind screen) display.
4	The 500-foot marker on end of runway is not needed. Too cluttered.	The aiming point is the better 1, 000-foot marking than the A configuration 1, 000-foot marker.
5		Likes aiming point on I and the half-way point.
Subject #2 Session #2	Would like to see 1, 000-foot aiming point.	The aiming point is good, but once over it pilot feels lost.
4	Normal the first half of the runway, but abnormal on the last half.	Prefer I for 1, 000-foot aiming point. Simplicity.

Digest of Pilot Comments During Experimental Sessions (Continued)

	Configuration A	Configuration I
Subject #3		
Session #3	Tends to require too much deep thinking, would be better without all the coding. I think 500-foot marker could be omitted.	Requires less concentration.
5	Would like to see A with aiming point and some of distance coding marks removed.	Likes I for general operating flying. Better for simplicity.
Subject #4		
Session #4	The 500-foot mark on A does not give pilot much help.	
Subject #5		
Session #3	Tends to require too much deep thinking, would be better without all the coding. I think 500-foot marker could be omitted.	Requires less concentration.
5	Would like to see A with aiming point and some of distance coding marks removed.	Likes I for general operating flying. Better for simplicity.
Subject #6		
Session #2		Likes the clear 1,000-foot aiming point and simplicity of I.
3		The 1,000-foot aiming point is one of the deciding factors for his choice.
Subject #7		
Session #2	Markings were visible, pilot reads distances easier.	

Digest of Pilot Comments During Experimental Sessions (Continued)

	Configuration A	Configuration I
Subject # 8		
Session #1		Most simple, less confusing, easier to interpret.
2	Too many markings, too much mental work.	
3		Easier to read but needs slight improvement.
Subject #9		
Session #1	Gives pilot more alignment. Better centerline guidance, better aiming point.	
2	Easier to read, receive more attitude information.	
3	Pilot sees better attitude information.	
Subject #10		
Session #1		Pilot likes 1,000-foot point on I.
2		Good longitudinal guidance.
4	Receive more roll guidance, can easily identify the 1,000 foot.	
5	More roll guidance.	