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SIMULATION STUDY OF CHEVRON MARKINGS FOR AREAS ADJACENT TO RUNWAY THRESHOLDS

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16. Abstract

To determine the minimum system of chevron markings that would give warning of potentially deceptive, nonload-bearing paved areas before a runway threshold, 20 pilots were given systematic exposure in a flight simulator to narrowed and more widely spaced chevron patterns, and also to the present U. S. Standard. The judgments made by these pilots were that both the conventional pattern of full-width chevrons spaced 100 feet apart and a pattern of standard-width chevrons spaced 200 feet apart provided distinct and unambiguous warning of the nonload-bearing surface. Further, they reported that these two patterns were not confusable with other markings such as the runway threshold stripes. Pilot judgments of the two patterns with narrowed chevrons were mixed. While a majority reported the narrowed chevrons not confusable, there was a marked increase in the number reporting absence of distinct and unambiguous guidance, particularly when the markings were viewed from a position low on glide slope and offset from the centerline.

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INTRODUCTION

Purpose

The purpose of this test was to determine the minimum system of chevron markings that would give warning of potentially deceptive, nonload-bearing paved areas before a runway threshold. There is a standard chevron configuration, but it seemed possible that a more widely spaced pattern, or one made up of narrower marks requiring less paint, would serve to give distinct and unambiguous visual warning enabling the pilot to distinguish undershoot/overrun areas from the runway proper. This test asked the questions: How wide do the marks have to be and how close to each other to provide adequate identification or warning?

Background

There has been an increasing tendency to pave areas adjacent to runways, taxiways, and aprons to prevent erosion due to jet blast. Such paving introduces the possibility of deceiving the pilot into thinking that there is a load-bearing surface where, in fact, there is not. Other requirements for special marking are recognized to exist for runways and taxiways that are closed for operations, but that still bear active markings because the unserviceability is expected to be temporary. Work has been accomplished on several special categories of markings of possibly deceptive areas, and the immediate focus of this effort is on those pavements that lead up to the runway threshold.

The 1970 International Civil Aviation Organization (ICAO) Visual Aids Panel Report on Agenda 1 stated that a special distinct marking was required for undershoot and overrun areas. Chevrons had been used extensively in the United States, and this marking pattern was acceptable to the international majority. While spacing at 100-foot intervals was recommended, according to the ICAO Visual Aids Panel, "It was thought that some economies might be made with a greater spacing, but this would require further testing."

Test Patterns

Three configurations were selected for formal testing and comparison with the present standard chevron configuration following preliminary tests of several variations in width and spacing. All variations that were considered required less paint, in line with the objective to determine the minimum acceptable for adequate warning of the underrun. Since the present 3-foot width of the paint stripes appears satisfactory, based on pilot reports and adoption by the ICAO, it was agreed by the test panel that a change in stroke width would not be considered. The preliminary

tests were confined to the overall chevron size, hereafter referred to as width, and the interval between the chevrons. Widths of the chevrons considered in the preliminary tests employing a 150-foot wide runway ranged from 50 to 200 feet. The test panel judging the preliminary tests concluded that a width of 75 feet should be considered as the minimum and 150 feet the maximum for formal testing (see FIG. 1). The selection of 150 feet as the maximum was influenced by user acceptance of the present U. S. Standard. According to the present specifications (Advisory Circular AC 150/5340-7A), the stripes making up the chevron can be terminated 5 feet short of the extended runway edges. This results in an overall chevron width of 140 feet for a runway width of 150 feet. In the preliminary simulation tests, the judging panel concurred that shortening the overall width by 10 to 15 feet was not readily detectable. Hence, a chevron of 135- to 140-foot width would be acceptable as representing a "full-width" marking.

The intervals between chevrons that were considered ranged from 50 to 200 feet. The panel accepted the interval of 50 feet as possibly required on very short pavements, but concluded that the more generally employed interval of 100 feet should be the minimum, and 200 feet should be the maximum interval for the formal tests. This resulted in the selection of the three patterns (FIG. 1) to be compared with the present U. S. Standard. All patterns were installed in an underrun area extending 1,000 feet from the model runway threshold.

Flight Simulation Environment

The simulation environment consisted of the Curtiss-Wright P-3 Flight Duplicator and the Dalto visual system attachment. The flight duplicator provided a single-pilot cockpit environment with standard flight instruments and controls.[1] The simulator was set up to simulate an automatic approach and landing on a 2.6° ILS glide slope with an approach speed of 130 knots. The deviations from localizer and glide slope for the various approaches to each test configuration are described under "Subjects and Test Procedures."

The visual system provided a visual scene of the approach lights (without strobe lights), runway underrun area chevron markings, and runway markings as it would appear under low-visibility, day-fog conditions. The simulated visual range was approximately 2,000 feet. The television picture, projected in front of the cockpit, was generated by a closed circuit

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

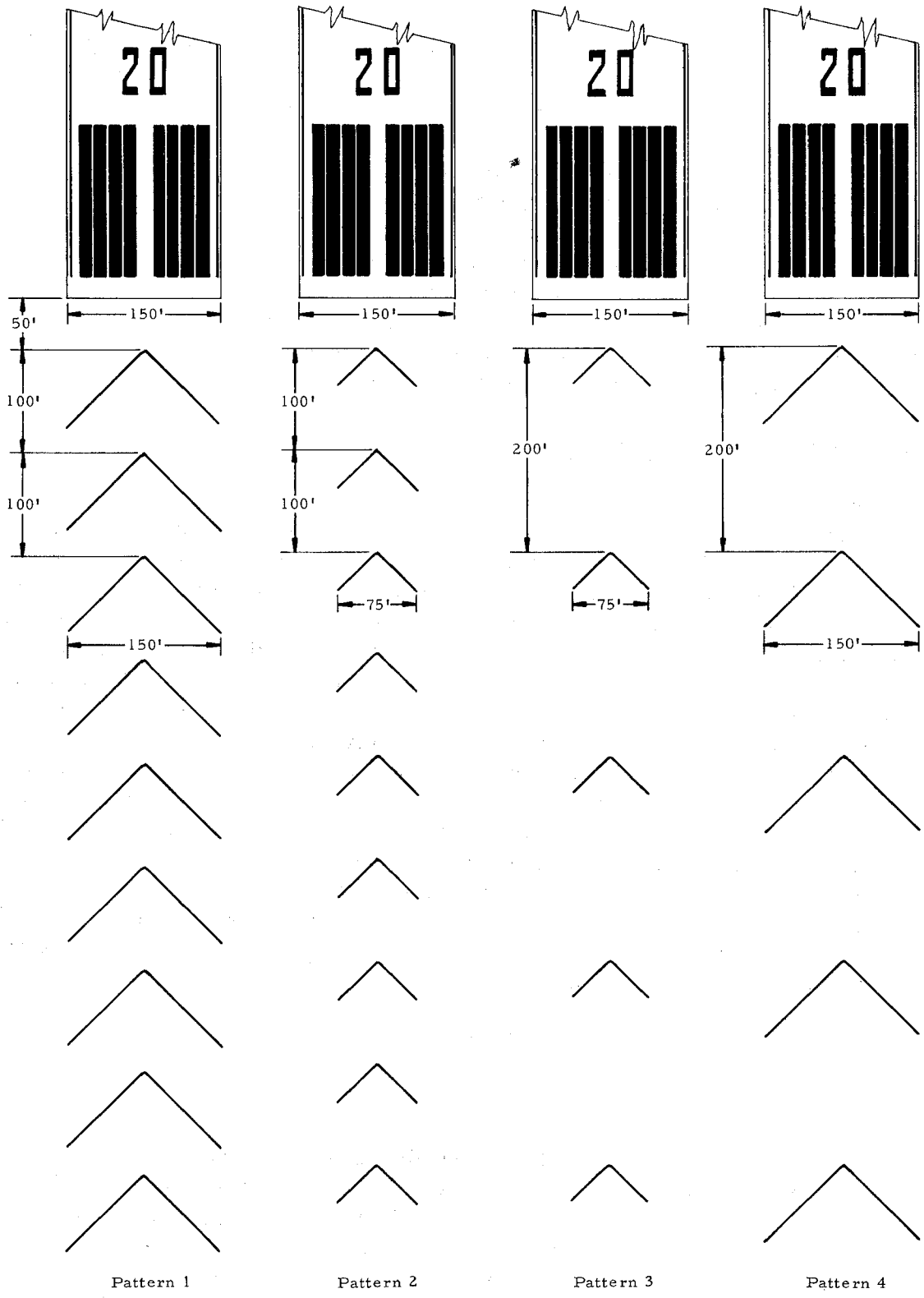

FIG. 1 CHEVRON TEST PATTERNS

video camera viewing a model. The model runway and approach path were installed on an endless moving neoprene belt with a scale of 300:1. For the test, it was necessary to remove the approach lights in the chevron test areas, extending 1,000 feet from the runway threshold, due to the design and scale of the model approach lights.* The speed of the model runway belt was controlled proportionally to the ground speed as computed by the simulator. The day-fog conditions were simulated by the use of fluorescent lights and appropriate light shields installed over the moving belt. The overall result was a quite realistic bright field, with no ground texture, and a reasonably realistic attenuation of the paint markings with distance. The black and white design of the television system precluded testing the chevron stripes in the recommended yellow color.

Subjects and Test Procedures

Twenty pilots employed by the FAA at NAFEC served as subjects. Ten pilots were from the NAFEC Flight Operations Branch, five from the Atlantic City Flight Inspection District Office (FIDO), and five were from other NAFEC organizations. All were considered well experienced and currently qualified. Fifteen were flying in a professional pilot status, four were recent military pilots experienced in flying high-performance aircraft, and one was a recent FAA flight inspection pilot. The subject pilots were briefed on the test as described under "Subject Briefing" in the Appendix. The subjects were given four approaches on each of the four test patterns. The first approach for each pattern was made on localizer centerline and on glide path. The second approach was on centerline, but low on the glide slope. The third was offset right or left of centerline and was high above the glide slope. The fourth approach was offset right or left of centerline and was low or below the glide slope. On completion of each approach, the subject was asked to answer the appropriate question on the questionnaire. The order of presentation of the four patterns was uniform.

DISCUSSION

Results

The results of this simulation study consist of the judgments, preferences, and comments of the 20 subject pilots who observed the alternative chevron patterns in repeated simulated approaches and landings. After each run, the question was asked, "Did you consider this pattern to provide distinct and unambiguous warning of the nonload-bearing surface?" (see Questionnaire, Appendix). Since there were 20 pilots and four runs on each of four patterns, this question was asked 320 times. Of this total, there were 263 instances in which the pilot answered yes and only 57 in which he reported less than distinct and unambiguous

warning. While on the basis of this overall result it may be said that the majority of judgments favored the four chevron patterns, it is important to note the marked differences in proportion of approving and disapproving responses to the individual patterns. Table 1 summarizes these data.

Table 1 data indicate that Patterns 4 and 1 were judged to give distinct and unambiguous warning 79 times versus 1 time, and 75 times versus 5 times, respectively. Thus, both the U. S. Standard, Pattern 1, and even more often, Pattern 4, a more widely spaced version of the U. S. Standard, full-width chevrons, received solid endorsement. Patterns 2 and 3, the 100-foot spaced narrow chevrons and the 200-foot spaced narrow chevrons, were less often endorsed. Pattern 2 received 19 yes against only 1 no when the subject pilot was on centerline and glide slope. The proportion remained high--15-5, when on centerline but low on glide slope, and was 16-4 when offset, but high. Hence, Pattern 2 failed to receive a heavy preponderance of endorsement only when the run was made offset to the side and low. Then the tally fell to 12 versus 8, which is not extremely different from 50-50.

Pattern 3, narrow chevrons widely spaced, received an approving vote only when viewed from an ideal approach (15-5). When low on glide slope the proportion fell to 12-8; when offset and either high or low on glide slope, the tally was 10-10.

Comments of the subject pilots, confirmed by the experimenter, were that when offset, particularly when offset and low, the narrow chevrons lost figural identity and appeared more like a transverse painted mark than like a chevron. A transverse mark seemed to have some possibility in low visibility of being mistaken for threshold or touchdown zone markings, confusions that could be most dangerous.

To evaluate the chance that divisions among the 20 pilots of the order of those reported above might be due to sampling variation, all results were compared to a table of probabilities in the binomial test. A majority of 17 to 3 or better is required to reduce below one chance in a hundred the probability that the actual fact is an equal likelihood of a yes or no response (two tails of the distribution). To attain a probability of 5 percent or less, a split of 15 yes to 5 no, or better, is required. Asterisks were added to Table 1 to indicate these values. It will be seen that Patterns 4 and 1 received favorable reports exceeding the requirements for a 1-percent risk. Pattern 2 failed to attain even the 5-percent criterion under the worst condition, low and offset, and Pattern 3 attained the 5-percent level only under the best condition, on centerline and glide slope.

These results suggest that either the wide or narrow chevron markings are satisfactory to the majority of pilots when viewed from a

TABLE 1. - NUMBER OF PILOT JUDGMENTS THAT EACH PATTERN GAVE DISTINCT AND UNAMBIGUOUS WARNING

Chevron Patterns	RUNS			
	Approach On Centerline and Glide Slope	Approach On Centerline but Low	Approach Offset and High	Approach Offset and Low
Pattern 1 150' Wide 100' Spacing	Yes = 20* No = 0	Yes = 17* No = 3	Yes = 20* No = 0	Yes = 18* No = 2
Pattern 2 75' Wide 100' Spacing	Yes = 19* No = 1	Yes = 15** No = 5	Yes = 16** No = 4	Yes = 12 No = 8
Pattern 3 75' Wide 200' Spacing	Yes = 15** No = 5	Yes = 12 No = 8	Yes = 10 No = 10	Yes = 10 No = 10
Pattern 4 150' Wide 200' Spacing	Yes = 20* No = 0	Yes = 20* No = 0	Yes = 19* No = 1	Yes = 20* No = 0

*Statistically significant $p = < .01$ two tails
**Statistically significant $p = < .05$ two tails

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*Statistically significant $p = < .01$ two tails
**Statistically significant $p = < .05$ two tails

position along the extended runway centerline. Difficulty occurred with the narrow chevron marks when the point of view was offset in the low-visibility conditions that blurred the contours making it possible in a glance to fail to see the chevron shape.

A followup question posed after each series of four runs with a given chevron pattern asked whether the just experienced pattern could be confused, for example, with the runway threshold stripes. On this question, as with the preceding, Pattern 4 received the strongest endorsement. On Pattern 4, 17 pilots said no chance of confusion versus 3 admitting the possibility. Next best was Pattern 1, the U. S. Standard, with 14 saying no confusion, 4 allowing the possibility, 1 pilot equivocating, and 1 failing to answer. Pattern 3 received a nearly similar vote with 14 saying no confusion versus 5 noting the possibility and 1 equivocating. Pattern 2 produced 13 no confusion responses versus 6 answering yes and 1 maybe.

The final two questions were asked after the pilots had experienced all four patterns. They were "... which of the three (reduced patterns) do you prefer?" and "which of the four patterns do you prefer, regardless of cost ...?" The responses to these two questions provided support to the interpretation of the earlier results; that is, that either of the patterns employing the wide chevrons was acceptable. In all, 15 pilots selected Pattern 4 from among the three reduced patterns. When the preference was stated "regardless of cost," Patterns 1 and 4 nearly tied in selections. Pattern 1 was ranked first by nine pilots, Pattern 4 was ranked first by eight pilots, Pattern 2 was ranked first by two pilots, and Pattern 3 was ranked first by one pilot. Only six of the pilots went on to rank all four patterns, as shown in Table 2.

Calculating average ranks from the data shown in Table 2, it was found that Pattern 4 obtained an average rank of 1.5 and Pattern 1 was nearly the same with 1.6. The two narrow chevron patterns obtained mean ranks of 3.0. This shows again the relatively consistent preference of the pilots for the two patterns with wide chevrons.

Implications for Varying Length Pavements

The present tests were run with a long (1,000 feet) length of runway overrun. From the results, it seems clear that full width chevrons may be spaced out from the present standard of 100 feet to as much as 200 feet when there is a substantial length of paved overrun to mark. Advisory Circular No. AC 150/5340-7A, "Marking and Lighting of Deceptive,

TABLE 2. - NUMBERS OF PILOTS SELECTING PATTERNS 1, 2, 3, and 4 AS PREFERRED, REGARDLESS OF COST

Chevron Patterns	First Choice	Second Choice	Third Choice	Fourth Choice
Pattern 1 150' Wide 100' Spacing	9	1	0	2
Pattern 2 75' Wide 100' Spacing	2	1	3	1
Pattern 3 75' Wide 200' Spacing	1	1	1	3
Pattern 4 150' Wide 200' Spacing	8	3	2	0

Closed, and Hazardous Areas on Airports,"[2] distinguishes between short paved areas of less than 250 feet and longer overruns. For the shorter areas such as a runway-end blast pad, the AC states "50' spacing may be used...the first full chevron starts at the index point." (The index point is shown at the threshold on the centerline.) For longer pavements, 100-foot spacing is specified with the first chevron cut off by the threshold at the midpoint of the two arms of the chevron. The ICAO Visual Aids Panel DOC 8862, "Report on Agenda Item 1," in contrast, notes that chevrons "...were not considered necessary on very short areas with a minimum length of 60 m (200 ft.)." The intent probably was to specify a maximum length that could be considered too short to warrant chevrons, not a "minimum" as stated. Choosing this interpretation, we have ICAO saying that chevron markings are optional when the overrun is 200 feet long or less, while the U. S. says spacing should be reduced to 50 feet when the pavement is less than 250 feet.

During the present tests, the experimenters viewed short pavements with chevrons as depicted by the simulator. The suggestion accepted between them was that four whole chevrons were sufficient to convey the guidance intended on a short pavement with a length of 700 feet or less. In addition, the impression was gained that the chevron terminating at the threshold was more distinctive when it was a complete chevron (index point at the threshold). If these impressions are accepted, the spacing for short pavements might be made contingent upon fitting in four chevrons. This would reduce the allowable 200-foot spacing, where there is 700 feet, to 50-foot spacing, where there is only 250 feet. From 100 to 250 feet, the area should more properly be considered a blast pad than an overrun, and it might be reasonable to specify spacing of 50 feet or more as appropriate to produce one, two, or three complete chevrons with an index point at the threshold.

Paralleling the differences in statement on short pavements, ICAO and the United States have stated slightly different chevron widths. The U. S. Standard said, "Terminate the chevrons not more than 5 feet inside the edge of the deceptive area but do not go beyond the extended edge of the useable runway." ICAO illustrated overrun area markings with a maximum of 25 feet between the extended runway edge and the chevron end. Thus, the United States would have chevrons not less than 10 feet narrower than the runway, while ICAO allowed 50 feet narrower. It may be desirable to harmonize the two statements in

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[2] Advisory Circular No. AC 150/5340-7A has been superseded by AC 150/5340-1C, "Marking of Panel Areas on Airports," dated 11/3/70, without change in the chevron markings.

view of the present finding that a narrow chevron, half the width of the runway, loses some guidance value when seen from a position offset and low. A reasonable compromise might be to call for chevrons of "full runway width" with an allowance of minus 15 percent in cases deemed desirable, for example, because of the slope of the pavement.

CONCLUSIONS

Based on the questionnaire responses of 20 pilots given systematic exposure to alternative spacings and widths of chevron-marking patterns for a runway overrun 1,000 feet in length adjoining a runway 150 feet wide, it is concluded that:

1. Wide, approximately full-runway-width chevrons, which gave distinct and unambiguous warning of the nonload-bearing surface, may be spaced at either the present 100-foot standard interval or at a lengthened 200-foot interval.

2. While narrow, approximately half-runway-width chevrons received a smaller pilot endorsement, it is apparent that some narrowing, estimated at 15 percent below runway width, would be acceptable.

3. Pilot preferences are nearly equal for the 100-foot and 200-foot intervals with the wide chevrons.

4. While not tested in the main series, there is some basis to believe that short (under 250 feet) overrun pavements may require spacing reduced to 50 feet.

APPENDIX

SUBJECT BRIEFING AND QUESTIONNAIRE

Investigation of Runway Underrun Area Paint Markings

The objective of this simulation test is to determine the minimum size and spacing of chevron paint markings that will give the pilot distinct and unambiguous visual warning of the runway underrun area. Since the chevron pattern is already established as the United States and ICAO standard pattern, the questions are: How wide do the marks have to be and how close to each other do they have to be to provide adequate identification or warning? Considerable criticism was made relative to the amount of paint used in the markings at the last ICAO Visual Aids Panel meeting, and the United States was asked to conduct tests. We would like to emphasize the fact that the chevrons are not intended to be used for visual guidance--their sole purpose is to provide identification of deceptive-appearing paved surfaces used as nonload-bearing overruns and underruns to runways.

Four variations of the marking pattern will be simulated in the test:

1. Wide chevron marks (150 feet) spaced 100 feet apart
2. Narrow marks (75 feet) spaced 100 feet apart
3. Narrow marks (75 feet) spaced 200 feet apart
4. Wide marks (150 feet) spaced 200 feet apart

It has already been established that the wide marks at the closer (100 feet) spacing are adequate. We now ask whether any of the alternate patterns are acceptable.

The chevron patterns (see drawing*) have been installed on the Dalto runway belt extending 1,000 feet from the runway threshold in the underrun area, and the approach lights have been removed in this area for the tests. Since the chevrons should be identified in low visibility as well as VFR conditions, a visual range of approximately 2,000 feet will be simulated for the tests. Simulated automatic approaches to the runway will be made on each pattern including approaches offset from the extended runway centerline. A few minutes will be required to change each configuration. On completion of the runs, we ask that you complete the attached questionnaire.

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*See FIG. 1

Subject _____

Organization _____ Date _____

QUESTIONNAIRE

Investigation of Runway Underrun Area Paint Markings, Project 430-301-05X

Please recall that the objective is to determine the minimum size and spacing of chevron markings that will provide distinct and unambiguous visual warning of the nonload-bearing underrun surface, not visual guidance to the runway. If the present standard can be reduced, the cost reduction for paint and installation labor could be substantial.

Also, please assume that you would take over manually and continue the approach when going visual; however, do not move the control column, since this will change the rate of descent which has been set up.

On completion of each approach with a pattern, we will ask you to respond to the following question:

1. Did you consider this pattern (wide 150-foot chevrons spaced 100 feet apart) to provide distinct and unambiguous warning of the nonload-bearing surface:

Run 1. When on centerline and on glide path? Yes ____ No ____

Run 2. When on centerline and low, below glide path? Yes ____ No ____

Run 3. When offset from centerline and high, above glide path? Yes ____ No ____

Run 4. When offset from centerline and low, below glide path? Yes ____ No ____

1a. Could this pattern be confused with another marking, for example, the runway threshold stripes? Yes ____ No ____

2. Did you consider this pattern (narrow 75-foot chevrons spaced 100 feet apart) to provide distinct and unambiguous warning of the nonload-bearing surface:

Run 1. When on centerline and on glide path? Yes ____ No ____

Run 2. When on centerline and low, below glide path? Yes ____ No ____

Run 3. When offset from centerline and high, above glide path? Yes____ No____

Run 4. When offset from centerline and low, below glide path? Yes____ No____

2a. Could this pattern be confused with another marking, for example, the runway threshold stripes? Yes____ No____

3. Did you consider this pattern (narrow 75-foot chevrons spaced 200 feet apart) to provide distinct and unambiguous warning of the nonload-bearing surface:

Run 1. When on centerline and on glide path? Yes____ No____

Run 2. When on centerline and low, below glide path? Yes____ No____

Run 3. When offset from centerline and high, above glide path? Yes____ No____

Run 4. When offset from centerline and low, below glide path? Yes____ No____

3a. Could this pattern be confused with another marking, for example, the runway threshold stripes? Yes____ No____

4. Did you consider this pattern (wide 150-foot chevrons spaced 200 feet apart) to provide distinct and unambiguous warning of the nonload-bearing surface:

Run 1. When on centerline and on glide path? Yes____ No____

Run 2. When on centerline and low, below glide path? Yes____ No____

Run 3. When offset from centerline and high, above glide path? Yes____ No____

Run 4. When offset from centerline and low, below glide path? Yes____ No____

4a. Could this pattern be confused with another marking, for example, the runway threshold stripes? Yes____ No____

5. If you will accept one of the three reduced patterns as a minimum adequate marking system for underruns, which of the three do you prefer?

_____

6. Which of the four patterns do you prefer, regardless of cost, as providing the best underrun signal?

1._____ 2._____ 3._____ 4._____

Comments: