

# Airport Pavement Marking Evaluation for Reducing Runway Incursion

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DOT/FAA/AR-TN01/2

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## EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) Office of Aviation Research, Airport Technology Research and Development Branch, AAR-410, has evaluated wider airport pavement markings in order to enhance their recognition. Results of this evaluation are aimed at reducing the potential of runway incursions and incidents by making airport pavement markings more visible for pilots and vehicular operators. A series of airport pavement marking variations were evaluated at the Atlantic City International Airport (ACY). Subject pilots were given the opportunity to view these variations and to express their opinions. Results from the evaluation showed the pilots preferred the runway holding position marking incorporating the 12-inch stripes. Pilots also preferred the Instrument Landing System/Microwave Landing System (ILS/MLS) holding position marking incorporating 24-inch paint stripes with 48-inch spacing. The pilots preferred the nonmovement area marking incorporating 12-inch stripes.

## INTRODUCTION

### BACKGROUND.

This project was undertaken by the Airport Technology Research and Development (R&D) Branch, AAR-410, in response to a request from the Federal Aviation Administration (FAA) Office of Airport Safety and Standards, Director, AAS-1. The project is a marking evaluation to assist the Airport Safety and Operations Division, AAS-300, in the revision of Advisory Circular (AC) 150/5340-1H, Standards for Airport Markings. This revision may incorporate several dimensional changes to holding position markings identified by the FAA Runway Safety Program Office. The work involves the testing of eight different marking Options to determine if any of these eight options will improve the visibility of the holding position markings. This project was created in response to a report dated August 1, 2000, which listed the ten initiatives for reducing runway incursions.

### RELATED ACTIVITIES/DOCUMENTS.

Related documents dealing with this evaluation project are:

- Ten Initiatives for Reducing Runway Incursions, dated August 1, 2000.
- Runway Safety National Summit, June 26-28, 2000.
- FAA Advisory Circular AC 150/5340-1H, "Standards for Airport Markings," dated 08/31/99. On page 10 of this document, it states "The width of the lines and spaces may be doubled to 12 inches (30 cm). The use of this wider marking is strongly encouraged at locations where pilots have had difficulty discerning the location of the holding position."

### OBJECTIVE.

This effort was directed specifically toward:

- Evaluating which runway holding position marking was most effective.
- Evaluating which Instrument Landing System/Microwave Landing System (ILS/MLS) holding position marking was most effective.
- Evaluating which nonmovement area marking was most effective.

## DISCUSSION

The FAA conducted a Runway Safety National Summit in Washington, D.C., June 26-28, 2000, to explore ways to improve safety on runways, particularly at the nation's busiest airports.

From this 3-day conference, a list of ten initiatives for reducing runway incursions was developed. In that document it stated: "That the purpose is to reduce runway incursion accidents/incidents and enhance the safe and efficient movement of aircraft by increasing the

visibility of runway hold line markings, improving flight crew/vehicular operator recognition. This initiative was consistently identified in the regional/national workshops. Currently, standard marking requirements are 6 inches in width and outlined in black for light-colored pavement. The widening of pavement marking evaluation was established in response to the ten initiatives for reducing runway incursions.

## EVALUATION

### METHOD.

Marking variations were painted on taxiway and ramp surfaces at the Atlantic City International Airport (ACY) and at the pavement test building for evaluation by professional test pilots.

There were eight paint markings evaluated: three runway holding position markings, two nonmovement area boundary markings, and three ILS/MLS holding position markings. The differences evaluated were in the dimensions and background but not in the basic configuration.

RUNWAY HOLDING POSITION MARKINGS. The runway holding position marking is used at airports with operating control towers to identify the location on a taxiway where a pilot is to stop when he/she does not have clearance to proceed onto the runway. At airports without operating control towers, these runway holding position markings identify the location where a pilot should assure there is adequate separation with other aircraft before proceeding onto the runway. Based upon the most critical aircraft using the runway, the runway holding position markings should be located on all taxiways that intersect runways. These markings are also located on taxiways crossing through the runway approach area so that an aircraft on the taxiway will not penetrate any of the following: the surface used to locate the runway threshold, inner approach obstacle-free zone, inner transitional obstacle-free zone, and clearway. The solid lines of these markings are always on the side where the aircraft is to hold. The markings are installed perpendicular to the taxiway centerline but may be canted from the perpendicular in unique situations. On an angled taxiway, consideration should also be given to locating the markings such that no portion of an aircraft (i.e., wing tip) placed at the holding position line will penetrate the runway safety area.

The following are the three types of runway holding position markings evaluated.

- Runway holding position markings Option #1 consists of a set of four yellow lines (two solid and two dashed) and three spaces each 6 inches (15 cm) in width, as shown in figure 1. The picture was taken at a distance of 20 ft and an eye height of 5 ft.



FIGURE 1. RUNWAY HOLDING POSITION MARKINGS OPTION #1

- Runway holding position markings Option #2 consists of a set of four yellow lines (two solid and two dashed) and three spaces each 12 inches (30 cm) in width, as shown in figure 2. The picture was taken at a distance of 20 ft and an eye height of 5 ft.



FIGURE 2. RUNWAY HOLDING POSITION MARKINGS OPTION #2



- Runway holding position markings Option #3 consists of a set of four yellow lines (two solid and two dashed) and three spaces, the two outboard lines are each 12 inches (30 cm) in width and the two inboard lines are each 6 inches (15 cm) in width, as shown in figure 3. The picture was taken at a distance of 20 ft at an eye height of 5 ft.



FIGURE 3. RUNWAY HOLDING POSITION MARKINGS OPTION #3

ILS/MLS HOLDING POSITION MARKINGS. The ILS/MLS holding position markings identify the location on a taxiway or holding bay where an aircraft is to stop when it does not have clearance to enter ILS/MLS critical areas. The critical area is the area needed to protect the navigational aid signal. The markings are installed perpendicular to the taxiway centerline but may be canted from the perpendicular in unique situations. ILS/MLS holding position markings on taxiways are yellow and will be outlined in black on light-colored pavements as presently stated in the Advisory Circular.

The following are the three types of ILS/MLS holding position markings evaluated.

- ILS/MLS holding position markings Option #1 consists of a set of two 1-foot (0.3-m)-wide parallel yellow lines spaced 2 feet (0.6 m) apart. In between these two lines and perpendicular to them, there are two sets of 1-foot (0.3-m)-wide parallel yellow lines 1 foot (0.3 m) apart and 10 feet (3 m) between sets, as shown in figure 4. The picture was taken at a distance of 20 ft at an eye height of 5 ft.



FIGURE 4. ILS/MLS HOLDING POSITION MARKINGS OPTION #1

- ILS/MLS holding position markings Option #2 consists of a set of two 2-foot (0.6-m)-wide parallel yellow lines spaced 4 feet (1.2 m) apart. In between these two lines and perpendicular to them, there are two sets of 1-foot (0.3-m)-wide parallel yellow lines 1 foot (0.3 m) apart and 10 feet (3 m) between sets, as shown in figure 5. The picture was taken at the edge of the marking at an eye height of 5 ft.



FIGURE 5. ILS/MLS HOLDING POSITION MARKINGS OPTION #2



- ILS/MLS critical area holding position markings Option #3 consists of a set of two 2-foot (0.6-m)-wide parallel yellow lines spaced 2 feet (0.6 m) apart. In between these two lines and perpendicular to them, there are two sets of 1-foot (0.3-m)-wide parallel yellow lines 1-foot (0.3 m) apart and 10 feet (3 m) between sets, as shown in figure 6. The picture was taken at the edge of the marking at an eye height of 5 ft.



FIGURE 6. ILS/MLS CRITICAL AREA HOLDING POSITION MARKING OPTION #3

NONMOVEMENT AREA BOUNDARY MARKINGS. Nonmovement area boundary markings are used to delineate the movement area, i.e., area under air traffic control from the nonmovement area, i.e., area not under air traffic control. A nonmovement area boundary marking is located on the boundary between the movement and nonmovement area. In order to provide adequate clearance for the wings of taxiing aircraft, this marking should never coincide with the edge of a taxiway. A nonmovement area boundary marking is yellow and will be outlined in black on light-colored pavements as presently stated in the Advisory Circular.

The following are the two types of nonmovement area boundary markings evaluated.

- The nonmovement area boundary marking Option #1 consists of two yellow lines (one solid and one dashed), as shown in figure 7. The solid line is located on the nonmovement area side while the dashed yellow line is located on the movement area side. Each line is 6 inches (15 cm) in width with a 6-inch spacing between lines. The dashes are 3 feet (1 m) in length with a 3-foot (1-m) spacing between dashes. The picture was taken at a distance of 20 ft at an eye height of 5 ft.





FIGURE 7. NONMOVEMENT AREA BOUNDARY MARKING OPTION #1

- The nonmovement area boundary marking Option #2 consists of two yellow lines (one solid and one dashed), as shown in figure 8. The solid line is located on the nonmovement area side while the dashed yellow line is located on the movement area side. Each line is 12 inches (30 cm) in width with a 12-inch spacing between lines. The dashes are 3 feet (1 m) in length with a 3-foot (1 m) spacing between dashes. The picture was taken at a distance of 20 ft at an eye height of 5 ft.



FIGURE 8. NONMOVEMENT AREA BOUNDARY MARKING OPTION #2

## PROJECT PARTICIPANTS.

EVALUATION SUBJECTS. A large majority of the FAA subject pilots were professional pilots from flight organizations based at the FAA William J. Hughes Technical Center. The itinerant commercial pilots were from Mesa Airlines and other private pilots from the Atlantic City International Airport.

SUPPORT PERSONNEL. Individuals from the AAR-411 organization, along with contract support personnel, accomplished the supervision of the paint marking installation and coordinated the effort required at ACY. They were also responsible for the collection of the data, analysis of the results, and preparation of this report.

## EQUIPMENT REQUIREMENTS.

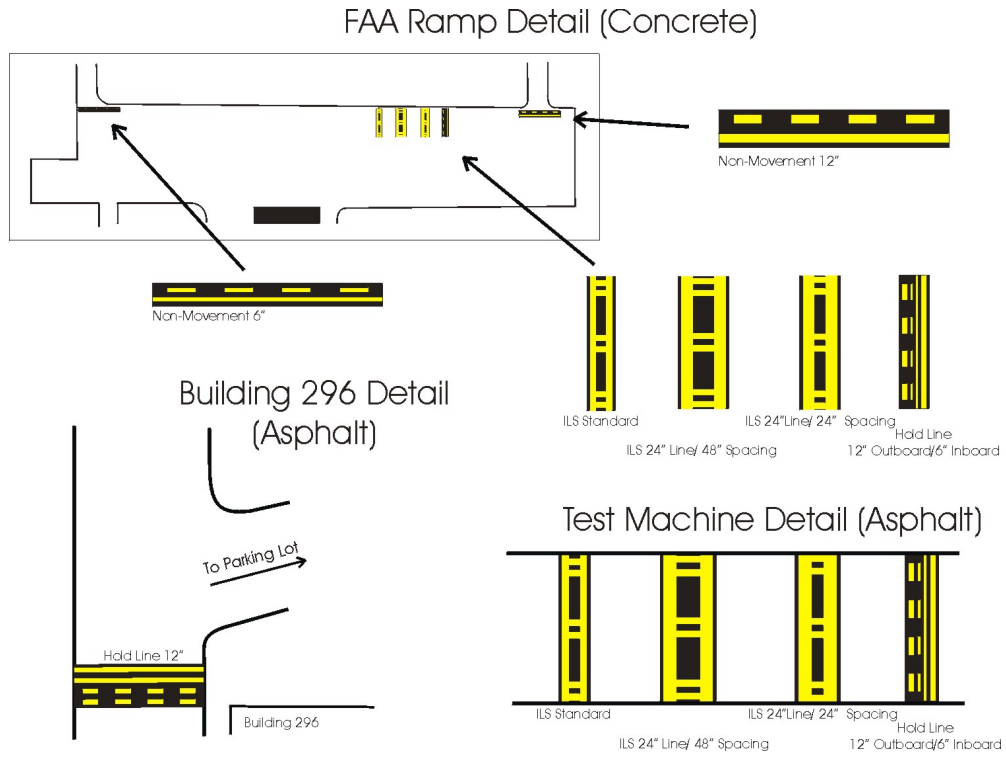
The following equipment was used for testing:

- Aircraft (Convair 580)—Eye height of a medium air carrier (12 ft)
- Vehicles—Eye height of a general aviation or business aircraft (5 ft)
- Pavement Test Machine—Eye height of a B747 or large air carrier (26 ft)

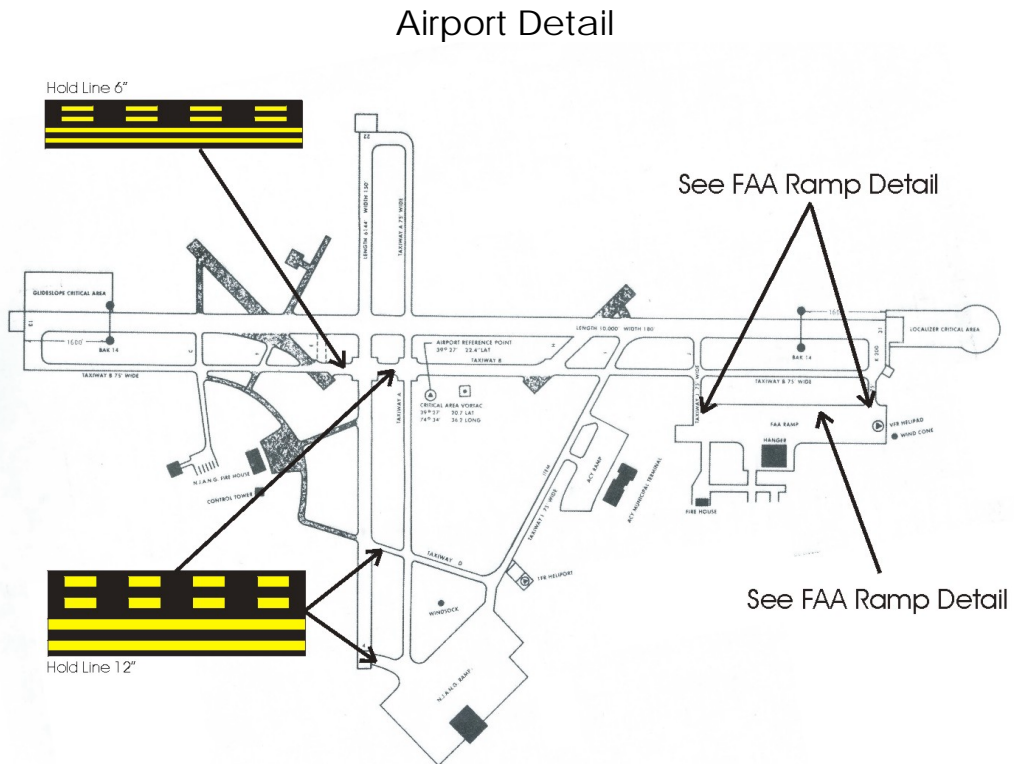
All testing was performed at the FAA William J. Hughes Technical Center, Atlantic City International Airport, Atlantic City, New Jersey, on the taxiways, runways, and FAA ramp.

## PROCEDURES.

The project lead met with the subject pilots from each of the participating organizations. Each pilot was briefed on the information and provided with briefing material and pilot questionnaires. The aircraft or vehicle was taxied/driven to the locations on the airport and FAA ramp where the paint markings were located. Figure 9 shows the paint markings on the FAA ramp. There were six markings placed there consisting of Option #1, Option #2, and Option #3 of the ILS/MLS holding position markings, Option #3 of the runway holding position markings, and Option #1 and Option #2 of the nonmovement area boundary marking. Figure 10 shows the airport detail of the Atlantic City International airport. This detail shows the FAA ramp locations, Option #1 runway holding position markings on taxiway Bravo at the intersection of 422 and Bravo North. It also shows the three Option #2 runway holding position markings on taxiway Bravo at the intersection of 422 and Bravo South, on taxiway D, and on the Air National Guard ramp. See figures 9 and 10.



**FIGURE 9. PAINT MARKINGS ON FAA RAMP**



**FIGURE 10. PAINT MARKINGS ON ATLANTIC CITY INTERNATIONAL AIRPORT**

Two questionnaires were created to obtain pilots opinions and record their comments. Below is an explanation of each questionnaire and then a blank questionnaire of each type.

The first questionnaire was for FAA subject pilots, which addressed the entire airfield at the Atlantic City International Airport. Completed questionnaires were handed over to the Airport Technology R&D Branch, AAR-411. See figure 11.

### MARKING SIZE EVALUATION QUESTIONNAIRE

Date: \_\_\_\_\_ Subject: \_\_\_\_\_ Organization: \_\_\_\_\_ Wx: \_\_\_\_\_

Please check the appropriate answers for the following questions.

---

#### A. Runway Holding Position Marking

Which of the three markings that you have viewed is in your opinion, the most effective?

Option #1                                      Option #3                                      Option #2  
6-inch stripes: \_\_\_\_\_      6- & 12-inch stripes: \_\_\_\_\_      12-inch stripes: \_\_\_\_\_

Which is the least effective?

Option #1                                      Option #3                                      Option #2  
6-inch stripes: \_\_\_\_\_      6- & 12-inch stripes: \_\_\_\_\_      12-inch stripes: \_\_\_\_\_

#### B. ILS/MLS Holding Position Marking

Which of the three markings that you have viewed is in your opinion, the most effective?

Option #1: \_\_\_\_\_                      Option #2: \_\_\_\_\_                      Option #3: \_\_\_\_\_

Which is the least effective?

Option #1: \_\_\_\_\_                      Option #2: \_\_\_\_\_                      Option #3: \_\_\_\_\_

#### C. Nonmovement Area Boundary Marking

Which of the two markings that you have viewed is in your opinion, the most effective?

Option #1                                      Option #2  
6-inch stripes: \_\_\_\_\_      12-inch stripes: \_\_\_\_\_

1. Regarding the configuration of runway holding position (A) Option #3 and the nonmovement area marking (C) Option #2, do you feel that there is a chance that these two could be confused, say in a foggy condition?

Possible: \_\_\_\_\_                      Yes: \_\_\_\_\_                      No: \_\_\_\_\_

FIGURE 11. FAA SUBJECT PILOT QUESTIONNAIRE

The second questionnaire for itinerant commercial pilots using the Atlantic City International Airport. It addresses only the 6-inch runway holding position marking and 12-inch runway holding position marking since these pilots would not be able to see the markings on the FAA ramp. Commercial pilots subsequently faxed or mailed back the completed questionnaires to the Airport Technology R&D Branch, AAR-411. See figure 12.

Date: \_\_\_\_\_ Subject: \_\_\_\_\_ Organization: \_\_\_\_\_ Wx: \_\_\_\_\_

Please check the appropriate answers for the following questions.

---

A. Runway Holding Position Marking

Which of the two markings that you have viewed is in your opinion, the most effective?

6-inch stripes: \_\_\_\_\_ 12-inch stripes: \_\_\_\_\_

Taxiway Bravo @ North  
of 4/22 intersection

Taxiway Bravo @ South of 4/22 intersection or  
Taxiway Golf @ 4/22 or Taxiway Delta @ 4/22

Neither is more effective than the other: \_\_\_\_\_

Comments: \_\_\_\_\_

FIGURE 12. ITINERANT COMMERCIAL PILOT QUESTIONNAIRE

In addition to the questionnaires, pilots were asked to note when the pavement markings became recognizable. Locations were recorded by project personnel and transferred into the appropriate viewing distances.

DATA COLLECTION.

The principal method for deriving performance data was through analysis of the pilot questionnaires, which were completed after the subjects had an opportunity to observe and evaluate the paint markings. Data was taken on the distance that the pilots recognized the pavement markings.

**RESULTS**

Test results, in the form of completed questionnaires and recorded comments, were compiled and subsequently analyzed by AAR-410 to obtain the results of the widening of paint markings analysis.

Subject pilots filled out the first questionnaire from ACT-370 and AAR-410. It addresses all the pavement markings at the Atlantic City International Airport, the FAA ramp, taxiways, and runways. See figure 13.

## MARKING SIZE EVALUATION QUESTIONNAIRE

Date: October 2000 Subject: 11 TOTAL Organization: AAR-411, ACT-370, Commercial Pilots Wx: VFR DAY

Please check the appropriate answers for the following questions.

---

### D. Runway Holding Position Marking

Which of the three markings that you have viewed is in your opinion, the most effective?

|                       |                             |  |
|-----------------------|-----------------------------|--|
| Option #1             | Option #3                   | Option #2                                |
| 6-inch stripes: _____ | 6- & 12-inch stripes: _____ | 12-inch stripes: <b><u>(11) 100%</u></b> |

Which is the least effective?

|                                       |   |                        |
|---------------------------------------|---|------------------------|
| Option #1                             | Option #3                                   | Option #2              |
| 6-inch stripes: <b><u>(5) 73%</u></b> | 6- & 12-inch stripes: <b><u>(3) 27%</u></b> | 12-inch stripes: _____ |

### E. ILS/MLS Holding Position Marking

Which of the three markings that you have viewed is in your opinion, the most effective?

|                  |                                  |                                  |
|------------------|----------------------------------|----------------------------------|
| Option #1: _____ | Option #2: <b><u>(9) 82%</u></b> | Option #3: <b><u>(2) 18%</u></b> |
|------------------|----------------------------------|----------------------------------|

Which is the least effective?

|                                  |                                  |                                  |
|----------------------------------|----------------------------------|----------------------------------|
| Option #1: <b><u>(6) 60%</u></b> | Option #2: <b><u>(1) 10%</u></b> | Option #3: <b><u>(3) 30%</u></b> |
|----------------------------------|----------------------------------|----------------------------------|

### F. Nonmovement Area Boundary Marking

Which of the two markings that you have viewed is in your opinion, the most effective?

|                       |  |
|-----------------------|--|
| Option #1             | Option #2                                |
| 6-inch stripes: _____ | 12-inch stripes: <b><u>(11) 100%</u></b> |

2. Regarding the configuration of runway holding position (A) Option #3 and the nonmovement area marking (C) Option #2, do you feel that there is a chance that these two could be confused, say in a foggy condition?

|                                 |                            |           |
|---------------------------------|----------------------------|-----------|
| Possible: <b><u>(9) 82%</u></b> | Yes: <b><u>(2) 18%</u></b> | No: _____ |
|---------------------------------|----------------------------|-----------|

FIGURE 13. SUMMARY AND ANALYSIS OF PILOT QUESTIONNAIRE RESPONSES



The second questionnaire for itinerant commercial pilots using the Atlantic City International Airport addressed only the 6-inch runway holding position markings and 12-inch runway holding position markings since these pilots would not be able to see the markings on the FAA ramp. See figure 14.

Date: October 2000 Subject: 3 Total Organization: Commercial Pilots Wx: VFR Day

Please check the appropriate answers for the following questions.

---

### B. Runway Holding Position Marking

Which of the two markings that you have viewed is in your opinion, the most effective?

6 inch stripes: \_\_\_\_\_  
Taxiway Bravo @ North  
of 4/22 intersection

12 inch stripes: **(3) 100%**  
Taxiway Bravo @ South of 4/22 intersection or  
Taxiway Golf @ 4/22 or Taxiway Delta @ 4/22

Neither is more effective than the other: \_\_\_\_\_

Comments: \_\_\_\_\_

- Flashing hold short lights are also very effective.
- Lighted area/flashing lights at hold line.
- Light hold lines.

FIGURE 14. MARKING SIZE EVALUATION QUESTIONNAIRE (ITINERANT)

### SUMMARY OF PILOT COMMENTS

The following are comments from the subject pilot as recorded by the pilots on their postflight questionnaire forms. The excerpts, while not necessarily direct quotes of individual pilots, reflect the general nature of their comments. The number in parenthesis is the number of pilots that made the same comment.

#### Comments: Question 1

- Flashing hold short lights are also very effective. (1)
- Lighted area/flashing lights @ hold line. (1)
- Lighted hold line. (1)

#### Comments: Question 2

- Why not put “ILS” or “ILS Hold” on the stripes. (1)

Comments: Question 3

- Pattern is not intuitive regardless of size. (1)
- Confused about solid and dashed lines. (3)
- Too hard to differentiate, until you're really close to line. Nonmovement Option #1 I feel is too small. (1)

General Comments

- Must have black background! (3)
- Love the wider marking! (1)
- Consider using different markings for nonmovement areas. (2)
- The black background paint was reflective in some places on approach thus diminishing the advantage of the contrast. (2)
- I like the wide stripe and spacing because it allows identification from a greater distance. (1)
- Black should not be beaded. Black is streaky. Needs to be put on more evenly. (1)
- Is there a reason to have the nonmovement line? It is not used very much at airports and is confusing. (1)
- Need to make the nonmovement line different from the runway hold line so that it is not confused. (1)

In addition to the questionnaires, pilots were asked to note when the pavement markings became recognizable. Table 1 is a compilation of that data.

TABLE 1. THE DISTANCE AT WHICH THE PILOTS COULD SEE THE  
RUNWAY MARKINGS

| Pavement Marking             | Day    | Night  |
|------------------------------|--------|--------|
| Runway Holding Position #1   | 200 ft | 100 ft |
| Runway Holding Position #2   | 250 ft | 150 ft |
| Runway Holding Position #3   | 100 ft | 70 ft  |
| Nonmovement Area Boundary #1 | 60 ft  | 40 ft  |
| Nonmovement Area Boundary #2 | 120 ft | 100 ft |
| ILS/MLS Holding Position #1  | 140 ft | 100 ft |
| ILS/MLS Holding Position #2  | 280 ft | 140 ft |
| ILS/MLS Holding Position #3  | 180 ft | 120 ft |



## SUMMARY OF DISTANCE RESULTS

- From the results above it is clear that the runway holding position marking, Option #2, incorporating 12-inch stripes, can be seen at a longer range for both day and night.
- From the results above it is clear that the nonmovement area boundary marking, Option #2, incorporating 12-inch stripes, can be seen at a longer range for both day and night.
- From the results above it is clear that the ILS/MLS holding position marking, Option #2, incorporating 24-inch paint stripes with 48-inch spacing, can be seen at a longer range for both day and night.

## CONCLUSIONS

Test results, in the form of completed pilot postflight questionnaires were collected and subsequently analyzed to determine the most effective marking sizes.

Larger more bold markings appear to be more effective, though there is no change in the relative perspective. The black background should be made mandatory on all types of surfaces with nonreflective paint.

Based on the results of this evaluation effort, it is concluded that:

- For the runway holding position marking, Option #2, incorporating 12-inch stripes, was most effective.
- For the ILS/MLS holding position marking, Option #2, incorporating 24-inch stripes with 48-inch background, was most effective.
- For the nonmovement area boundary marking, Option #2, incorporating 12-inch stripes, was most effective.
- The runway holding position marking, Option #3, and the nonmovement area boundary marking, Option #2, could be confused in low visibility.
- Three of the pilots recommended that the nonmovement area boundary markings be changed so that they are of a different pattern, not so similar to the runway holding position marking.
- The black background should be made mandatory, since it makes the contrast much better.