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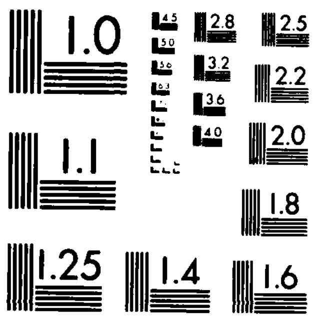

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Evaluation of Retroreflective Pavement Markers for Precision and Nonprecision Runways

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December 1982

Interim Report

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16. Abstract

The purpose of this program was to evaluate the use of retroreflective pavement markers, installed in a configuration duplicating runway centerline and touchdown zone lighting system of a Category II runway on Category I or Nonprecision Approach runways with edge lighting to determine if these retroreflective markers will enhance nighttime visual guidance to provide increased safety of operations and possible reduction in minimums, particularly under wet runway conditions.

Visual contact height with the retroreflective pavement marker systems was not enhanced prior to reaching Minimum Descent Altitude (MDA) or Decision Height (DH) for nonprecision or Category I approaches respectively; therefore, this system will not permit the reduction in approach minimums for Category I precision or nonprecision approaches. However, the test program demonstrated that the system is effective in improving the safety of operation for final approach, flare and touchdown, landing rollout, and for takeoffs. Particularly under rainy, wet nighttime conditions, the pavement retroreflector significantly enhanced the visual guidance, supplementing that provided by the standard runway edge lights and paint markings which are difficult to see under wet conditions.

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METRIC CONVERSION FACTORS

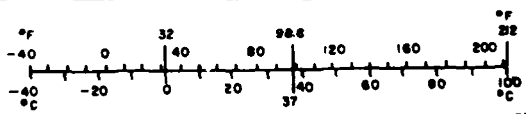
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

The purpose of this project was to evaluate retroreflective pavement markers installed to duplicate the patterns of runway centerline and touchdown zone lighting systems used for Category II runways. The objective was to determine if pavement markers enhance nighttime visual guidance to provide increased safety of operations and possible reduction in minimums for Category I precision approaches or nonprecision approaches, particularly under wet runway conditions. Under these conditions, the aircraft landing lights tend to reflect off the surface of the water instead of highlighting the white paint of the runway centerline and touchdown zone markings. The retroreflective markers are intended to supplement runway edge lighting and offer similar guidance to that provided by, but not to replace, Category II inpavement lighting. Even though the use of runway centerline markers, color coded for distance remaining information, have been approved for some time, they have not been commonly used and have not been evaluated in reduce visibility or wet runway conditions nor in conjunction with markers in the touchdown zone.

The retroreflective pavement markers, made of plastic, are 4 inches square by 0.75 inches high. Two sides have sloping surfaces with one or two prismatic reflective faces as required to reflect incident light from single or dual directions. The markers were installed on runway 4-22 at the Technical Center using an epoxy compound. The spacing and colors used were the same as those specified for Category II centerline and touchdown zone lighting systems.

Flight tests to evaluate the retroreflective markers were conducted at night in VFR weather conditions and under reduced visibility conditions with rain and water accumulation on the pavement. The test runway is a nonprecision approach runway but with precision approach touchdown zone and centerline paint markings. A standard VASI, later replaced with a Precision Approach Path Indicator (PAPI) system, was used to provide a 3-degree visual glidepath on final approach.

A cross section of 20 professional and general aviation pilots evaluated the markers. Six pilots were employed at the Technical Center and 14 were local and transient volunteer pilots. The pilots completed a questionnaire and made pertinent comments after each flight. The altitude on final approach, at which pilots were able to first obtain meaningful guidance while descending on a 3-degree visual glidepath from the retroreflectors, was recorded by the Technical Center pilots. Such data were not available from local and transient pilots.

The cross section of aircraft ranged from light single engine personal aircraft to multi-engine jet aircraft used for charter or commuter operations. All were equipped with nose or nosewheel mounted landing/taxi lights, which location provides the optimum light return from the retroreflectors to the pilot's eye. Some aircraft were also equipped with wing mounted lights, however, they are ineffective due to the design of the retroreflective device.

From the results of the visual contact height determination portion of the evaluation, it was concluded that installations of this type will not provide a basis of possible reduction in minimums for either Category I Precision or Nonprecision Approaches. The results are consistant, however, in demonstrating that a diversified sample of pilots, flying widely different aircraft, rated the retroflective pavement markers as effective and as improving safety of the operations for final

approach, flare and touchdown, landing rollout, and for takeoff in VFR conditions and in rain with visibility conditions of 1 to 2 miles. For rain conditions at night when water tends to obscure paint markings, as well as better visibility conditions, it is concluded that the markers can provide enhanced visual guidance to supplement that provided by standard runway edge lights. The guidance overcomes landing in the "black hole" and is essentially the same as that provided by inpavement lighting of the touchdown zone and color coded centerline used for Category II operations.

It is further concluded that operational in-service tests should be conducted, using precision approach ILS runways to obtain additional operational experience and data with rain and water on the runway in visibility conditions as low as one-half mile. Also, such inservice testing, will provide additional pilot opinion as to the potential improvement in the safety of operations offered by an abbreviated touchdown zone and centerline marker system designed for shorter runways of about 3000 feet in length. Such runways may be near the critical length for many of the aircraft operating under reduced visibility and rain conditions. Acceptance of an abbreviated system could also provide the basis for adopting a reduced Category II lighting configuration standard for shorter length runways. Additional experience should further prove the value of the touchdown zone and color coded runway centerline and more fully justify such installations.

INTRODUCTION

The work described herein was accomplished in response to: (a) a Request for Research, Development and Engineering (R,D&E) Effort from the Associate Administrator for Aviation Standards and (b) a request for Engineering Support from the Airport Development Division, Systems Research and Development Service. The latter office provided program direction and coordination under SRDS Program Number 071-500-01. The work was conducted under Technical Center Program Document Number 08-493, subprogram 081-502, project 520. The Project Manager and author is Guy S. Brown and the Technical Program Manager is Thomas M. Paprocki.

PURPOSE.

The purpose of this project is to evaluate retroreflective pavement markers installed to duplicate the patterns of runway centerline and touchdown zone lighting systems used for Category II runways. The objective was to determine if pavement markers enhance nighttime visual guidance to provide increased safety of operations and possible reduction in minimums for Category I precision approaches or nonprecision approaches, particularly under wet runway conditions when inpavement lights are not available. It should be noted that the retroreflective markers are intended to supplement standard runway edge lights used for nonprecision and precision approach Category I runways and are not intended to replace touchdown zone and centerline lighting systems used for Category II runways.

BACKGROUND.

Runway paint markings in good condition provide visual daytime guidance even when the visibility is significantly less than 2400 feet Runway Visual Range (RVR). At night, however, those same runway markings provide only minimal guidance and still less guidance when there is water standing on the runway. Under such wet runway conditions, the aircraft landing lights tend to reflect off the surface of the water instead of highlighting the white paint of the runway marking surfaces.

Retroreflective pavement markers have been successfully used on highways for a number of years and a substantial increase in usage has been noted in the past few years. Guidance is greatly improved in adverse weather conditions of rain and fog, as well as in good weather, by such markers.

Pavement markers have been evaluated previously at the Center for use on small or secondary airport runways under visual flight rule (VFR) conditions (references 1 and 2). Testing was not conducted under reduced visibility conditions or at night with rain or water on the runway. Also the installations did not include retroreflective markers in the touchdown zone configuration.

It is noted that even though the use of clear and color coded runway centerline markers have been approved for some time (references 3 and 4), they have not been commonly used. Also, they have not been evaluated in conjunction with markers in the touchdown zone to be used as a system, as with inpavement lighting systems used for Category II runways.

DESCRIPTION OF RETROREFLECTIVE MARKERS.

Retroreflective pavement markers (figure 1) consist of an acrylic plastic shell fitted with a potting compound and having overall dimensions of 4 inches by 4 inches by 0.75 inch high. Two sides have sloping surfaces with one or two prismatic reflective faces, as required, to reflect incident light from single or dual directions. The area of each reflecting surface is 3.25 square inch. The unit used for this evaluation was the Stimsonite Model 911 marker which is their Model 88 modified by the company to provide an improved abrasion resistant surface. Surface modification is accomplished by adding a thin layer of untempered glass bonded to the prismatic reflective face. The Model 88 retroflective marker is listed under Federal Aviation Administration (FAA) Approved Airport Lighting Equipment and Specification L-853 (references 3 and 4).

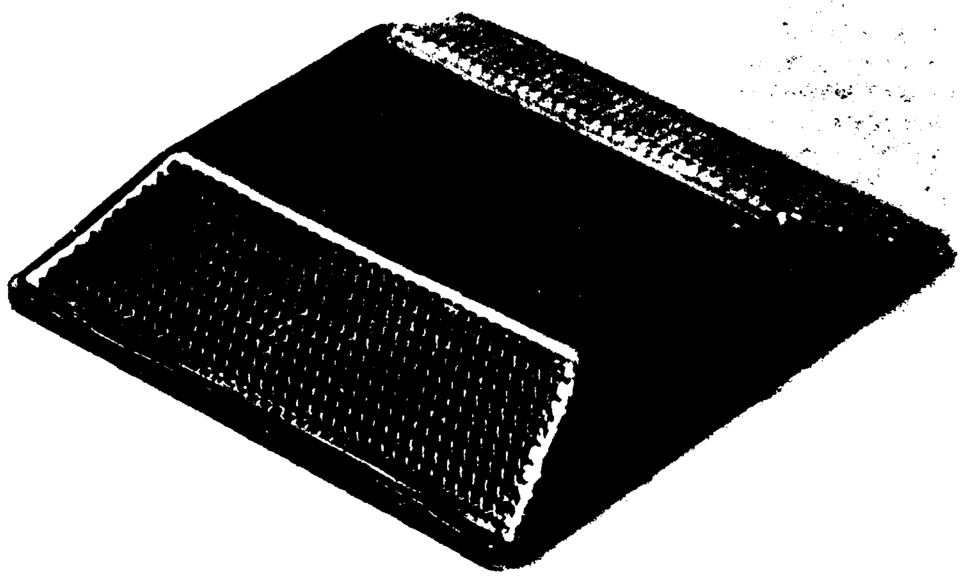


FIGURE 1. RETROREFLECTIVE PAVEMENT MARKER

INSTALLATION OF RETROREFLECTIVE MARKERS.

The retroreflective markers were installed on runway 4-22 at the FAA Technical Center, Atlantic City, New Jersey. The spacing and colors used were the same as those specified for runway centerline and touchdown zone lighting in accordance with FAA Advisory Circular Number 150/5340-4C, "Installation Details for Runway Centerline and Touchdown Zone Lighting Systems," see appendix A for description and layout details. Bidirectional markers were spaced at 50-foot intervals on the 6,144 foot runway centerline with color coding for distance information on the last 3,000 feet. In this 3,000-foot zone, the bidirectional markers were installed to provide alternate red and white markers for 2,000 feet and all red for the last 1,000 feet; the same layout was used on the opposite end. Hence, white or clear markers were provided on the first 3,144 feet of the runway centerline and color coding was provided on the remaining 3,000 feet in both directions. This conforms to the standard as specified in FAA Advisory Circular Number AC 150/5340-20, "Installation Details and Maintenance Standards for Retroreflective Markers for Airport Runway and Taxiway Centerline."

The retroreflective markers in the touchdown zone, which was the first 3,000 feet of runway 4, were unidirectional white or crystal and were installed to be seen only from the direction of approach and landing, see appendix A. Three markers spaced laterally 5 feet apart were located on each side of the runway, with the inboard markers 34 feet on each side of the centerline. The first set of three markers on each side of the centerline was located 100 feet from the runway threshold. Subsequent sets were located at 100-foot intervals for a total of 3,000 feet, thus providing rows of retroreflective markers on each side of the runway centerline, with a gauge of 68 feet between the inboard markers. The spacing or gauge of 68 feet is within the specification limits for both touchdown zone lighting and paint markings.

Testing of snowplow resistent retroreflective markers was not conduc[illegible] and may be considered later, depending upon whether or not the use of marker[illegible] ppear sufficiently advantageous to justify the expense of their installation [illegible] commercial airports. However, markers designed to allow snowplow blades to [illegible]e over the units without damaging either blades or markers have been extensi[illegible] tested and successfully used on highways in several states for a number of year[illegible]

DISCUSSION

FLIGHT TEST EVALUATION.

Flight tests to evaluate the retroreflective markers on runway 4 were conducted at night in VFR weather conditions and under reduced visibility conditions with rain and with water accumulation on the runway pavement. The test runway is a nonprecision approach runway with precision approach runway paint markings, including both centerline and touchdown zone markings. A standard Visual Approach Slope Indicator (VASI) later replaced with a Precision Approach Path Indicator (PAPI) system, was used to provide a 3-degree visual glidepath on final approach.

The pilots participating in the evaluation consisted of a cross section of professional test pilots and general aviation pilots, all employed at the FAA Technical Center. Also contributing evaluation responses were volunteer professional and general aviation pilots, both locally based and transient. A cross-section of aircraft ranging from small single engine to turbojet transport aircraft were included.

A total of 20 pilots participated in the evaluation, including one helicopter pilot. Of the 20 pilots; six were employed at the Technical Center, four as professional test pilots; and two were nonprofessional pilots with experience in the evaluation of visual aids. Of the remaining 14 pilots, six were classified as professional commuter or charter aircraft pilots.

VISUAL CONTACT HEIGHT DETERMINATION.

On final approach, the altitude was recorded by FAA Technical Center subject pilots when the retroreflective markers were first seen by the pilot descending on a 3-degree glidepath. These data were not available from participating local and transient pilots. The small sample of data obtained does correspond, however, with that reported in previous test (reference 1). Table 1 provides a listing of aircraft type which participated in the evaluation along with visual contact height data.

TABLE 1. PARTICIPATING AIRCRAFT AND VISUAL CONTACT HEIGHT VALUES

TYPE AIRCRAFT	AVERAGE VISUAL CONTACT HEIGHT (Feet)	NUMBER OF OBSERVATIONS
Single Engine-Propeller		
Cessna 172	200*	(4)
Cessna 177 RG	N/R	
Cessna 210	215*	(7)
Piper PA-28R	145*	(3)
Twin Engine-Propeller		
Aero Commander 680	201*	(10)
Beech 55 Baron	233**	(6)
Beech King Air	50**	(1)
Cessna 402	N/R	
EMB-110	N/R	
Piper Cheyenne	N/R	
Piper PA-44	N/R	
Multi-Engine Jet		
Boeing 727	N/R	
Douglas DC-9-30	N/R	
Helicopter		
H-52	N/R	
All Recorded Aircraft	199.94	(31)

N/R - Transient A/C, Questionnaire Completed, Height not Recorded.

* Nose/Nose gear mounted lights
** Wing mounted lights

POST-FLIGHT QUESTIONNAIRE RESPONSES.

After each flight, the subject pilot completed a questionnaire and made comments on his evaluation of the guidance experienced. Also recorded on the questionnaire was the type aircraft, prevailing weather, and runway conditions, see appendix B. Of the local and transient pilots, it is estimated that about 40 percent were briefed to some extent prior to their flight. The remaining were not briefed and probably were not aware of the markers and evaluation until their arrival when they obtained a copy of the questionnaire.

Six responses to the questionnaire were made for operations in rain and wet runway conditions with visibility conditions as low as one to two miles. Of the six responses, four were from professional FAA test pilots operating an Aero Commander and a Cessna 172 aircraft. The remaining were professional commuter and charter pilots operating a Piper Cheyenne turbo-prop and a DC-9 jet transport aircraft. The few responses in rain conditions is attributed to uncooperative weather including clouds below published minimums and the common use of another runway in such poor weather conditions. An evaluation in visibility conditions as low as one-half mile would require use of a runway having a precision approach ILS system.

RESULTS

VISUAL CONTACT HEIGHT DETERMINATION.

Recorded heights at which pilots were able to first obtain meaningful guidance from the installed retroreflectors are shown in table 1. For the total of 31 recorded observations, an average contact height of 199.94 feet was calculated. Assuming a nominal glidepath angle of three degrees, the aiming angle of the VASI system installed to provide vertical guidance to the participating pilots, the average distance from threshold at which the pilots first sighted the retroreflector systems was calculated to be just slightly less than one-half nautical mile (0.46 nmi).

All of the participating aircraft were equipped with nose or nosewheel mounted landing lights, which location provides the optimum light return from the retroreflectors to the pilot's eye. Some of the aircraft were also equipped with wing-mounted landing lights, and during flights with aircraft so equipped the wing-mounted landing lights were used alone to determine their affectiveness. In each instance, the retroreflectors were not perceived by the pilot until such time as the aircraft was over or past the runway threshold. This is due to the fact that, for the type of retroreflector used, the design is such that the reflected light is returned to or near the light source. The quantity of light returned toward the pilots eye is a function of the distance between the location of the light source and the pilot's eye. This distance is much greater for the case of the wing-mounted landing light than for that of the nose mounted light, and accounts for the greatly reduced effectiveness of the retroreflector system under such conditions. Prototype retroreflector designs intended for use with wing-mounted landing lights have been tested, but have proven to be virtually useless for use with aircraft having nose mounted lights. These retroreflectors are not presently available in quantity.

While the average visual contact height obtained during testing was 199.94 feet, the extremes of the observed and recorded contact heights varied from a minimum of 50 feet to a maximum of 275 feet. This was due to variations in pilot technique, wind and resultant crab angles required to maintain runway centerline position, location of nose-mounted landing light and, finally, aiming of the landing light itself. Subject pilots were requested prior to the evaluation flights, to attempt to maneuver the aircraft so as to maintain the landing light illumination upon the runway whenever possible. Pilots in routine flight operations will probably not make this conscious effort to insure the most effective use of the retroreflector system, and consequently the visual contact heights achieved will probably be somewhat lower than those reported herein.

POST-FLIGHT QUESTIONNAIRE RESPONSES.

In addition to the altitude at which the retroreflective markers were first observed by the pilot on final approach (table 1), the post-flight questionnaire covered five specific topics. The results of the responses and pilot comments are summarized in appendix B and are discussed in tables 2 through 6. As noted in appendix B, there were 20 responses under all of the weather conditions encountered. O these, there were only six responses for operations in rain and wet runway conditions due to uncooperative weather and other factors, as previously mentioned.

The first question asked the pilots to rate the effectiveness of the retroreflective markers (touchdown zone and runway centerline) during certain flight conditions. A summary of responses are shown in the following tables, and expressed in percentage of total responses.

TABLE 2. OPERATIONAL EFFECTIVENESS

Flight Conditions	Responses With Rain Conditions			Responses Under All Conditions		
	Excellent to Good	Fair to Poor	No Response	Excellent to Good	Fair to Poor	No Response
Approach	83%	17%	0	65%	35%	0
Flare	100%	0	0	90%	10%	0
Landing Rollout	100%	0	0	95%	5%	0
Takeoff	100%	0	0	80%	0	20%

Since some of the pilots did not observe the markers until descending to lower altitudes on final approach, primarily due to poorly aimed aircraft lights which was indicated in the pilot comments, there were fewer "excellent to good" responses for the approach phase than for other phases. The pilots' ability to recognize and to decrab the aircraft in crosswind conditions is another variable, as will be shown in the responses to the next question.

For the flare, touchdown and landing rollout phases of the flight, the responses were quite favorable, and again, would be rated higher with better/aiming of the lights on some aircraft.

For the takeoff phase, the "no responses" can be attributed to those pilots who completed the questionnaire on arrival and had not experienced the takeoff situation.

In summary on this aspect of the evaluation, the pilots found the markers to be very effective in providing useful visual guidance overall and, in particular, under the rain and wet runway conditions.

The second question concerned crosswind landing conditions and the pilot's ability to decrab sufficiently early during the final approach for the aircraft landing/taxi lights to illuminate the pavement markers. The responses are listed in table 3.

TABLE 3. CROSSWIND OPERATIONS

Responses With Rain Conditions			Responses Under All Conditions		
Yes	No	No Response	Yes	No	No Response
67%	0	33%	50%	5%	45%

Some of the pilots could not respond since many landings did not have a crosswind condition which required a decrab maneuver, as noted in the pilots comments. Considering this fact, the majority of the pilots who experienced crosswind conditions responded positively. One pilot commented - "had to decrab much earlier than normal." This shows that, in crosswind conditions, pilots must learn to decrab by maneuvering the aircraft into a wing-down slip condition much earlier than normal in order to aim the lights toward the runway and illuminate the markers.

The third question concerned the color coded centerline markers on the last 3,000 feet of the runway. On the question of the usefulness of the red/white and all red coding to indicate distance remaining, the responses are listed in table 4.

TABLE 4. OPERATION WITH COLOR CODED CENTERLINE

Responses With Rain Conditions			Responses Under All Conditions		
Yes	No	No Response	Yes	No	No Response
100%	0	0	70%	0	30%

Of the pilots who did not respond, their comments indicate most were able to land and turnoff the runway before encountering the color coded markers on the last 3000 feet of the 6,144 foot runway. When considering the "yes" responses from the larger aircraft using more than half of the runway, it is clearly shown that pilots consider the coding quite useful. This corresponds to data obtained in an earlier evaluation of the centerline system (reference 1).

The fourth question asked the pilots to rate the landing/taxi lights on his aircraft as to illumination or brightness and aiming. The responses are shown in table 5.

TABLE 5. RATING OF AIRCRAFT LIGHTS

	Responses With Rain Conditions			Responses Under All Conditions		
	Excellent to Good	Fair to Poor	No Response	Excellent to Good	Fair to Poor	No Response
Illumination/ Brightness	67%	33%	0	75%	25%	0
Aiming	83%	17%	0	75%	20%	5%

As noted in the pilots comments (appendix B) several pilots indicated that their lights were aimed low. As noted in reference 1, the effectiveness of the markers, in addition to proper aiming, is a function of the intensity and location of the light relative to the pilots line of vision. The further the light is displaced from the pilot's line of vision, the less light is reflected to the pilot's eyes. Consequently, aircraft lights mounted on the wing, some 15 to 20 feet from the pilots eye, are ineffective. It is believed that few aircraft are equipped with wing lights alone, and that most later model aircraft have lights mounted in the nose, on the nose wheel, or on the wing root.

The fifth and final question asked whether the additional guidance provided by the retroreflective markers, considering the weather conditions encountered, improved the safety of operations during certain flight conditions; responses are listed in table 6.

TABLE 6. IMPROVED SAFETY OF OPERATIONS

Flight Condition	Responses With Rain Conditions			Responses Under All Conditions		
	Yes	No	No Response	Yes	No	No Response
Takeoff	100%	0	0	65%	5%	30%
Approach	67%	33%	0	55%	30%	15%
Flare & Touchdown	100%	0	0	95%	0	5%
Landing Rollout	100%	0	0	90%	0	10%

With respect to the question on improving safety on takeoff, it is noted again that several pilots completed the questionnaire on arrival without exposure to the takeoff situation. For the approach, the previously noted problems with respect to aircraft lights and pilot techniques resulted in poor illumination of the markers on final approach. For the critical flight conditions of flare and touchdown and landing rollout, most of the pilots said that the safety of operations was improved. Obviously, the helicopter pilot did not respond to the question on landing rollout and did not flare and touchdown on the runway but airtaxied, commenting that retroreflective markers were "great on the taxiway."

CONCLUSIONS

Results of the visual contact height determination portion of the evaluation effort indicate that pilots will not, with any degree of reliability, be afforded significant guidance from the runway retroreflector systems prior to or upon reaching the Minimum Descent Altitudes (MDA) associated with nonprecision approach instrument flight operations (250 feet above ground level (AGL) or more). Likewise, the retroreflector system will not afford any significant visual guidance to the majority of pilots conducting a Category I Instrument Landing System (ILS) instrument approach before they have reached the minimum Decision Height (DH) of 200 feet AGL. In fact, the reduced visibility weather conditions of 1/2 nautical mile that may be encountered during Category I instrument approach will considerably reduce the ranges at which the retroreflector systems can be expected to be effective from those values attained during the conduct of this evaluation. We must conclude, therefore, that installations of this type of retroreflective system will not provide a basis of possible reduction in either Category I Precision or other Non-precision Approach minimums.

Even though instrument approach minimums may not be reduced, the results of this evaluation are consistent in demonstrating that a diversified sample of pilots, flying widely different aircraft, rated retroreflective runway pavement markers effective in improving safety of the operations for final approach, flare and touchdown, landing rollout, and for takeoff. The most critical visual guidance condition at nighttime may be one with rainwater on the runway tending to obscure the paint markings. For rain conditions with visibilities above 1 mile, as well as for better nighttime visibility conditions, it is concluded that the retroreflective markers on the pavement can provide enhanced visual guidance to supplement that provided by standard runway edge lights. The guidance overcomes landing in the "black hole" situation and under certain operational conditions, is essentially the same as that provided by inpavement lighting of the touchdown zone and color coded runway centerline used for Category II operations.

It is further concluded that operational in-service tests should be conducted, to obtain additional data and operational experience with rain and water on the runway in lower visibility conditions. For lower visibility conditions of one-half mile, a runway having an ILS system will be required. Such in-service testing will provide additional pilot opinion as to the effectiveness and potential improvement in the safety of operations offerd by an abbreviated touchdown zone and centerline marker systems for shorter runways of about 3,000 feet in length.

Such runways may be near the critical length for many of the aircraft operating under reduced visibility and rain conditions. Acceptance of an abbreviated system could also provide the basis for adopting a reduced Category II lighting configuration standard for shorter length runways.

Additional experience by pilots and operators should further prove the value of the touchdown zone and color coding of the runway centerline for distance information and more fully justify such installations.

REFERENCES

1. Twichell, N. H. and Phillips, Cecil P., Testing of Reflective Markers for Indicating the Threshold and Centerline of Runways for Small Airports, Report No. FAA-RD-66-71, NAFEC, FAA/DOT, September, 1966.

2. Brown, Guy S., Evaluation of Retroreflective Taxiway Edge Markers, Report No. NA-79-44-LR, NAFEC, FAA/DOT, July 1979.

3. FAA/DOT, Advisory Circular No. AC: 150/5345-1F, Approved Airport Lighting Equipment, FAA/DOT, January 16, 1981.

4. FAA/DOT, Advisory Ciruclar No. AC: 150/5345-39B, FAA Specification L-853, Runway and Taxiway Retroreflective Markers, December 9, 1980.

APPENDIX A

Excerpts From Advisory Circular No. 150/5340-4C, dated May 6, 1982

"INSTALLATION DETAILS FOR RUNWAY CENTERLINE
AND TOUCHDOWN ZONE LIGHTING SYSTEMS"

"1. INTRODUCTION. The runway centerline and touchdown zone lighting systems are designed to facilitate landings, rollouts, and takeoffs. The touchdown zone lights are primarily a landing aid, while the centerline lights are intended to provide after-touchdown rollout and takeoff guidance.

"2. BACKGROUND. These lighting systems were developed to be used in conjunction with electronic precision approach aids and the standard approach lighting systems under limited visibility conditions. Installation techniques described here can be applied to similar semiflush lighting installations.

"3. CONFIGURATION.

a. Runway Centerline Lighting. (See Figure 1 for general layout)

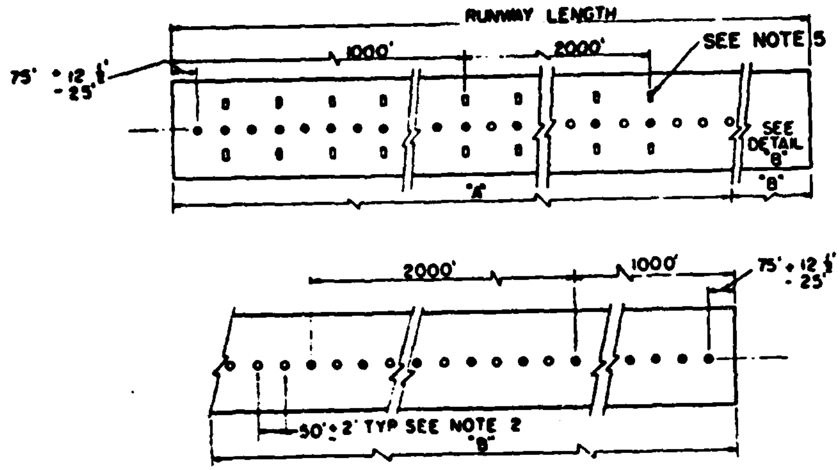
(1) Spacing. Install the single lights along the runway centerline in a straight line. Space the light fixtures at 50-foot intervals. Locate the first centerline light 75 feet from the landing threshold. Extend these lights to a similar point at the opposite end of the runway. Offset the line of lights 2 feet (maximum) to the right or left of the designed centerline to avoid the painted stripe. The offset should be to the opposite side of the centerline from the major taxiway turnoffs.

(2) Color Coding. Use color coding on the end 3,000-foot portions of the runway centerline lights as shown on Figure 1. Provide alternate red and white lights as seen from the 3,000-foot to the 1,000-foot points, and all red lights for the last 1,000-foot portion of the runway centerline lighting system.

b. Touchdown Zone Lighting. (See Figure 2 for general layout)

(1) Longitudinal Spacing. Provide the runway touchdown zone lighting system with rows of transverse light bars located symmetrically about the runway centerline. Each light bar consists of three unidirectional lights facing the threshold. Extend the system for a distance of 3,000 feet along the runway. Reduce this basic length to one-half the runway length for those runways less than 6,000 feet. Locate the first pair of light bars 100 feet from the landing threshold, followed by each succeeding pair at 100-foot intervals to the end of the system.

(2) Lateral Spacing. See Figure 2."



DETAIL "B"

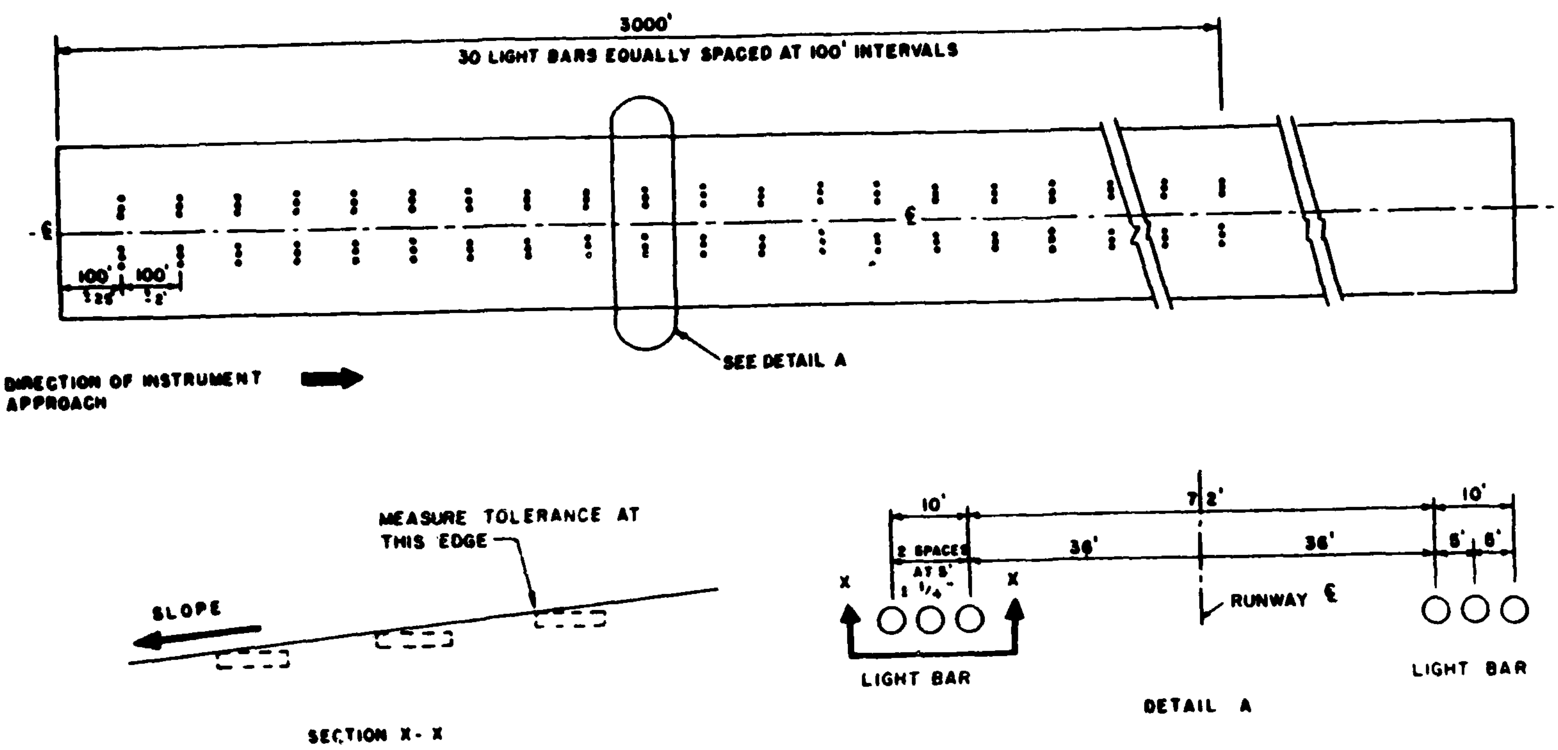
SYMBOLS

- ▯ – Unidirectional touchdown zone light bar, 3 lights per bar
- o – Bidirectional runway centerline light white both directions
- r ● w – Centerline lights white (w) one direction and red (r) opposite direction.

NOTES

1. Centerline lights may be offset 2' to the right or left of the runway centerline to avoid the centerline paint markings.
2. The centerline lights may have a longitudinal tolerance of ± 2', a lateral tolerance of ± 1/4".
3. The last 3000 - foot to 1000 - foot section of the runway centerline displays an alternate red and white light signal
4. The last 1000 - foot section of the runway centerline displays an all red signal.
5. The touchdown zone light bars are not required to be located at the same stations as the centerline lights. See figure 2 for configuration.

FIGURE A-1. RUNWAY CENTERLINE LIGHTING LAYOUT



NOTES

1 THE LONGITUDINAL INSTALLATION TOLERANCE IN LOCATING THE PAIRS OF TRANSVERSE LIGHT BARS SHOULD NOT EXCEED 2 FEET LATERAL TOLERANCE OF LIGHTS IN A BAR IS ± 1/4"

2 THE SPACING BETWEEN THE INNERMOST TOUCHDOWN ZONE LIGHT FIXTURES SHOULD BE UNIFORM THROUGHOUT THE LENGTH OF THE SYSTEM THIS SPACING IS 72 FEET EXCEPT WHERE CONSTRUCTION PROBLEMS PREVENT THIS SEPARATION IN THIS CASE, THE UNIFORM SPACING IS REDUCED TO NOT LESS THAN 65 FEET.

FIGURE A-2. TOUCHDOWN ZONE LIGHTING LAYOUT

APPENDIX B

PILOT BRIEFING
EVALUATION OF RETROREFLECTIVE PAVEMENT MARKERS
FOR PRECISION AND NONPRECISION RUNWAYS
PROJECT 081-502-520

The objective is to determine if retroreflective pavement markers, installed to duplicate runway centerline and touchdown lighting, will enhance nighttime visual guidance to provide increased safety of operations and possible reductions in Category I and nonprecision approach minimums, particularly under wet runway conditions.

Flights will be conducted in VFR and reduced visibility conditions as low as 1/2 mile, if practicable, with rain, fog, and/or wet runway conditions and with crosswinds ranging from minimum to maximum, to the extent possible.

From the threshold or takeoff position on runway 4, the distance or number of retroreflective markers and the number of paint marking stripes that can be observed when illuminated by the aircraft lights will be recorded with the aircraft:

(a) Aligned with the runway centerline (C/L); and

(b) Aligned midway between the C/L and TDZ (touchdown zone) markers.

After takeoff, four approaches and landings will be made, weather and other conditions permitting. The first approach with a touch-and-go landing should be made with the aircraft aligned with the runway C/L; the second and third to the left/right of C/L, and the fourth, a full stop aligned with the C/L and roll-out to the end of the runway. For comparison purposes, a takeoff and landing can be made on a runway without markers.

The first three approaches will be made on a 3-degree glide slope using a "Two Box PAPI" visual glidepath system. As with the standard VASI, a red and a white signal is "on glidepath;" two red signals indicate "low;" and two white signals indicate "high" on the glidepath. The system will be turned off for the fourth and final approach to allow you to make a steeper approach path if desire.

On each approach, you will be asked to call-out when you have the green threshold lights in sight with the altitude (above field level). Another call-out with altitude when you first see the retroreflective markers on the pavement and, when operating in a crosswind, when the aircraft is decrabbed, and the lights are aimed toward the runway. The retroreflective markers cannot be seen, of course, unless they are illuminated.

You will be asked to judge the quality of visual guidance obtained from the visual aids and to complete a post-flight questionnaire after each flight. Please review these questions before each flight. If possible, we would like to have each pilot make additional flights in the same type with different weather conditions.

Attention: All Pilots

EVALUATION OF RETROREFLECTIVE RUNWAY PAVEMENT MARKERS

Runway 4/22, Atlantic City Airport (ACY)

Retroreflective runway pavement markers, similar to those used on highways, have been installed on Runway 4/22 for evaluation by the FAA Technical Center's Airport Technology Division.

The evaluation is to determine whether the retroreflective markers provide improved visual guidance to aid the pilot and improve the safety of night-time operations, particularly during reduced visibilities with rain, fog and wet runway conditions.

Taxiway Exit Markers. Installed on Runway 4 as an aid in identifying the exit at Taxiway Bravo and on Runway 22 as an aid in identifying Taxiways Bravo and Delta.

Runway Centerline and Touchdown Zone Markers. Installed on Runway 4 (to duplicate the standard runway centerline and touchdown zone lighting configuration used for runways approved for Category II operations), as an aid for takeoff, approach, landing and rollout on the runway.

Completion of the attached questionnaires would be gratefully appreciated. Please return to the box located on the Operations Desk.

Thank you for your cooperation.

Summary of All Responses

EVALUATION OF RETROREFLECTIVE RUNWAY PAVEMENT MARKERS

Runway 4/22, Atlantic City Airport (ACY)

Type and Model Aircraft__________ Date__________

Location of Taxi/Landing Lights Used: Wind CALM to 010/15G22

Nose 20 Wing 6 Both 6 Other____ Pavement: Wet 6 Dry 14

Visibility:

<1 Mile ___ 1 to 2 Miles ___ 2 to 3 Miles ___ >3 Miles 20

Precipitation/Visibility Restrictions:

Rain 6 Snow___ Fog___ Haze or Smoke___ None 14

Exit Taxiway Retroreflectors

~~Runway Used: Taxiway Used to Exit Runway:~~

~~Rwy. 4___ Rwy. 22___ T/W Bravo___ T/W Delta___~~

~~How much help were the reflective markers in finding the exit taxiway?~~

~~No Help___ Some Help___ Great Help___~~

Centerline and Touchdown Zone Retroreflectors

For the type aircraft and weather conditions experienced, please answer the following questions.

1. Please rate the effectiveness of the markers during the:

a. Approache	Excellent 5	Good 8	Fair 4	Poor 3	
b. Flare & Touchdown	Excellent 14	Good 4	Fair 2	Poor 0	
c. Landing Rollout	Excellent 15	Good 4	Fair 1	Poor 0	
d. Takeoff	Excellent 12	Good 4	Fair 0	Poor 0	NoResp. 4

Comments:

2. During crosswind conditions, were you able to decrab sufficiently early during the approach to illuminate the pavement markers?

a. Yes 10 No 1 No Response 9

Comments:

Continued on next page.

3. Did you find the red/white and all red coded centerline markers useful in determining distance remaining on the runway?

   Comments: *Yes 14 No 0 No Response 6*

4. How would you rate the landing lights on your aircraft as to:

   a. Illumination/Brightness — Excellent *7* Good *8* Fair *5* Poor *0*

   b. Aiming — Excellent *7* Good *8* Fair *1* Poor *3* *No Resp 1*

5. Considering the weather conditions encountered, do you feel that the additional guidance provided by the retroreflective markers improved the safety of operations during:

				No Response
a.	Takeoff?	Yes *13*	No *1*	*6*
b.	Approach?	Yes *11*	No *6*	*3*
c.	Flare & Touchdown	Yes *19*	No *0*	*1*
d.	Landing Rollout?	Yes *18*	No *0*	*2*

   Comments:

Please include any additional comments or remarks:

Name ______________________________
(Optional)*
Organization* ______________________________

*Name and Organization will not be used when test results and comments are reported.

Summary of Responses With Rain/Wet Runway Conditions

EVALUATION OF RETROREFLECTIVE RUNWAY PAVEMENT MARKERS

Runway 4/22, Atlantic City Airport (ACY)

Type and Model Aircraft ____________ Date ____________

Location of Taxi/Landing Lights Used: Wind ____________

Nose ___ Wing ___ Both ___ Other ___ Pavement: Wet 6 Dry ___

Visibility:

<1 Mile ___ 1 to 2 Miles ___ 2 to 3 Miles ___ >3 Miles 6

Precipitation/Visibility Restrictions:

Rain 6 Snow ___ Fog ___ Haze or Smoke ___ None ___

Exit Taxiway Retroreflectors

~~Runway Used:~~ Taxiway Used to Exit ~~Runway:~~

Rwy. 4 ___ ~~Rwy.~~ 22 ___ ~~T/W Bravo~~ ___ T/W Delta ___

How much help were the reflective markers in finding the exit taxiway?

~~No Help~~ ___ Some Help ___ Great Help ___

Centerline and Touchdown Zone Retroreflectors

For the type aircraft and weather conditions experienced, please answer the following questions.

1. Please rate the effectiveness of the markers during the:

a. Approache	Excellent 2	Good 3	Fair 1	Poor 0	
b. Flare & Touchdown	Excellent 4	Good 2	Fair 0	Poor 0	
c. Landing Rollout	Excellent 5	Good 1	Fair 0	Poor 0	
d. Takeoff	Excellent 3	Good 3	Fair 0	Poor 0	No Resp. 4

Comments:

2. During crosswind conditions, were you able to decrab sufficiently early during the approach to illuminate the pavement markers?

a. Yes 4 No 0 No Response 2

Comments:

Continued on next page.

3. Did you find the red/white and all red coded centerline markers useful in determining distance remaining on the runway?

Comments: Yes 6 No 0 No Response 0

4. How would you rate the landing lignts on your aircraft as to:

						No Resp.
a.	Illumination/ Brightness	Excellent 2	Good 2	Fair 2	Poor 0	0
b.	Aiming	Excellent 2	Good 3	Fair 1	Poor 0	0

5. Considering the weather conditions encountered, do you feel that the additional guidance provided by the retroreflective markers improved the safety of operations during:

				No Response
a.	Takeoff?	Yes 6	No 0	0
b.	Approach?	Yes 4	No 2	0
c.	Flare & Touchdown	Yes 6	No 0	0
d.	Landing Rollout?	Yes 6	No 0	0

Comments:

Please include any additional comments or remarks:

Name ______________________
(Optional)*
Organization* ______________________

*Name and Organization will not be used when test results and comments are reported.

APPENDIX C

SUMMARY OF PILOT COMMENTS

General Comments

Boeing 727-100 - An excellent addition in terms of centerline guidance. They would be a welcome addition to small airports and alternate runways at large airports.

Cessna 172 - Didn't really see touchdown zone (markers) until about 100 feet, mainly due to the way the A/C's landing light was positioned.

Cessna 172 - For the conditions experienced (light to moderate rain) the system is completely satisfactory, as effective as lights. The lights were very effective from 200 feet.

Cessna 177RG - They don't seem to angle high enough. A great idea, Teterboro (airport) desperately needs them.

Douglas DC-9-30 - Evaluation is based on several flights; both conditions, dry and rain. Would like to see this equipment at all airports where lighting is presently not available.

Embraer EMB-110 - Centerline reflectors not too visible until close in.

Reflectors better than nothing but inferior to imbedded lighting.

Piper PA-28 - Good close in.

Piper PA-28 - They are good to use to keep you lined up with center of runway.

Piper PA-28 - Even when lights were not on the touchdown zone retroreflectors, you could still spot them peripherally to provide additional roll guidance and help alleviate the "black hole." The centerline lights (markers) were very bright.

Piper PA-28R - Light is presently aimed much too low. It illuminates bare ground short of the threshold during the approach rather than the runway surface.

Piper PA-44 - Believe it helped on flare height.

Crosswind Comments

Aero Commander-680 - Yes, (able to decrab) but pilot has to decrab much earlier than normal.

Miscellaneous Aircraft - No crosswind, no significant cross wind. (Responses from six pilots).

Centerline Color Coding Comments

Cessna 177RG - Did not use enough runway (to evaluate).

H-52 Helicopter - didn't notice (color coded centerline) - great on taxiway (to helipad).

Piper PA-28R - Did not see, short landing (and turnoff).

Piper PA-28R - Didn't see any red or red/white markers (probably landed and turned off before last 3000 feet).

Piper PA-44 - On both landings, did not pass Runway 13/31, therefore, red markers were not in range.