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Reduced Approach Lighting Systems (ALS) Configuration Simulation Testing

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July 2002

Final Report

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16. Abstract

The availability of Global Positioning System (GPS) approaches has already increased the number of runways capable of handling Instrument Flight Rule (IFR) approach operations. A major factor in upgrading the instrument capability of these runways is, and will remain, the need for installation of many new approach lighting systems (ALS). Therefore, it has become necessary to re-evaluate the present standard systems to identify possible means by which installation, operation, and maintenance costs can be reduced.

In an effort to reduce the overall length of ALS's, this report describes the methods, using simulation, by which the minimum visual cues with respect to length of an ALS is needed by pilots during an approach at Category I minimums. The current US standard is the 2400-foot-long Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR). Subject pilots evaluated ten different length configurations and were given questionnaires for each configuration flown.

The results indicate that shortening the system to a length of 1600 feet was not acceptable. Shortening the system to a length of 1800 or 2000 feet may be conceivable if enhancements to the visual segment portion of the system (i.e., additional steady-burning barrettes at 1600,1800, and/or 2000 feet) would be considered. Shortening the system to a length of 2200 feet will only provide minimal reduction in ground area required and result in virtually no benefit in reduced equipment or power requirements.

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EXECUTIVE SUMMARY

The availability of Global Positioning System (GPS) approaches has already increased the number of runways capable of handling Instrument Flight Rule (IFR) approach operations. A major factor in upgrading the instrument capability of these runways is, and will remain, the need for installation of many new approach lighting systems (ALS). Therefore, it has become necessary to re-evaluate the present standard systems to identify possible means by which installation, operation, and maintenance costs can be reduced.

In an effort to reduce the overall length of ALS's, this report describes the methods by which the minimum visual cues with respect to length of an ALS is needed by pilots during an approach at Category (CAT) I minimums of 200-foot decision height (DH) and 2400-foot runway visual range (RVR). This was evaluated through simulation and provides analysis and interpretation of the results. The current US standard is the 2400-foot-long Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR).

In addition, it includes an evaluation of the standard Short Simplified Approach Lighting System (SSALS) for use in support of Category I operations with less restrictive RVR minimums of 3200 feet.

An evaluation of reduced length variations of the standard Federal Aviation Administration (FAA) MALSR configuration to determine the minimum length of approach lighting needed to complete an approach and landing operation without diminishing safety was conducted using a Boeing 727/200 simulator. Boeing 727 type-rated pilots from various air carrier organizations (airlines, ALPA, etc.) and the FAA were called upon to comprise the pilots for the final evaluation. The flight sessions were limited to approximately 3 hours, with the subject pilot participating as Captain (Pilot-in-Command).

The results indicate that shortening the system to a length of 1600 feet was not acceptable. Shortening the system to a length of 1800 or 2000 feet may be conceivable if enhancements to the visual segment portion of the system (i.e., additional steady-burning barrettes at 1600,1800, and/or 2000 feet) would be considered.

Shortening the system to a length of 2200 feet will only provide minimal reduction in ground area required and result in virtually no benefit in reduced equipment or power requirements.

The data verifies the adequacy of the existing standard CAT I system the MALSR. Even when reduced to three lights per barrette the MALSR configuration was acceptable.

The reduction to a 1400-foot length and increased intensity of the lamps in configuration C for use in visibilities of 5/8-statute miles (3200 RVR) received 100% acceptance. The 660-foot (5280'/8) increase in the visibility requirement would most likely compensate for the shorter length in real operation. It is, of course, questionable whether the 1/8-statute mile gain, over the 3/4-statute mile minimum available without any ALS at all, would be worthwhile.

INTRODUCTION

OBJECTIVE.

This project is in response to a request from the Integrated Product Team for Navigation and Landing, AND-740. The objective of the project is to determine whether the current standard for the visual cues, with respect to length of approach lighting for a Category I approach, can be improved. Current Category (CAT) I minimums are a visibility of 2400 feet runway visual range (RVR) and a decision height (DH) of 200 feet above ground level (AGL). This was evaluated through simulation and provides analysis and interpretation of the results. The current U.S. standard is the 2400-foot-long Medium Intensity Approach Lighting System with Runway Alignment Indicator Lights (MALSR). The intent is to provide data and statistics that will point toward efforts that may be taken to improve CAT I Approach Lighting System (ALS) effectiveness and/or facilitate funding and siting of future installations. This was performed by showing subject pilots varying lengths of approach lighting systems from 1600 to 2400 feet.

In addition, it includes a minimal evaluation of the standard Short Simplified Approach Lighting System (SSALS) for use in support of Category I operations with less restrictive RVR minimums.

This testing effort was undertaken as a continuation of alternate/reduced ALS configuration evaluations conducted earlier at the Federal Aviation Administration (FAA) Aeronautical Center.

BACKGROUND.

Recent events have caused the FAA to revisit current airport lighting requirements and specifications.

The availability of Global Positioning System (GPS) approaches has already increased the number of runways capable of handling Instrument Flight Rule (IFR) approach operations. A major factor in upgrading the instrument capability of these runways is, and will remain, the need for installation of many new approach lighting systems. Therefore, it has become necessary to re-evaluate the present standard systems to identify possible means by which installation, operation, and maintenance costs can be reduced. Obviously, if the physical configuration size and/or component density (i.e., number of light fixtures or supports) can be reduced without compromising safety and considerable savings in installation cost, maintenance cost, and effort will be realized.

RELATED ACTIVITIES/DOCUMENTS.

In January 1995, the FAA William J. Hughes Technical Center published a technical note report entitled “Visual Guidance Requirements for Global Positioning System Approaches,” DOT/FAA/CT-TN94/40.

The report concludes that visual aids intended to support GPS approach and landing operations should be identical to those currently provided to support other forms of instrument operations (NDB, VOR, ILS, etc.), and of the configuration dictated only by the category of operations (i.e., CAT I, II, or III). In addition, however, the report further states that:

> "This is not to say, however, that our existing MALSR and ALSF-2 systems are optimum with regard to efficiency and/or economy. There are still certain areas within which they might be improved and made much more cost efficient without negatively impacting pilot acceptance. For example, the number of lights in each ALS barrette, now five, might be reduced to three with virtually no loss of visual effect. Every light fixture eliminated reduces the attendant cost of installation and maintenance. Energy costs would also be reduced significantly."

A preliminary simulation evaluation of reduced density ALS configurations was accomplished during 1995 at the FAA Boeing 727 flight simulator facility at the Mike Moroney Aeronautical Center in Oklahoma City, OK. Results of this research effort indicated that further testing, with the visual presentation of the flight simulator and with actual weather flight sessions, would significantly advance the search for a more economical, yet entirely safe, CAT I ALS configuration. The work is described in FAA Final Report DOT/FAA/AR-96/17, "Reduced Configuration Approach Lighting System Simulator Evaluation."

The evaluation effort described herein can certainly be considered as a follow-on investigation of the extent to which the widely used MALSR system (figure 1) may be made more cost efficient through a reduction in the number of components such as light barrettes, flasher units, and associated equipment. These savings might be amplified even further, in some instances, by concomitant reductions in the land areas needed for a reduced configuration. Indeed, such modifications would even permit system installations in locations previously deemed unsuitable.

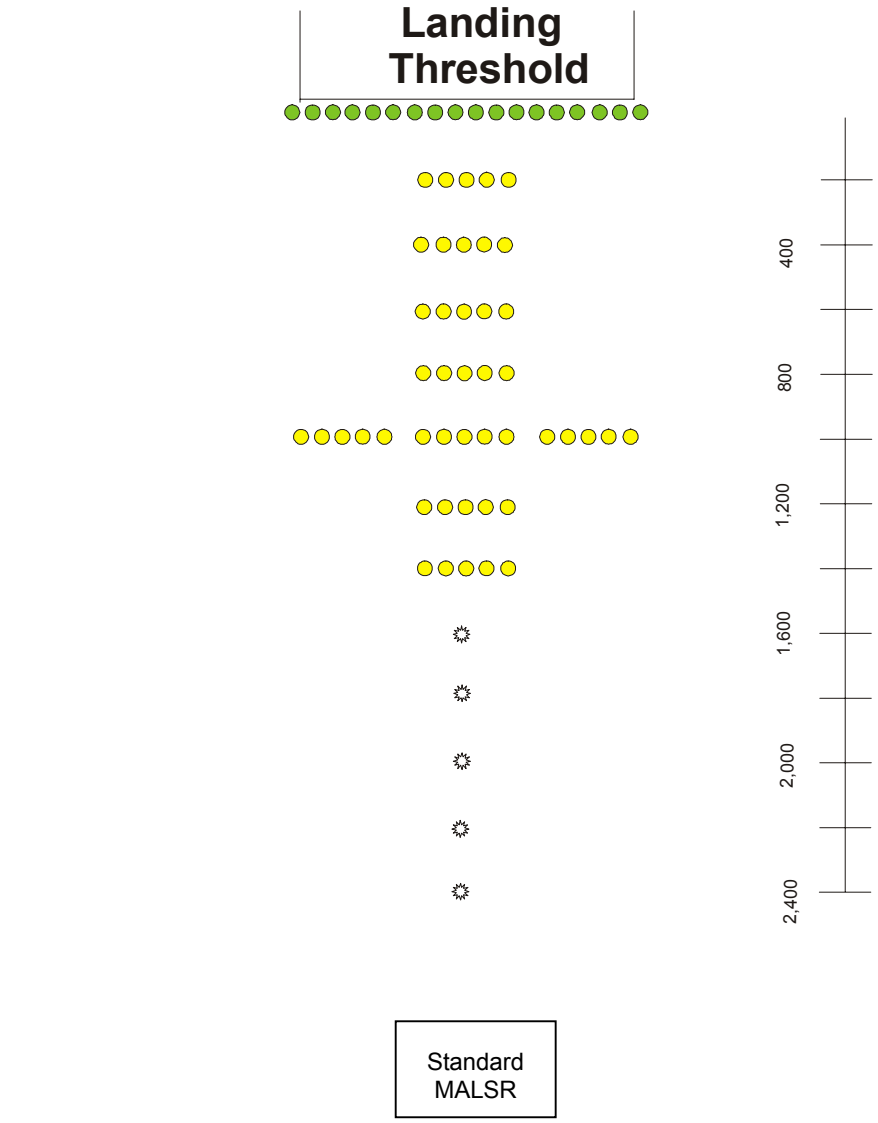


FIGURE 1. STANDARD MALSR SYSTEM

DISCUSSION

STATEMENT OF WORK.

The task undertaken involved the evaluation of reduced length variations of the standard FAA MALSR configuration to determine the minimum length of approach lighting needed to complete an approach and landing operation without diminishing safety. Once this minimum is determined, an attempt can be made at determining if reduction of the standard system can be achieved. If the standard system can be reduced safely, this can achieve real estate needed, installation, and operating cost benefits.

The effort did not address possible reductions in the standard Category II/III ALSF-2 configuration. However, possible changes to the MALSR system would apply also to the configuration of the standard SALSR system, since it is identical, except for the use of high-intensity Par-56 lamps.

VISUAL SEGMENT.

A concern when contemplating a change in the standard CAT I system is what portion of the visual segment pilots see during a CAT I approach. CAT I approach minimums are currently 200-foot altitude above ground level and 2400-foot (1/2sm) runway visual range. The 200-foot criterion is the lowest altitude the pilot is permitted to descend to before making a decision to proceed or perform a "missed approach." The visual segment is dependent upon the altitude above the ground of the aircraft, the pitch angle of the aircraft, and the aircraft cockpit cutoff angle. It is also dependent on the visibility from the pilot's eyes to the ground. Two visibility terms associated with visibility during aircraft approach operations are RVR and slant visual range (SVR).

RVR is a instrumentally derived value that represents the horizontal distance a pilot will see down the runway in a given weather condition. It is surface based with no provisions for the effects of vertical visibility restrictions (fog, snow, etc.).

SVR is the visual range relative to pilot eye height at any given position during an approach to a point on the ground.

Over the years, the United Kingdom and the United States have accumulated data on SVR and RVR relationships. This information is recorded in the following reports:

- Report DRA/AS/MSD/CR95146/1 "Simplified Approach and Runway Lighting Patterns for Low Visibility Operations," a simulator and actual low visibility flying trials conducted to determine if a shortened ALS was possible.

- Report FAA-RD-77-34 (NA-76-50) "Slant and Runway Visual Range Relationships," actual weather tests using tower-mounted transmissometers.

- "Appearance of the Visual Segment Under Low Runway Visual Range Conditions", a mathematical analysis of illuminance at the aircraft windscreen by an approach or runway light as a function of RVR.

The common results of these independent studies were

1. Fog is not usually homogeneous.

2. Fog, which becomes denser with height, is the most prominent type of fog.

3. Slant range calculations (mathematical analysis) were extremely close to actual weather tests.

As a result of these findings, an SVR can be calculated for any point in space given an RVR and a combination of glide slope angle and altitude and/or distance from the aircraft to the theoretical touchdown point.

VISUAL SEGMENT CALCULATION FOR THE SIMULATION.

The simulator used was a Boeing 727-200. The aircraft's normal pitch angle of 3 degrees and the cockpit cutoff angle of 15 degrees was used. The final approach speed of the B-727-200 was 145 knots per hour. It is generally accepted that a pilot needs approximately 3 seconds before decision height (DH) to recognize the necessary cues and make the decision to proceed or perform a missed approach.

With this information, the visual segment can be calculated for any point during the approach (for worse case conditions at 2400-foot RVR). The visual segment was computed for 3 seconds, 2 seconds, and 1 second before DH and also at the DH of 200 feet. The results are shown below.

Seconds Before Decision Height	3	2	1	DH
From*	2421	2249	2062	1875
To*	2350	2086	1799	1511
Visual Segment	71	163	263	364

* Distance from Runway Threshold

The data indicate the portion of an ALS visible at CAT I minimums from 3 seconds before DH-to-DH is from 2421 to 1511 feet from threshold (T/H).

DEVELOPMENT OF REDUCED SYSTEM CONFIGURATIONS.

Approach lighting system changes to lower installation, maintenance, and operational costs involve, primarily, the use of fewer lights. This can be achieved by reducing the number of lamps on each centerline barrette or by changing the number and/or location of steady-burning light barrettes and strobe lights.

Since previous testing had indicated that a reduction in the number of steady-burning lights during simulation, from five to three lamps in each barrette, would not diminish system effectiveness for the simulation effort, each of the test configurations contained this change from the standard.

The following configurations, listed in order of increasing overall length, were evaluated:

- Configuration C (figure 2)—SSALS with five lights per centerline barrette and no strobe lights. Light intensity set to simulate output of PAR-56 high-intensity lamps. Total system length of 1400 feet.

- Configuration A (figure 3)—Reduced density CAT I with three lights per centerline barrette and four strobe lights on 200-foot spacing from the 1000-foot bar to 1600 feet from T/H. Total system length of 1600 feet.

- Configuration I (figure 4)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 100-foot spacing from the 1200 foot bar to 1600 feet from T/H. Total system length of 1600 feet.

- Configuration B (figure 5)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 200-foot spacing from the 1000-foot bar to 1800 feet from T/H. Total system length of 1800 feet.

- Configuration J (figure 6)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 100-foot spacing from the 1400-foot bar to 1800 feet from T/H. Total system length of 1800 feet.

- Configuration G (figure 7)—Reduced density CAT I with three lights per centerline barrette and three strobe lights on 200-foot spacing from the 1600-foot point to 2000 feet from T/H. Total system length of 2000 feet.

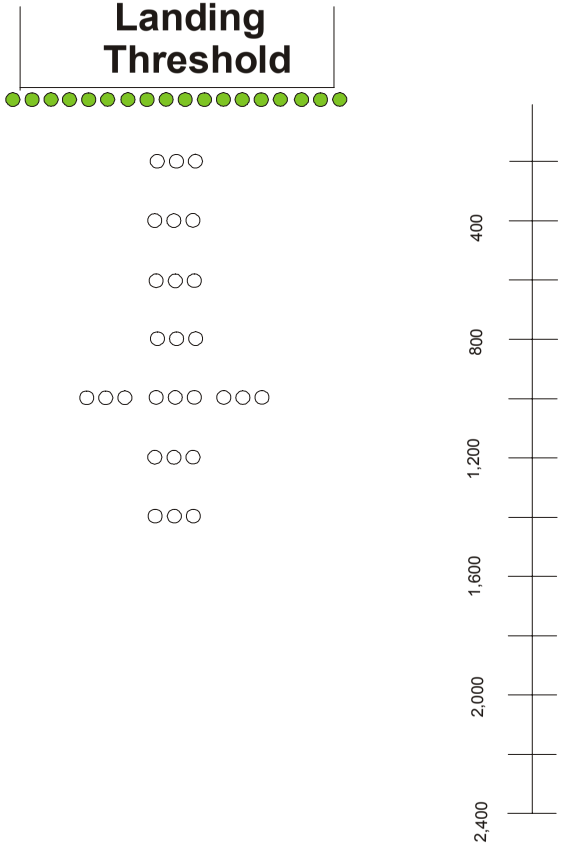
- Configuration D (figure 8)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 200-foot spacing from the 1200-foot bar to 2000 feet from T/H. Total system length of 2000 feet.

- Configuration K (figure 9)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 100-foot spacing from the 1600-foot point to 2000 feet from T/H. Total system length of 2000 feet.

- Configuration H (figure 10)—Reduced density CAT I with three lights per centerline barrette and four strobe lights on 200-foot spacing from the 1600-foot point to 2200 feet from T/H. Total system length of 2200 feet.

- Configuration E (figure 11)—Reduced density CAT I with three lights per centerline barrette and five strobe lights on 200-foot spacing from the 1400-foot point to 2200 feet from T/H. Total system length of 2200 feet.

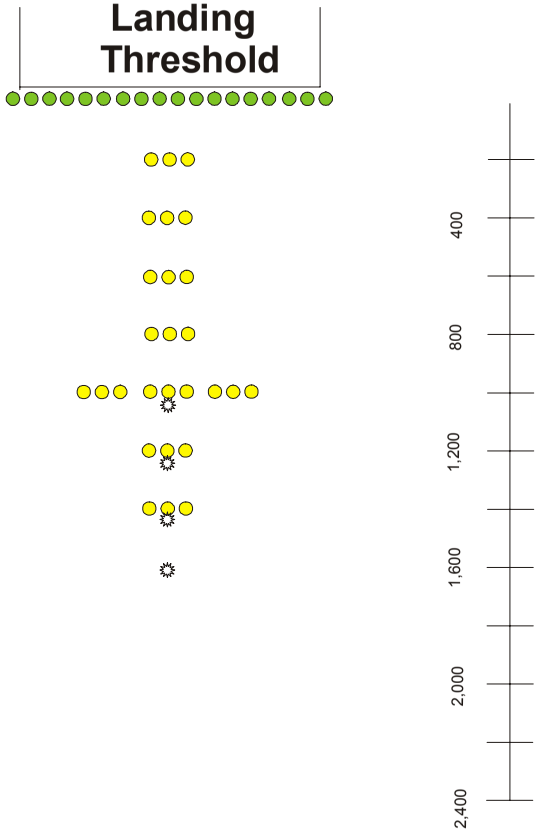
- Configuration M (figure 12)—Reduced Density CAT I with three lights per centerline barrette and five strobe lights on 200-foot spacing from the 1600-foot point to 2400 feet from T/H. Total system length of 2400 feet.



SSALS
Config. C

○ = Steady-Burning High Intensity Par-56 Lamps
☼ = Sequenced Flashers

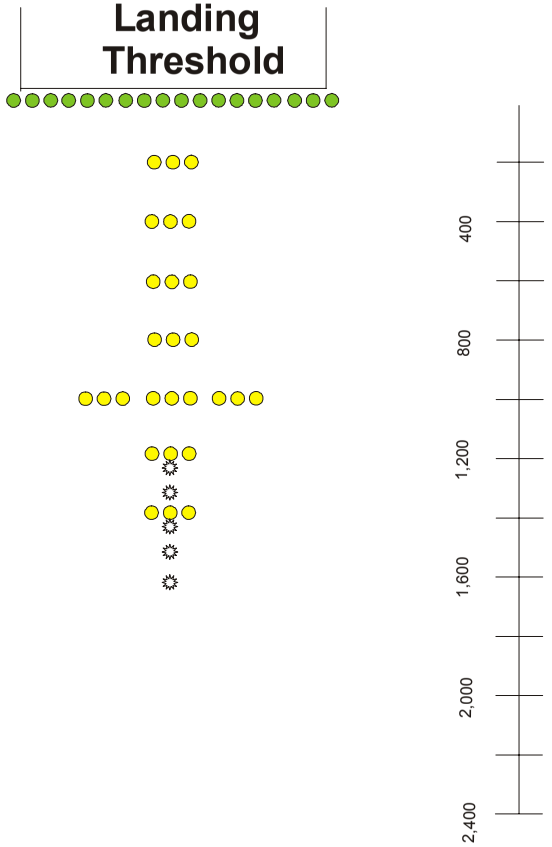
FIGURE 2. CONFIGURATION C



4 Strobes 1,000 to 1,600 feet
Config. A

● = Steady-Burning Par-38 Lamps
☼ = Sequenced Flashers

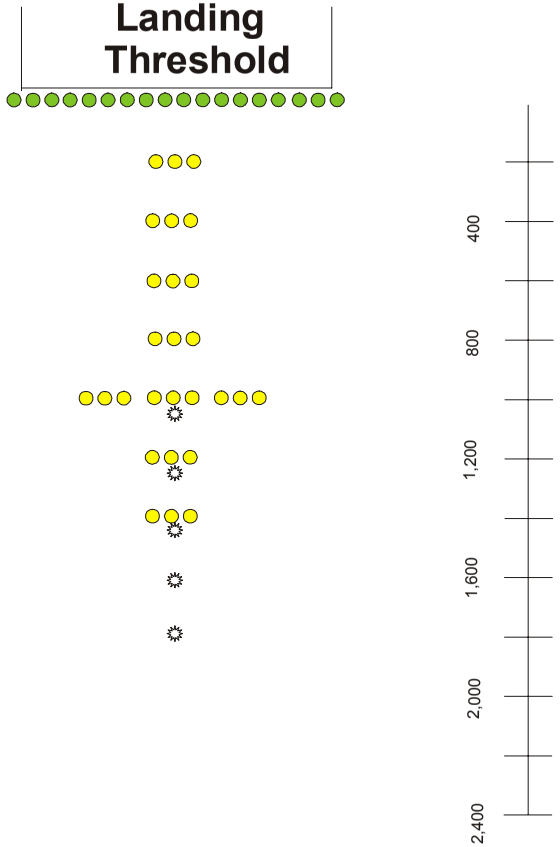
FIGURE 3. CONFIGURATION A



5 Strobes 1,200 to 1,600 feet
@ 100 foot spacing
Config. I

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

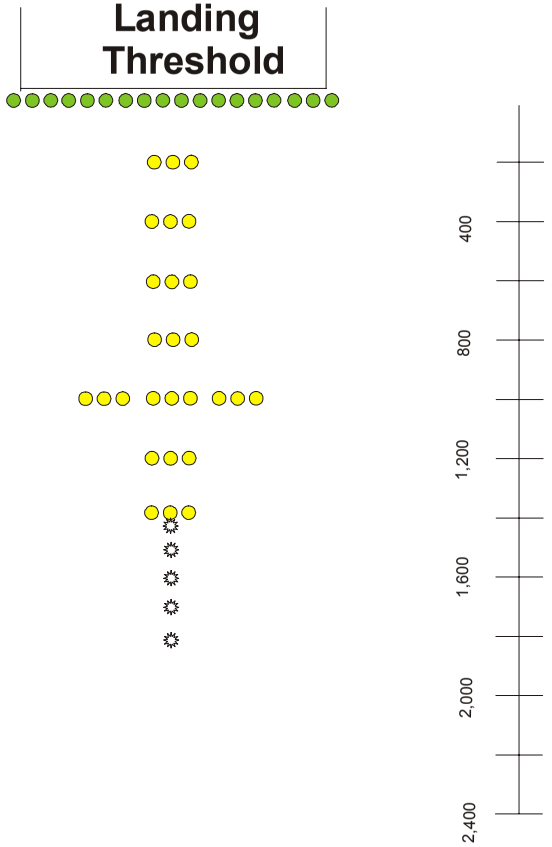
FIGURE 4. CONFIGURATION I



5 Strobes 1,000 to 1,800 feet
Config. B

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

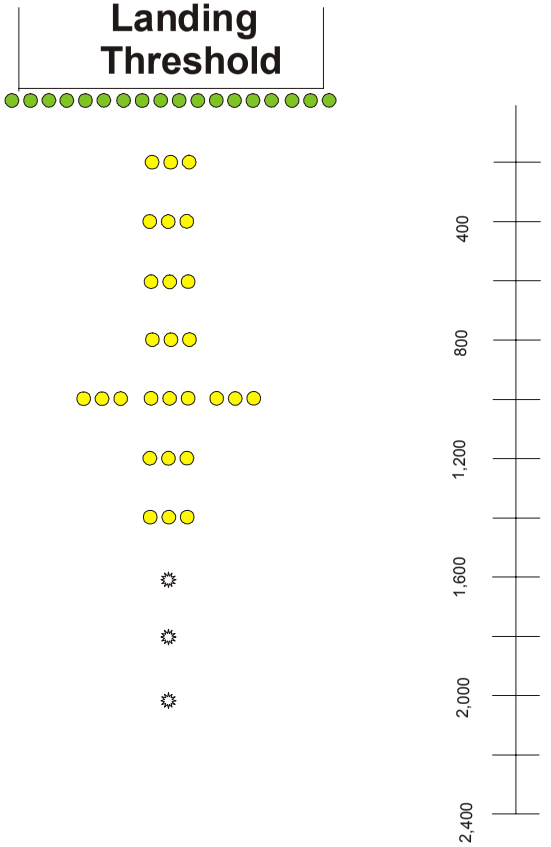
FIGURE 5. CONFIGURATION B



5 Strobes 1,400 to 1,800 feet
@ 100 foot spacing
Config. J

○ = Steady-Burning Par-38 Lamps
☼ = Sequenced Flashers

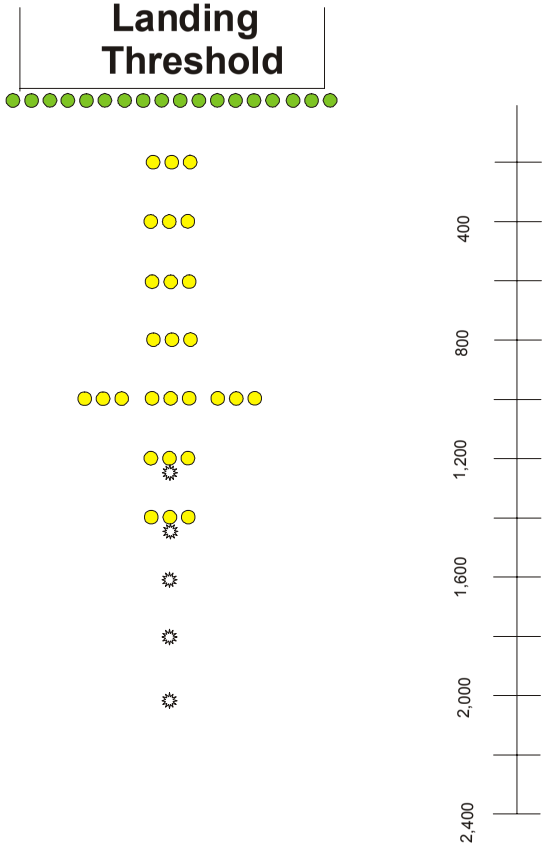
FIGURE 6. CONFIGURATION J



3 Strobes 1,600 to 2,000 feet
Config. G

○ = Steady-Burning Par-38 Lamps
☼ = Sequenced Flashers

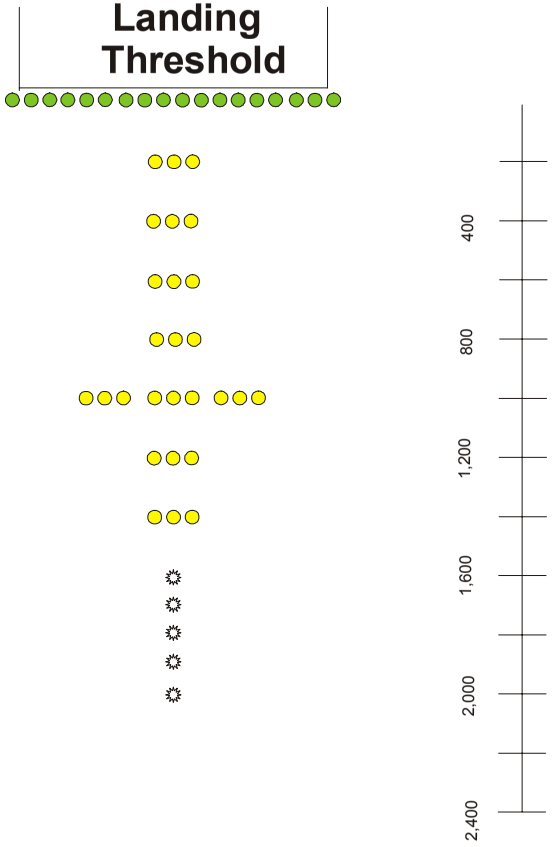
FIGURE 7. CONFIGURATION G



5 Strobes 1,200 to 2,000 feet
Config. D

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

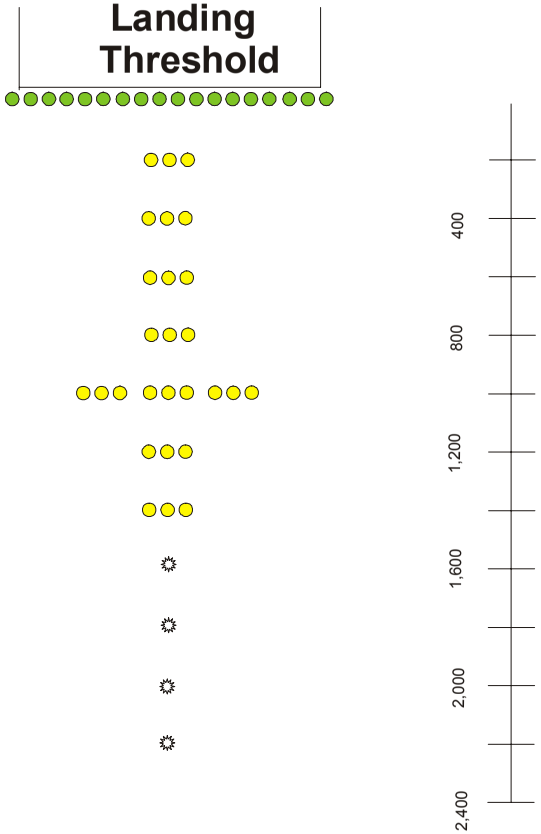
FIGURE 8. CONFIGURATION D



5 Strobes 1,600 to 2,000 feet
@ 100 foot spacing
Config. K

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

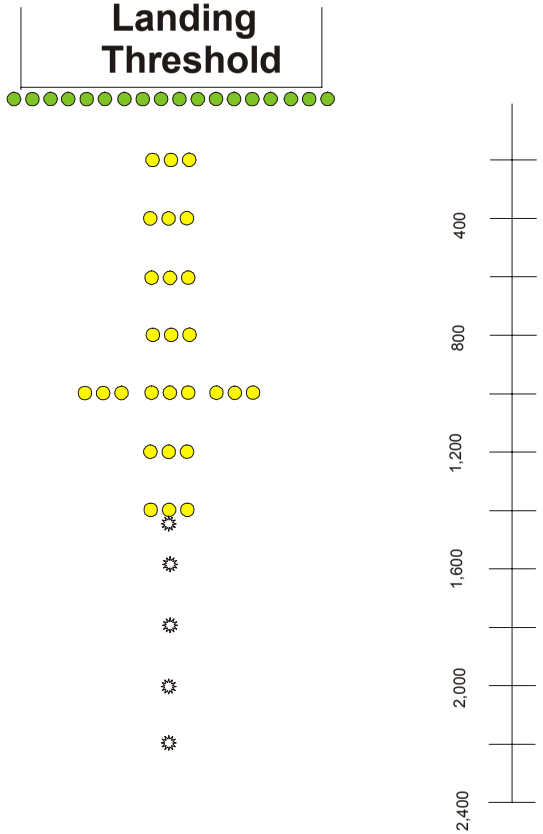
FIGURE 9. CONFIGURATION K



4 Strobes 1,600 to 2,200 feet
Config. H

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

FIGURE 10. CONFIGURATION H



5 Strobes 1,400 to 2,200 feet
Config. E

= Steady-Burning Par-38 Lamps
= Sequenced Flashers

FIGURE 11. CONFIGURATION E

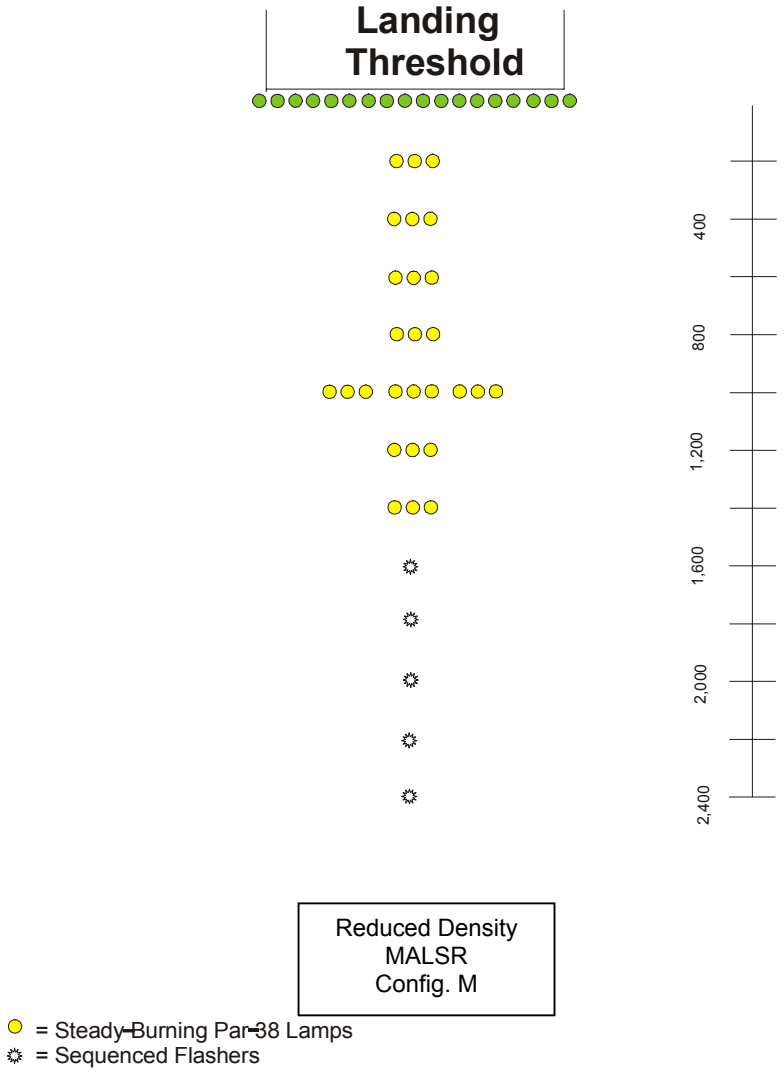


FIGURE 12. CONFIGURATION M

Note: All of the above configurations are variations of the MALSR system except the first, configuration C, which is the SSALS system.

It should be noted additionally that configuration C, which is basically the SSALSR without any strobe lights in the outer portion of the system, has been proposed by Flight Standards for use in adjusted minima of 3200-feet (5/8-statute mile) visibility. This was the shortest (1400 feet) configuration evaluated.

EVALUATION APPROACH

METHOD.

In view of the fact that all of the evaluations to be accomplished involve testing of major lighting system configuration effectiveness/adequacy under reduced visibility conditions (CAT I), it

would have been very difficult to conduct actual flight tests under existing weather conditions using modified full-scale ALS systems. As a result, the evaluations were accomplished using the FAA Boeing 727 Flight Simulator located at the Mike Moroney Aeronautical Center in Oklahoma City, OK. The visual display component of the flight simulator was upgraded and calibrated in such a manner as to significantly enhance the lighting system presentation and to suite it better to visual aid evaluations.

The simulator was equipped with an SP-1T texturized dusk/night visual display, with a full range of visual weather effects available. These included clouds (base and top selectable), scud, homogeneous fog, patchy fog, and selectable visibility and RVR.

Using a dynamic slant visual range formula instead of the standard runway visual range information has enhanced the simulator's visual presentation. This gives a more accurate representation of actual visibility (at minimums) to the pilot.

SUBJECT PILOTS.

While preliminary "weeding out" of obviously unsuitable ALS configurations were accomplished by FAA test pilots and visual guidance engineers, B-727 type-rated pilots from various air carrier organizations (airlines, ALPA, etc.) and the FAA were called upon to comprise the majority of pilots making the final evaluation. The flight sessions were limited to approximately 3 hours, with the subject pilot participating as Captain (Pilot-in-Command).

SCENARIOS.

Since all evaluations were conducted under CAT I simulated conditions, the initial segment of the approach, to a point 100′ above the decision height, was flown coupled with autothrottle engaged. The captain then, when comfortable with the situation, decoupled and, at decision height, either completed the landing visually or conducted a missed approach maneuver. A qualified FAA pilot occupied the right seat in the simulator and performed such duties as would normally have been assigned to the first officer.

EVALUATION IMPLEMENTATION

GENERAL PROCEDURES.

Subject pilots were briefed prior to each simulated flight session and given an opportunity to familiarize themselves with the nature of the postflight questionnaire that they would be required to complete. Briefings and questionnaires addressed only those evaluations to be accomplished during the associated simulated flight session. Postflight questionnaires were completed in the simulator immediately after each lighting configuration was evaluated.

Questionnaires used for the evaluation were designed to indicate preferences of one configuration over another. Choosing a configuration was not the purpose of this evaluation. The questions do provide, however, an indication of what is sufficient or lacking in the ALS configurations. A typical questionnaire form is shown as figure 13.

POSTFLIGHT SESSION QUESTIONNAIRE

REDUCED ALS CONFIGURATION SIMULATOR TEST

RUN NOS. 1 TO 6—CONFIGURATION "A"

REDUCED VISIBILITY COND: 1800′ RVR

SUBJECT PILOT NUMBER:_____ DATE:_____

Please place a check in the appropriate square to indicate the relative usefulness of this lighting configuration in providing the following forms of guidance.

1. FINDING THE RUNWAY:

Excellent	Good	Acceptable	Almost Acceptable	Absolutely Unacceptable

2. AWARENESS OF ALTITUDE ABOVE THE GROUND:

Excellent	Good	Acceptable	Almost Acceptable	Absolutely Unacceptable

3. LATERAL ALIGNMENT WITH THE RUNWAY:

Excellent	Good	Acceptable	Almost Acceptable	Absolutely Unacceptable

4. ROLL GUIDANCE:

Excellent	Good	Acceptable	Almost Acceptable	Absolutely Unacceptable

FIGURE 13. SAMPLE POSTFLIGHT SESSION QUESTIONNAIRE

5. Did the guidance that was provided by the displayed Approach Lighting System (ALS) configuration allow you to complete the approach and landing safely?

Yes:_____ No:_____ Could Not Judge:_____

Comments:_____

_____

_____

6. What guidance information (roll, height, direction, etc.), if any, did you feel was lacking or deficient?

None:_____ or See Comments Below:_____

Comments:_____

_____

_____

_____

7. Do you feel that this ALS configuration merits further consideration as an approach lighting system to support operations down to 1800′ RVR. (i.e., actual weather flight testing)?

Yes:_____ No:_____

Comments:_____

_____

_____

_____

COCKPIT OBSERVER:_____

Comments: **Decision** _____ **AGL** _____
AutoPilot **AGL**

_____

_____

FIGURE 13. SAMPLE POSTFLIGHT SESSION QUESTIONNAIRE (Continued)

Qualified observers were present in the simulator cockpit during each evaluation session to record pertinent subject pilot comments. They also noted any unique cockpit occurrences, such as abrupt maneuvering, but only if it appeared to be a result of insufficient or inadequate visual guidance provided by the system under evaluation.

No aircraft equipment failures were incorporated into this portion of the evaluation effort, since the intent was to evaluate approach lighting configurations and not the subject pilot's ability to handle emergency situations. In some cases, however, aircraft location at decision height, when the lights should first have been sighted, were adjusted (offset) so as to present the lighting system in a slightly different orientation than would normally occur. All offsets introduced were restricted to 60 feet to the right or left of the runway centerline. These values are within the limits of a normal approach.

The data analysis consisted of 14 pilots flying approximately 18 approaches each, for a total of 252 runs. These subject pilots were B-727 type-rated, CAT I qualified pilots from a number of different carriers and the FAA.

Every effort was made to automate the testing procedure and simulator setup as much as possible to ensure repeatability and high-quality data collection for future analysis and evaluation.

All tests were flown using the Oklahoma City airport visual model, simulating an approach to runway 35R. The necessary CAT I features were available on this runway depiction, and the quality of the visual model was such as to ensure valid test results.

WEATHER SIMULATION.

All configurations, with the exception of configuration C (SSALS), were evaluated under simulated CAT I weather conditions of 2400′ (1/2sm) RVR. Configuration C was evaluated under conditions of 3200′ (5/8sm) RVR.

In addition, to avoid having the lighting system first appear in the same segment of the windshield each time, a wind condition offset was introduced on selected approaches. The correct set of weather conditions, with correlated visual effects, was automatically activated depending upon the test scenario selected.

The following defines the six different simulated weather sets.

WEATHER SET	CONDITIONS
1	Fog, 2400′ RVR, no wind condition
2	Fog, 2400′ RVR, X-wind (Right at 10 kts, gusting to 15)
3	Fog, 2400′ RVR, X-wind (Left at 10 kts, gusting to 15)
4	Fog, 3200′ RVR, no wind condition
5	Fog, 3200′ RVR, X-wind (Left at 10 kts, gusting to 15)
6	Fog, 3200′ RVR, X-wind (Right at 10 kts, gusting to 15)

INITIAL AIRCRAFT CONDITIONS.

Initial conditions, as set prior to each approach, were as follows:

- Gross Weight 154,500 lbs.
- Center of Gravity 25%
- Fuel Freeze Set
- Visual Control CRT
- Visibility As required
- Ceiling 3000 feet
- Turbulence 8%

PILOT OPERATING PROCEDURES.

The cockpit operator initiated each test approach from the pilot instructor's station. When the scenario number was entered and activated, the aircraft was repositioned to a point 6.2 nm from touchdown and placed in flight freeze.

As soon as the aircraft was stabilized at the approach position, the pilot set the following initial conditions:

- Stab Trim 5.5
- EPRs 1.5
- F.O. Flight Director OFF
- Capt. Flight Director As desired
- Auto Throttle On
- Flaps 30
- Gear DOWN

When the operator was ready to initiate the run, and the pilot concurred, flight freeze was released and the pilot flew the manual or coupled approach as directed in the briefing. Just prior to release, the pilot verified the following:

- Spoilers Closed
- Autopilot Engaged
- ALT Hold ON
- Autopilot Auto GS

A pilot initiating a "go-around," in response to "unsafe" conditions (usually lack of visual guidance at minimums), continued his climb-out on the runway current heading, stabilized the aircraft, and leveled off at 500′ above ground level (AGL). This permitted the automatic test facilities to complete processing of the run.

The test runs, from operator initialization until test complete, averaged approximately 4 minutes.

TEST RESULTS

DATA FORMAT.

The data collected can be characterized as being of both objective and subjective form. Pilot performance, as revealed in the number of missed approaches resulting from exposure to differing ALS configurations, can certainly be considered as objective data. Likewise, the opinions expressed by subjects as ratings and answers to the pilot questionnaires can surely be considered as subjective in nature. Hopefully, in any evaluation effort of this type, the two types of data will be consistent and lead to a logical conclusion as to the safest, and yet most economical, system tested.

It should be noted, and borne in mind when discussing results, that the alphabetical order of the systems in no way relates to overall length. For convenience and clarity, however, the charts and graphs provided have been arranged so that the order of configurations depicted (i.e., A, I, B, J, G, D, K, H, E, and M) does reflect increasing overall length of the particular system.

OBJECTIVE DATA.

Occurrences of missed approaches, expressed as percentages of total approach attempts, for each of the ten CAT I configurations are depicted graphically in figure 14. Missed approach frequency for the configuration C SSALS system will be shown and discussed separately.

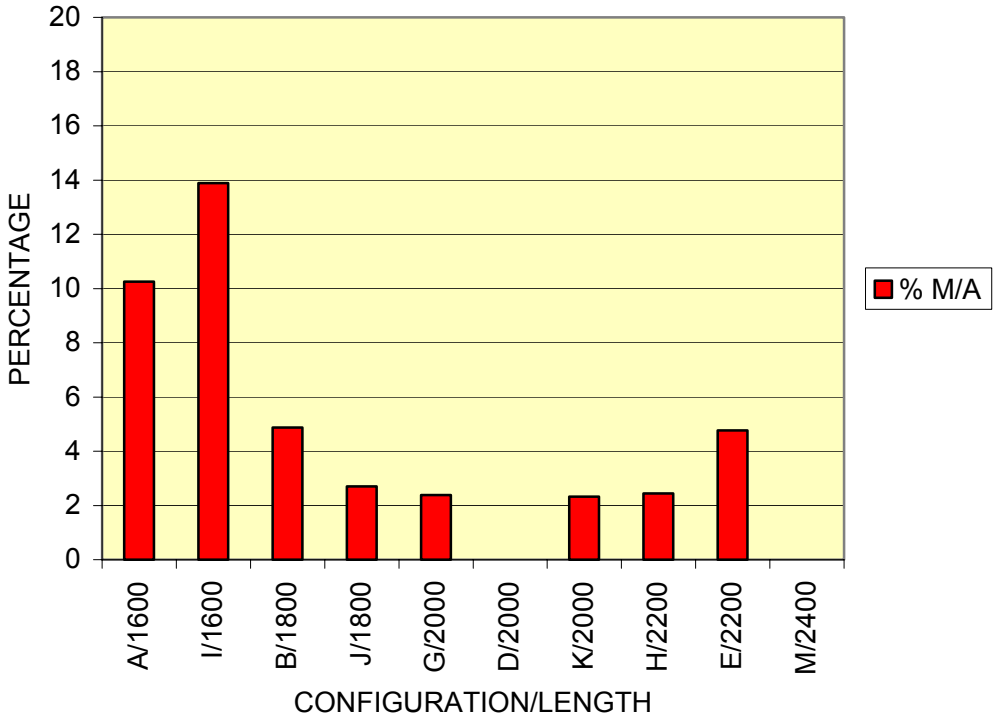


FIGURE 14. MISSED APPROACH FREQUENCY

All but two of the configurations tested produced missed approach frequencies of 5% or less, with configuration D (2000-foot overall length) and M (2400-foot overall length) showing the lowest values of 0%. If the total number of approaches accomplished for each of these configurations is considered, the results are shown in table 1.

It does not appear that pilot performance, as indicated by the occurrences of missed approaches, is very indicative of the importance of overall system length for the range of 1800 to 2400 feet. In fact, performance was better, to a slight degree, with a system (D) some 400 feet shorter than the 2400-foot length of the standard CAT I system.

TABLE 1. MISSED APPROACH PERCENTAGES

Configuration	Total Number of Approaches	Number of Missed Approaches	Percentage of Missed Approaches
A (1600′)	39	4	10%
I (1600′)	36	5	14%
B (1800′)	41	2	5%
J (1800′)	37	1	3%
G (2000′)	42	1	2%
D (2000′)	43	0	0%
K (2000′)	43	1	2%
H (2200′)	41	1	2%
E (2200′)	42	2	5%
M (2400′)	21	0	0%
C (3200′)	33	1	3%

Referring back to figure 14, however, a considerable increase in the percentage of missed approaches occurs when the configuration is shortened to less than 1800 feet. Certainly missed approach percentages of 10% to 14% (configurations A and I) would place the configurations in the unacceptable category, and even a rate of 5% (configuration B) prompts some concern about the effectiveness of an 1800-foot system length. If this latter concern about a 5% value is valid, however, then there might also be a valid issue over the same 5% value occurring with configuration E of 2200-foot length.

It should be noted that missed approach percentage of 5%, as obtained in this evaluation, would be considered extreme in the real world. This should not cast doubt upon the validity of simulation testing, however, for three very significant reasons. First, actual weather Category I approaches are very seldom conducted under true 2400-foot RVR conditions, but rather occur in weather varying greatly above that extreme limit but yet below Visual Flight Rule (VFR) conditions. As opposed to this, all of the approaches conducted in this evaluation were conducted under simulated weather conditions of precisely 2400-foot RVR with a slant range considerably less. In this situation, it would be expect to have a much higher rate of missed

approaches. Second, intensities are not easy to simulate accurately (lights appear somewhat dimmer than in real life). Third, the "blooming" effect of flashing lights was not simulated. These factors can constructively or adversely affect the ability to acquire the lights.

With regard to the SSALS system (configuration C), one-missed approaches occurred during the course of 33 attempted approaches, for a missed approach percentage of 3 percent. This would appear to be an acceptable configuration, considering the fact that the testing of this configuration was conducted with simulated RVR conditions of 3200 feet (5/8sm).

SUBJECTIVE DATA.

All subject pilots were required to answer seven questions while still in the cockpit and immediately after flying each of the ALS configurations. For the first four questions, the results are shown as graphs (figures 15 to 18) of the pilots' rating for each configuration in providing the following guidance:

- Finding the Runway—The direction in which to fly toward the threshold.
- Awareness of Altitude Above the Ground—Continuing height information.
- Lateral Alignment with the runway—Track along the runway centerline extended.
- Roll Guidance—Attitude of the aircraft relative to a wings level condition.

The ratings were derived by assigning a numerical value for each descriptive assessment as follows:

• Excellent	+2
• Good	+1
• Acceptable	0
• Almost Acceptable	-1
• Absolutely Unacceptable	-2

The total of the numerical ratings were then averaged to obtain the results depicted on the graphs.

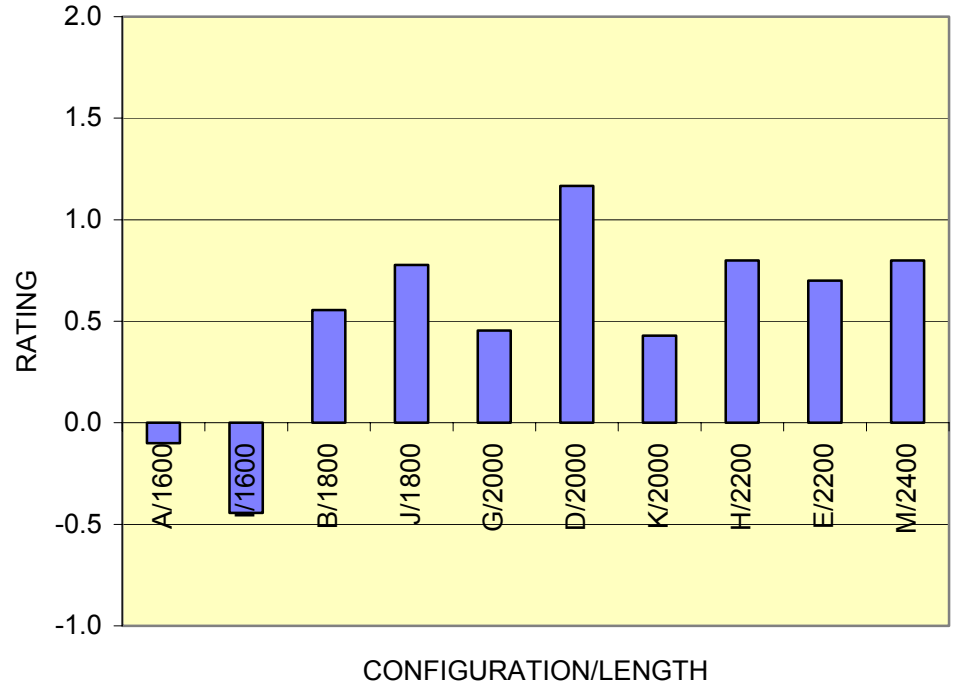


FIGURE 15. QUESTION 1—FINDING THE RUNWAY

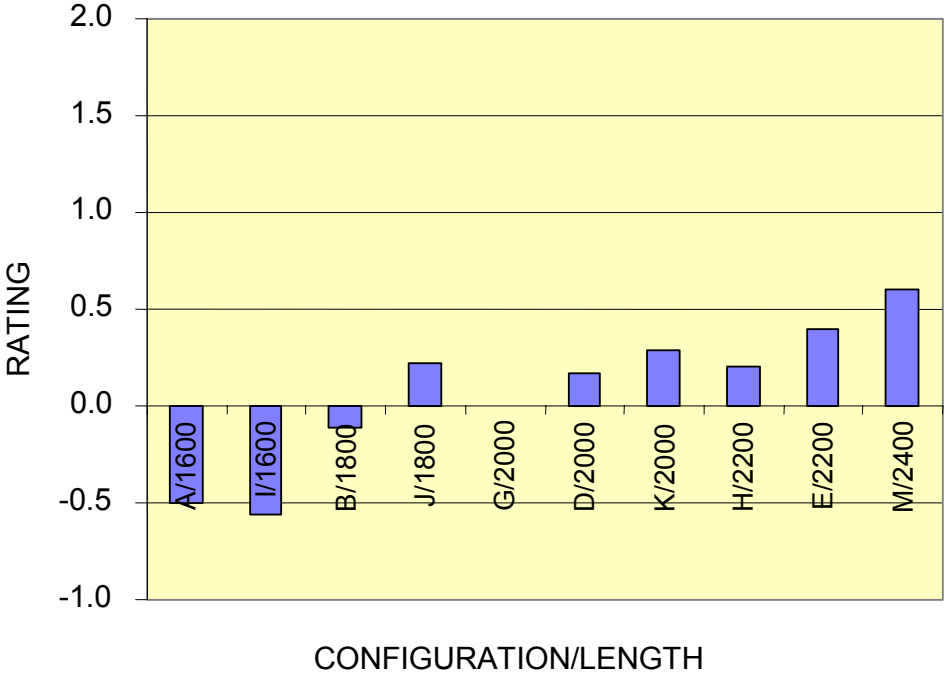


FIGURE 16. QUESTION 2—AWARENESS OF ALTITUDE

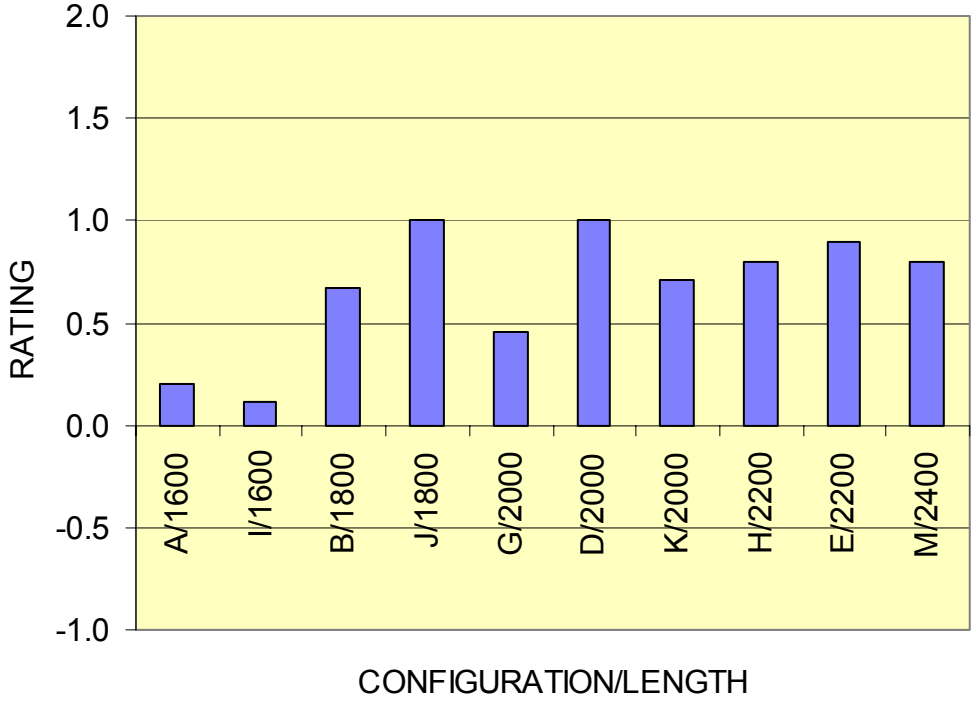


FIGURE 17. QUESTION 3—LATERAL ALIGNMENT

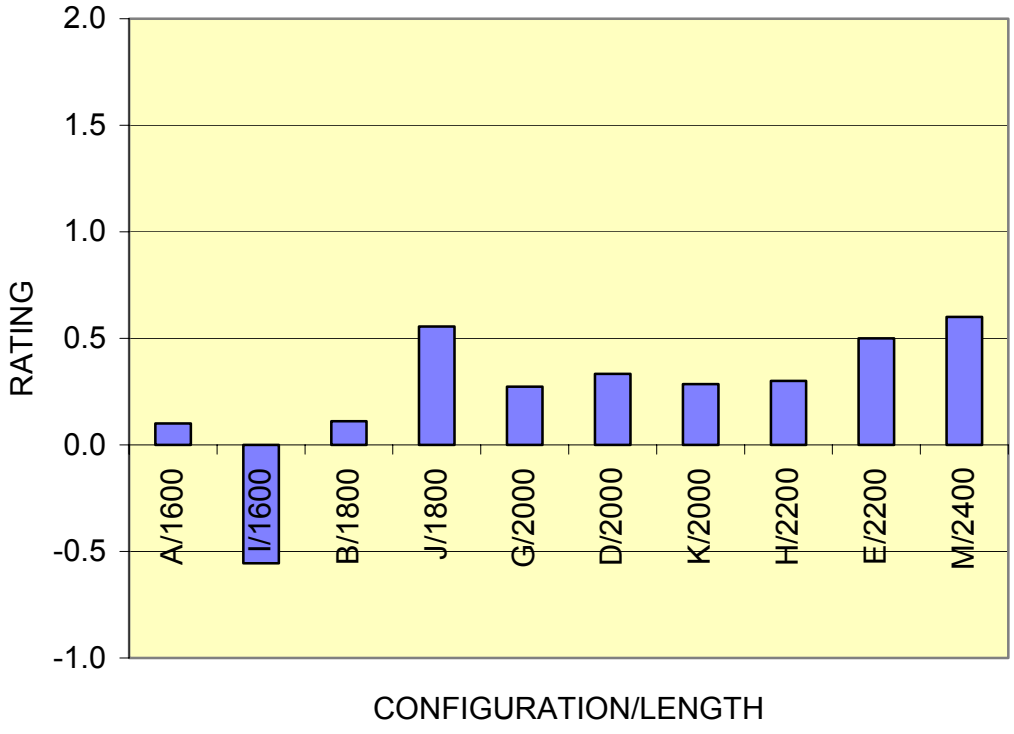


FIGURE 18. QUESTION 4—ROLL GUIDANCE

Questions 5 and 7 involved subject pilot opinion as to whether the particular configuration provided sufficient overall visual guidance to permit a safe approach and landing (question 5) and as to whether the configuration merited further consideration as a suitable replacement for the standard MALSR (question 7). Responses, as a ratio of yes to no answers, are shown graphically in figures 19 and 20.

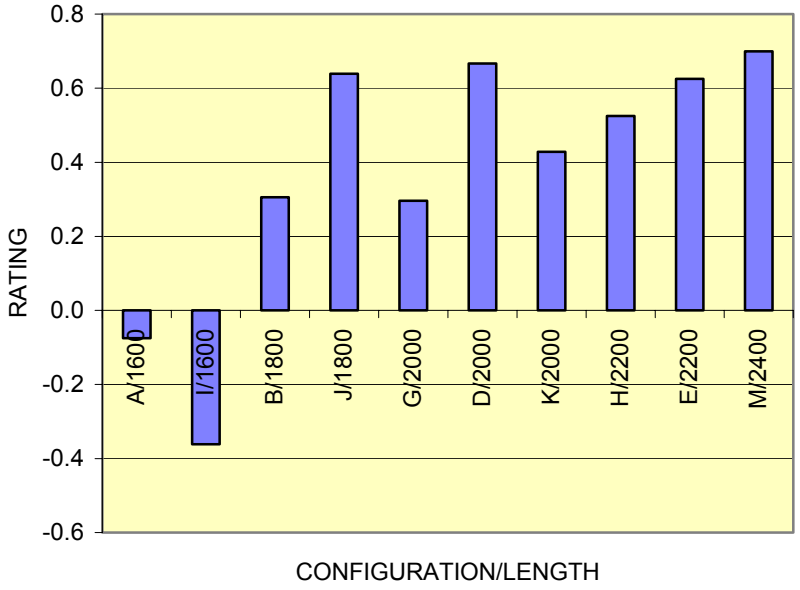


FIGURE 19. OVERALL RATINGS

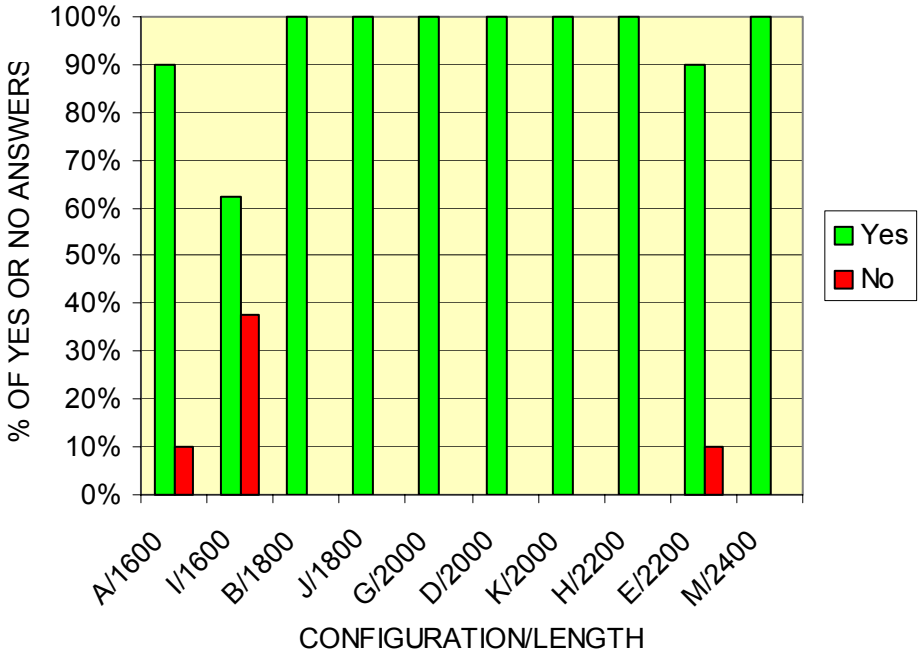


FIGURE 20. OVERALL GUIDANCE SUFFICIENCY

Question 6 asked for subject pilot opinion as to deficiencies worth noting for each configuration, and the answers will be discussed separately, since they do not lend themselves to depiction as a graph or chart.

QUESTIONS 1 THROUGH 4 (FIGURES 15 TO 18). As might be expected, the ratings for all of the first four questions, concerning the effectiveness of guidance provided, tend to be more favorable as the length of the configurations increased.

Question 1. In question 1 (figure 15), guidance, as to the direction toward the runway, appears to be derived principally from the first seen, and brightly illuminated, strobe light portion of each configuration. Further, it would seem that reducing the length of this segment, as a means of reducing overall system length, lessens its impact and reduces the directional information perceived. Thus, the configurations displaying shorter sequenced flashing light lengths are judged by the subject pilots to be less effective in pointing the direction to the "target," the runway. In other words, the longer the length of the sequenced flashing indicator, the stronger the direction impression.

Question 2. Question 2 (figure 16), concerning altitude awareness, shows an even more pronounced subject preference for the longer system lengths. Here again, the probable reason for this is that the resultant earlier acquisition provides a longer time period for interpretation of available guidance.

Question 3. The affect of system length variation is not quite so evident when viewing the results of question 3 (figure 17), which addressed the quality of tracking guidance. One must realize that tracking guidance depends upon retention, in the mind's eye, of a series of objects (lights) that define the line representing the runway centerline extended. Sequenced flashing lights, the sole variable in each of the different configurations, do not serve this purpose very well. The 1400 feet of steady-burning light barrettes are the major ALS component performing this function, however, and their appearance is constant and uniform throughout the variety of configurations under test. Taking this into consideration, it should not be expected that there would be much difference in the subject pilot's opinion as to the effectiveness of the tracking guidance capability.

Question 4. With regard to results for question 4 (figure 18), concerning roll guidance, it is again a rather marked increase in effectiveness is seen as system length is increased. This is rather surprising, since many subject pilots in the past have expressed the opinion that ALS systems provide very little in the way of roll guidance, and that the subject pilot derives most of his "wings level" information from cockpit instruments and not from the lights. The results here would seem to contradict this.

Overall, or composite, ratings are graphically presented in figure 19. They were obtained by adding the configuration rating values for all four questions and then dividing by four. This, of course, presumes equal importance for each of the four guidance categories but does provide some measure of comparative general effectiveness for the configurations.

QUESTIONS 5 THROUGH 7. Results on these two rather general questions concerning whether overall guidance for each configuration was sufficient and for whether each pattern would be a candidate for further testing was somewhat less than definitive. Any interpretation of this data should be approached with caution, and only the most basic of conclusions can be drawn.

Question 5. Answers to question 5 (figure 20), dealing with sufficiency of overall guidance, would indicate that all but the shortest (1600 feet) configurations provided at least the minimum amount of visual guidance necessary for completing the approach and landing safely. Looking back to figure 14, virtually the same results are found reflected in the much higher rate of missed approaches for the two shortest configurations. Both subjective and objective data agree in this case and would seem to validate the subject pilots' opinion that configurations as short as 1800 feet may provide at least the minimal required guidance.

Question 6. This question asked that the subject pilots indicate the type(s) of guidance that they felt might have been missing or deficient. Listed in table 2, by configuration, are the principal deficiencies noted. Appendix A provides a complete compilation of all of the deficiencies expressed by the subject pilots and noted by the FAA cockpit observer.

TABLE 2. PRINCIPAL DEFICIENCIES

Configuration	Major Deficiencies Noted
A	Deviation from centerline not obvious. Roll, height guidance lacking.
I	Roll cues and height guidance weak. Would like strobes extended further out.
B	3 Lights not enough, each barrette too narrow.
J	Roll, height guidance lacking.
G	3-Light centerline bars provide better roll guidance (than strobe lights).
D	Strobes further out would help, but ALS was adequate.
K	More steady-burning lights would be acquired earlier and help with drift.
H	1000-foot bar too far from runway—barrettes too far apart.
E	Very good ALS (2 positive comments).
M	More side lights (on barrettes) would be better. Liked this ALS—Good guidance to T/H.
C	Strobes lacking for early alignment, but (3200′ RVR) ALS adequate. Lack of R/W centerline (strobe) lights did detract a little.

Question 7. Results of question 7 (figure 21), addressing the issue of whether any of the configurations evaluated warrant further consideration, show no clear cut preference for any of the patterns with overall lengths of 1800 feet or more. Here once again, it is seen that a rather marked subject dissatisfaction with the two shortest 1600-foot configurations, reflected in the opinion that no further testing of such minimum length systems would be worthwhile.

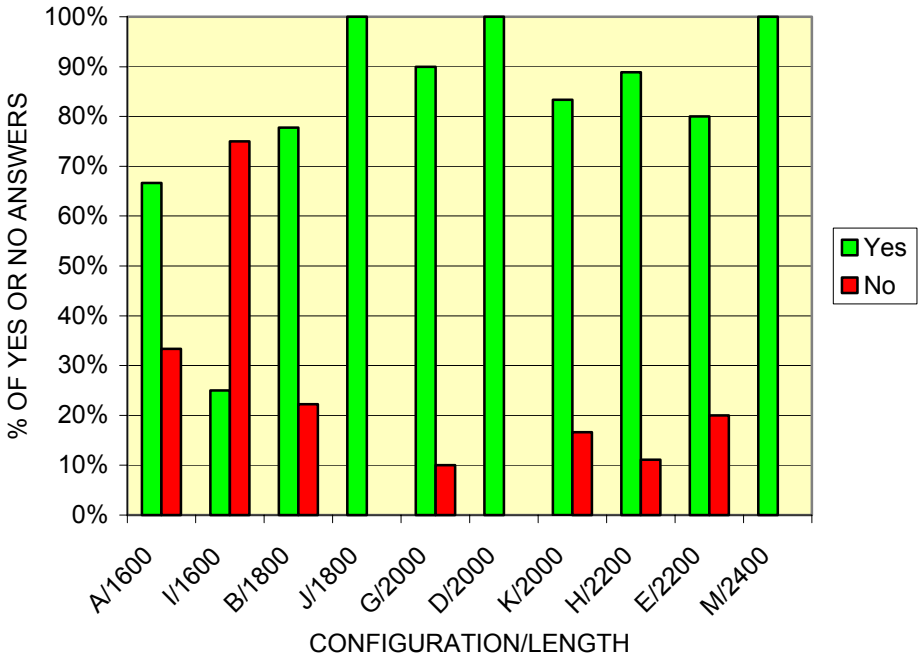


FIGURE 21. FURTHER TESTING WORTHWHILE

Configuration C, the SSALS of 1400-foot length, was evaluated under 3200-foot RVR conditions and is discussed separately at this point. Referring to figure 22, it can be seen that it was very favorably considered in providing all four guidance characteristics and the numerical values indicate average ratings by all subjects of good to excellent.

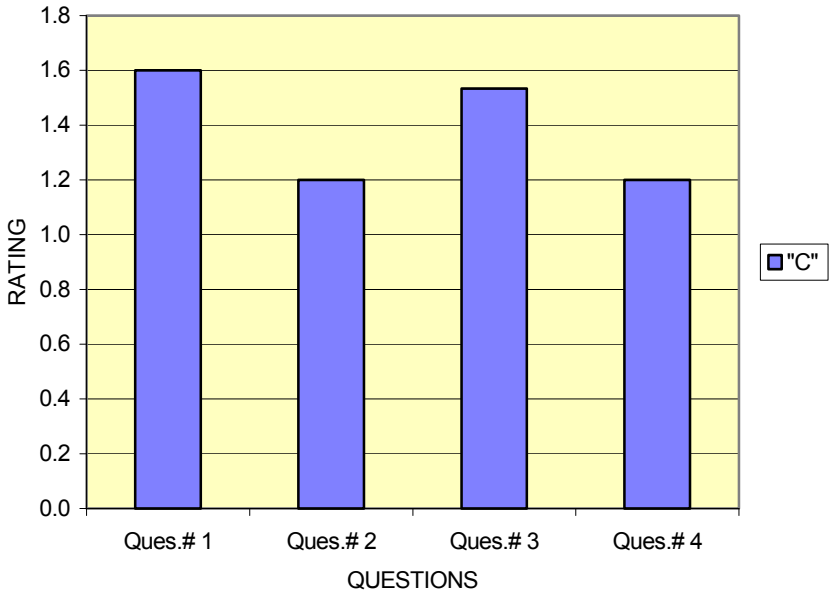


FIGURE 22. CONFIGURATION C—QUESTIONS 1 THROUGH 4

OBSERVATIONS

While the results of this evaluation may suggest that configurations of less than 2400 feet in overall length may be acceptable alternatives to the standard CAT I configuration, some consideration must be given to a number of other factors.

A prime concern is the need for a certain degree of redundancy to insure that the system will continue to provide adequate guidance in the event of minor outages or failures. Reducing the number of steady-burning lights on each centerline barrette from five to three, as was done for this evaluation, would probably not result in excessive loss of guidance for single-lamp outages. Even loss of a full three-lamp barrette could be tolerated, as they are all in the inner portion of each configuration. Loss of a single strobe light in the outer portion of the shortened systems could be a serious deficiency, and limited early acquisition of the ALS to the degree that execution of a missed approach at minimums would be necessary. The affect of lamp and/or strobe outages was not addressed in the evaluation and should certainly be considered in making any decision to reduce the length of the standard CAT I system.

Each of the shortened systems used at least four strobe lights, with most retaining the standard five-strobe battery; and all included the standard 1400 feet of steady-burning light barrettes. The only shortened configuration containing less than four strobe units was G, with three strobes, and this 2000-foot system was consistently rated lower in all respects. Power requirement reduction, due to eliminating a single strobe unit, would be inconsequential.

It should be noted that only one of the subject pilots had a negative reaction to the reduction in the number of steady-burning lights within the system, even though they all were appraised of the change. Such a reduction could be made quite easily in the field and, since the MALSR is a parallel type of system, would only entail removing the appropriate lamps from the barrettes and sealing the empty lampholders in some manner. A considerable reduction in power consumption would also result from such a modification to the standard configuration.

The MALSR has been used for over 20 years. If the amount of missed approaches were to large due to this system, this would impact the airlines economically, which would generate complaints of inadequate guidance. This has not been the case however, which seems to indicate this configuration is sufficient.

With regard to the 1400-foot length C configuration for use in visibilities of 5/8-statute miles (3200 RVR), the reduction in overall system length would not appear too drastic. The 660-foot (5280′/8) increase in the visibility requirement would most likely compensate for the shorter length. It is, of course, questionable whether the 1/8-statute mile gain, over the 3/4-statute mile minimum available without any ALS at all, would be worthwhile.

CONCLUSIONS

As shown by the data, shortening the system to a length of 1600 feet was not acceptable.

Shortening the system to a length 1800 or 2000 feet may be conceivable if enhancements to the visual segment portion of the system (i.e., additional steady-burning barrettes at 1600, 1800, and/or 2000) would be considered.

Shortening the system to a length 2200 feet will only provide minimal reduction in ground area required, and result in virtually no benefit in reduced equipment or power requirements.

The data also verifies the adequacy of the existing standard CAT I system the MALSR. Even when reduced to three lights per barrette the MALSR configuration was acceptable.

APPENDIX A—COMPLETE LIST OF QUESTION DEFICIENCIES

Configuration A—1600′ system with four strobe lights:

- Stayed on autopilot longer, which helped with height. Visual cue was good enough to continue.
- Felt comfortable, but probably due to more use of autopilot.
- This ALS less helpful than previous, barely visible at DH.
- Without siderow bars (ALSF-2 Red Bars?) amount of deviation from centerline not obvious.
- (Need) more steady burning bars. Only 1 visible.
- At 200′ (DH) don't really see ALS.
- Direction O.K.; roll, height, not much info.
- Marginal—visual guidance lacking.
- Couldn't detect drift (alignment) in time to correct.
- Location of R/W, and touchdown point (lacking).
- Roll (guidance lacking)—lighting system too narrow.
- ALS did not help much w/visual cues. Only good enough to make approach "legal".
- Roll (guidance lacking), none until 1st barrette is visible. Edge of barely acceptable and unsafe.

Configuration I—1600′ system with five strobe lights:

- Height (guidance lacking) even pick up "rabbit".
- Difficult to have sense of height and safe feeling about height perception.
- Low comfort level, but approach can be completed.
- Roll cue is weak. Height guidance is weak.
- ALS not adequate.
- Looked like a normal ALS. Would like siderow bars (Like ALSF2)—can't have too many lights.

- No centerline R/W lights. Very uncomfortable. (Need) wider roll bar @ 1000′.
- Height, roll (guidance lacking) until 1000′ bar is visible.
- Height, depth (guidance lacking).
- Initial access info, seeing 1-3 lights, makes you (feel) secure if it's enough. Would like to see strobes extended further.

Configuration B—1800′ system with five strobe lights (200′ spacing).

- (I) typically look @ ALS very little, and hard to give feedback.
- 3 (steady-burning) lights not enough, each barrette too narrow.
- More light bars (needed) closer to runway.
- Roll guidance (lacking).
- Height, roll (guidance lacking).
- Borderline ALS, almost missed (on run) #18.
- Strobes visible before DN—very comforting.
- Would prefer glowing strobes, system as is is good enough.

Configuration J—1800′ system with five strobe lights (100′ spacing).

- Felt comfortable—possibly due to getting familiar with simulator.
- Lateral alignment with centerline (guidance lacking).
- Best ALS so far.
- ALS visible slightly sooner.
- Depth (perception lacking). Want more light bars.
- Roll mainly lacking. Apparent "hole" in the middle of the ALS.
- Roll, height (guidance lacking).
- System was adequate.

Configuration G—2000′ system with three strobe lights (200′ spacing)

- Space with no lights between last bar and threshold more than (I) would expect.
- Range (guidance lacking).
- ALS very minimal.
- More light bars on both sides of centerline, like ALSF2, would help with drift.
- Guidance is adequate.
- 3 light centerline bars provide better roll guidance (than strobes).
- Good—do not need strobes all the way.
- ALS is marginal.
- Want more roll guidance.
- Initial lack of info in general.

Configuration D—2000′ system with five strobe lights (200′ spacing)

- ALS—Dangerous because initially they look OK and you can continue approach, but then the visual guidance is greatly lacking and the situation become potentially dangerous.
- Threshold not in sight, guidance not good enough.
- ALS seen sooner, possibly due to not operating throttles.
- More bars for drift, inboard of 1000′ bar (needed).
- Best so far.
- This ALS best so far. More roll guidance is needed.
- Best system so far.
- Strobes further out would help, but ALS was adequate.

Configuration K—2000′ system with five strobe lights (100′ spacing)

- Lack of guidance from "Rabbit" (strobes)—"Dark Are".
- Better than 3 light barrettes (subject wrongly thought barrettes had 4 lights in this configuration).
- More steady-burning lights, acquired earlier, would help with drift.
- (There is) gap in improving visual guidance between 1000′ bar and threshold.
- Would prefer brighter barrettes—like the strobes.
- Strobes visible before minimums—helped with early alignment. Steady burning (lights) visible just after minimums.
- Good roll info. Need more intense lights for lateral guidance on L and R of 1000′ bar.

Configuration H—2200′ system with four strobe lights (200′ spacing)

- Centerline oriented sooner. Plenty of lights leading to threshold.
- Good centerline guidance—low workload.
- ALS visible before DH.
- 1000′ bar too far from R/W. Barrettes are too far apart.

- ALS OK.
- Drift (perception lacking).
- Trouble with alignment, don't know why.
- Roll, height (guidance lacking).
- ALS is marginal, in simulator. Some other pilots would do missed approaches, based on ALS's that were visible after minimums.
- Runway lights too dim. ALS was adequate.
- Good cues.
- Best ALS yet—a little bit better than others.
- Anytime lights visible before DH, pilot feels much more comfortable.

Configuration E—2200′ system with five strobe lights (200′ spacing)

- Range to threshold (guidance lacking)—comfortable ALS.
- Low workload—ALS gives good guidance.
- ALS was seen in time.
- 1000′ bar missing—(need) 1000′ bar and closer spaced strobes.
- (Need) more lights for drift—ALS OK.
- Marginal ALS; roll, height (guidance lacking).
- ALS adequate.
- Liked the strobes and triple lights in each barrette.
- Very good ALS.
- Much more comfortable when lights are visible before DH (as with this configuration). Good system.

Configuration M—2400′ system with five strobe lights (200′ spacing)

- Liked this ALS—good guidance to threshold.
- Good roll guidance.
- In sight before DH (on) all approaches.

- Didn't like it. Want more lights on centerline barrettes.
- More side lights would be better (ALSF2 siderows).
- ALS's with strobes look alike. It is the intensity difference that is noticeable.
- ALS seen just before DH.

Configuration C—1400′ system with no strobe lights and five steady-burning light per barrette.

Note: This system was flown in 3200′(5/8sm) RVR conditions, as opposed to 2400′ (1/2sm) RVR conditions for all other configurations.

- Do not like this ALS—used to seeing more lights.
- Missed the touchdown zone and centerline lights.
- Definitely (guidance adequate). Absolutely (should be considered for further testing).
- Bright, simple ALS—easy to use, (I) liked it.
- Lacked lateral cues.
- ALS seen just before minimums—ALS too short.
- Rollout (runway guidance lacking). Lateral (guidance) in the late stages of the approach was somewhat lacking.
- Roll and height (guidance) better than with other ALS's.
- Lack of strobes a neg. Wider (5 light) barrettes seem to help with roll (perception).
- Strobes lacking for early alignment, but ALS adequate.
- Prefer less, but brighter, lights and further out.
- Best ALS for situational awareness. Very good as is.
- Very comfortable—probably due to increased RVR.
- Roll guidance could have been better. Lack of runway centerline lights did detract a little.