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An Evaluation of

Surface-Mounted Lights For Runway Guidance

Final Report

THE INSTITUTE OF TRANSPORTATION AND TRAFFIC ENGINEERING
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Special Study

An Evaluation of

Surface Mounted Lights For Runway Guidance

Final Report

Conducted for the Operations Analysis Directorate, Bureau of Research and Development, Federal Aviation Agency, Contract No. FAA/BRD-4

By Dan M. Finch
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University of California

Berkeley, June 1960

Acknowledgments

The staff is appreciative of the cooperation and helpful suggestions received from the Operations Research Directorate, Bureau of Research and Development, Federal Aviation Agency, the sponsors of this project, particularly to Dr R H Jordan, Director, Mr P S Ball, Chief, Airport and Terminal Analysis Division, Dr H R Van Saun, Chief, Human Factors Division, and Mr E A Cutrell, Consultant

Special thanks are extended to the Public Utilities Commission of the City and County of San Francisco for the use of the facilities at San Francisco International Airport and to Mr Belford Brown, Manager, Airport Department, Mr Victor Philpot, Airport Civil Engineer, and the staff for their assistance in the installation of the experimental lighting pattern

We are also indebted to Mr E P Sullivan, Chief Controller, San Francisco Airport Tower and his staff for their splendid cooperation in handling traffic during installation of the lights and for operation of the system during the period of evaluation

On behalf of the Federal Aviation Agency, the University staff is grateful to the Air Transport Association of America, the Air Line Pilots Association, and the individual pilots for their participation in the evaluation of the experimental lighting pattern

For the Institute, Messrs Don Dunlop, Jerry Howard, Russell G Newcomb, John W Nauta, Thomas W Pickrell, and Gordon Brown assisted in the installation of the test facilities and conduct of the tests Mr Wayne H Snowden edited the report and supervised its production

Contents

Summary

This report concludes work that has been in progress since 1958 on runway and taxiway guidance under contract FAA-BRD-4, particularly that phase having to do with an experimental lighting system at San Francisco International Airport

The concept of providing visual guidance by means of closely spaced, low-wattage light sources mounted on the surface of the runway or taxiway in lineal patterns is described in this report as well as in the prior reports related to this contract

The centerline lighting system at San Francisco International Airport was rehabilitated after the 1958-59 tests to permit further evaluation during the winter of 1959-60 It turned out that the 1959-60 winter season was very mild, there were, however, some periods of reduced visibility wherein a limited amount of bad weather evaluation was obtained

The 1959-60 test data verified the previous observations in which very favorable pilot reactions were obtained in clear weather operations The few observations that were made in poor visibility also indicate that the centerline system is a desirable adjunct to the existing lighting system But an evaluation of the system in very poor visibility conditions is still incomplete

Hardware development and installation problems associated with the application of small, low-wattage lights have for all practical purpose been solved through the work of various agencies The roughness has not proved to be a problem and new designs are now available with even lower projections above the runway

The principal problem that remains to be solved is what pattern and brightness will best serve the visual requirements of the pilot? The narrow-gauge arrangement now under evaluation is only one of several which need to be investigated In fact, there is some evidence that it may not be the best configuration Work needs to be continued on this aspect of the visual aids problem

1. Introduction

This report covers an extension of work on runway lighting that has been underway since 1958 and previously reported upon in an Interim Report dated April 1959,[1] as well as in a report on exit taxiways dated August 1958.[2] This report concludes the work on runway lighting under contract AMB-BRD-4

The previous reports covered (1) the initial experimental work on taxiway guidance at McClellan Air Force Base, (2) the development work on patterns of light in an experimental fog chamber, (3) the San Francisco Airport installation of the runway centerline lighting system, (4) a pilot evaluation of the San Francisco installation, and (5) a report on the exploratory work on roll-out guidance that was done at the Dow Air Force Base in conjunction with Project Narrow Gauge

The present report covers the continuation of operational tests at the San Francisco International Airport and other work that has been completed since the submission of the Interim Report

After reviewing the Interim Report, the Federal Aviation Agency felt that it would be advisable to continue operating the centerline lighting system at San Francisco for at least one additional winter season in order to get more pilot evaluation and experience on the installation in low-visibility weather This decision stemmed primarily from the fact that the evaluation by pilots had been largely under conditions of relatively clear weather In addition, it was thought desirable to obtain more pilot reactions to the mechanical effects experienced as aircraft travelled over the fixtures Finally, additional data on maintenance of the lights in the touchdown zone was deemed to be desirable

2. Procedure

A description of the installation including the basic information on the lighting fixtures and the wiring is given in the previous Interim Report referred to above The layout of the system is shown in Fig 1, and the installation details are shown in Fig 2

Because the original installation was designed for experimental purposes, not for permanent operations, continuation of the project for another winter season required rehabilitation of the centerline system This meant that all of the wires, some of which were previously taped to the runway surface, had to be imbedded in the pavement This was accomplished by cutting grooves 1/4 in wide and 3/4 in deep in the runway adjacent to the line of fixtures, using a concrete saw details are shown in Fig 2

Other changes included soldering all pigtail connectors to the feeder lines and soldering all electrical joints where the lateral supply lines met to furnish power to the longitudinal centerline branch circuits (after various types of solderless connectors had been tried without success) The variable-spacing circuits previously used were eliminated, providing an installation in which all centerline lights were switched on or off together. The lights at the threshold end (in the 200-ft-long parallel lines) and in the transverse bars (on 100-ft centers) could, however, be

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1 Finch, Dan M , Horonjeff, Robert, Ahlborn, Gale, Howard, Jerry, and Dunlop, Don An Evaluation of Surface Mounted Lights for Runway Guidance An Interim Report conducted for the Operations Analysis Directorate, Bureau of Research and Development, Federal Aviation Agency, Contract No FAA/BRD-4 April 1959 31 pp

2 Horonjeff, Robert, Finch, Dan M , Belmont, Daniel M and Ahlborn, Gale Exit Taxiway Location and Design A Research Project conducted for the Airways Modernization Board, Contract No AMB-4 August 1958 90 pp

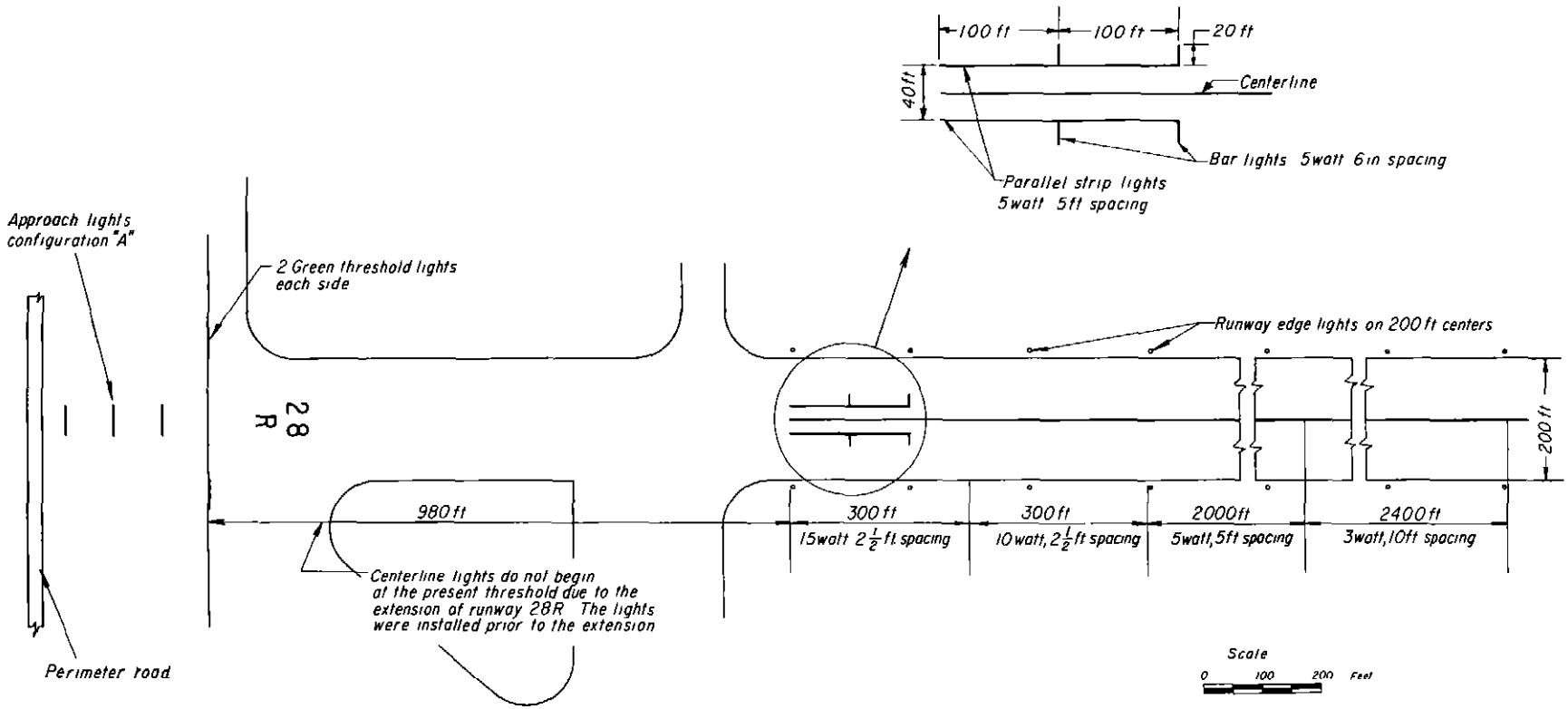

Fig 1 — Installation at San Francisco International Airport after Dec 15, 1959 (extension to Runway 28R completed)

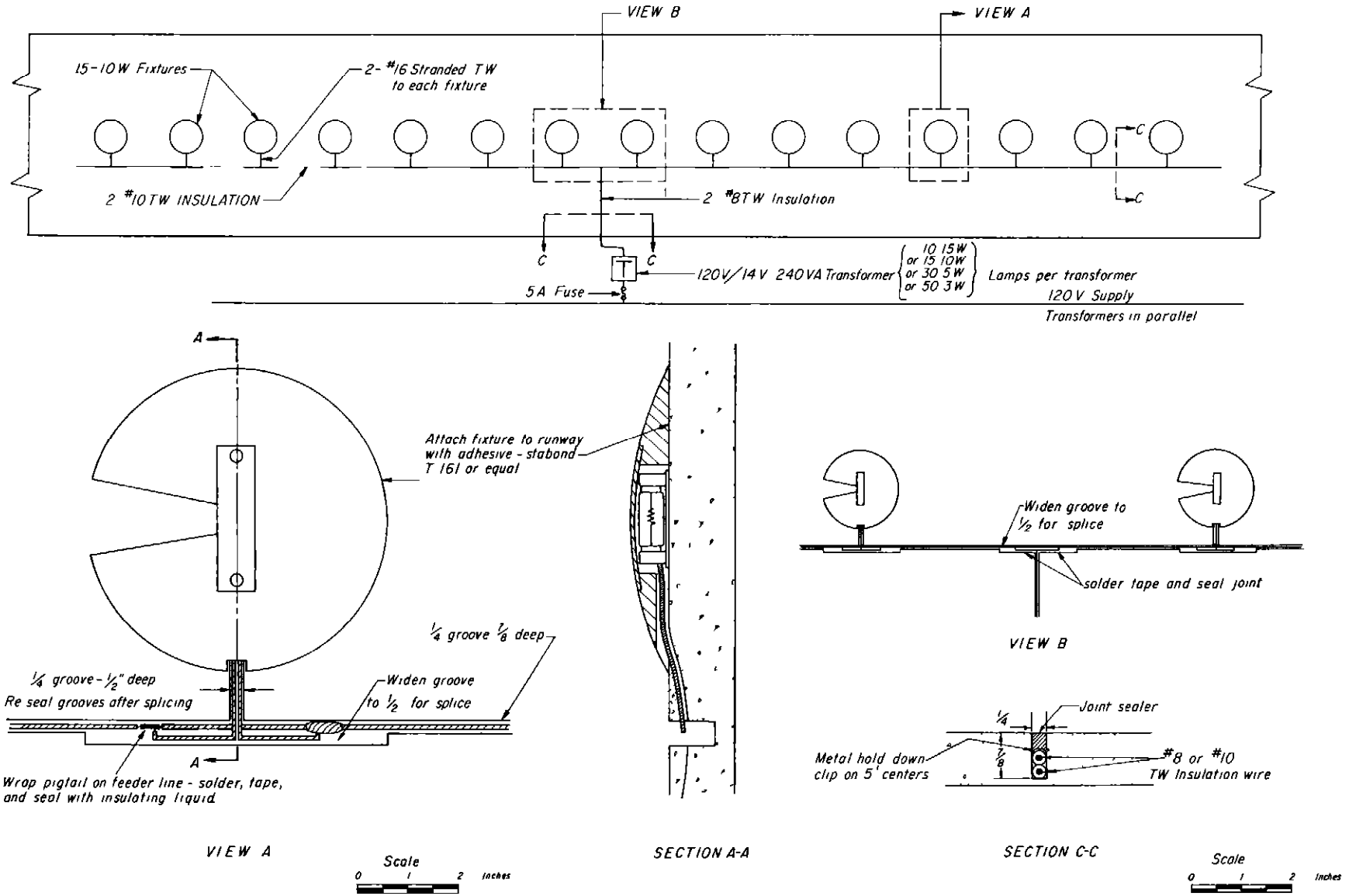

Fig 2 — Detail of fixture and wiring connections

switched separately Each lighting circuit was independently fused and supplied by its own transformer at the side of the runway (previously, several circuits had been interconnected in a parallel system) The separation facilitated trouble-shooting and maintenance

Primary distribution wires were placed along the edge of the runway, lying on the ground The supply wires were all bussed together and additional copper was added to the initial system to reduce the voltage drop at the threshold end of the runway Additional copper was provided in several parts of the system to reduce previously observed voltage drop

In order to determine how many times the system was used and how long it was in use each time, a set of counters and time registers were added to the control system in the Field Lighting Building

Flight questionnaires were again distributed to the airlines The Operations Office of each airline was asked to have a few key pilots use the lighting system preferably under conditions of IFR (poor visibility) and to fill out the questionnaires A sample of the questionnaire is included in the interim report

The control tower personnel were asked to obtain comments of the pilots during low visibility weather conditions whenever feasible

Arrangements were also made to fly in a small aircraft (Cessna 310) equipped with full instrument landing facilities, so that observations and photographs could be made by project personnel during conditions of minimum visibility

The lights were in place on runway 28R continuously from the start of the project in October 1958 Between March 1959 and December 1959, they were available to the pilots, but they were not maintained on a regular basis The rehabilitation of the centerline lighting system was completed on December 15, 1959, the counters and time registers were in operation on December 18, 1959, and the lights were in operation through March 7, 1960, after which they were disconnected and dismantled

3. Results

The total usage for landings as automatically recorded is shown in Table 1 It will be noted that the low brightness setting was requested 4 times for 3 5 hours, medium brightness, 34 times for 22 5 hours, and high brightness, 33 times for 17 0 hours In 79 days, 71 landing aircraft requested the use of the lights They were in operation for 43 hours, always in conjunction with the approach and runway edge lights

The requests were made directly to the control tower by the pilots No record is available of the visibility conditions when the requests were made It is known, however, that poor visibility conditions did prevail at times during the 79-day period

On the assumption that at least some of the landings occurred in poor weather, the large number of requests for medium and high brightness would seem to indicate that the low brightness setting was not satisfactory for conditions of restricted visibility

Under conditions of partially restricted visibility the medium setting was probably satisfactory, while for the more severe weather conditions — near the minimum permissible for landing at San Francisco (200-ft ceiling and 1/2-mile visual range) — the high brightness setting was apparently desirable

Unfortunately, there were very few periods during the winter of 1959-60 when minimum weather conditions were encountered Thus the question of the brightness requirement still remains unanswered

On December 11, 1959, between 9 45 and 10 15 a m , eight aircraft landed when the weather was near 1/2-mile visual range and 200-ft ceiling The weather was clearing rapidly toward the end of the interval The airport had been closed for more than an hour because of ground fog There were a number of aircraft in the stack waiting to land The pilot of the first aircraft requested that the centerline lights be turned on at the high brightness setting More aircraft landed later in the morning, but both the visual range and ceiling were rising rapidly Each time an aircraft landed the control tower personnel solicited comments from the pilots concern-

TABLE 1 – RECORD OF USE OF CENTERLINE LIGHTS

Date of Recording of the Registers	No Days in Interval	Low Brightness		Medium Brightness		High Brightness	
		No Times Operated	No Hrs Used	No Times Operated	No Hrs Used	No Times Operated	No Hrs Used
Dec 18 1959	0	0	0	0	0	0	0
Dec 28	10	3	0 5	3	2	3	0 1
Jan 9 1960	12	0	0	7	1 5	3	4 1
Jan 15	6	0	0	2	0 5	2	0 1
Jan 21	6	0	0	4	3	3	0 1
Jan 27	6	0	0	5	2	2	0 2
Jan 30	3	0	0	1	3	3	1 9
Feb 2	2	0	0	0	0	8	6 3
Feb 12	10	0	0	0	0	1	1 8
Feb 18	6	1	3	0	0	2	1 2
Feb 19	1	0	0	0	0	1	0 7
Feb 23	4	0	0	6	6 5	0	0
Mar 2	8	0	0	5	3	0	0
Mar 7	5	0	0	1	1	5	0 5
TOTALS	79 days	4 times	3 5 hrs	34 times	22 5 hrs.	33 times	17 0 hrs.

ing the experimental lights The pilots of the first two aircraft indicated that the lights were quite helpful in maintaining alignment and in identifying the runway surface The other pilots, especially Nos 6, 7 and 8 in the sequence, indicated that the lights were not of any particular help to them This is understandable since the fog was dissipating rapidly toward the end of the above period and the pilots could clearly see most of the essential surface detail on the runway including the paint markings, edges, etc Under such conditions in the daylight it is questionable whether any lighting system is necessary

On October 22, 1959, a Pan American Airways aircraft landed during the early morning hours before daylight in near minimum visibility conditions After holding a nominal amount of time he was permitted to make an approach The centerline lights were turned on at the high brightness setting The aircraft came in and landed The airport operations supervisor on duty at the time made an entry in his daily log book of which the following is an extract

"Building and areas quiet through most of this shift The ceiling and visibility was up and down from midnight to about 0600 Pan American flight 516 arrived about 0500 with a reported 300 feet and 1/2 mile, while taxiing in a special was sent that showed 1/2 mile and 100 feet Talked to the pilot and asked his opinion of the centerline lights and he stated that they were the answer to weather landings He also stated that without them he didn't think that he could have made it This info might be forwarded to Mr Horonjeff The field construction inspector was in and stated that they had a lot of work to do at the end of 28R and requested that the runway be closed for landing This request was granted "

No extensive criticisms have been received with regard to visual problems created in landing or take-off on lights imbedded in the runway Only a few pilots have objected to landing on top of

an array of lights The few objections were usually to the initial experience After a few trials the objections usually subsided

During the year and a half that the lights were on Runway 28R at San Francisco, pilots registered no complaints as to roughness, either with the operations office at the airport or with their own company representatives During interviews with pilots and in general discussions on the subject of roughness, it was brought out that the bumps were noticeable but not objectionable

In order to gain first-hand experience with the lighting system and to get some photographs of the installation, personnel of the project made test flights on February 24, March 2, and March 7, 1960 The March 2 flights included several simulated landings, made at about 10 a m with a 300-ft ceiling and 1-mile visual range It was found in these tests that as soon as one broke through the well-defined ceiling and had more or less unrestricted forward visibility, it was not necessary to have any lighting on the field When the plane was at a substantial distance from the threshold, on the approach, the strobe lights in the approach lighting system were helpful, and at a later time, while still in the overcast, the regular approach lights became visible This occurred at about the time that the ceiling was penetrated, and from there on in little if anything was gained from any lights

The landings were recorded on 16 mm film and are submitted as part of this report In addition, still photos were taken in clear weather at night from various positions along an approach path (Figs 3 to 11)

4. Other Developments Since Interim Report

Since the issuance of the interim report, additional pilot questionnaires were received The questionnaire is shown in the Interim Report Table 2 summarizes the results of the additional questionnaires The 10 responses shown in Table 2 are supplementary to the 60 reported in the Interim Report Although the lighting installation was designed primarily for use in low-visibility conditions, the 10 questionnaires received since the Interim Report were all for clear weather The clear-weather performance of the system is generally very good as indicated in Table 2 and in the comments included below The same reaction was noted previously in the Interim Report We would now expect more of the same in any future clear-weather evaluation The unedited comments of the pilots on these supplementary 10 questionnaires are as follows

1 Centerline lights very good for directional guidance
2 These lights are a distinct assist and, I believe, a better aid than the runway side bar or fluorescent lighting such as is installed at DCA, which seems to me to include leveling off a little high
3 This system is far superior to any I've used to date
4 Do not feel this system any better than floods used at Washington National in conjunction with flashing strob light on approach lights However, I have only used this SFO light system twice and both times under CAVU conditions It is possible that using it under low visibility – IFR conditions will bring out its best and new abilities
5 I have made three landings using the centerline lighting at San Francisco and find they were all effected by poor depth perception due to reflection from the centerline lights one in particular was made on a wet runway with light rain, reflection distorted depth perception so bad that we found it necessary to apply power and drag the runway and feel for a landing In my opinion the system presents no improvement over the conventional system having lights along the edges of the runway
6 Runway approach lites, threshold lites, and lites on touch down area are desperately needed with faster equipment coming on and wet runways requiring the jet to touch down in the proper spot to make a safe stop A report on one landing, such as this, is not sufficient to judge a system I urge you to use your good offices to set up many testing and evaluation procedures so we can get good lighting and standard lighting so one can make the same safe approach and landing no matter which terminal or runway he may be using

TABLE 2 — SUMMARY OF PILOT EVALUATIONS

Total of 10 questionnaires

	Evaluation	Number of Answers				
		For nighttime visibility of			For daytime visibility of	
		More than 2 miles	1 to 2 miles	Less than 1 mile	More than 2 miles	1 to 2 miles
1	The centerline lights were first seen					
	a Before reaching the middle marker	9			1	
	b After reaching the middle marker	0			0	
	c Not until the runway threshold was seen	0			0	
2	Brightness of centerline lights at threshold was					
	a Satisfactory	9			1	
	b Too bright	0			0	
	c Not bright enough	0			0	
3	Brightness of centerline lights at flare-out was					
	a Satisfactory	7			1	
	b Too bright	2			0	
	c Not bright enough	0			0	
4	The bar and parallel strip lights					
	a Were a help in identifying the runway threshold	8			1	
	b Were NO help in identifying runway threshold	1			0	
	c Were a help in aligning aircraft with centerline	7			1	
	d Were NO help in " " " "	2			0	
	e Were an aid in perceiving height above runway	7			1	
	f Were NOT an aid in " " " "	2			0	
	g Helped in defining aircraft attitude	2			1	
	h Were of NO help in defining aircraft attitude	7			0	
5	Extension of the parallel strip and bar lights					
	a Would have been an aid to you in this landing	3			1	
	b Would have been of NO aid in this landing	6			0	
6	Directional guidance of centerline light was					
	a Superior to conventional system of lights along runway edges	8			1	
	b NO improvement over the conventional system	1			0	
7	Roughness caused by rolling over the fixtures					
	a Was tolerable	8			1	
	b Was NOT tolerable	1			0	

7 This was my first experience with these lights and I thought they were great! The DC7C has very poor landing lights compared to previous aircraft I have flown and these new runway lights illuminated the runway so that a better and safer landing could be made

I believe, from the first experience, that the combination of these lights and the conventional lights are better than either one alone There was no question at any time of exactly where one was — both in last minute altitude and distance down runway after landing It is a lot simpler to look ahead down runway rather than be glancing sideways at lights on edges of runway

An extension would probably be a "refined improvement" but I would like more experience on that before reaching final decision They should not be less than the 5000' as during certain conditions a long landing might be made In that case it would be necessary to know how much runway remains With the present 5000' of lights, after rolling beyond them, the pilot then would know how much runway remained and therefore with that knowledge would not have to execute a 'go around "

I think they are excellent and contribute to better approaches, better landing, and safer conditions all around

8 Roughness of raised lights as nosewheel passed over same at high speed was marginal The impact was clearly felt in the aircraft

9 Parallel lines of lights would be more useful than single row

10 Weather — overcast @ 50T — Very light rain — pre-dawn
Lights appear "grouped" @ middle marker — unable to pick out markers, etc Centerline lights are bothersome — most pilots landing to one side or the other to avoid them

The lack of visual assistance noted in answers 4d, 4f and 4h in the questionnaire in correcting the attitude of the aircraft is explained by the fact that a single centerline will not give complete information on bank, pitch, height, or distance-to-go along the runway It does provide directional guidance and in conjunction with the runway edge lights a centerline will fill in much of the needed information in attitude and height But more pattern on the runway such as the parallel lines suggested by one pilot will be required in a final system

The objection to landing on the lights as expressed by one pilot is a matter of experience and training With very few exceptions, the commercial airlines pilots using the San Francisco installation have not expressed any objection to landing on the lighted runway It may be noted, however, that at flare out in clear weather, a substantial percentage of the pilots objected to the high brightness of the lights

It was with this in mind that the wattages were tapered from 15W to 10W to 5W to 3W along the centerline Perhaps the transition used at San Francisco was not rapid enough This feature should be noted by designers of runway lighting systems and caution should be used in placing high wattage, high brightness sources in the flare-out region of the runway

Since the initial concept of small button lights was introduced, a number of significant developments have occurred which have established the practicability of the concept as follows

1 The Dow AFB tests on Project Narrow Gauge have been completed * It was observed in these tests that the 3,000 ft of narrow gauge lights placed on a 60-ft gauge beginning at the threshold was not entirely adequate for landing aircraft during very low visibility conditions The aircraft were touching down at or near the end of the 3,000-ft narrow gauge system The pilots needed additional guidance beyond the end of the system A centerline was installed using 10- and 5-watt lights spaced 12-1/2 ft centers The centerline system provided adequate roll-out guidance for all aircraft in the test program and was a very desirable supplement to the narrow gauge lights Accordingly the U S Air Force is advocating the use of the small button lights for delineating the centerline of the runway beyond the narrow gauge lights

2 Military specification No MIL-L-27237 (USAF), was issued on September 9, 1959, specifying the button lights to be used on military airfields a unit approximately 8 in in diameter,

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* Strong, Col Roy L Category III Test of an Integrated Approach and Landing Aid System Westover AFB, Mass Eighth Air Force, June 1959

with a 45-watt quartz lamp, installed so that its top is essentially flush with the runway surface This specification, other than the power of the lights, is a direct outgrowth of the hardware and concept which was conceived at the University and tested at Dow Air Force Base (10- and 5-watt lamps proved satisfactory in the Dow tests)

3 The U S Army Corps of Engineers has developed a procedure for installing the button lights at military airfields This procedure is summarized on drawing No V-2-17-1, "Installation Details Pancake Centerline Lighting in Rigid Pavement Runway" which has been prepared by the Ohio River Division Laboratories, Mariemont, Ohio, dated November 1959 The Corps of Engineers has worked out details concerning concrete sawing, grooving, cylindrical core cutting and the use of epoxy resins

4 The Federal Aviation Agency's reaction to the concept of small, closely spaced, low-wattage lights has been favorable Using this concept, the FAA undertook to develop the hardware for general airport use The FAA refers to these lights as "pancake," and to the experimental lights developed by the University as "button," over-all dimensions of the two units are nearly the same

The "pancake" lights have been installed on a runway and a taxiway at the National Aviation Facilities Experimental Center* at Atlantic City, N J along with other types of lights The evaluation of the "pancake" lights is now under way under the project name of "Operation White Way " The pancake light utilizes a 45-watt lamp

5 On February 2, 1960 the New York International Airport placed in service a new runway (4R-28L) that is equipped with centerline lights of the Elfaka design on 100-ft centers This runway has four high-speed exit taxiways (two in each direction) that are also equipped with centerline lights, these are pancake type on 20-ft centers It is expected that operational results will be available soon Preliminary information from the Port of New York Authority engineers and personal observations by our personnel indicate that the guidance system on the runway and the exit taxiways is working very well Pilots regarded the centerline lights on the exit taxiways as too bright when they were operated at the full 45-watts, they have since been operated at about 10-watts

6 A centerline lighting system consisting of small 5-watt, button-type lights spaced 25-ft has recently been installed on a 1500-ft taxiway at San Francisco International Airport It is planned to have the switching arranged so that the centerline or edge lights or both will be available Pilots' opinions of the installation will be obtained

7 A number of foreign airport operators are experimenting with the button lights At Malmo, Sweden, a combination of centerline lighting and modified runway edge flood lighting is being used At Stuttgart, Germany, a research group has several of the University of California lights and is experimenting with the centerline patterns and hardware In England, several firms are building button-type units for experimental use In France, several airports including Orly Airport at Paris are experimenting with the button lighting concept

8 Manufacturers of the lighting fixtures and components have been busy during the interval since the completion of the Interim Report The manufacturers of low-wattage bulbs in Europe, namely, Osram, Phillips, and Lucas, at our suggestion, have worked on improvements in tubular bulbs We now have samples of the improved bulbs in all wattage sizes in the same size glass envelope so that the 3-, 5-, 10-, and 15-watt bulbs can easily be interchanged A treated glass is now available which will improve the thermal shock characteristics The end cap contacts are attached with a waterproof cement to provide better weathering These improvements should eliminate many of the service failures experienced during the initial investigations Several American manufacturers (General Electric Co and the Tung Sol Electric Co) have also developed tubular-type bulbs that will serve both for airport lighting units and for automotive purposes

In the field of higher wattage bulbs, the quartz-incandescent lamp has appeared in 25-, 45-, 100-, and 200-watt sizes These are currently being made by the General Electric and Sylvania companies The quartz lamp has several features that are claimed as advantages

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* Along the centerline of the entire runway on 20-ft centers, and along the centerline of one high-speed exit taxiway on 10-ft centers

It operates on an iodine cycle which keeps the bulb walls clean on the inside by removing the black tungsten deposits that normally occur If operated at the design temperature the bulbs remain almost constant in brightness throughout their life The quartz envelope is impervious to thermal shock, as from rain, snow, cold blasts of air, etc The surface temperature of the quartz bulb is said to be high enough to burn up dirt accumulations on the surface (this claim remains to be verified by service testing) The 45-watt quartz lamps are being used in the NAFEC tests and in the lamps installed at New York on Runway 28L-4R Service test results should be forthcoming in the near future

Manufacturers of transformers and service components have indicated a willingness to build direct-burial transformers to FAA specifications for use with the 45- and lower wattage bulbs A tentative design has been worked out by one of the manufacturers for the 5-watt lamps to be installed in the taxiway centerline of the San Francisco International Airport

Film cut-out units have been made available for the 45-watt bulbs, permitting their use in series circuits If one lamp burns out, the film cut-out will short and the remaining lamps in the circuit will continue to operate Series circuits have the advantage of simpler wiring

5. Observations and Conclusions from Tests

1 Pilot reactions to the lighting system set in at the San Francisco International Airport on Runway 28R have generally been favorable for the nighttime and semi-dark conditions, in clear weather and in the few times when visibility was restricted Many personal interviews with pilots who have used the lights have corroborated the above conclusion The test program is inconclusive insofar as very poor visibility conditions are concerned

2 Daytime operation of the centerline lighting system with ceilings of 200 ft or more indicate that under these conditions the lights are of questionable benefit When an aircraft breaks through a 200-ft or higher ceiling in daytime, the pilot can see the runway threshold, the edges, the markings on the surface, and other items in the surrounding terrain which give him the required visual information to proceed with the landing The lights can be seen, but they add very little This conclusion does not imply that the lights would not be helpful in the daytime if the overcast extended to the ground Under such conditions the aircraft would not break out into relatively clear air and the visual range would be restricted all the way to the touchdown point Under such conditions the lights would undoubtedly aid the pilot

3 The roughness of the button lights on the surface of the runway in the touchdown zone and in the roll-out zone was not a problem with any of the commercial aircraft The pilots did not complain about the roughness, but when asked, stated that they could feel the lights The surface roughness is more pronounced for smaller aircraft While no actual structural damage was rendered to any of the aircraft using the runway, the pilots may have had psychological reactions against the periodic bumping caused by the lights, especially if they did not know what the bump was due to After the pilots had gained a little experience with the lights and found they would not cause structural damage, there was practically no hesitation in using them and they merely moved slightly to one side to eliminate any psychological annoyance

4 The installation techniques are now largely solved The electrical circuit for the system can be set up on either a series or a multiple system Transformers, current regulators, and control gear are all available The wire sizes and connections have been worked out with practical methods developed by the Corps of Engineers, the Federal Aviation Agency, the Port of New York Authority, and the University of California There are practical methods of sawing, slotting, and counterboring in concrete and asphaltic materials, and epoxy materials have provided a means of setting and holding the fixtures in place

5 Dirt accumulation was not a problem on taxiways or on the roll-out area of the runway Propeller or jet blasts tended to sweep dirt out of the lamp compartment In the touchdown zone, however, accumulation of rubber proved troublesome Upon tire contact at touchdown some rubber is vaporized, this vaporized rubber condenses on all objects nearby — including

fixture and bulb if the point of contact happens to be near them After repeated tire contact bulbs became nearly black and sometimes almost opaque Cleaning with carbon tetrachloride by means of a small, power-rotated brush proved effective but somewhat laborious It is possible that a better cleaning technique can be developed

Proponents of the 45-watt quartz bulb indicate that its 350°F surface temperature, being high enough to evaporate rubber, may make cleaning unnecessary This would argue for use of this bulb in the touchdown zone

6 Snow was not involved in the tests at San Francisco It is understood however that in snowplow tests at NAFEC and at New York International Airport lighting units sealed in an epoxy resin stood up adequately Snowplows operated at up to 45 miles per hour with blades resting on the runway surface without structural damage to the lighting units or plows Ice, rain, snow, and other slush or muck conditions will not bother the electrical operation of the units Adequate heat is developed in even the low-wattage units to melt ice under most temperature conditions In extreme cold, it may be necessary to use the higher-wattage units, such as the 45-watt quartz lamp Rain and slush will not cause failure due to thermal shock in any of the units using improved low-wattage sources

6. Concluding Remarks

It has been several years since the initiation of the first project in this country concerned with placing lights in the runway It may be helpful to review the accomplishments to date The experiments at Dow Air Force Base, at San Francisco International Airport, and the permanent installation at New York International Airport all indicate that lights in the runway pavement proper are an improvement over the conventional system of lights along the edges of the runway Rapid strides have taken place in the development of the hardware for installation in the pavement

What is urgently needed is the establishment of the light pattern which will be most beneficial to the pilot More information is needed on spacing and intensity Neither has been demonstrated in a conclusive manner by the live tests to date The fact that pilots are favorably inclined to the narrow-gauge pattern (as at Dow AFB) or centerline (as at San Francisco) merely indicates that something installed in the pavement surface is more desirable than nothing at all

In the San Francisco tests only a single centerline was used This was considered to be far better than no centerline and did give alignment information and some feeling for the surface in the central area of the runway Additional parallel lines have been proposed and have been tried on the DALTO Simulator at NAFEC The parallel line pattern has been favorably received by most pilots that have used the simulator Also, the continuity or degree of discontinuity that a line may have and still remain useful as a guideline is still not settled

The live tests that are continuing at NAFEC and the installation at New York International Airport will possibly shed some light on the problem of intensity and spacing but not much on pattern The lighting installations at both places are on 20-ft centers and use 45-watt lamps in the lighting units

The importance of the direction of the lines on the runway is quite evident in the tests that have been made to date Both still photographs and motion pictures make it apparent that in restricted visibility the longitudinal lines are more visible than the transverse lines This statement has been verified by observations of many people The longitudinal pattern provides a system where the individual light sources add up to develop a higher effective brightness This effect occurs under both static and dynamic conditions if the longitudinal spacing between light bulbs is close to the minimum angle of resolution In longitudinal lines, even though the spacing is quite substantial, the effect of motion causes a foreshortening in the longitudinal direction and the persistent trace on the retina of the eye further merges these sources together to help develop a continuous lighting pattern Transverse lines, on the other hand, tend to be seen as individual light sources The above effects under reduced weather conditions are even more startling Our tests point out the desirability of building up the brightness pattern on the runway using longitudinal rather than transverse lines

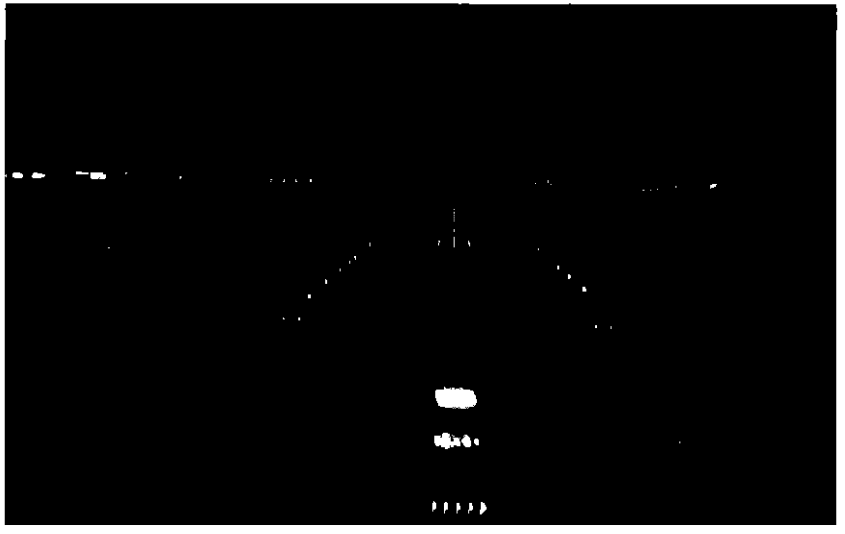

Fig 6 — On ISL glide path, 1,000 ft from threshold

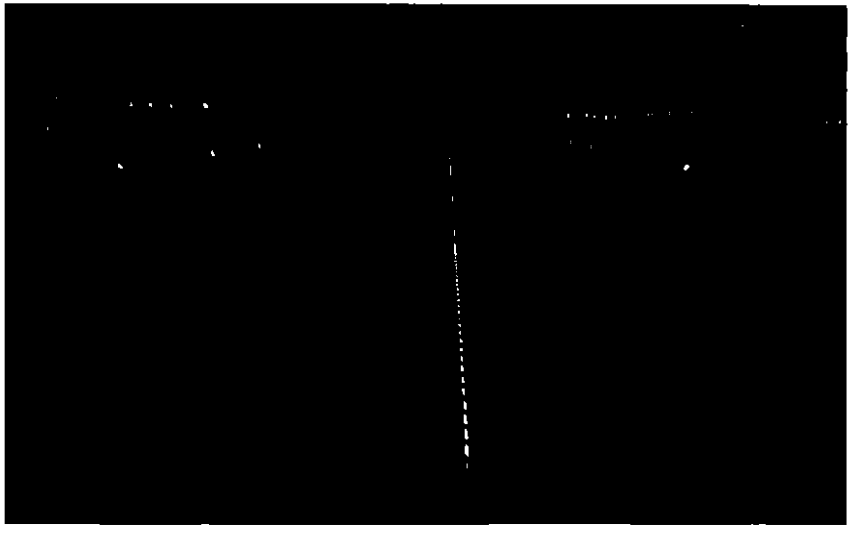

Fig 10 — On roll-out, 2,000 ft past threshold

Fig 5 — On ILS glide path, 3,000 ft from threshold

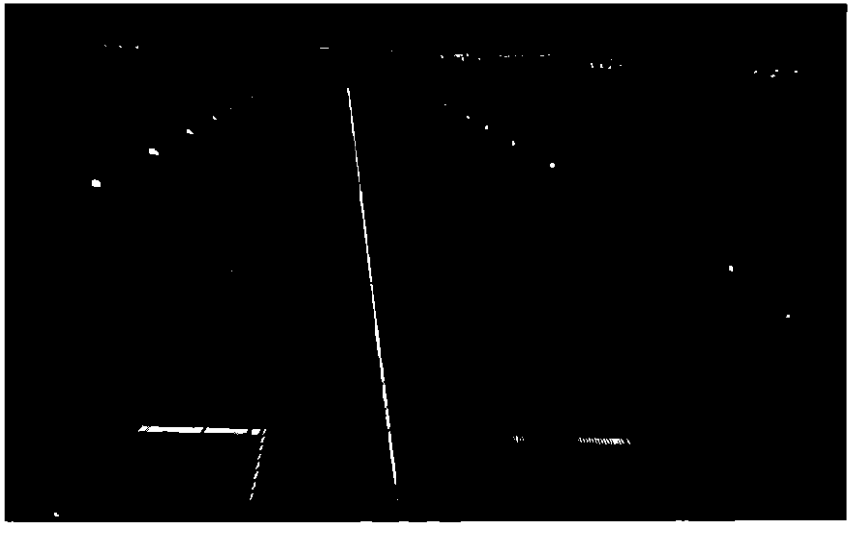

Fig 9 — At flare-out, 20 ft up, 1,000 ft past threshold

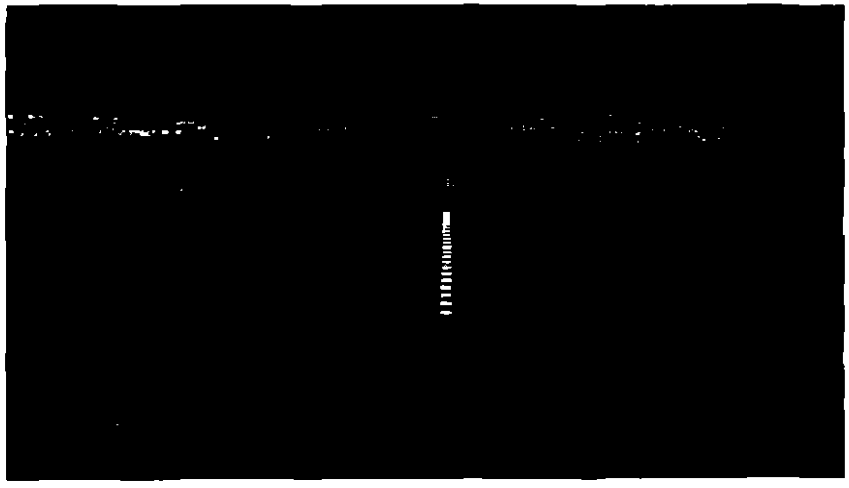

Fig 4 — On ILS glide path, 1-1/2 miles from threshold

Fig 8 — Past threshold by 800 ft

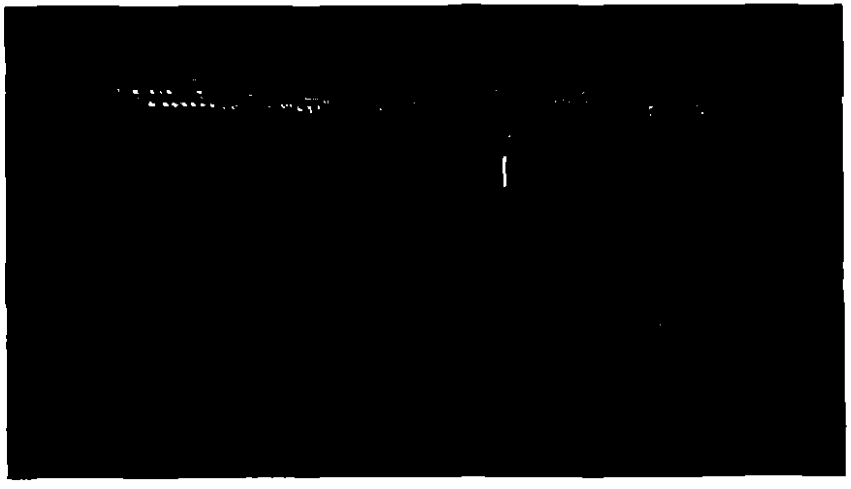

Fig 3 — On ILS glide path, 3 miles from threshold

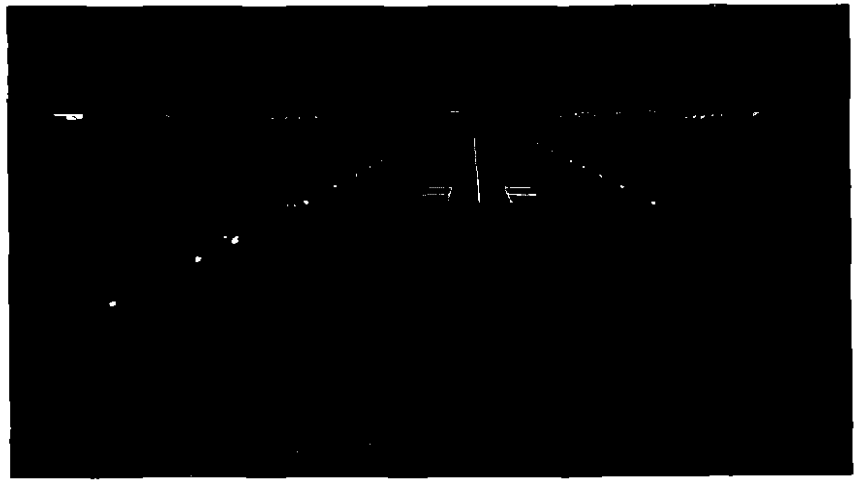

Fig 7 — Over threshold

Figs 3 to 10 depict in sequence (left bottom to top, then right bottom to top) a landing on Runway 28R at San Francisco International Airport, Feb 24, 1960 Lights are set for medium brightness Spacings and bulb ratings are as shown in Fig 1 (page 2)

The need for meaningful patterning of the lights in the runway is also evident from the tests and the photographs The supplemental information that was supplied by the small amount of additional lighting at the threshold is quite significant if one compares the visual information in and around the threshold region with that after the threshold is passed This effect may be noted in the sequence of pictures shown in Figs 3 to 10 There is evidence to show that the centerline does provide directional information in the air and adequate information on the ground for roll-out But it does not give enough information on height or rate of closure with the runway, or distance left to go along the runway Also a single centerline can be confusing insofar as roll or bank is concerned if one is not directly over or aligned with the centerline pattern Under conditions of lateral displacement, it is not immediately evident from a single centerline whether or not the aircraft is in a bank or is laterally to one side of the line Such information becomes abundantly clear, however, when multiple lines are present in the field of view Thus, the runway edge lights plus the centerline are adequate under normal conditions to supply most of the visual information needed On the other hand, when the weather is bad, additional linear patterns and surface texture information in the pavement are quite desirable

The question that may arise is just what has the San Francisco installation accomplished? It has not settled any of the basic issues (pattern, intensity, spacing) previously mentioned However, by exposing the system to a wide cross-section of line pilots and aircraft (including jets) the project has been useful in demonstrating the practicability of using small closely spaced lights for guidance Scientific analysis and experiments are important steps in research of this kind but final acceptance must come from the operators of aircraft We believe that the installation at San Francisco has been useful in this regard

So far, only the runway and exit taxiways have been discussed It seems to us that button lights are ideal for general taxiway guidance On other than high-speed exit taxiways it would seem to us that a fixture more economical than the one currently developed for the FAA can be devised The taxiway installation at San Francisco International Airport previously mentioned will provide information on this matter With centerline lighting on taxiways the need for conventional blue side lights should be investigated

Finally, there is a need to establish the role of the conventional runway edge lights If lights are placed in the pavement as a centerline or in other patterns, do they and the runway edge lights need to be high intensity? Our experiments and experience to date would lead us to question the need for high-intensity lights, except in the approach zone