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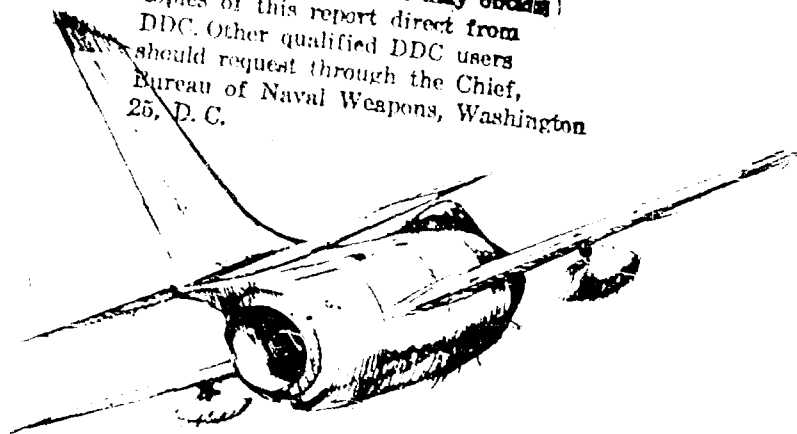
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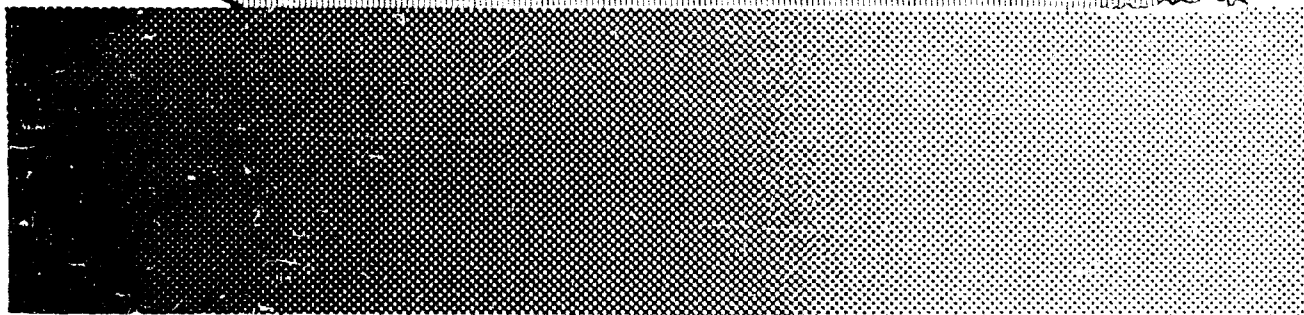
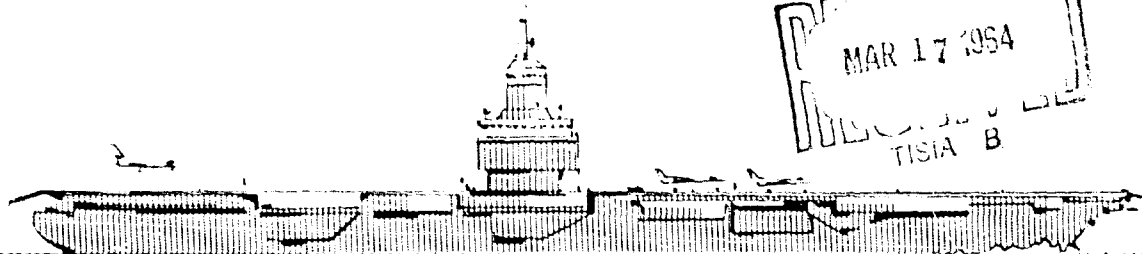
REPORT 10129

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FINAL REPORT of PHASE 1
A Study for the Development of
Improved Visual Landing Aids

DDC
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HAZELTINE

Final Report of Phase 1

A STUDY FOR THE DEVELOPMENT OF
IMPROVED VISUAL LANDING AIDS

Contract No. 156-44303

Problem Assignment No. RSSHO5-104/1

February 24, 1964

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SUMMARY

This report describes the findings and recommendations of a study conducted by the Hazeltine Corporation in accordance with Contract N-156-44303 issued by the Naval Air Engineering Center in Philadelphia. The object of the study was to investigate possible methods of improving the capability and performance of visual landing aids for aircraft carriers of the U. S. Navy.

The Study included observation of present carrier aircraft operations, consultation with personnel of a number of cognizant agencies, and a review of literature relating to developments in aircraft visual aids in Australia, the United Kingdom, and the United States. The data indicated a special need for improvements in visual cues for night operations.

Starting with a list of possible types of visual cues, and possible installation sites for carrier visual aids, twelve new design concepts were generated. These concepts were then evaluated from the standpoints of feasibility, expected system gain, and probable magnitude of developmental effort required for implementation.

As a result of this analysis, certain concepts are recommended for further development in the next phase of the program.

Two other concepts, which were slightly outside the terms of reference for this study, emerged as by-products of this program. One is recommended as a supplementary visual aid for airfields (particularly SATS facilities); the other is recommended for development as a future instrument approach system for carrier operations. Descriptions of both concepts are included in Appendix A of this report.

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SECTION I

INTRODUCTION

A. BACKGROUND

Since World War II, the approach speeds of carrier-based Navy aircraft have increased greatly without a comparable increase in the dimensions of the usable landing area. These factors, together with the relatively slower response of these aircraft under approach conditions, have further increased the need for accurate and precise control of the flight path, approach speed, and sink rate of carrier landings.

Over the years, the Navy has sought continually to improve the safety and efficiency of carrier operations. Two of the most important improvements which have emerged since World War II are the angle deck and the optical landing system.

The angle deck has increased safety by providing a missed approach path which is completely clear of the takeoff and parking areas. The angle deck has increased traffic capacity by allowing takeoffs and landings to be conducted independently, at the same time.

The optical landing system has simplified the landing of high-performance jet aircraft by providing approach guidance along a standardized visual glide path to the desired touchdown point on the deck.

There is now an urgent need for increasing the safety and the efficiency of carrier landing operations. Both of these qualities are related directly to the accuracy of the carrier landing system. The need for increased safety is especially critical; the present carrier landing accident rate is equivalent to the

loss of one squadron per year. A higher system accuracy can increase safety by reducing the percentage of potential ramp strikes, hard landings, and overshoots.

A higher landing system accuracy can increase efficiency by reducing the percentage of wave-offs and bolters; thereby increasing the average landing acceptance rate. This, in turn, tends to further increase safety by reducing holding and delays which, in turn, decreases the number of fuel emergencies.

An increased acceptance rate has a direct effect on the number of sorties which can be completed within a given period. It is also important from a purely tactical standpoint, as a carrier is most vulnerable during the aircraft recovery operation. The need for getting all aircraft aboard as quickly as possible can be especially critical if the carrier is running out of sea room, or if the recovery heading is taking it further and further off the intended course toward its next objective or destination.

System accuracy is the payoff or end result of the operation of all the elements in the control loop, which is shown in figure 1-1.

In this loop, the visual landing aid is a key element since the pilot's control actions are based on his perception and interpretation of the visual landing aid display.

Thus, the improvement of the form and presentation of the data displayed by the visual landing aid holds the key to increased landing accuracy, and ultimately to the increased safety and efficiency of carrier aircraft operations.

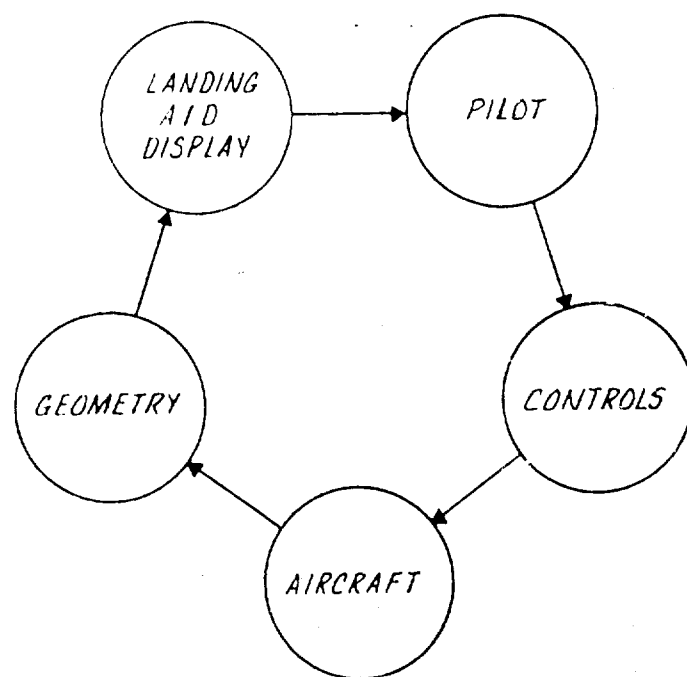


Figure 1-1. Basic Control Loop

1-3

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B. SCOPE AND OBJECTIVES OF STUDY

This study was based on Phase 1 of a proposed program for the improvement of visual landing aids for aircraft carriers of the U. S. Navy. The proposed program was outlined in an unsolicited proposal, Hazeltine Corporation Report No. 6120, dated May 28, 1963, and prepared for the Chief, Bureau of Ships, U. S. Navy. In this proposal, the Phase 1 study was defined as follows:

"The initial phase of the Hazeltine study will be to review the field by becoming thoroughly familiar with the technical and operational problem areas, from study of the applicable reports of NATC, NRL, ONR, NAEL (SI), BuWeps (Code RSSH-5), FAA, the Air Force, and the Royal Aircraft Establishment (U. K.). This study will be supplemented by personal liaison with a number of these groups."

"At the end of this survey, and in accordance with the program objectives detailed in Section III of this proposal, certain concepts and proposed solutions will be recommended for detailed analysis. Mutual agreement will be reached by Hazeltine and the Navy at this time, as to which concepts should be selected for further testing."

The Section III program objectives referred to above, defined the following specific technical goals:

- "1. Increasing the usable range
2. Providing directional guidance to assist the pilot in aligning the aircraft on the centerline of the approach path.
3. Extending vertical guidance all the way to touchdown.
4. Increasing the flyability^{*} of the system."

* The term "Flyability" embraces the dynamics and the human factors involved in the display/pilot/aircraft combination. Increasing the flyability means reducing the pilot workload associated with the task of intercepting and following the prescribed approach path to a successful landing.

In addition to these goals, the Navy added two additional specifications:

- a. The visual presentation of the new concepts shall be easily interpreted by the pilot.
- b. Both lineup and glide slope information shall be given simultaneously.

From preliminary conferences with cognizant Navy offices, there was also a verbal understanding that no new concepts proposed under this study would require the addition of any new equipment in the aircraft.

C. METHOD OF APPROACH

The first task in this program was to become as thoroughly immersed in present carrier operating problems as possible. This was done by direct observation of carrier flying activities, by discussions and conferences with cognizant agencies and user groups, and by an intensive study of all available literature on the subject. The direct observation included a three-day cruise on the U. S. S. Forrestal by two Hazeltine personnel during extensive carrier qualification activities. A list of persons who supplied useful background information, in discussions and conferences, is included at the end of this report. A bibliography of the literature used in this study is also included.

The methods described above furnished an immense amount of background data, which was carefully analyzed to obtain a detailed understanding of the requirements and constraints of the present system.

Correlation of comparative day and night carrier accident rates pointed out an apparently serious deficiency of visual cues available for night operations.

Using a technique known as morphological analysis, lists of possible visual cues, and possible shipboard installation areas were then combined in various ways to generate a number of possible new design concepts which might meet the technical goals of an improved system.

Some of the more promising concepts were then given a preliminary evaluation by synthesizing how they would appear in typical approach situations. This technique known as perspective analysis, consisted of plotting the pilot's outside visual cues, as they would appear at different times during the approach, on a consistent X-Y scale based on vertical and horizontal angles. The visual obstructions of the cockpit of a typical Navy aircraft, as seen from the pilot's eye location, was also plotted on the same scale. This so-called "Cockpit cut-off" chart was then superimposed over the outside perspective drawing to show what the pilot of this aircraft would actually be able to see at any given moment of the approach. This technique was used as a method of making a first feasibility evaluation of the new design concepts.

Each concept was then rated for its expected contribution toward system effectiveness in terms of the four technical goals: increased range, provision of directional guidance, extension of guidance to touchdown, and increased flyability. Each concept was also checked for expected compatibility with the Navy requirements for easy interpretation and for simultaneous lineup and glide slope information.

Each design concept was then reviewed in terms of the probable magnitude of the development effort required for implementation. The combined results of the foregoing analyses formed the basis for the final recommendations as to which concepts should be selected for further study in Phase II of this program.

SECTION II

SYSTEM REQUIREMENTS

A. APPROACH PATH GEOMETRY

In carrier landing operations, the final approach path may be described geometrically as the intersection of two imaginary plane surfaces in space; one of which is the vertical plane which contains the centerline of the landing runway, and the other is the sloping horizontal plane which forms the glide slope. Both of these planes move with the ship. The runway centerline is offset approximately 10 degrees from the direction of ship travel.

The glide slope is normally $3\frac{1}{2}$ to 4 degrees below the horizontal, a value which normally assures that the rate of vertical closure between the aircraft and the flight deck will not exceed 17 feet per second. The glide slope intersects the carrier deck at a point where the tail hook of the aircraft can engage one of the arresting cables.

To make a carrier approach, the aircraft must intercept and follow both geometric planes. Successful interception requires that the aircraft reach a condition where the displacement from the plane, the rate of closure, and the rate of change of the rate of closure are all gradually and simultaneously reduced to zero.

It is usually easier to intercept one of the two planes at a time. Normally the approach procedure is planned so that the pilot intercepts and becomes stabilized on the approach plane centerline, first, before he intercepts the glide slope plane.

The function of a visual landing aid is to furnish visual guidance to the pilot for the purpose of assisting him in intersecting and tracking one or both of the geometric planes which form the final approach course. Present types of visual aids furnish only glide-path guidance. Such aids define the desired optical path by furnishing visual cues regarding direction and angular displacement from the desired course.

B. ACCURACY REQUIREMENTS

To stay on the final approach path, the pilot must maintain the three quantities for each plane (displacement, rate of closure, and rate of change of rate of closure) at zero. He must also maintain the speed of the aircraft between, (a) a speed high enough to avoid loss of control or stalling, and (b) a speed low enough to avoid damage to the aircraft or arresting gear.

Successful engagement of the arresting gear normally requires that the pilot bring the tail hook of the aircraft through an imaginary "window" approximately seven feet high and twenty feet wide, as shown in figure 2-1. If the hook is below the desired path, it may come dangerously close to the ramp, or it may hit very hard on the aft deck and bounce over the arresting cables without engaging them. If the tail hook is above the desired path, it will probably miss the cables completely and the aircraft will not be arrested. If the aircraft is offside, and the tail hook engages a cable at a point left or right of the desired impact zone, the increased strain can result in a possible cable failure.

C. H/E COMPENSATION

The indirect, but ultimate, objective of any carrier landing system is to guide the tail hook of the aircraft down an established path to a point where it will engage a cross-deck pendant (cable) of the arresting gear. As shown in figure 2-2,

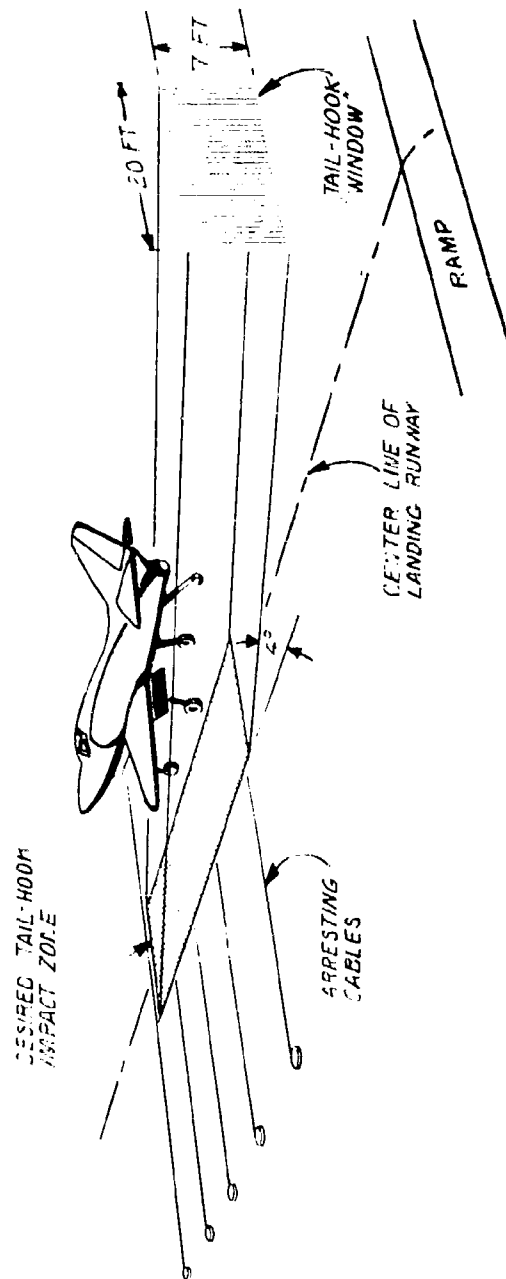


Figure 2-1. Spatial Accuracies Desired for Successful Cable Engagement



Figure 2-2. Hook-to-Eye Distances

the tail hook path is offset from the optical path furnished by the visual glide slope. The offset distance, which is known as the hook-to-eye or H/E distance, is different for different types of aircraft. It varies from 11 to 19 feet for the types of Navy aircraft in current use. As every foot of variation makes a difference of 14.3 feet in the tail hook impact point with a 4 degree glide slope (16.35 feet with a 3-1/2 degree glide slope), some method of compensating for specific offset distances is necessary.

There are four basic methods of compensating the glide slope for different Hook-to-Eye distances. The first is to move the optical unit up or down, vertically. The MOLS unit employs a parallelogram linkage for this purpose. The Deck Landing Projector Sight employed by the U. K. Royal Navy uses a worm drive for vertical H/E adjustments. A potential disadvantage to this compensation method is that, in the raised position, the unit may become a collision hazard to aircraft taking off or landing on the deck.

A second method of providing H/E compensation is to tilt the glide slope unit on its fore-and-aft axis as shown in figure 2-3. This is the method used in the present FLOLS equipment. Advantages of this method are that a minimum amount of mechanical movement is required, and that the collision hazard is not increased. The disadvantage of this method is that the laterally tilted glide slope will not provide a true indication to any pilot unless he is on the center-line of the approach course.

The third method of providing H/E compensation is to move the glide slope visual aid fore-and-aft. To our knowledge, actual movement along a deck-edge track has not been tried. To accommodate the present range of Navy aircraft types, a visual glide path unit using this type of compensation would need a track at least 120 feet long for a 4 degree glide slope, or 135 feet long for 3-1/2 degree glide slope. As compared to the present tilting method, the fore-and-aft track method appears relatively cumbersome and expensive.

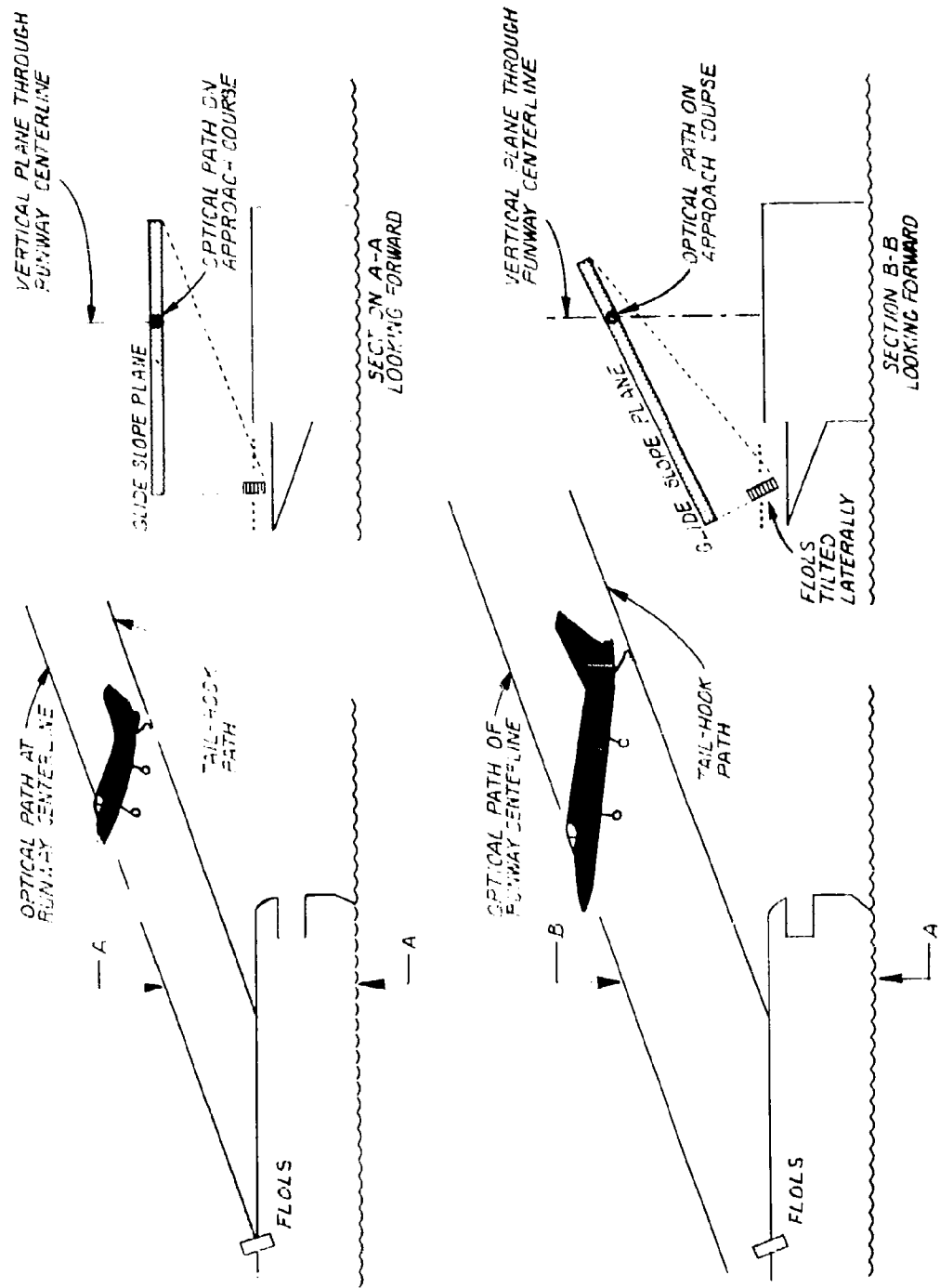


Figure 2-3. FLOLS H/E Compensation Method

A fourth method of providing H/E compensation is employing a series of glide slope optical units, appropriately spaced, and selecting a specific unit for a specific aircraft type. This method was used in the initial FLOLS installation on the U.S.S. Ranger. In this case three FLOLS units were spaced 40 feet apart fore-and-aft along the port deck edge. Only one unit was used at a time, depending on the type of aircraft being landed.

D. STABILIZATION

System operation is complicated at times by the fact that a landing deck is not a fixed surface, but is part of a surface ship which is subject to motion in several directions at once. The most important motions are pitch and roll. It is desirable that any visual landing aid compensate for such motions, to maintain a stable, easy-to-follow flight path, and also to place the tail hook in the desired impact zone.

Existing visual aids use servo mechanisms, operated by inputs from the ship's gyro, to compensate for deck motion. Most of these systems only stabilize the glide path at a single point, about 1,000 feet behind the carrier. A new line-stabilization method is now being tested for the FLOLS equipment. With this new development, the FLOLS optical unit is tilted on its fore-and-aft, as well as its athwartship axes, to stabilize the entire glide slope on the centerline of the approach course for pitch and for the vertical component of roll.

Normally, flight operations are suspended if the pitch exceeds ± 2 degrees or the roll exceeds ± 5 degrees. During the 1960-62 period, deck motion was listed as a cause of 26.8% of the hard-landing accidents, 3.1% of the overrun accidents, and 13.0% of the undershoot accidents of jet aircraft in night carrier recovery operations.

E. CONSPICUITY

On final approach, the pilot presently uses four important visual cues:

1. The runway centerline, for lateral guidance.
2. Transverse lines, such as the horizon, or the patterns formed by the symmetrical deck light pattern for a horizontal (zero bank) reference.
3. The visual glide slope, for vertical guidance
4. The angle of attack indicator, for power and pitch control.

These items are included in a continuous scan pattern. From time to time the pilot may also have to make quick checks on other instruments within the cockpit.

Because of the critical visual problem, it is necessary that the pilot's perception of these aids be as easy and positive as possible. This, in turn, requires that any visual aid should stand out distinctly from its environment so that no time is lost in searching for this aid in a background of confused details. Its indication must be perceived and interpreted instantly, consistently, and without ambiguity.

F. ENVIRONMENT

The visual landing system must be able to operate satisfactorily throughout the complete range of natural lighting conditions, from tropical noonday sunlight to complete darkness. Lights must have sufficient intensity to be visible to the maximum design range on the brightest day, yet they must not produce a glare problem on the darkest night. Present systems utilize dimming devices, to adjust the lamp intensity in accordance with the ambient lighting conditions.

In common with other shipboard equipment, a visual landing system must operate dependably day and night, in all weather conditions likely to be encountered from the tropics to the polar regions. The exposed units are subject to high winds, driving rain, salt spray, and icing. As part of a tactical ship, the entire installation must be able to survive heavy vibration, shock, and concussion.

G. SAFETY ASPECTS

Care must be taken in the design of any exposed structure to avoid the creation of an unnecessary obstruction or hazard to flight operations.

SECTION III

EXISTING TYPES OF VISUAL LANDING AIDS

Up to now, the only visual landing aids in regular use on aircraft carriers have been glide-slope aids. Pilots presently obtain centerline guidance only from the centerline lights and markings on the landing deck. Following is a brief description of the glide-slope aids which have been commissioned up to the present time.

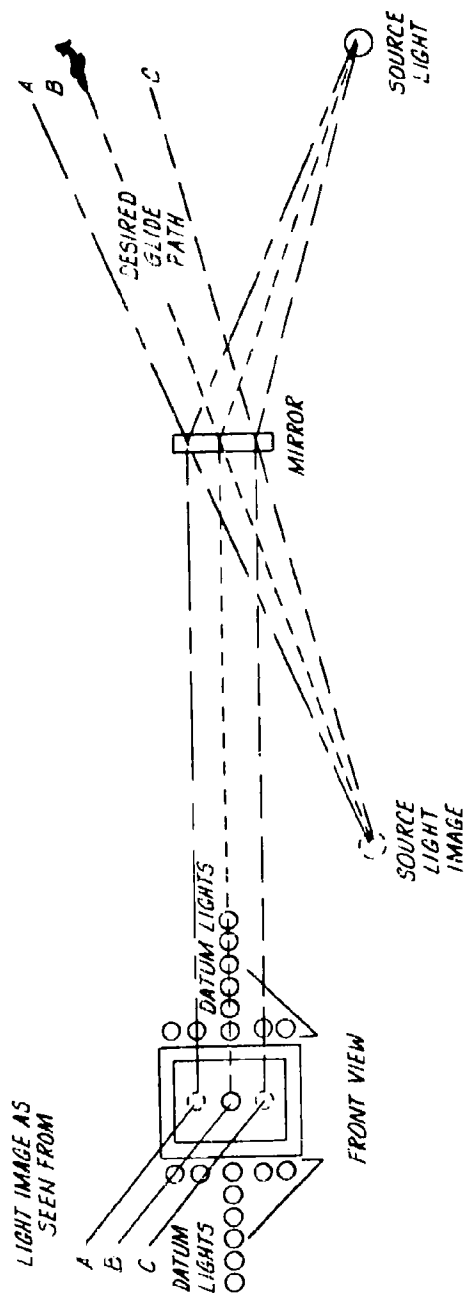
A. MOLS

MOLS (Mirror Optical Landing System) was the U. S. version of the British deck-landing mirror sight, which was suggested originally by CMDR. H. C. N. Goodhart, R. N. , shortly after World War II. He proposed the use of a concave mirror of part-cylindrical section mounted with its axis of curvature vertical, and flanked on both sides by a horizontal centerline of green datum lights. The mirror faced aft, toward a bank of yellow source lights.

The MOLS mirror equipment was installed on a wheeled platform, for portability. In operation, it was usually sited on the starboard side of the landing runway, about 150 feet forward of the source lights which were sited near the aft end of the deck.

On approach, the pilot could see the reflection of the source lights in the mirror. As shown in figure 3-1, the apparent position of the source-light mirror image or "Meatball" in relation to the horizontal datum lights indicated the vertical displacement of the observer relative to the correct glide path.

To stabilize the visual glide path, a servo mechanism, driven by inputs from the ship's gyro, tilted the mirror to compensate for the pitch and roll of the ship.



3-2

Figure 3-1. MOLS Display

B. FLOLS

Although the mirror glide-path landing aid represented a significant technical advance, it had the following disadvantages:

1. Moisture or frost on the mirror tended to degrade the presentation.
2. The installation of the source light and the mirror on the starboard side of the flight deck tied up a large amount of deck space, as the area between the two units had to be kept clear when the landing system was in operation.
3. The source light caused considerable glare in the island area and interfered with the night vision of the flight deck personnel.
4. Under certain conditions, the sun could cause confusing reflections in the mirror.
5. With the starboard mirror installation, smoke from the carrier stacks often obscured the pilot's view of the mirror.

To eliminate these disadvantages, the Fresnel Lens Optical Landing System (FLOLS) was developed. It has now superseded the MOLS equipment on the attack carriers of the U. S. Navy.

As shown in figure 3-2, FLOLS includes two groups of green datum lights in a horizontal line, with a gap in the center. Within the gap is an optical system which produces a virtual image 150 feet behind the datum lights (as seen from the final approach path). This image and the datum lights form a plane. The intersection of this plane, with the vertical plane through the longitudinal centerline of the landing runway, is the established approach path for the eye of the pilot.

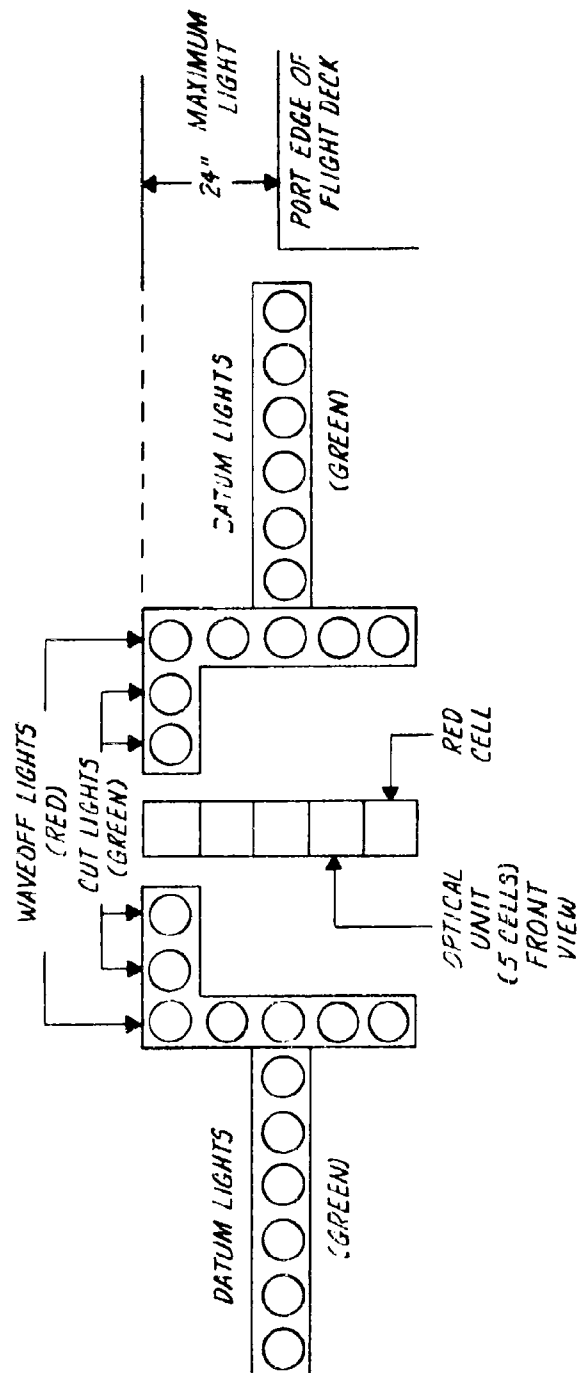


Figure 3-2. FLOLS Display

The optical portion of FLOLS consists of five vertically-stacked lens cells approximately one foot wide. The total height of the five-cell unit is approximately four feet. The lens system is highly directional; the total vertical coverage of all five cells is only 1-1/2 degrees.

The FLOLS equipment is installed outboard of the port deck edge, approximately 230 feet forward of the desired tailhook touchdown point. The outboard location is necessary to keep the equipment from becoming a collision hazard to aircraft. In order to minimize this hazard, the highest point of the FLOLS equipment is held to a maximum installed height of 24 inches above the deck line as shown in figure 3-2.

Sensing of the visual glide-slope system is similar to that used in the mirror system. When the pilot's eye is within the plane of the established glide-slope, the light from the lens unit appears in line with the green datum lights. Displacement of the pilot's eye, above or below the plane of the established glide-slope, is indicated by a corresponding displacement of the lens light, above or below the row of datum lights.

A vertical row of red lights is located on each side of the optical unit. These lights are flashed at a rate of about 90 flashes per minute to order a waveoff. Also, a horizontal row of green lights is located above the 5-cell optical unit. The green row is turned on to indicate a "Cut" signal to pilots of propeller-driven aircraft. To avoid a glare problem at night, the intensity of all lights is adjustable over a very wide range.

The glide slope is stabilized for pitch and roll. Using inputs from the ship's gyro, the Fresnel cell box is rotated about its horizontal axis in order to stabilize the visual glide slope course at a point about 1000 feet aft of the lens.

In order to improve the stability of the glide slope or close ranges, a new line-stability arrangement is being tried. This development goes a step farther than the old single-axis stabilizing system by also rotating the Fresnel lens box on its fore-and-aft axis in order to compensate for the vertical component of roll. The resulting motion stabilizes the glide slope along the entire centerline of the approach, instead of only at a single point on the centerline. It still does not compensate for heave (vertical motion of the entire ship) which normally is a relatively minor effect.

C. DECK-LANDING PROJECTOR SIGHT

About the same time that FLOLS was being developed in the United States, the deck-landing projector sight was being developed in England, for the same purpose; to eliminate the disadvantages of the mirror landing system.

The projector sight consists essentially of a projector box, housing twelve projectors in a vertical row. A horizontal row of datum lights bisects this row of projectors. Two wave-off lights are also installed. The entire unit can be raised and lowered over a range of 6-1/2 feet to compensate for differences in the hook-to-eye distances of different aircraft.

Figure 3-3 shows a cross-section of the optical system. Each projector uses a 24V-150w lamp shining through a horizontal slit and an objective lens. Each projector resembles a slide projector, except that the slide is replaced by a horizontal slit 4-1/2 inches wide and 0.093 inches high. The resulting beam has a wide horizontal spread and a very narrow vertical spread. The vertical coverage of the entire assembly is slightly over 1-1/2 degrees. The coverage of the adjacent projectors overlap each other slightly so that when viewed from a distance, three adjacent projectors appear bright. System accuracy is very good. In the vertical direction the equipment has an accuracy of $\pm$ one minute of arc.

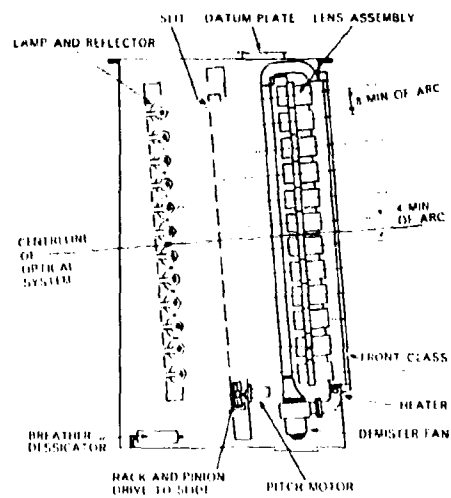


Figure 3-3. Deck Landing Projector Sight

Sensing is identical to that of the **MOLS** and **FLOLS**; when on the glide slope, the projector image appears centered on the row of datum lights. If the aircraft goes above the glide slope, the image goes up; if the aircraft goes below the glide slope, the projector image goes below the row of datum lights.

Stabilization of the beam is for pitch only, and is accomplished by moving the horizontal slits up and down by means of a servo drive which is activated from the ship's gyro. The advantage of this principle of moving the slits instead of the entire projector box is that moving less mass requires less servo power, and moving less mass creates less probability of lag due to inertia.

Apparently the operation of the projector sight has been quite successful. All mirror systems in the U. K. Royal Navy have been slated for replacement by projector sight systems.

D. HILO

The two-color glide slope indicator was developed in England several years ago and has been standardized recently by ICAO as an airport aid. The general concept is shown in figure 3-4.

A somewhat smaller adaptation of this device, known as **HILO**, has been tested recently by the Royal Navy for use in conjunction with the deck-landing projector sight. In this installation, the **HILO** units are substituted for the datum lights. Depending on his position in relation to the glide slope, the pilot sees a solid horizontal bar of either red, pink, or white. The vertical coverage angle is about ten degrees. The lower sector is red, the upper sector is white. In between is a pink sector approximately one degree wide, which forms the on-course indication.

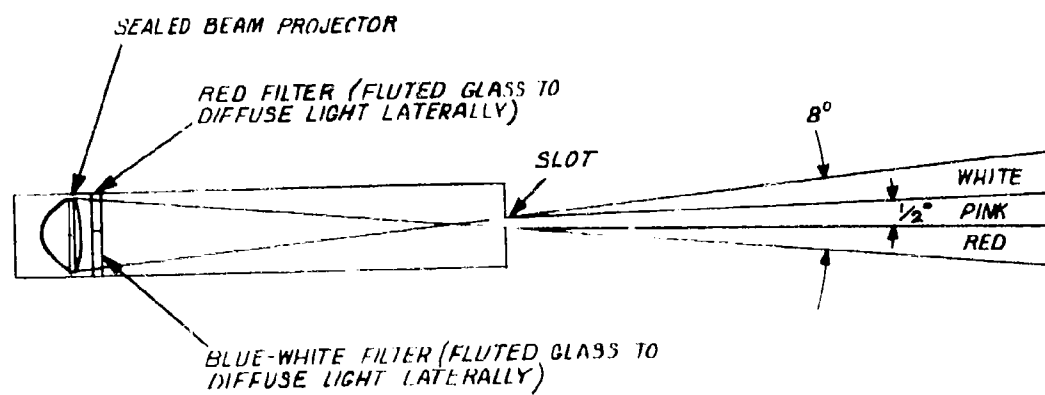


Figure 3-4. HILO

The HILO unit has a usable range of more than three miles. If the pilot keeps the aircraft within the pink sector, he will be within the coverage of the projector sight when he gets close enough to resolve its precise indications. From that point on, the HILO unit is used as the horizontal datum line for the projector unit, and the color of the horizontal bar forms a gross verification for cross-checking the indication of the projector sight.

Since the coverage angle of the HILO unit is wider than that of the projector unit, the HILO unit can also assist the pilot in getting back into coverage of the projector sight should he suddenly become displaced from the glide slope for any reason.

SECTION IV

PRESENT OPERATIONAL PROBLEMS

A. TIME COMPRESSION

One of the most important factors which characterizes present carrier landing operations is the fast tempo, as manifested in the critical shortage of time available to the pilot. This shortage has become more acute since the advent of jet aircraft. Because of the higher approach speeds of these aircraft, there is less elapsed time from interception of the final approach path to touchdown. Higher flight speeds increase the difficulty of intercepting the glide slope without overshooting.

High approach speeds also tend to increase the turning radius of the aircraft. Sharp, abrupt corrections are no longer possible; instead, any course correction requires a much longer distance to complete than would a similar correction in a slower aircraft. Therefore, it is important that any significant lateral displacement from the course be corrected as early in the approach as possible. This is an important reason for adding long-range directional guidance to the visual landing system.

The slower response of the jet aircraft requires that the pilot allow more time for any control action to take effect. In a propeller aircraft, a sudden application of engine power results in immediate lift, due to the increased airflow over the wings, from the propeller slipstream. In a jet aircraft, the engine itself responds slower, and there is no propeller slipstream over the wings. If the forward speed is constant, an increase in lift first requires an increase in pitch. The resulting control lags require that the pilot be able to anticipate any necessary corrections earlier, and take corrective action sooner, than he would need to with a propeller aircraft.

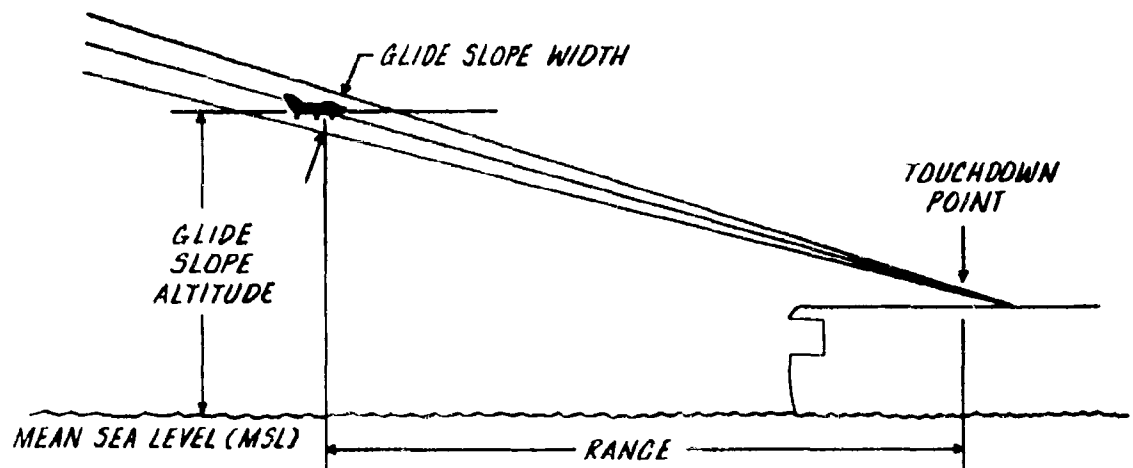
This need for anticipation is one of the main reasons why the landing visual aid should provide rate-of-change information regarding displacement from the desired path. Without a feedback of rate information, it is difficult for the pilot to determine whether he has provided enough, or too much correction at any time; the result can be a series of overshoots and oscillations which contribute to the inaccuracy of the final touchdown.

Figure 4-1 translates the situation at various points on the final approach path into terms of vertical tolerance and time-to-go for closing speeds of 100 and 120 knots. Within the last half-minute of the final approach the pilot must be able to intercept the glide slope and adjust his sink rate to follow this slope with gradually increasing accuracy; meanwhile he must keep the aircraft lined up on the centerline, and keep the angle of attack within very close limits.

Herein lies one of the most important requirements for increasing the usable range of the glide slope visual aid. If the range were double the present range, the pilot would have double the present amount of time to intercept the final glide slope, and get the aircraft stabilized in a steady descent at the proper sink rate.

B. RANGE LIMITATIONS

The usable range of the standard FLOLS equipment is approximately one nautical mile under normal conditions. To provide pilots of high-performance aircraft with more time to become aligned and stabilized on the final approach path, it would be desirable to at least double the present usable range of the present system.



RANGE, FEET FROM TOUCHDOWN	APPROXIMATE ALTITUDE 4° GLIDE SLOPE		VERTICAL WIDTH OF GLIDE SLOPE IN FEET	TIME TO TOUCHDOWN, SEC, AT CLOSURE SPEEDS OF	
	ABOVE DECK	MSL		100 KT	120 KT
6300	450	530	167	33.5	27.9
5600	400	480	148	29.8	24.8
4900	350	430	130	26.1	21.7
4200	300	380	111	22.3	18.6
3500	250	330	93	18.6	15.5
2800	200	280	74	14.9	12.4
2100	150	230	56	11.2	9.3
1400	100	180	37	7.4	6.2
700	50	130	19	3.7	3.1
0	0	80	0	0	0

Figure 4-1. Time and Distance Factors on Final Approach

Increasing the usable range is not simply a matter of increasing the light intensity at the source. Indeed, this change would generate additional glare problems at close ranges, unless careful attention were given to the design of suitable baffles. The ultimate problem is not visibility but usability, i. e., the ability to supply usable visual cues for pilot guidance throughout the coverage area.

At ranges beyond one mile, the marginal usability of MOLS and FLOLS is due primarily to a visual resolution problem caused by constraints on the height of the optical unit. The fixture height has been limited to about four feet in order to keep the unit from becoming an obstruction to aircraft. With the reference line crossing the center of the vertical display, the meatball can never be more than two feet away from the datum line.

Under ideal conditions, the human eye can resolve objects which subtend a visual angle of one minute of arc. Under conditions of fatigue, stress, or poor lighting, the limit of visual resolution approaches five minutes of arc. At a distance of one nautical mile, the two-foot maximum vertical displacement of the meatball subtends an angle of only $1\frac{1}{6}$ minutes of arc. Thus, its ability to provide a perceivable cue of even maximum meatball displacement is marginal, and smaller displacements are nearly impossible to resolve at this range.

As one means of alleviating the problem, the lower cell of the FLOLS optical unit is being changed to show a flashing red light, thus the pilot is given a gross indication that he is below the glide path. Preliminary results indicate that this feature provides an unambiguous below-glide-path indication, out

to the limits of signal visibility. However, at long range, the limited resolution of the remaining FLOLS cells makes it difficult for the pilot to determine his displacement from the center of the glide path. It is also difficult to obtain an immediate feedback as to how any control action has affected this displacement. An oscillating overcontrolled path often results.

At the normal range of the present FLOLS equipment, one mile from the carrier, the center of a 4 degree glide path is approximately 500 feet above the water. To be assured of proper interception of the glide path, the pilot must bring the aircraft down to 500 feet in his initial penetration procedure, and level off at this altitude until he receives a glide path indication.

During 1960-62, there were 21 carrier accidents in which the aircraft flew into the water. Nearly all of these occurred at night. It is believed that the present requirement for this low level-off altitude was an important contributing factor in these accidents.

Herein lies another important reason for increasing the usable range of the visual landing system. Doubling the present usable range would permit the glide path interception altitude to be approximately doubled. This would allow the pilot to maintain a safer clearance above the water until he had the meatball in sight.

C. TURBULENCE

A significant complicating factor in carrier landing operations is the airflow disturbance produced by the ship itself. Aft of the ramp, the airflow converges to fill in the space behind the moving ship. This results in a significant downdraft immediately aft of the ramp, with a variable updraft, or

standing wave, about 1000 feet downstream. These effects are encountered in the reverse order; pilots, on approach, first encounter an upward displacement from the glide slope, followed by a downward displacement starting about 400 feet aft of the ramp.

The latter effect can be particularly detrimental, as it occurs at a point on the approach where the altitude tolerance is extremely small, and where there is little time available for making a correction before reaching the touchdown point.

The air mass through which the pilot must fly is also affected by the disturbance, or burble, caused by the island structure. So far in carrier design, aerodynamic streamlining of the island structure has been subordinated to other functional considerations.

The magnitude of the turbulence produced by the island structure is affected considerably by the relative direction and velocity of the wind-over-deck (WOD). The airflow in the landing area is steadiest when the relative wind is parallel to the centerline of the landing runway. Although this condition is desired for carrier landings, it is not always possible to obtain, particularly when the surface wind is nearly calm and the carrier must "make its own wind." In this case, the average WOD may be as much as 10 degrees crosswind from starboard, and the aircraft must cross through this turbulence to reach the touchdown point. During the 1960-62 period, stackwash, or airwake, disturbance was listed as a cause of 4.0% of the hard-landing accidents, 3.1% of the overrun accidents, and 7.4% of the undershoot accidents of jet aircraft in night carrier recovery operations.

D. VISIBILITY RESTRICTIONS

When there is a crosswind from starboard, smoke from the ship's funnel can blow across the approach path and temporarily obscure the pilot's view of the visual landing aid or the deck lighting. This effect is particularly serious at night, as it can occur suddenly without warning. It would not be encountered with nuclear-powered carriers. Dirt or condensation on the aircraft windscreen can also reduce the outside visibility. Rain has a similar effect, and on some aircraft can produce a refraction which can make outside objects appear as much as 5 degrees lower in elevation than they actually are. During the 1960-62 period, reduced windshield visibility was listed as a cause of 4.8% of the accidents in which aircraft flew into the water, 3.1% of the hard-landing accidents, and 2.5% of the undershoot accidents of jet aircraft in night carrier recovery operations.

E. NIGHT ILLUSIONS

The main difference between night and day carrier recovery operations lies in the ambient lighting conditions. However, the night accident rate for jet recovery is nearly five times as high as the day rate.

Figure 4-2 shows how the five main causes of jet recovery accidents compare, as to percentage of total accidents, and as to their night-to-day ratio. It will be noted that undershoots, overruns, and flying into the water show the largest increases during the hours of darkness. These three types of accidents all result from errors in the control of altitude.

From the foregoing data, it would appear then that the present system has a serious deficiency in the availability of visual cues for night operations; particularly those cues which would assist the pilot in the proper control of altitude.

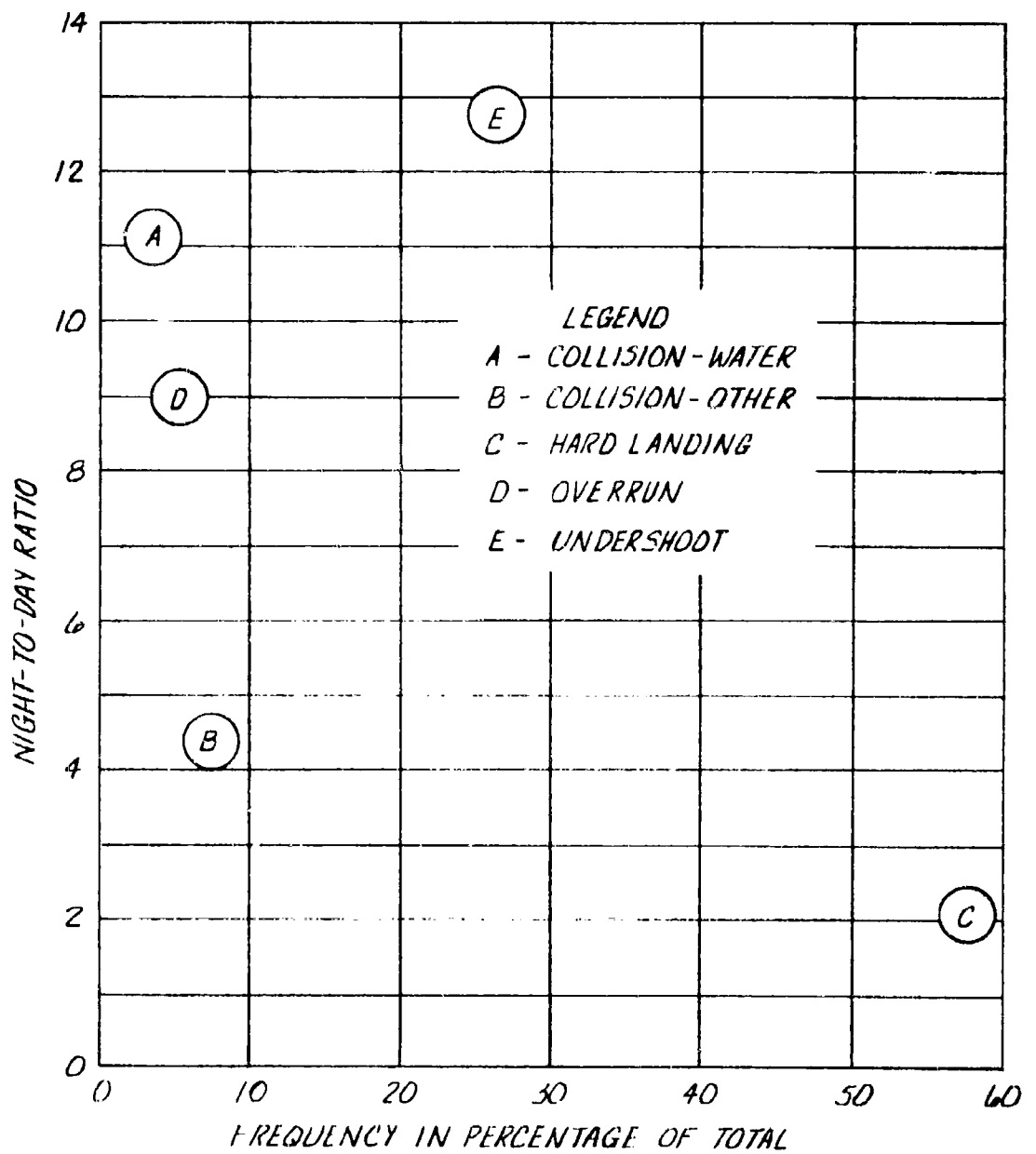


Figure 4-2. Carrier Landing Accident Data

During the course of this study, pilots reported three different phenomena relating to night illusions. Each is related to a lack of visual cues.

1. On a dark night, with the horizon obscured, the only outside visual reference is the pinpoint pattern of the deck lights and the FLOLS. Under these conditions, the pattern takes on a very abstract, unreal appearance. With the absence of any other visual cues in the black void, it requires very strong concentration by the pilot to interpret what these visual lines and angles are saying, as far as the attitude of the pattern, and his relation to the desired course is concerned. The entire visible pattern lies essentially in one horizontal plane; cues for depth perception are lacking. As the aircraft approaches, the visible pattern grows in apparent size very slowly, until at the last moment it seems to explode in a breath-taking fashion as the aircraft comes in over the deck.

2. Pilots report that the brightness of the deck lights sometimes result in spatial misjudgments, and sudden attempts to take unnecessary control action just before touchdown. When the deck lights are on high intensity settings, they appear larger and closer than normal. Under such conditions, pilots sometimes underestimate their distance and altitude. Unnecessary control action at this time may result in an overshoot.

3. The athwartship lights on the ramp not only mark the near edge of the deck surface, but also form the pilot's closest and most sensitive visible horizontal reference. From several hundred feet behind the ramp, these lights are obscured behind the nose of the aircraft. At this point, this useful horizontal reference is no longer available, and the pilot now sees only a diminishing portion of the flight deck runway lights. There is now an extremely strong illusion that the aircraft has passed the ramp at too high an altitude, and is going to overshoot the arresting cables. The result is a strong tendency for the pilot to dive for the deck and take off the "excess" altitude, a maneuver which can result at this point in a severe or even disastrous undershoot.

One reaction to the foregoing examples might be: "If the pilot is sufficiently disciplined to believe the meatball indication, it will make no difference what these illusions tell him; he should continue to fly the meatball indication only." In actual practice, however, the meatball is only one of the visual cues which the pilot receives, and it is not always easy to read because of its low resolution and its very limited zone of coverage.

For the pilot to proceed down the flight path with what the French call "tranquility of spirit," and what we might call "quiet assurance," the other visual cues must back up or confirm what the pilot sees in the meatball indication. In daylight, there are an almost infinite number of cues which can confirm this: the visible horizon, the surface and texture of the water, the deck of the carrier, and the details of the island superstructure.

At night, however, the visual cues are limited to the deck surface, and are rather abstract at that. If all of the other visual cues, including the illusions, do not confirm the pilot's interpretation of the meatball, there will be a strong tendency for him to give at least equal weight to these other visual cues. This tendency may be magnified by the pilot's desire to get aboard if he is under extreme stress, such as in a situation where he has already had one or two wave-offs and is reaching a critical fuel state.

There is the possibility that the pilot may suddenly lose sight of the meatball due to smoke or to some distraction within the cockpit. Until he can interpret its indication again, he will instinctively use his other visual cues, illusions and all.

Where there is definite conflict among the pilot's perception of available outside visual cues, instrument cues, and his own kinesthetic sensing of the aircraft attitude, vertigo can result. On a dark night, with very few outside cues available, the loss of orientation can be very sudden and very dangerous.

SECTION V

SYNTHESIS OF TENTATIVE SOLUTIONS

In attempting to develop improvements in visual landing aids, it becomes evident that there are two sets of limitations, or constraints, which will govern any design of this nature: first, the possible types of visual cues which can be employed; and second, the possible locations where they can be installed on the carrier. Following is a brief description of these two sets of possibilities.

A. VISUAL CUES

The various types of visual cues which could conceivably be used for transmitting guidance information include color, shape, alignment, modulation, brightness, and motion (direction and speed). Each type of cue has a range of information-transmitting possibilities which is limited by the number of different levels, thresholds, or combinations, which can be readily discriminated and identified by the human observer.

1. Color

Color-coding of various categories of information is very useful in reducing the search time for sorting out a particular category under conditions where a number of different categories of data must remain on display at the same time.

The number of different colors which can be recognized from a single display element is quite limited, although a somewhat finer gradation between similar colors can be discerned if the observer can compare the colors of two different display elements which are visible at the same time.

Due partly to a characteristic of the human eye, and also to the light transmission characteristics of the atmosphere itself, the actual colors of lights cannot be determined at long ranges in certain ambient conditions.

Physiologically, the photo-chromaticity (PC) ratio of signal color threshold to signal threshold is different for lights of different colors. Both red and white lights have PC ratios of about 1 to 1, however, green lights have PC ratios of more than 2 to 1. Thus, the color of green lights cannot be determined nearly so far away as the light source itself can be detected by the human eye.

In addition, transmission of light through the atmosphere is affected in two ways; (1) when the water droplets suspended in the air are of a certain size, the transmitted color will be biased toward the red end of the spectrum, (2) in daylight, the illuminated atmosphere between the light source and the observer adds white light to the colored signal and thus has a desaturating effect. The net result of these two effects is that both red and white lights tend to appear orange at long ranges.

From the design standpoint, the long-range color fade problem may be minimized by (1) avoiding the use of green signals for long-range transmission, (2) increasing the light intensity at the source, and (3) designing the system so that some other cue, such as pattern shape or modulation (flashing) rather than color, is used to supply the visual information at long ranges. Blue is generally unsuitable, not only because of its closeness to green, but because of the very high attenuation of light energy which occurs when light passes through a blue filter.

One problem which occurs in the use of color-coded displays, using incandescent lamps, is that white lights tend to appear yellow when turned down to low intensity. This effect can be alleviated by the use of a very pale blue-white filter over any lamp which must appear white under all conditions.

2. Shape

Shape-coding is a very versatile method of transmitting both displacement and rate information, due to the relatively large number of different pattern shapes which can be recognized. However, to be usable at any given range, the display pattern must be large enough that the eye can resolve all its strategic elements (those elements which positively identify it from all other shapes used in the set).

3. Alignment

The relative position or alignment of an information display element, in relation to a reference element (for example, the position of a meatball in reaction to the row of datum lights), forms a useful method of transmitting displacement and rate information. However, like the shape-coding mentioned above, the usability of the display depends on its size; at any given range, the scale must be large enough that the information element can be resolved separately from the reference element.

4. Modulation

Modulation or flashing is a useful cue for attracting attention as it disturbs the display presentation. It is also useful for adding supplementary information in lieu of color. However, the range of information-transmitting

capabilities of flash-coding for landing aids is severely limited, as it is difficult for a busy pilot to discriminate between similar flashing characteristics if he can view only one of them at a time. It may be somewhat easier to compare two widely contrasting duty cycles such as all dots or all dashes.

The maximum usable flashing rate is 75CPM, as interruption of an incandescent light by switching becomes indistinguishable at higher rates; 30 CPM appears to be too slow a rate because of the time required to wait for a full cycle to occur in order to identify that the signal is flashing.

A flash rate of 45 CPM has been found satisfactory for the lower cell of the FLOLS, in order to extend the usable range of its information beyond the pilot's spatial and color perception capabilities.

It is desirable that the use of flash-coding be limited to show off-course, rather than on-course, indications. It would have a tendency of being distracting to watch when the pilot was trying to concentrate on staying in the center of the course (particularly at night), and might tend to make him want to stay off-course until the last possible moment if the flashing were visible only when the aircraft was on course.

5. Brightness

The use of brightness coding was proposed at one time for the so-called "Delta" landing system. The proposed system used three lights arranged at the corners of an isosceles triangle set into the deck. On course, all three lights appeared to be of the same intensity. If the aircraft were off course: high, left or right, the respective high, left, or right light would appear brighter than the other two in the pattern. If the pilot were low, the (lower) left and right lights would appear brighter than the upper light in the pattern. The pilot would use the rule, "Fly away from the bright" to get centered on the approach path.

No information has been received as to the performance of this system. It would appear that the use of brightness coding could be subject to difficulties associated with keeping all the lamp units of equal cleanliness and equal brightness at all operating voltage levels and at all visibility conditions. There might also be a light-distribution problem in keeping the dim positions visible without causing a glare problem in the bright position.

6. Motion

Moving chains of lights, similar to moving chains on electric signs or theater marquees, conceivably could be used for guidance, with the apparent direction of motion indicating the direction the pilot should fly to get on course, and with the speed of apparent motion indicating the relative displacement from the desired course. Such systems conceivably would have the limitation of providing guidance to only one aircraft at a time.

To be usable at any given range, the visible elements of the light chain would have to be far enough apart to allow visual resolution of the apparent motion without strobing effect. In some cases a stationary reference element might be necessary to make the motion apparent.

No experience has been reported on the use of this type of visual cue for guidance.

B. POSSIBLE INSTALLATION AREAS

If we start with the assumption that any carrier-based visual landing aid must be visible to a pilot who is within a certain coverage zone centered about the desired approach path, it becomes apparent that display installation

areas are limited to those portions of the ship which are visible from the aspect shown in figure 5-1. Following is a brief description of the characteristics and limitations of each area as they would affect the design of a visual landing aid for vertical or lateral guidance.

1. Area A — Port Side of Flight Deck

The present FLOLS is located on an outrigger installation, off the port edge of the flight deck, approximately 230 feet forward of the desired hook touchdown point. There is a need to place the display as close to the centerline of the landing path as possible in order to keep the display within the pilot's forward field of vision during the final moments of the approach. The display must not extend more than two feet above the actual deck line to avoid becoming a collision hazard to the underslung external loads of an aircraft taking off from the port catapult or landing on the runway and veering off toward the port side (an occasional result of the fact that the runway is actually travelling 10 degrees sideways toward starboard).

The display must also be mounted high enough so that its lower portion is never hidden from an incoming pilot by any portion of the deck surface.

The height limitations of the port side of the landing deck, as an installation site for any proposed new landing aid, thus are the same height limitations which are already apparent in the present FLOLS installation.

2. Area B — Landing Runway

At first thought, the idea of mounting the visual landing aid in the surface of the landing runway would appear to be extremely advantageous. It would simplify the pilot's scanning problem during the final portion of the approach as the display would always remain ahead of him all the way to touchdown instead of swinging out of his normal forward visual span as he approached the deck.

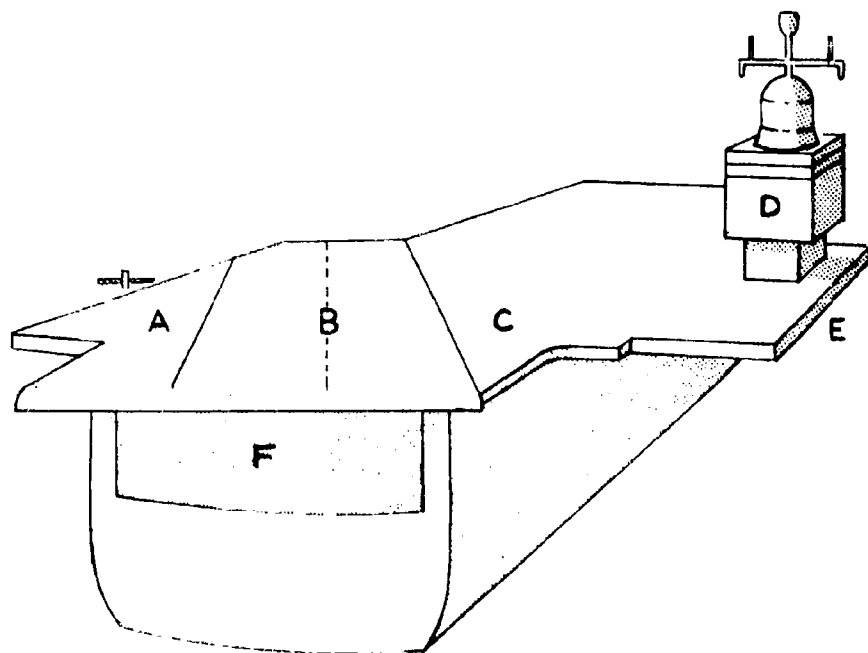


Figure 5-1. Possible Installation Areas

However, there are two objections to such an installation. First is that the aircraft closest to the touchdown point would tend to obscure a full view of the display as seen from a following aircraft on the approach path. This factor would tend to limit the landing rate.

The second, and most important objection, is the extremely large space required when the displayed information is presented on a horizontal deck surface instead of a vertical indicator. This is because of the extremely acute viewing angles which must be accommodated in the operation of the system.

Suppose, for example, that the glide slope display must be able to present displacement information over a coverage angle of $1\text{-}1/2$ degrees, centered about a four degree glide path. The lower edge of this coverage is only $3\text{-}1/4$ degrees above the horizon. Suppose also that the system must be used under conditions when the ship is pitching ± 2 degrees. When the bow goes down, the lower edge of a stabilized glide slope would be only $1\text{-}1/4$ degrees above the deck; to a pilot viewing the display from this aspect, the information would appear foreshortened to about $1/46$ th of its actual horizontal distance. (Two deck lights 46 feet apart, fore-and-aft, could now be resolved by a pilot on approach only as well as two lights mounted vertically only one foot apart.) When the bow pitches up two degrees, the lower edge of the beam is now $5\text{-}1/4$ degrees above the deck. To a pilot viewing the display from this aspect, the foreshortening has now changed to a ratio of 1:11. From the pilot's viewpoint on the approved path, the displacement of a meatball from a center reference line in flush-mounted display would appear to be over four times as great in the two degree bow-up position as it would in the two degree bow-down position. This display characteristic would probably be irritating, if not downright disconcerting, to pilots.

Perhaps the most critical problem in designing a flush-mounted display to be installed in the landing deck is to provide a wide enough aperture for the light to be viewed at extremely low elevation angles out to the maximum range of the system, but without creating undue bumps or long slots in the deck surface.

An additional factor is the need for protection of such lights against impact or engagement by the tail hook of a landing aircraft. To enable a tail hook to pass over such a fixture without damage, the maximum width of any opening in the deck should not exceed four inches.

As compared to a vertical display, designing a visual landing aid for flush-mounting in the deck tends to require a wide dispersion of the various lighting elements. Moving and synchronizing all these elements to correct for ship motion, as well as H/E adjustments, becomes a formidable engineering problem.

For the foregoing reasons, a glide slope display, flush-mounted in the surface of the landing runway, does not appear desirable. Conceivably the area might be a satisfactory location for a centerline line-up aid. However, in this respect, the possibility of creating unnecessary bumps in the deck surface or glare in the pilot's eyes might make it less desirable than the area under the ramp (Area F).

3. Area C -- Starboard Side of Flight Deck

This area is the most constantly occupied of any portion of the flight deck; it is heavily used for aircraft parking purposes. Also, every landing aircraft taxis off to starboard to vacate the landing runway. The MOLS was formerly located in this area, but one of the main reasons for its early replacement was the need to keep this area free for aircraft taxiing and parking. Any visual aid in this area would be more subject to smoke interference than aids located in Area A or Area D.

Because of the foregoing reasons, Area C is not considered a desirable location for any new visual aid.

4. Area D -- Island Structure

The lower portion of this structure would often be hidden from the view of an approaching pilot, by parked aircraft on the aft starboard elevator or parking area. Higher up, any installation of a new visual aid would have to be carefully configured to avoid interfering with any radar pattern, obstructing the view, or creating a glare problem in relation to PRI-FLY or the skipper's bridge. The optical projector for a glide slope visual aid must be within the geometric plane of the optical glide path; a high location for the projector would be undesirable because the plane would have to be cocked at a large angle to get the path down to the carrier deck.

5. Area E — Starboard Side of Ship

As compared to a port-side outrigger installation such as presently used for FLOLS, a starboard outrigger installation for a glide-slope installation would be almost completely free of height restrictions. However, because of the island structure, an outboard display mounted off the starboard side of the ship probably would not be visible all the way to touchdown. However, this location might be suitable for a supplementary long-range aid.

6. Area F — Stern

This area is almost free of height or width limitations. As the vertical plane of the runway centerline crosses this area, it appears to be an ideal location for a centerline line-up aid.

C. MORPHOLOGICAL ANALYSIS

To provide a thorough look at all the apparently suitable design combinations for a possible new landing aid, a matrix was constructed, listing the various combinations of possible visual cues and installation locations. This matrix is shown in table I. The designations appearing in the matrix refer to the tentative solutions which are listed in section VI of this report.

TABLE I
POSSIBLE DESIGN COMBINATIONS

Equipment Installation Areas Visual Cues	Port Side of A Deck	B Landing Runway	Starboard Side C of Deck	D Island Structure	Starboard Side E of Ship	F Stern
Color	5 6				1	9
Shape (Pattern)		11				10
Alignment	2 ³ 4 ⁷	12			1	
Modulation	6					
Brightness						
Motion						8

Legend

- 1 - Expanded Starboard FLOLS
- 2 - Thinline Datum
- 3 - Double Datum FLOLS
- 4 - High Sensitivity Datum Lights
- 5 - HILO/FLOLS
- 6 - Modulated HILO/FLOLS
- 7 - Extended Threshold Reference Lights
- 8 - Contra-Rotating Line-up Beacons
- 9 - Double Bar Line-up System
- 10 - Crossbar Line-up System
- 11 - Diamond Glide Slope Marker *
- 12 - Carrier Integrated Landing System *

*See Appendix A

SECTION VI

TENTATIVE SOLUTIONS

Following is a brief description of the design concepts which emerged as a result of this study. These ideas all received a preliminary evaluation during the course of the study, with the results shown in table II.

A. AIDS TO VERTICAL GUIDANCE

1. Expanded Starboard FLOLS

In systems such as MOLS and FLOLS where the relative position of an indicator light is used as a visual cue, a direct method of increasing the gain or resolution of the system would be to expand the scale along which the light can move, and thus magnify any displacement of the indicator light. This solution cannot be used for the present port-side FLOLS because of the severe height constraint shown in figure 3-2. However, the starboard side of the ship has no such constraint. True, a starboard visual aid could not be seen all the way to touchdown because of the island superstructure. Suppose however, that the system were designed on the basis that the present FLOLS would still be used at close ranges, but it would be supplemented by a longer range unit which would be used only at longer ranges.

Figure 6-1 shows several possible adaptations of the present FLOLS for long-range use. The scale would be expanded by separating the present Fresnel cells by a distance equal to the cell height. This change would almost double the height of the Fresnel Optical System without requiring any modification of the cells themselves. The optical system would now subtend an angle of slightly over four minutes when viewed from a range of one nautical mile. The increased resolution should nearly double the present usable range of the system.

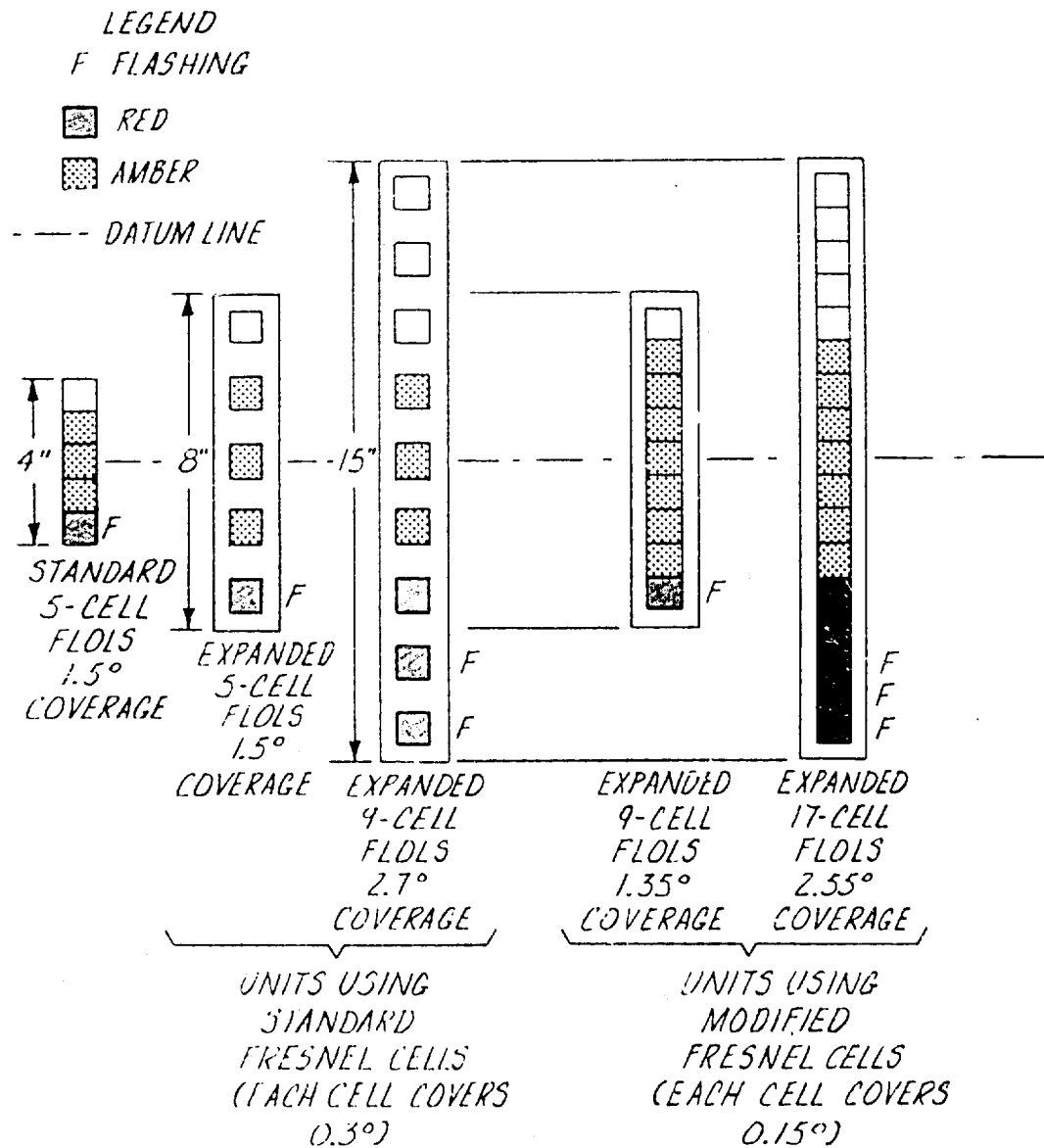


Figure 6-1. Alternate Optical Units for Expanded Starboard FLOLS

With the gaps between the individual cells, the meatball would tend to dwell on one unit, and then jump to the next unit as the glide-slope displacement varied. However, when viewed from longer ranges, the subtended angle of the jumps would be very small indeed.

It would be desirable to test such an installation to see how much improvement in range it actually offered, and also to determine if the non-linear movement of the meatball was detrimental to the useability of the system at long range. If the performance were satisfactory, a big advantage of this concept would be that it would not require a redesign of the Fresnel lighting cells. This in turn would speed up the development and simplify the logistics problem.

However, if the performance of the separated-cell unit were not satisfactory, the same concept could be pursued using a new optical unit with a continuous series of cells, but with each cell redesigned for an angular vertical spread of about 0.15 degrees.

In either case the glide slopes from the Port and Starboard units would coincide on the centerline of the approach course. The expanded starboard FLOLS unit would be stabilized for pitch and roll, and would also be compensated for various Hook-to-Eye distances, in the same manner as the present port-side FLOLS unit.

Figure 6-2 shows how the expanded FLOLS would appear to a pilot on a four degree glide slope, 1500 feet from touchdown. It is anticipated that the pilot would follow the expanded starboard FLOLS until he was close enough in to obtain adequate resolution from the port-side FLOLS unit. Normally the visual changeover would be made approximately 2500 feet from touchdown. From this point on, the pilot would follow the port-side FLOLS on in to touchdown. From figure 6-3, it will be noted that the expanded starboard

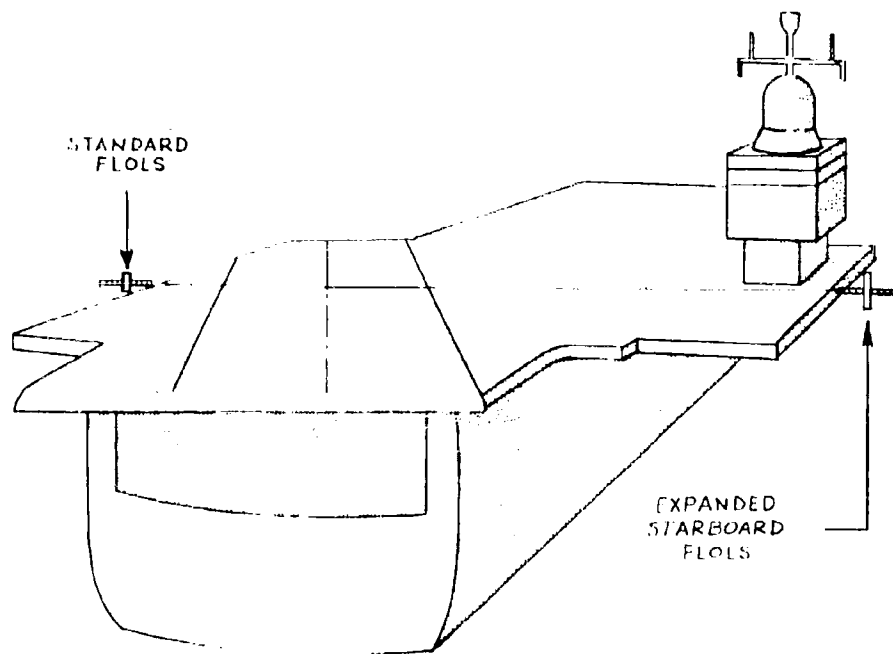


Figure 6-2. View of Expanded Starboard FLOLS, from 1500 Feet Out

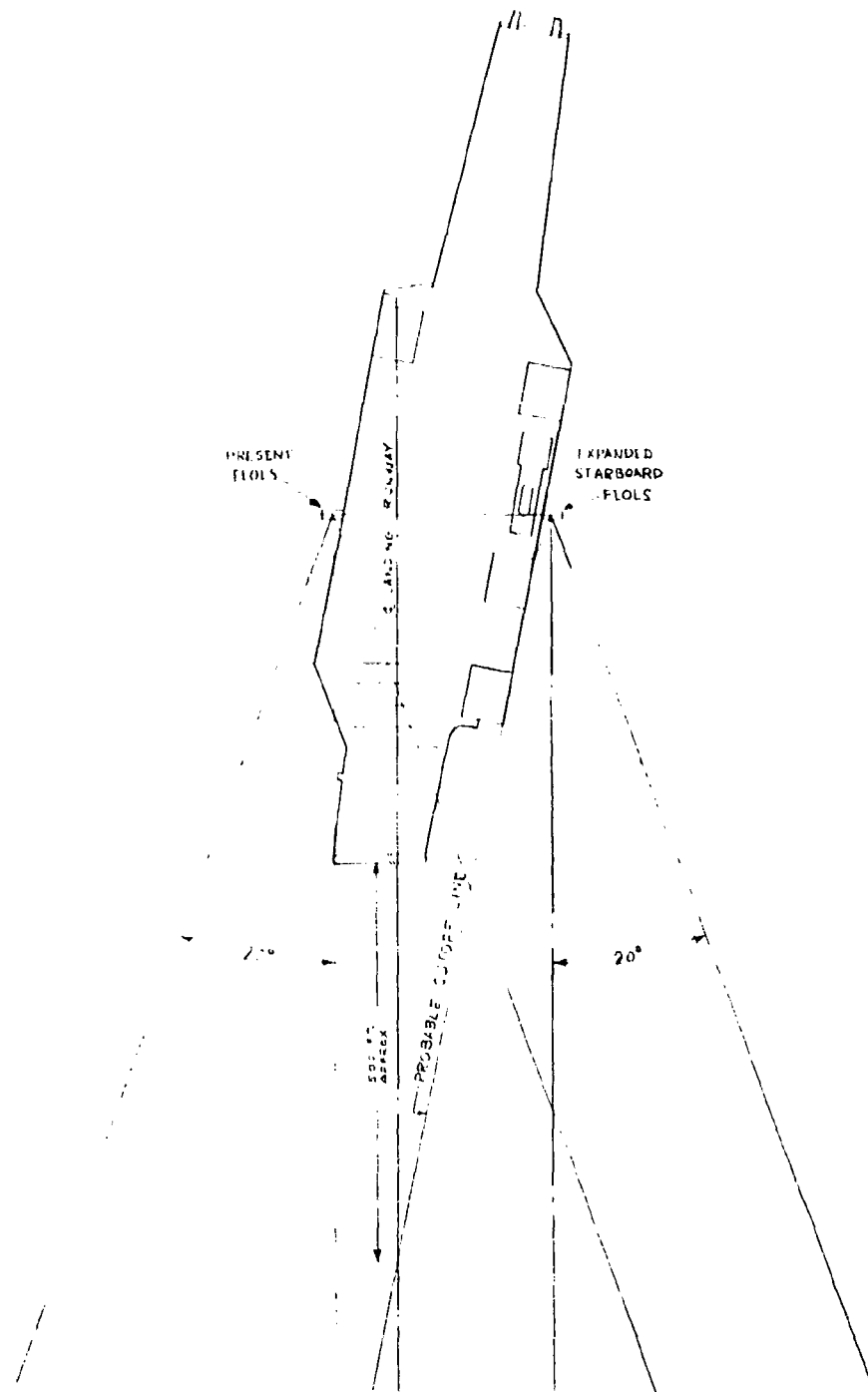


Figure 6-3. Coverage of Port and Starboard FLOLS Units

FLOLS would be eclipsed by the ship structure at close ranges. Because of this factor, it should be possible to operate the starboard FLOLS at a higher light intensity than the port-side FLOLS, without causing a glare problem to the pilot at close range.

2. Thinline Datum

It appears that a small gain in resolution and effective range may result from replacing the row of circular datum lamps on each side of the Fresnel Optical System with a long narrow fixture containing a single row of narrow-filament lamps, as shown in figure 6-4. The object would be to replace the circular blobs of light with a thin, clean-cut reference line, making it easier for the pilot to detect small changes in alignment.

3. Double-Datum FLOLS

In viewing the present FLOLS from maximum range, there is a tendency for the meatball to merge with the row of datum lights so that it is difficult to determine whether it is centered, or slightly above or below the center-line.

As a possible method of increasing the long-range readability of the FLOLS without increasing the actual height of the unit, it is suggested that the present row of datum lights be replaced by a double row, as shown in figure 6-5. The pilot's object now would be to center the meatball midway between the two rows.

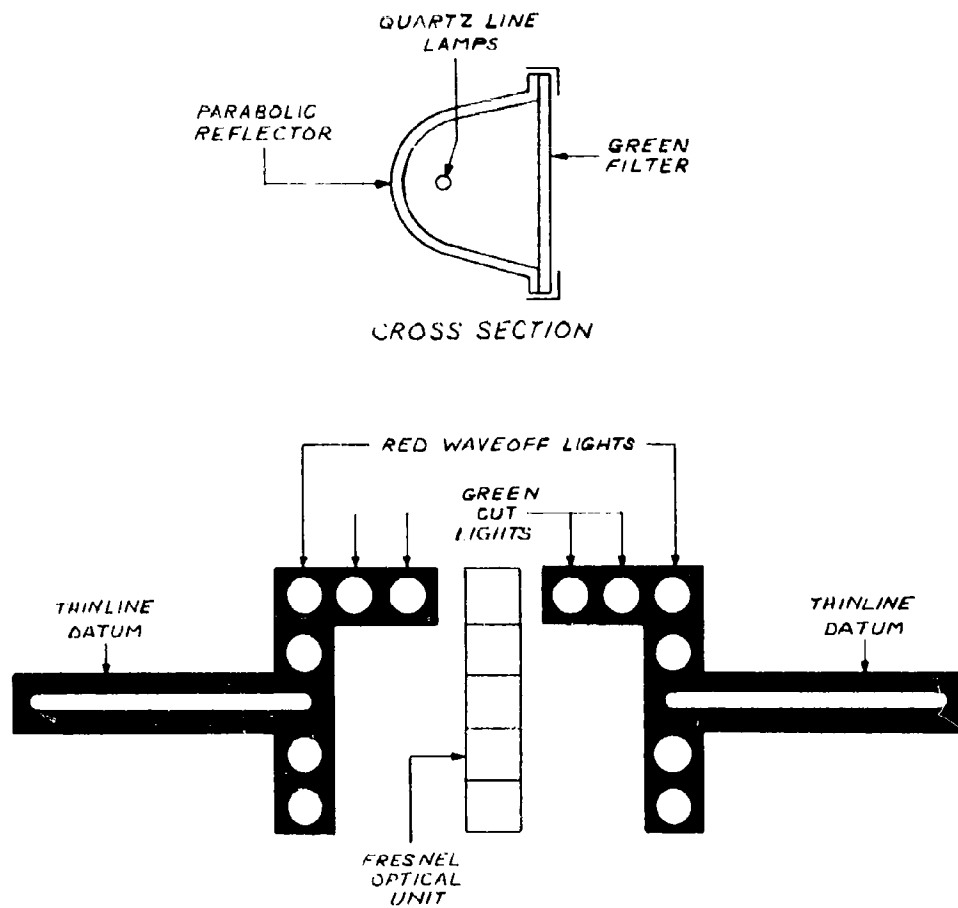


Figure 6-4. Thinline Datum

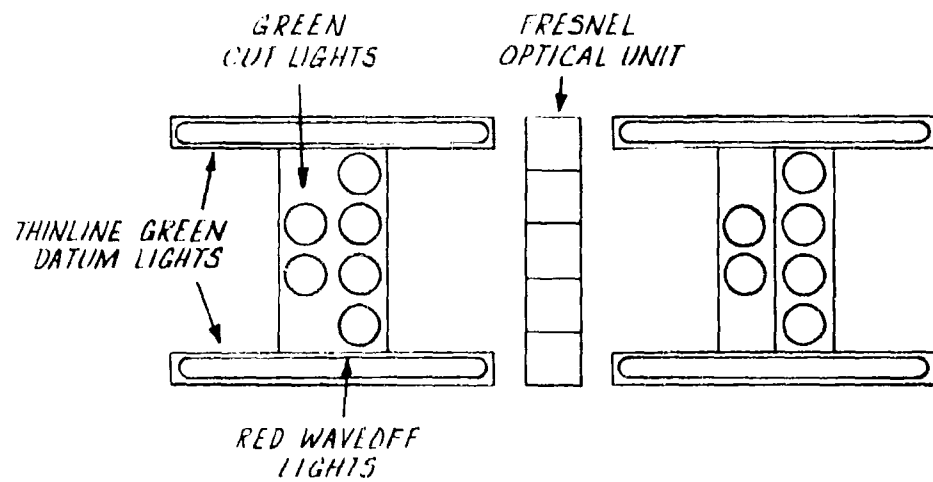


Figure 6-5. Double-Datum FLOLS

A possible gain in resolution may result from the fact that if this merging effect does take place there may be a tendency for the light to merge more with the upper or lower row depending on whether the light is above or below the centerline, respectively. If this difference in merging characteristics (which should be pronounced with the meatball is near either end of the vertical scale) can be readily detected by the pilot, a gain in effective resolution, and thus effective range, may be possible.

Closer in, the pilot will compare the relative closeness of the meatball to the two ends of the scale, as shown by the datum lights, to keep it centered. There is also a possibility that having the scale ends visibly defined may facilitate the determination of rate of change information, particularly at night.

This simple change in configuration appears worth trying, because it will require no new optical components, or changes in the present stabilizing and H/E compensation methods. In addition, it can be readily tested in model form to determine whether the proposed configuration will result in increased resolution and range.

It is possible that a further gain in resolution will result from replacement of the rows of circular datum reference lamps with single fixtures containing thin-filament lamps, as described in the preceding section, "Thinline Datum."

4. High-Sensitivity Datum Lights

Because of height restrictions, the present FLOLS unit is only about four feet high. As the datum reference is centered vertically, the maximum vertical separation between the meatball and the datum lights can never exceed two feet.

The resolution and effective range of the present system could be doubled, without increasing the over-all size of the unit, by replacing the present datum bars with Fresnel optical units which have been modified to displace their light images in the opposite direction from the image displacement of the standard Fresnel light unit, as shown in figure 6-6.

Without any increase in the over-all dimensions of the present FLOLS equipment, the design would provide the resolution equivalent to a FLOLS optical unit at least eight feet high.

It is suggested that the present Fresnel meatball unit be retained with its present color scheme, and that the new modified units match the green color of the present datum lights. Retaining the present color scheme should make it easy for pilots to adapt to the new display without any ambiguity.

Because the new datum lights are directional, they should be stabilized and compensated for in the same manner as the present Fresnel unit. Figure 6-6 shows a recommended method.

A relatively simple method of modifying the present Fresnel optical unit, to produce the reverse sensing, is illustrated in figure 6-7.

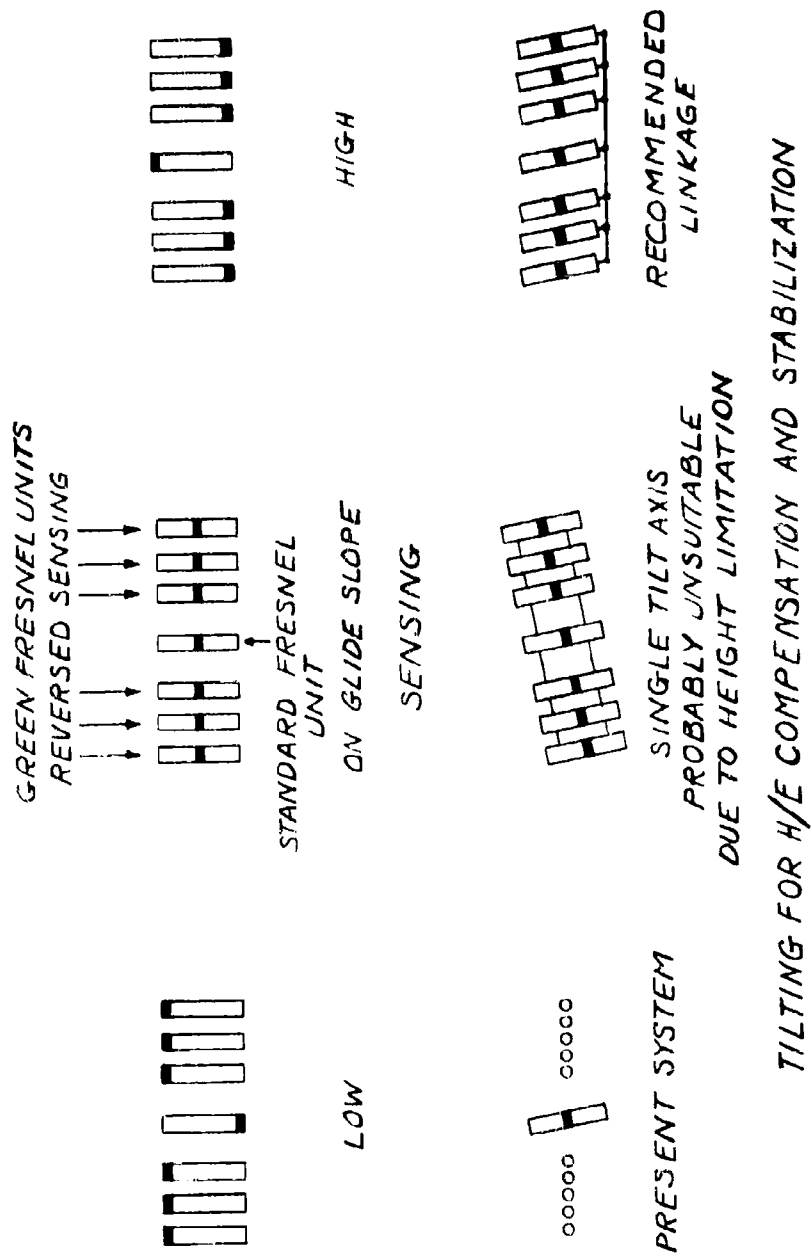
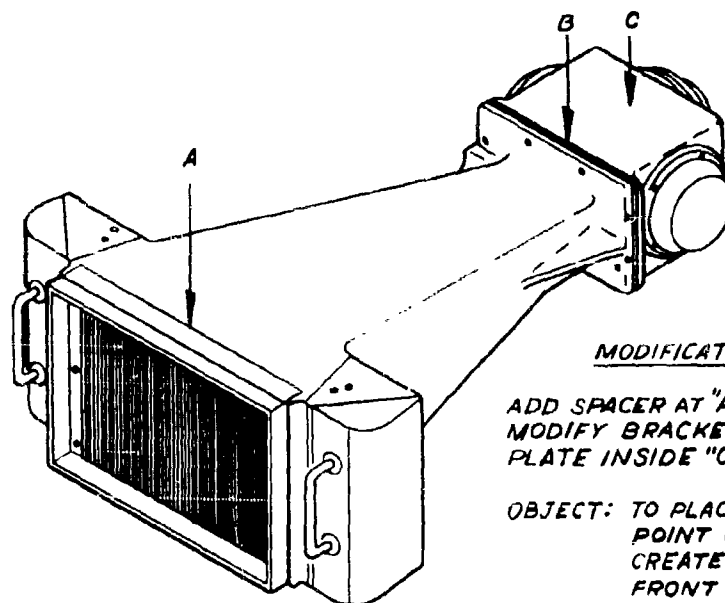


Figure 6-6. High-Sensitivity Datum Display



MODIFICATIONS TO CELLS

ADD SPACER AT "A" AND/OR "B"; AND/OR
MODIFY BRACKETS FOR LAMP MOUNTING
PLATE INSIDE "C".

OBJECT: TO PLACE LAMPS BEHIND FOCAL
POINT OF FRESNEL LENS, AND
CREATE REAL IMAGE 150 FEET IN
FRONT OF LENS.

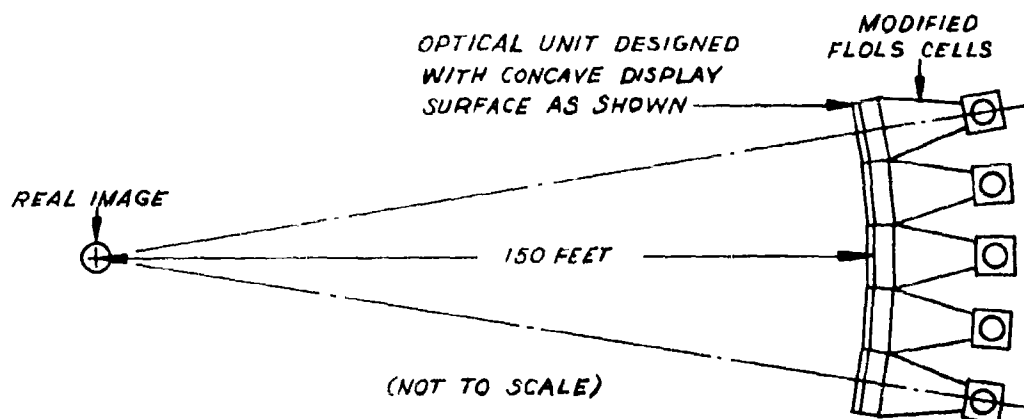


Figure 6-7. Possible Means of Implementing High-Sensitivity Datum System

5. HILO/FLOLS

As mentioned in section III of this report, the U. K. Royal Navy has recently employed two HILO units to replace the row of datum lights on their deck-landing projector sight system. The results have been successful.

The same concept can be used with the FLOLS equipment, i. e. , replacing the row of datum lights with the HILO units. The resulting combination should widen the zone of guidance from 1-1/2 degrees to eight degrees, thus facilitating interception. The range of the HILO unit should increase the system range to at least 3 miles.

In operation, the pilot would pick up the HILO indication first, and he would get the airplane stabilized in the pink on-course zone which should lead him directly into the meatball coverage zone. As soon as he was close enough to resolve the indication of the meatball, he would use its more sensitive, precise indication for accurate tracking of the desired glide path. From this point on, the HILO units would serve as a datum line for the meatball, and as a gross indicator to confirm its indications and to get back on course should he temporarily lose the meatball indication for any reason.

One advantage of this concept is that it should require no new development of optical components. However, it probably will be necessary to stabilize the HILO units for pitch and roll, and also to provide them with H/E compensation.

6. Modulated HILO/FLOLS

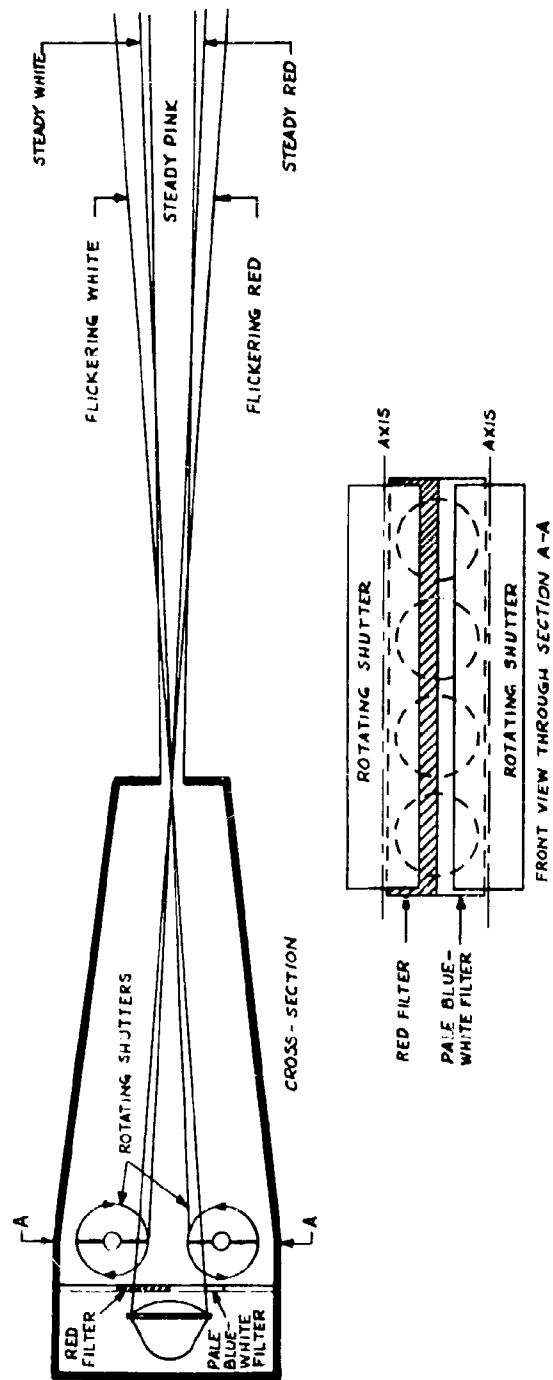
As a further development of the proposed HILO/FLOLS combination, it should be possible to add modulation to the vertical edges of the HILO coverage zone by means of a motor-driven shutter mechanism, as shown in figure 6-8. This change would create at least two more discernible visual cues: to further divide the HILO coverage and warn the pilot when he was on the upper or lower edge, and to assist in locating the center of the beam.

7. Extended Threshold Reference Lights

There are two possible methods of attacking the special problems of night operations. One is to improve the content and form of the information presented by the visual landing system. The other is to provide new strategic visual cues which would supplement and confirm the correct interpretation of the visual aid. The concept described below fits into the latter category.

Perhaps the most critical phase of the approach is that phase which starts at the moment the ramp lights can no longer be seen by the pilot. It is also at this point in the approach that the aircraft is most likely to be subjected to sudden downdrafts caused by airflow filling in behind the moving carrier.

The pattern of the deck lights is a useful reference, not only for centerline guidance, but for relative height and angle to the touchdown point. The sensitivity of the latter reference depends on the total length of the pattern



6-15

Figure 6-8. Modulated HILO Unit

visible to the pilot. With the near end of the pattern obscured, the sensitivity of the remaining visible pattern, in warning the pilot of any change in his angle to the touchdown point, is reduced. However, it is at this point that the aircraft may be most likely to sink below the glide path due to downdrafts. It is also at this point that the pilot may get the illusion of overshooting. The result is a definite tendency, pointed toward the most dangerous type of carrier accident, the ramp strike.

To eliminate this hazardous situation, it is suggested that the athwartship ramp lights be retained, and supplemented by lateral extensions mounted on booms, as shown in figure 6-9. The extensions would form a horizontal reference which would remain after the ramp lights were obscured by the nose of the aircraft. They would remain in sight so that the pilot would still be aware (through his peripheral vision) of the location of the ramp until he had passed it. This would postpone, and perhaps eliminate altogether, any tendency for the overshoot illusion just described.

More important from the safety standpoint is the function of the extension lights as a relative height reference. In a normal approach they could be expected to stream past the cockpit in the pattern shown in figure 6-10(A). Suppose however, that after the ramp lights passed out of sight, the aircraft started to sink below the glide path. The extension lights would still be visible, and their apparent streamer pattern would change, as shown in figure 6-10(B), to warn the pilot instantly of the sink.

Expressing this function in a different way, we could say that because of the extension lights, the full sensitivity of the deck pattern as an indicator of angle to the touchdown point is still available as a visual cue to the pilot, to confirm the meatball indication. This principle is shown in the profile view of figure 6-11.

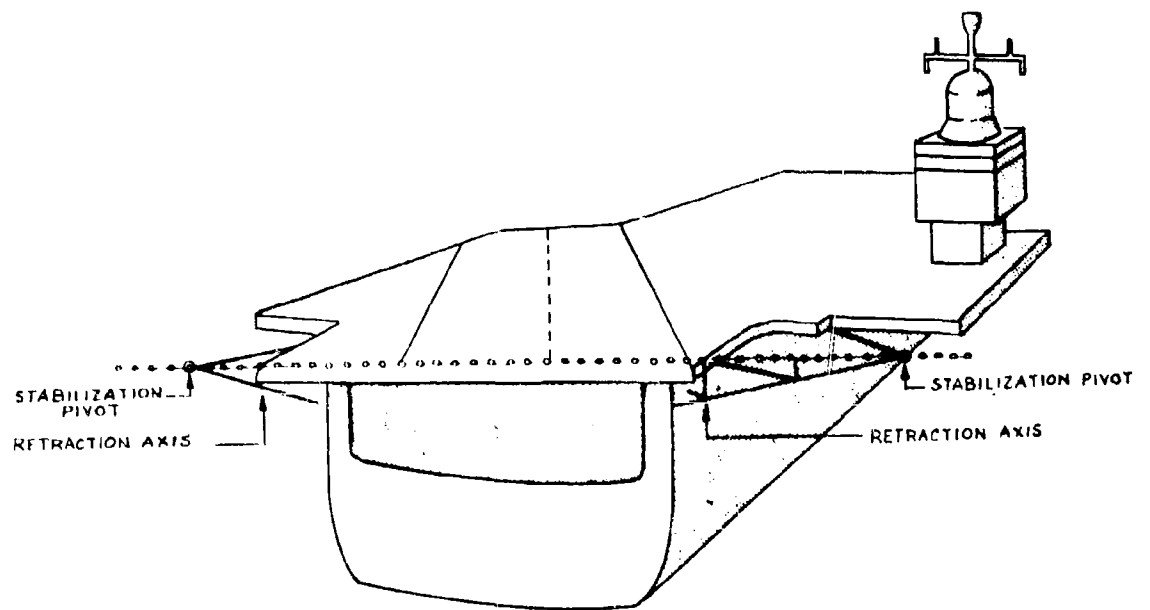
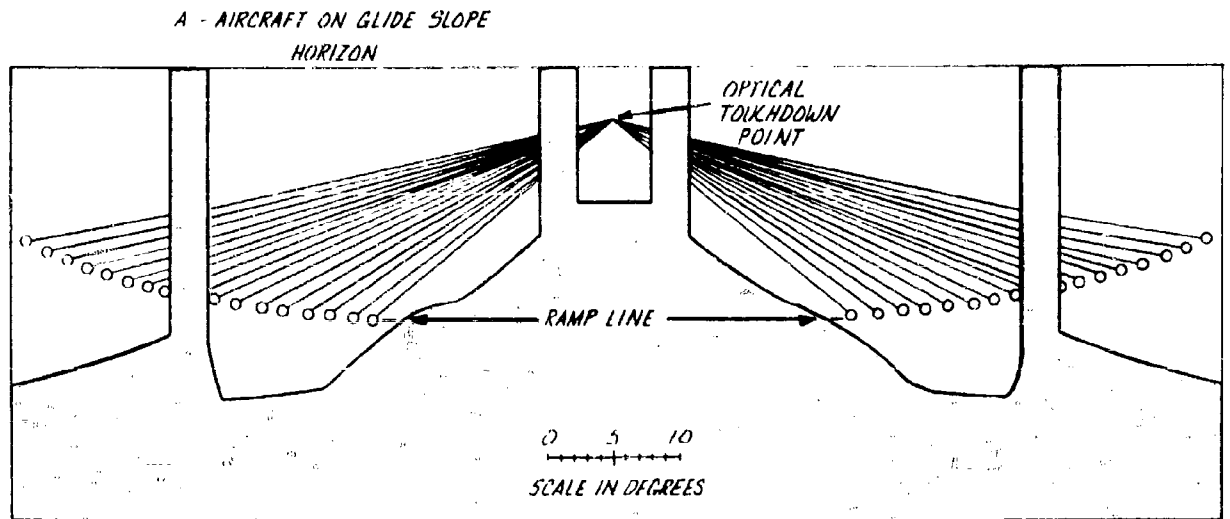
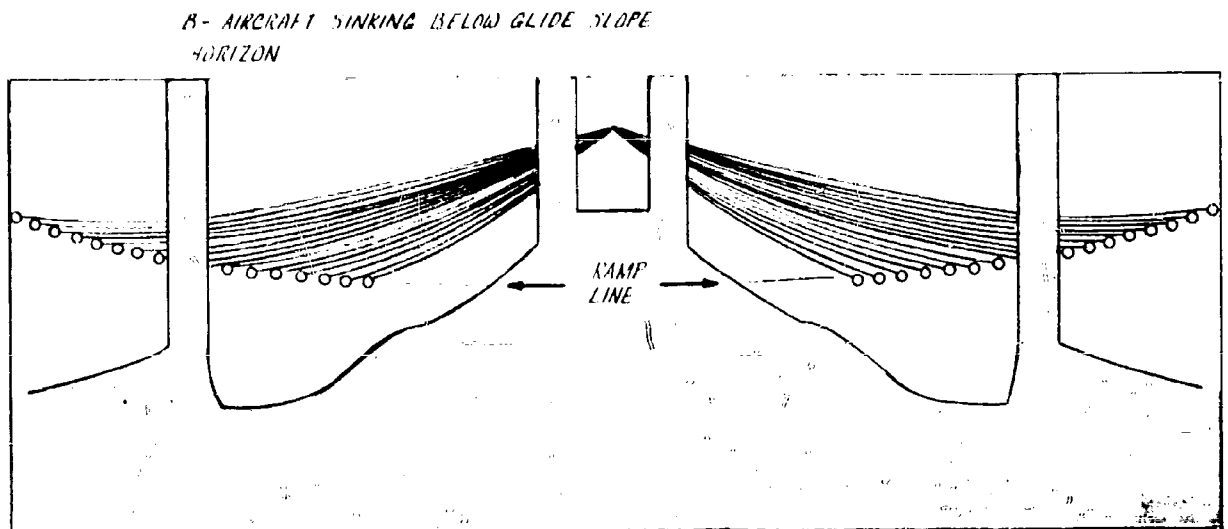


Figure 6-9. Extended Threshold Reference Lights



APPARENT MOTION OF THRESHOLD EXTENSION LIGHTS AS SEEN FROM F8A COCKPIT DURING NORMAL APPROACH ON 4° GLIDE SLOPE. LIGHTS ARE SHOWN IN POSITION THEY WOULD APPEAR WHEN AIRCRAFT WAS 100 FEET AFT OF THE RAMP.



CHANGE IN STREAMER PATTERN CAUSED BY SUDDEN DOWNDRAFT. AIRCRAFT ON GLIDE SLOPE AT 200 FEET FROM RAMP, $3\frac{1}{4}^\circ$ LOW AT 100 FEET FROM RAMP.

Figure 6-10. Streamer Patterns

A - RUNWAY LENGTH AVAILABLE AS VISUAL REFERENCE WITHOUT EXTENSION LIGHTS
 B - RUNWAY LENGTH AVAILABLE AS VISUAL REFERENCE WITH EXTENSION LIGHTS

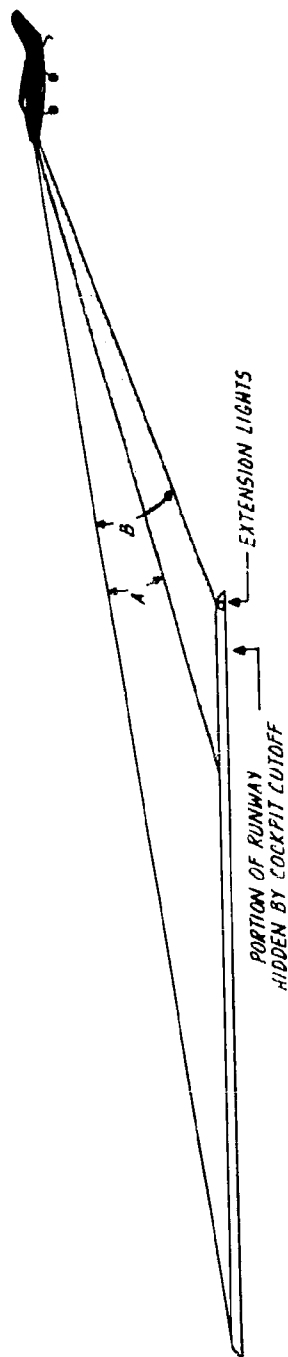


Figure 6-11. Profile View of Threshold Reference Lights

Although the extension lights represent a very simple addition to the carrier, it is expected that their use will result in a significant reduction of overshoots and undershoots during night operations.

The extension lights can be mounted on booms which can be retracted for maintenance, docking, or refueling-at-sea operations.

It would be desirable to keep the light pattern symmetrical for night operations, just as the other deck lights form a symmetrical pattern.

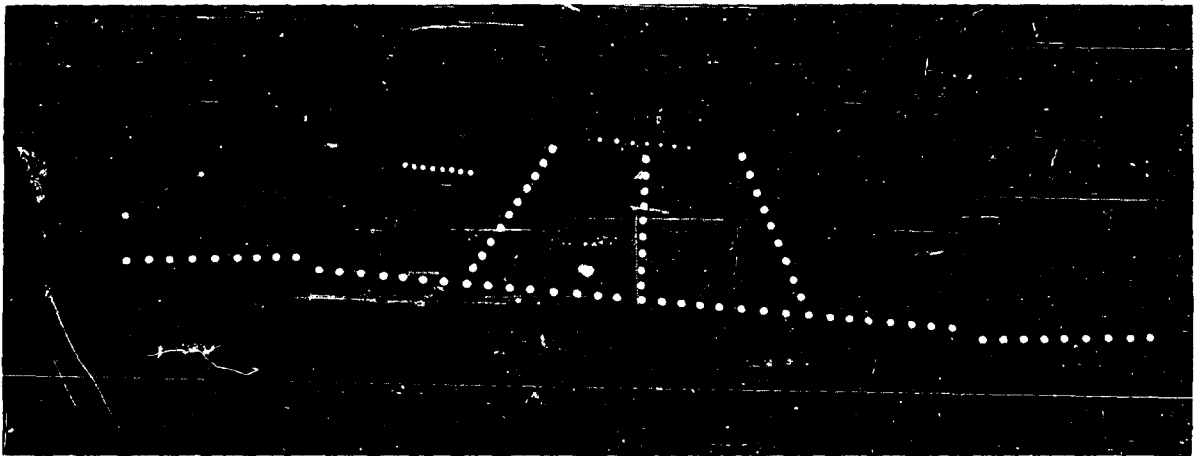
It may also be considered desirable to stabilize the extension lights to form a true horizontal reference rather than a deck-roll indicator for the pilot. Stabilization would be complicated somewhat by the fact that the landing runway is not symmetrical with respect to the deck, or even with respect to the ramp; most carriers have additional ramp area on the port side of the landing runway, as shown in figure 5-1. If the extension lights were to be stabilized, it would probably be practical only to stabilize the extreme outer portions, as shown in figure 6-12.

B. AIDS FOR LATERAL GUIDANCE

1. Contra-Rotating Lineup Beacons

A relatively simple and economical method of providing long range centerline guidance is to mount two beacon lights under the ramp, as shown in figure 6-13. The beacons rotate in opposite directions, and are synchronized (one is slaved to the other), so that the beams converge in the approach area and are in isophase as they pass down the centerline of the approach path.

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*APPEARANCE OF LIGHT PATTERN, WITH CARRIER ROLLING
5° TO STARBOARD*

Figure 6-12. Stabilized Threshold Reference Lights

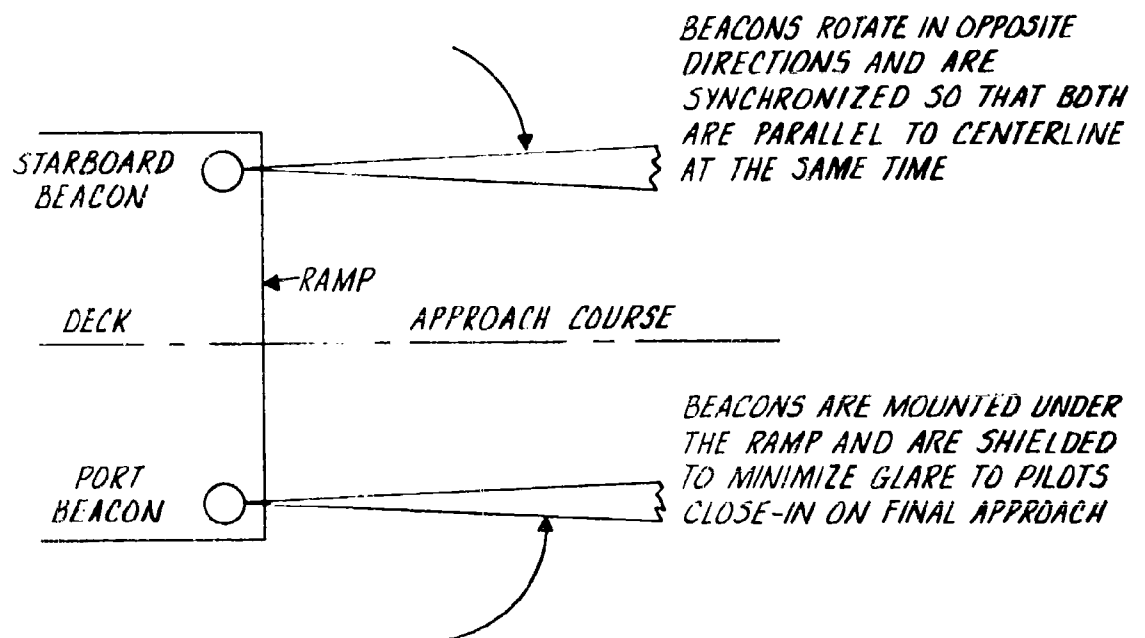


Figure 6-13. Contra-Rotating Line-up Beacons

Thus, when a pilot is directly on course, he sees the flashes from both beacons simultaneously. When he is to the left of course, the twin flashes occur in a left-to-right sequence to guide him to the right. When he is to the right of the course, the two flashes occur in a right-to-left sequence to guide him to the left. The time interval between the visible flashes is proportional to the angular displacement of the pilot from the desired course.

The beacons would be installed far enough apart to provide adequate left-right resolution by the pilot at the maximum usable range. The visual cues for guidance would depend on the ability of the pilot to see both beacons during any cycle. The beacons would be blanked off to shine only in the aft sector. The coverage area could extend 60 degrees on each side of the approach portion of the approach pattern.

Mounts for the two contra-rotating beacons could be stabilized for pitch and roll, if desired, to maintain a stable centerline path within a vertical plane to the carrier deck.

As an alternate version of this system, an additional stationary strobe light, with coverage extending 60 degrees on each side of the approach course, could be installed midway between the contra-rotating beacons. Strobed to flash once each cycle, at the instant the two contra-rotating beacons were exactly parallel to the final approach course, the strobe would provide a 1-2-3 visible sequence, left-to-right or right-to-left, depending on whether the pilot was left or right of the centerline. When on course, the pilot would see the flashes from all three beacons simultaneously.

Normally all beams would be focussed at an elevation angle of about two degrees above the horizon. They would thus not shine directly at an aircraft on the final glide slope. Being installed under the ramp, they would automatically be shielded from the view of a pilot close in on the final approach, thus eliminating a possible glare problem prior to touchdown.

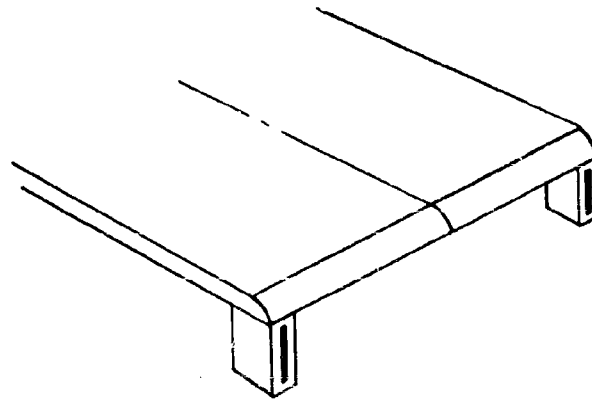
2. Double-Bar Lineup System

Figure 6-14 shows a proposed centerline system which consists of two modified HILO units mounted vertically under the ramp. The proposed modification consists of widening the coverage to provide guidance information over a wider angle. The horizontal spacing between the two units must be wide enough so that a pilot, at the maximum usable range and the outside edge of the coverage angle, can resolve distinctly the two separate light sources.

The two units are mounted with the red zones to the outside and the white zones toward the center. Sensing of the system exploits the ability of the human eye to compare the colors of two separately resolved light sources. On course, the colors are matched on a pink hue. A slight displacement from the centerline has a double effect: one beam goes more red while the other goes more white. The rule, "FLY AWAY FROM THE RED," is used by the pilot to determine which way to change course to get back on the centerline.

3. Crossbar Lineup System

Figure 6-15 shows a stern-mounted centerline guidance system which includes a vertical row of lights mounted under the ramp. This row is lined up laterally with the runway centerline lights on the deck, and is designed to be visible throughout the coverage angle of the system. Bisecting this



*BARS INSTALLED VERTICALLY
UNDER RAMP, RED SECTORS TO OUTSIDE
BARS COULD BE STABILIZED
IF DESIRED*

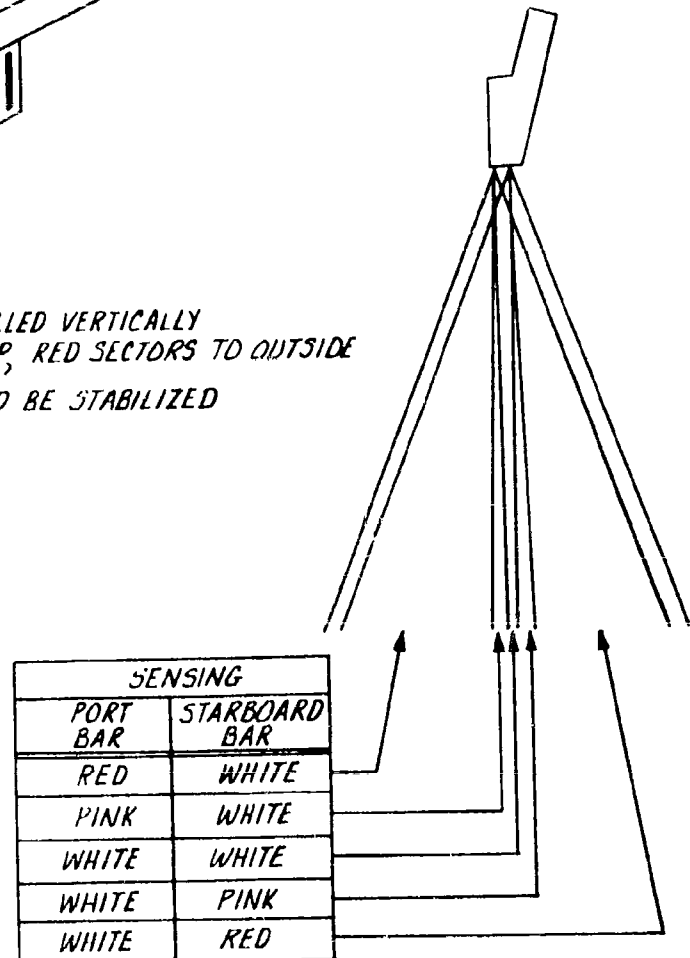


Figure 6-14. Double-Bar Line-up System

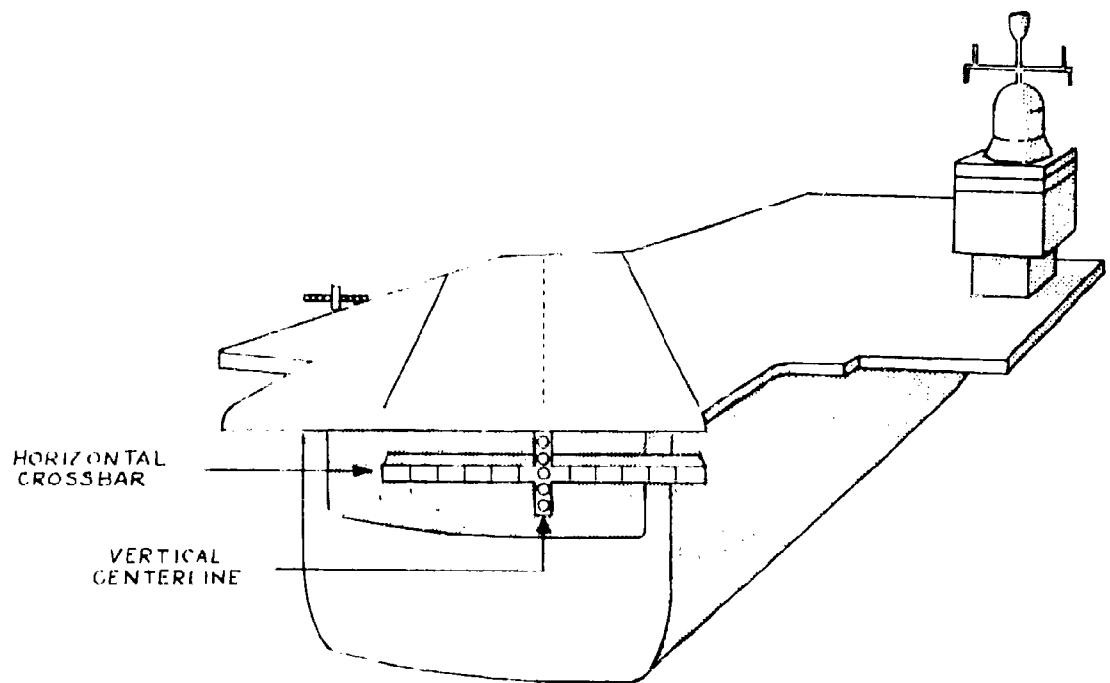


Figure 6-15. Crossbar Line-up System

vertical centerline is a horizontal row of lights. These lights are shielded to appear progressively at different angles from the centerline.

When on the centerline of the approach, the pilot sees only the vertical centerline which appears as an extension of the row of centerline lights on the deck. If the aircraft deviates from the centerline, the horizontal lights appear progressively, as shown in figure 6-16, to form a lengthening horizontal "T" pattern which points toward the direction the pilot must fly to get to the centerline; the relative length of the horizontal line indicates the relative displacement angle of the aircraft from the desired course. Thus the light pattern provides rate information to aid the pilot in intercepting the final approach course.

It is recommended that the lights of the crossbar centerline system be colored amber to distinguish the vertical and horizontal rows from the centerline and athwartship lights of the deck surface.

As shown in figure 6-17, the intersection of the vertical centerline with the deck centerline lights forms a supplementary visual cue for displacement, even without the cues provided by the horizontal row of lights. In addition, the geometrical plane of reference defined by the crossbar system should supply the pilot with an important depth perception aid.

Because the crossbar centerline system displays displacement information in incremental units, it can provide the pilot not only with information as to which way to turn, but how much to turn to bring the aircraft smoothly into the final approach course. This is done through use of a proportional correction system known as the tangential approach principle.

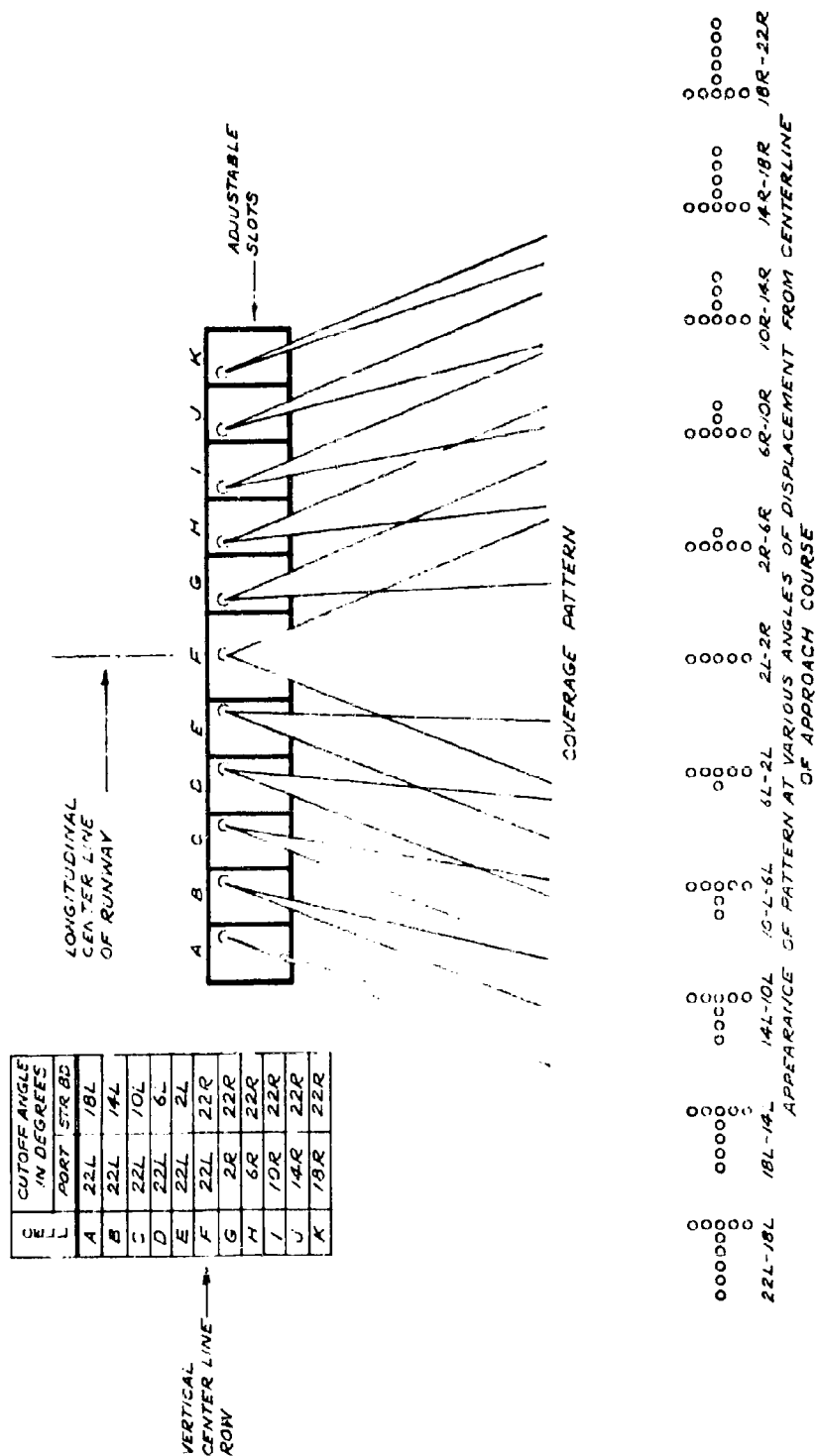
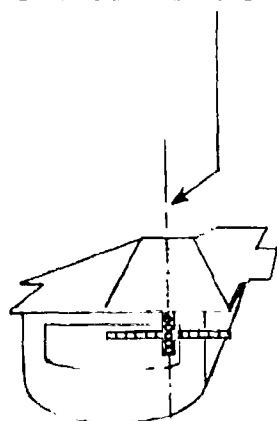


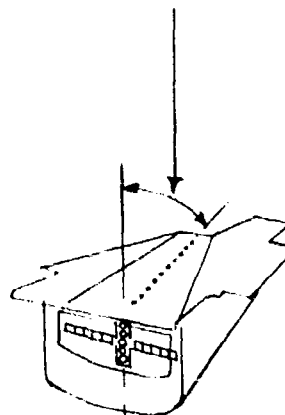
Figure 6-16. Details of Crossbar Line-up System

AXIS OF VERTICAL ROW
COINCIDES WITH CENTER
LINE DECK LIGHTS



ON COURSE

AXIS OF VERTICAL ROW
MAKES ANGLE WITH
CENTER LINE DECK LIGHTS



OFF SIDE

Figure 6-17. Supplementary Displacement Cue

As shown in figure 6-18, the tangential approach principle may be expressed by the formula $c = Kd$, where

C = Correction angle

K = Any constant greater than unity

(The higher the value, the tighter the course)

d = Angle of displacement

Suppose that, in figure 6-18, the crossbar centerline system displayed one lateral light for every 4 degrees of displacement. Using a K factor of 2.5 the pilot would correct 10 degrees toward the course for each 4 degrees of displacement, or 10 degrees for each visible lateral light. This method of applying and taking off course corrections leads the aircraft into the final approach course with a minimum amount of overshoot. Overcorrection is minimized by keeping the correction angle proportional to the actual displacement angle.

If the correct inbound heading is known, following the headings of the tangential correction system quickly stabilizes the aircraft on the centerline of the final approach course. If there is a slight error in the tentative final approach course (it will seldom be more than 10 degrees), the headings of the tangential approach system stabilize the aircraft on an inbound heading, closing in on the landing point but approaching at a small angle of displacement. As soon as the pilot realizes that his heading has stabilized, the display will indicate his approximate displacement angle. He can then revise his tentative final approach course for this displacement angle, and apply the tangential corrections to the revised course. These corrections will quickly align the aircraft on the centerline of the approach course.

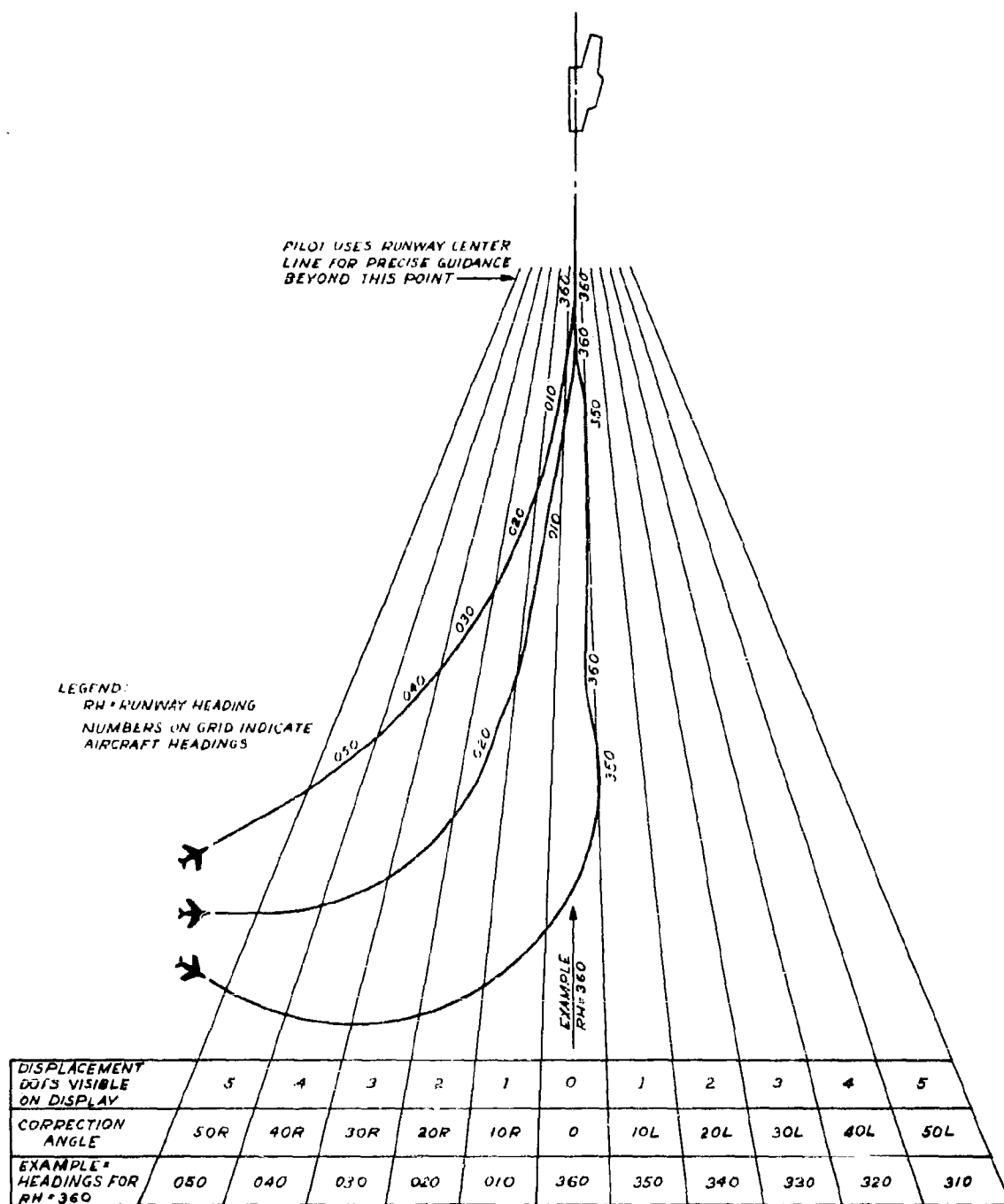


Figure 6-18. Tangential Approach Principle

In most cases, the course revision procedure described in the preceding paragraph will not be necessary, as the initial tangential procedure normally will bring the aircraft so close to the final approach course that the pilot can make whatever further corrections are necessary simply by reference to the centerline lights of the deck. However, the system does provide the information necessary to revise the final approach course if the pilot wants to use it.

SECTION VII

RECOMMENDATIONS

A. CONCEPTS

Table II lists the various design concepts which have been described in this report, together with the results of the preliminary evaluation conducted during the study. In this evaluation, an attempt was made to analyze the system gains which might reasonably be expected from the implementation of any concept. This list is not exhaustive, as it may be possible to combine two or more concepts. For example, it might be desirable to combine the double-datum idea with the expanded starboard FLOLS; or it might be desirable to mount the high-sensitivity datum on a starboard FLOLS, for long-range use, with the pilot reverting to the present lower-sensitivity port-side FLOLS at close range.

As we are not aware of the amount of funds available for the improvement of carrier visual landing aids, we do not know whether the primary objective for the continuance of this program will be to aim for low-cost improvements, which would tend to be realizable in a relatively short period, or to aim for maximum-gain developments which would tend to cost more in money and time. For this reason, table II contains two sets of recommendations:

(1) A "Quick-Reaction Package" which is made up of aids which appear realizable at a relatively early date; and (2) a "Maximum Gain Package" which is pointed toward devices which may take longer to develop but which appear to offer higher gains in the end. In some cases, the same concept is included in both packages.

TABLE II. PRELIMINARY EVALUATION

DESIGN CONCEPT	INTENDED FUNCTION	EXPECTED SYSTEM GAINS				Easy Interpretation of Display	Permits Lineup plus Glide Slope
		Increased Useable Range	Directional Guidance	Guidance Extended to Touchdown	Increased Flyability		
EXPANDED STARBOARD FLOLS	8 Ft 5 Cell	Long Range Glide Slope	Large			Check	
	8 Ft 9 Cell	Long Range Glide Slope	Large			Yes	
	15 Ft 9 Cell	Long Range Glide Slope	Large			Check	
	15 Ft 17 Cell	Long Range Glide Slope	Large		mod- erate	Yes	
THINLINE DATUM	Long and Short Range Glide Slope	Very small			Very small	Yes	
DOUBLE-DATUM FLOLS	Long and Short Range Glide Slope	Small			Small	Check	
HIGH-SENSITIVITY DATUM	Long and Short Range Glide Slope	Large			Check	Check	
HILO/ FLOLS	Long and Short Range Glide Slope	Large			Large	Check	
MODULATED HILO/ FLOLS	Long and Short Range Glide Slope	Large			Large	Check	
EXTENDED THRESHOLD REFERENCE	Altitude Reference and Safety Aid				Large at short range	Yes	
CONTRA-ROTATING LINEUP BEACONS	Long Range Lineup		Yes		mod- erate	Check	
DOUBLE-BAR LINEUP	Long Range Lineup		Yes		Large	Check	
CROSSBAR LINEUP	Long Range Lineup		Yes		Large	Check	
*DIAMOND MARKER	Long Range Glide Slope and Lineup	Large	Yes		mod- erate	Check	
*CARRIER INTEGRATED LANDING SYSTEM	**	Very large	Yes	Yes	Very large	Check	

* SEE APPENDIX A

** GLIDE SLOPE AND LINEUP
FOR ENTIRE PENETRATION,
FINAL APPROACH AND LANDING.

Check - Flight tests required

1

TABLE II. PRELIMINARY EVALUATION SUMMARY

ED ON	EXPECTED SYSTEM GAINS				Easy Interpretation of Display	Permits Lineup Plus Glide Slope Information	PHASE II RECOMMENDATIONS		
	Increased Useable Range	Directional Guidance	Guidance Extended to Touchdown	Increased Flyability			Quick-Reaction Package	Maximum-Gain Package	DEVELOPMENT EFFORT REQUIRED FOR PROTOTYPE
de Slope	Large				Check	Yes	X		1. Minor mechanical design 2. Cell modifications if 0.15° spread found desirable 3. Stabilization if large unit desirable
le Slope	Large				Yes	Yes			
le Slope	Large				Check	Yes		X	
le Slope	Large			mod- erate	Yes	Yes			
pe	Very small			Very small	Yes	Yes			1. Minor mechanical design
pe	Small			Small	Check	Yes			2. Minor mechanical design
pe	Large			Check	Check	Yes		X	1. Optical modification to cell 2. Mechanical design of optical unit 3. Stabilization linkage
pe	Large			Large	Check	Yes	X		1. Minor mechanical design 2. Stabilization for HILO's
pe	Large			Large	Check	Yes			1. Same as HILO/ FLOLS 2. Design of modulated HILO unit
nce				Large at short range	Yes	Yes	X	X	1. Minor mechanical design of boom lights 2. Roll stabilization if required
		Yes		mod- erate	Check	Yes			1. Synchronization circuitry 2. Roll stabilization if required
		Yes		Large	Check	Yes	X	X	1. Modification of HILO units 2. Roll stabilization if required
		Yes		Large	Check	Yes	X	X	1. Minor mechanical design 2. Roll stabilization linkage if required
de up	Large	Yes		mod- erate	Check	Yes	}	Outside Scope of present terms of reference	
	Very large	Yes	Yes	Very large	Check	Yes			

Check - Flight tests required

Each package includes (A) two promising concepts for improved glide slope guidance, (B) the extended-threshold-reference concept, which is believed important as an anti-undershoot aid, and (C) two promising concepts for lineup guidance.

Table II also includes a preliminary summary of the basic development efforts which would be necessary in the development of either concept.

Four concepts are not included in either of the recommended Phase II packages. Two of them (thinline datum and double-datum FLOLS) probably would produce only a relatively small increase in system effectiveness. The modulated HILO can wait for tests of the HILO/FLOLS; if these tests indicate that modulation would be desirable, this rather minor development could be done later. The contra-rotating lineup beacon concept was not considered as desirable as either of the other two lineup systems, as its indication is intermittent rather than continuous, and its flashing characteristics might prove annoying to pilots on the final approach.

B. PROGRAM

The original proposal for this study (Hazeltine Report No. 6120) outlined a comprehensive visual-aids development program, of which the study reported herewith was the first phase. The entire outline is listed below.

"Phase I - The initial phase of the Hazeltine study will be to review the field by becoming thoroughly familiar with the technical and operational problem areas, from study of the applicable reports of the organizations listed above, as well as the FAA, the Air Force, and the Royal Aircraft Establishment (England). This study will be supplemented by personal liaison with a number of these groups."

"At the end of this survey, and in accordance with the program objectives detailed in Section III of this proposal, certain concepts and proposed solutions will be recommended for detailed analysis. Mutual agreement will be reached by the Navy and Hazeltine at this time, as to which concepts should be selected for further testing."

"Phase 2 - The selected concepts will then be implemented, in model form where possible, to determine basic operational parameters, and to make simple simulation tests to demonstrate technical and operational feasibility, including the effects of human factors. The results of these laboratory tests and analyses will be reported to the Navy. This informal interim report will include recommendations as to the concepts which appear to offer the most favorable avenue of approach toward early implementation."

"Phase 3 - Based on the desires of the Navy, and subject to the amount of funds available, procurement specifications will be developed for implementing one or more of the selected concepts in prototype form. A final report will be prepared, summarizing the work accomplished during the entire program. The report will be submitted to the Navy for approval prior to publication."

As a result of this study, we have reached the point described in the second paragraph of the foregoing outline, where certain concepts and proposed solutions are being recommended for detailed analysis. The next step is for mutual agreement to be reached by the Navy and Hazeltine, as to which concepts should be selected for further testing. When this agreement is reached, Hazeltine will submit a detailed technical proposal and cost estimate to cover the scope of work desired by the Navy. Hazeltine is prepared technically to develop any of these concepts through Phase II and Phase III to implementation of the actual hardware.

APPENDIX A

BY-PRODUCTS OF CARRIER LANDING STUDY

A. RELATIONSHIP TO STUDY

Two new concepts which were generated during the course of this study are somewhat beyond the original terms of reference of the Hazeltine Study Contract. However, as it appears they have useful applications for the Navy, detailed descriptions are included herewith for whatever use the Navy desires to make of them.

The first concept is an extremely simple and inexpensive method of extending visual glide path guidance out to several miles, day or night, for land-based airport facilities such as Naval Air Stations, but particularly for SATS (Short Airfields for Tactical Support). This concept is not recommended as a Carrier Visual Landing Aid because it requires a fixed landing surface, and it has no provision for pitch and roll stabilization.

The second concept is an electronic system for carrier instrument approach and landing. It is outside the terms of reference for the original Hazeltine Visual-Aids Study Contract because it requires additional equipment in the aircraft. However, it appears to offer major advantages in conducting the entire approach and landing in a more positive and safe manner in weather conditions down to perhaps a ceiling of 200 feet (above deck) and a visibility of one-half mile. Furthermore, it utilizes portions of presently installed systems, and should require only a relatively small amount of new development.

B. DIAMOND GLIDE-SLOPE MARKER

As previously stated, the resolution of the present **FLOLS** Glide Slope is marginal at a distance of about one nautical mile. This limitation results in two adverse effects: (1) it requires the pilot to level off at approximately 500 feet altitude prior to glide path interception, and (2) it gives the pilot only about 30 seconds (and often less time) to intercept the final approach course, stabilize the aircraft speed, sink rate, and alignment on the glide slope and centerline prior to touchdown.

A Visual Aid which would double or triple this range, and also provide lineup information, would tend to increase safety by allowing the aircraft to maintain a proportionally higher altitude prior to glide path interception. It also would tend to produce more accurate and safer landings by giving the pilot lineup and glide slope information at a greater distance from the runway, thus providing a proportionally greater amount of time for the pilot to stabilize the aircraft on the final approach path.

As shown in figure A-1, the Diamond Glide Slope Marker is a simple shape coded parallelogram pattern painted on the runway surface. The short axis of the pattern coincides with the desired optical touchdown point; the long axis coincides with the longitudinal centerline of the runway. Geometrically, the diamond pattern is proportioned so that, when viewed from an aircraft which is on the centerline of the approach course, and on the desired glide slope, the pattern will appear as an exact square. If the observer is above the desired glide slope, the square pattern will appear lengthened in the longitudinal direction of the runways. Conversely, if the observer is below the glide slope, the square will appear flattened. If the observer is on the centerline of the

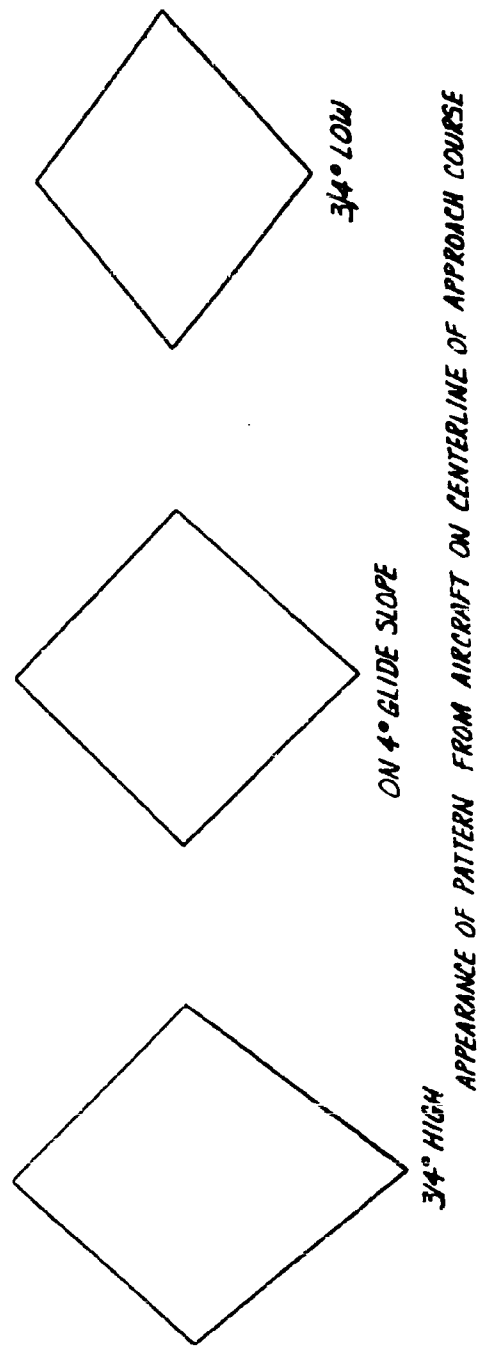
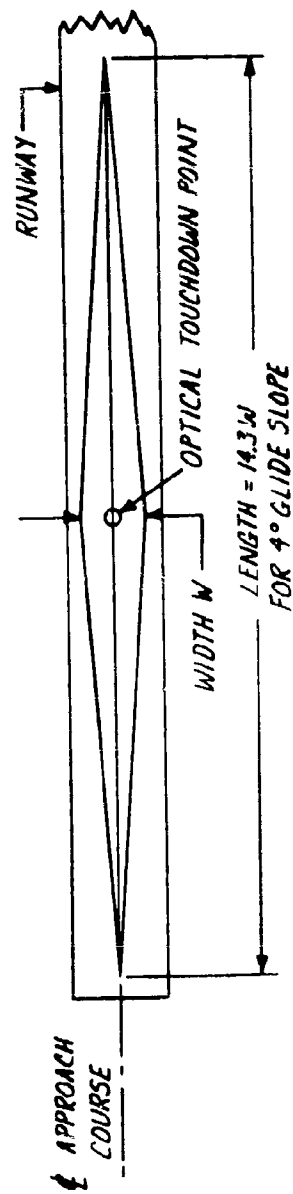


Figure A-1. Diamond Marker

approach course, the pattern will appear symmetrical about a vertical axis. If the observer is off the centerline of the approach course, the pattern will appear skewed laterally, as shown in figure A-2.

Factors to be considered in laying out the pattern are the lateral and longitudinal space available as well as the desired glide slope. For a four degree glide slope, the aspect (length/width) ratio of the pattern should be 14.3 to 1, as the co-tangent of four degrees is 14.3; similarly, for a 3-1/2 degree glide slope, the aspect ratio should be 16.35 to 1.

The pattern dimensions should be large enough (together with the line width employed) to be seen clearly at the range corresponding to the glide slope interception altitude. However, there is a disadvantage in making the pattern larger than necessary, in that the pattern retains its square characteristic only down to a minimum range equal to about four times its maximum length (2000 feet for a 500-foot pattern). At shorter ranges, the relative difference in distance to the near and far ends begins to distort the pattern, as shown in figure A-3.

While a pilot experienced in using the pattern probably could still fly an accurate glide path at somewhat shorter ranges, the sole use of the pattern as a visual aid is not recommended where very accurate touchdown placement is required. In such cases, the pattern should be considered as a supplemental aid to the FLOLS or MOLS installation. The function of the diamond pattern would be to get the aircraft lined up on the glide path at much longer ranges than are possible with the optical aid. Later, when the pilot arrives within the usable range of the optical aid, already lined up on course, he should disregard the diamond pattern and concentrate on flying the optical meatball to a precision landing.

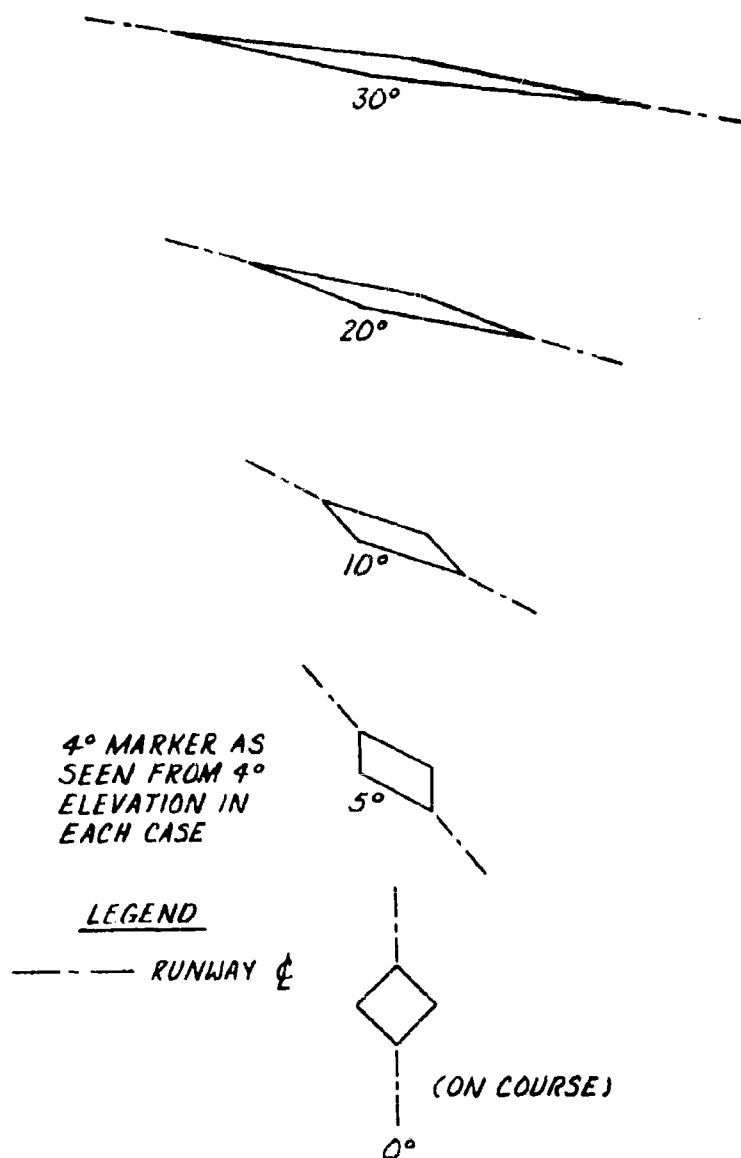


Figure A-2. Appearance of Diamond Marker When Off Course

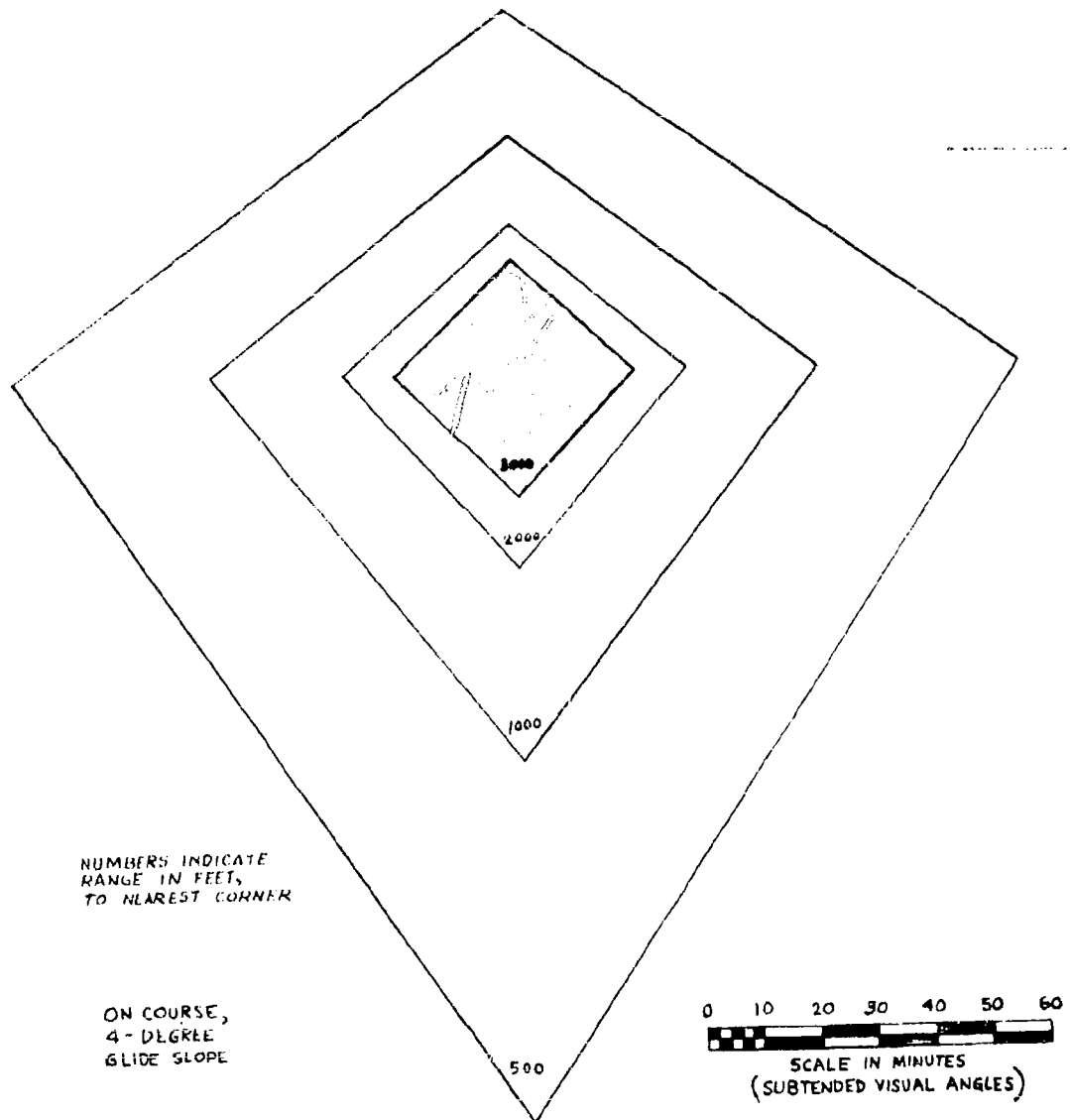


Figure A-3. Apparent Distortion of 40 ft x 572 ft Diamond Marker at Close Ranges

Additional advantages to the diamond glide slope concept are its extremely low cost, and the fact that it has no moving parts to get out of order. As shown in figure A-4, it can be lighted very simply for night operations. A special advantage of the diamond marker in the SATS application is its ability to provide a much higher minimum glide path interception altitude over rough terrain.

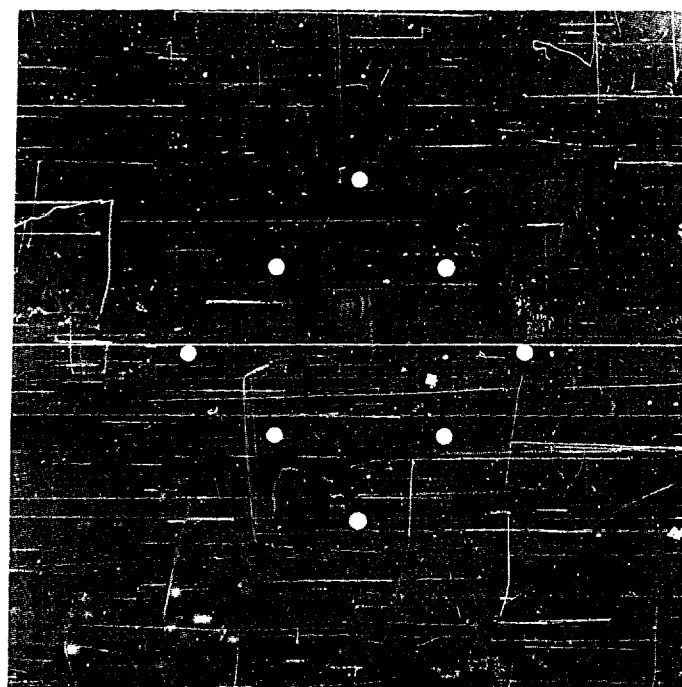
C. CARRIER INTEGRATED LANDING SYSTEM (CILS)

1. Need for Integrated Approach

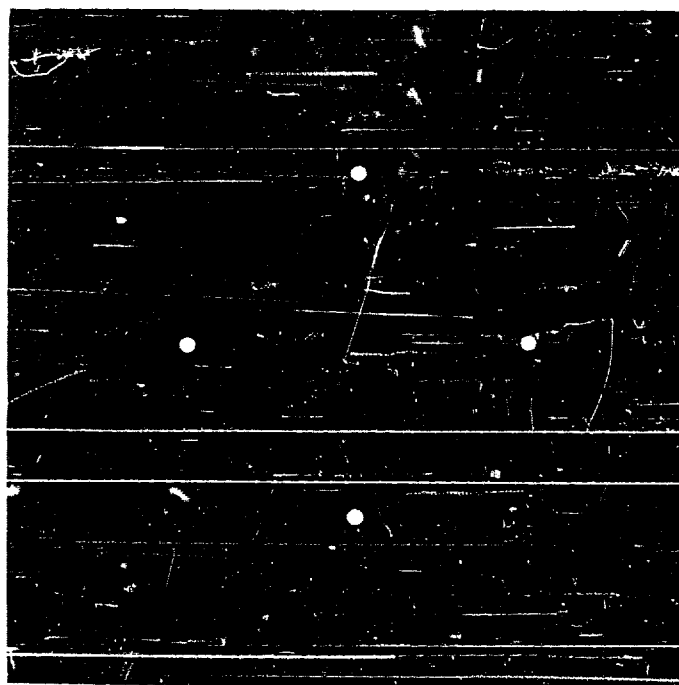
Although it has been convenient, in looking at the problems of carrier landings, to consider the visual approach and landing as an isolated flight operation, it may ultimately be more useful to consider the carrier landing in the context that, as far as the pilot is concerned, it is the final critical climax to a penetration procedure which may begin as much as 45 miles away from, and 30,000 feet higher than, the touchdown point.

Seen in this aspect, the problem takes on a new perspective leading to the idea that perhaps the entire penetration and final approach operation could be improved, simplified, and placed on a more positive basis with one phase transitioning smoothly into the next. The necessity for recovering aircraft in weather down to 200-foot ceiling and 1/2 mile visibility leads to a need for getting the aircraft lined up and stabilized on the glide slope during the instrument portion of the approach. This, in turn, implies a need for very accurate directional and vertical electronic guidance down a sloping path.

Because of the extremely small dimensional tolerances which are demanded at the end of the approach path, it would appear desirable to base the final portion of the approach system on direct optical, rather than electronic, measuring techniques. Popping out of an overcast at 200 feet above deck level, with



CORNERS AND LATERAL MIDPOINTS



CORNERS ONLY

Figure A-4. Diamond Marker Lighting Patterns

A-8

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with only 3000 feet to touchdown, does not leave the pilot with much time to re-focus his eyes, obtain visual orientation, and align the aircraft in relationship to a meatball and runway centerline. To simplify this critical transition problem, it may be desirable to integrate the optical portion of the system with the electronic portion of the system. Fortunately, the recent development of the heads-up display should offer a solution to this problem.

2. System Concept

An integrated electronic/visual landing system is proposed, based on the employment of a precise electronic glide slope (PEGS) for the initial portion of the approach, all the way from holding or initial acquisition altitude, with an adaptation of the present pilot landing aid television (PLAT) system supplying guidance for the final (visual) portion of the approach. Displays for the two stages of the proposed system would be integrated on a heads-up cockpit presentation for the pilot. A block diagram of the proposed system is shown in figure A-5.

3. PEGS

The precise electronic glide slope (PEGS) would utilize an altitude input from a radio altimeter, and a precise distance input from an improved TACAN system to generate a sloping glide slope from the initial approach altitude to the landing deck. The sloping path could be a straight descent all the way, or the initial portion could be programmed specifically for different aircraft types if separate segments at different descent rates were mandatory. The latter portion of all descent programs would be standardized for either the four degree or 3-1/2 degree straight descent slope to the carrier deck.

The accuracy of the TACAN distance input to the PEGS computer would be considerably higher than that attained with present EGS (Electronic Glide Slope) equipment. This would be due to the following features:

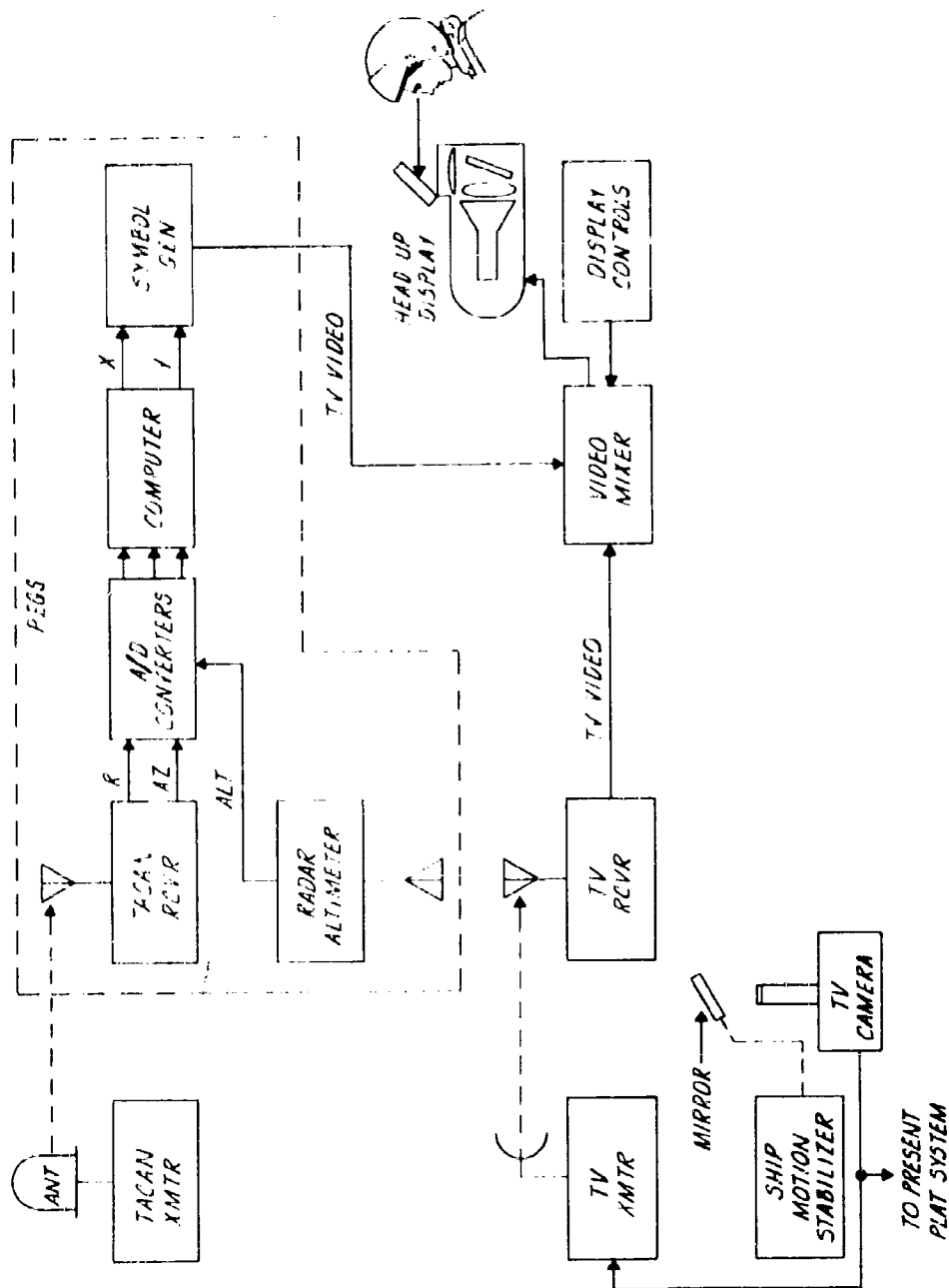


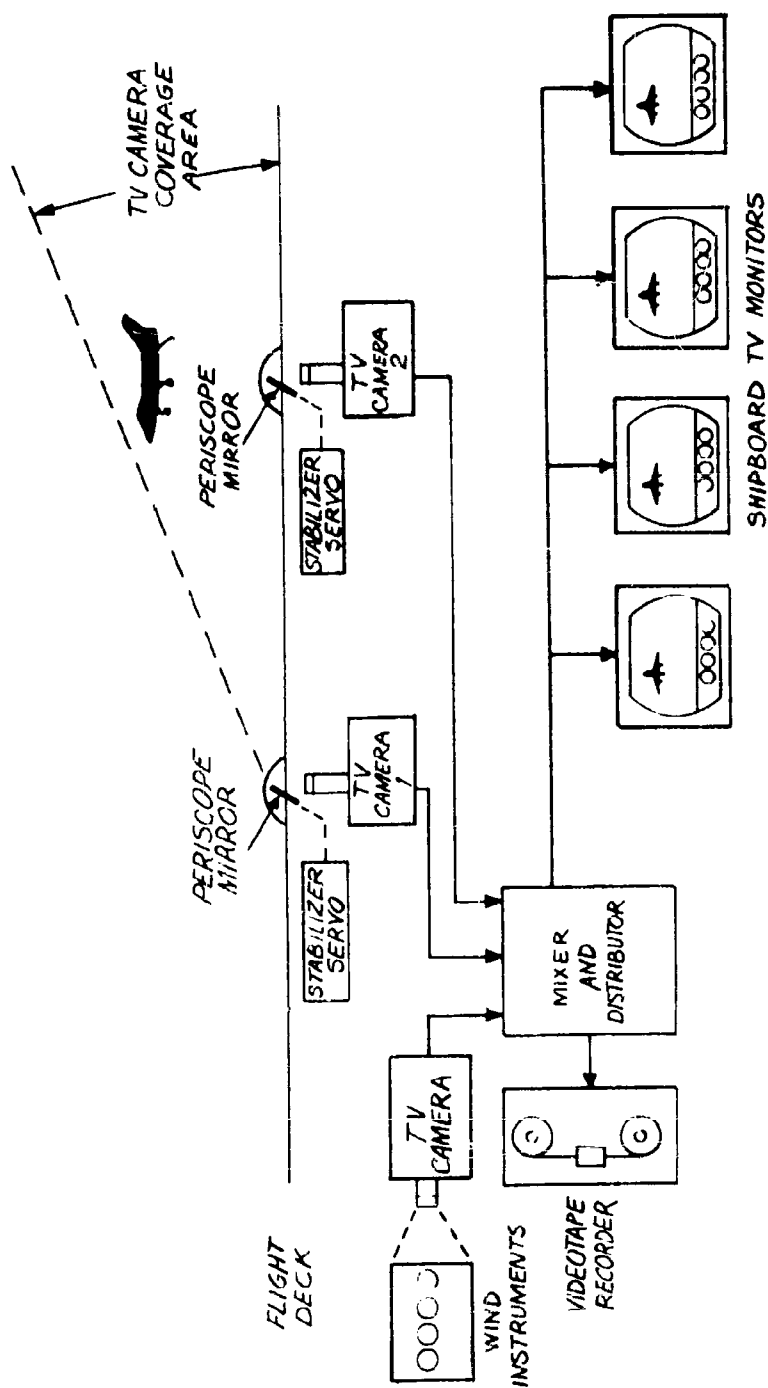
Figure A-5. CILS Block Diagram

- a. Operating the airborne transponder in the search mode instead of the track mode whenever utilizing the approach system. In this mode, the PRF is five times as high as the PRF used in the track mode. However, because of the relatively low number of aircraft which would ever be on approach simultaneously, the transponder duty cycle would not be compromised.
- b. Calibrating the shipborne transponder for maximum system accuracy in the presence of strong signals.
- c. Adjusting system error to provide maximum range accuracy at minimum, instead of medium, range.

4. PLAT

Most of the attack carriers of the U.S. Navy are being equipped with the PLAT system which is shown in figure A-6. The present PLAT system includes two TV cameras which are mounted below the centerline of the landing runway, and which look through periscopes flush-mounted in the deck surface, to monitor the final approach path. The periscopes are stabilized by pitch signals received from the ship's gyro so that the center of the TV scan coincides with the center of the final approach path. Only one TV camera is used at a time. The camera output is fed to TV monitors at various locations on the ship, and is also recorded on video tape for subsequent training sessions or accident investigations.

A useful adaptation of this existing system would provide direct landing guidance, through a TV link, to a heads-up display in the aircraft. Such a system would furnish the pilot with precise vertical and lateral guidance, as well as an indication of range, in day and night final approach operations. As shown in figure A-5, the system would require the addition of a TV transmitter to the ship, and a TV receiver feeding the heads-up display in the aircraft.



A-12

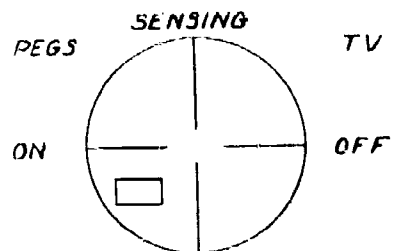
Figure A-6. Present PLAT System

5. System Operation

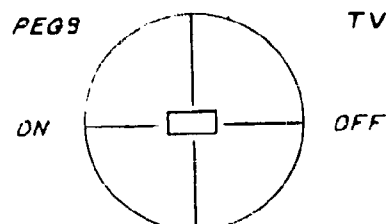
The CILS would be utilized for the entire approach procedure all the way from the initial approach altitude. The pilot would use TACAN or GCA (Radar) guidance to the point of glide slope interception on the approach path. The PEGS would show continuously, by the displacement of a small video symbol from vertical and horizontal centerlines, the horizontal and vertical displacement of the aircraft from the approach path set up by the PEGS computer. As shown in figure A-7, the displacement data would be shown on a heads-up display by positioning and movement of an open-centered symbol generated by raster scan techniques.

During the final portion of the approach, the output from the TV link would be superimposed on the display. If the two stages of the system are properly aligned, the TV image of the aircraft will pop up in the middle of the open-centered PEGS symbol when the aircraft gets in range of the camera. In good visibility, this will occur when the aircraft is about two miles from touchdown; at night (using landing lights on the aircraft) the TV image should be visible when the aircraft is about five miles out.

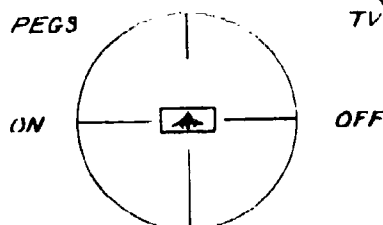
As shown in figure A-7, since the aircraft on approach would be headed in a direction opposite to the direction in which the camera is looking, the TV scan system would be designed to provide the pilot with a mirror image (left and right reversed) of the actual situation as viewed from the periscope site in the flight deck. This would provide the same sensing as that provided by the PEGS symbol, and would provide smooth transition from the PEGS portion to the PLAT portion of the approach.



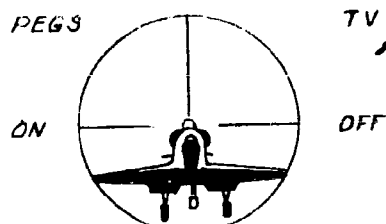
AIRCRAFT BELOW GLIDE SLOPE
AND LEFT OF APPROACH COURSE



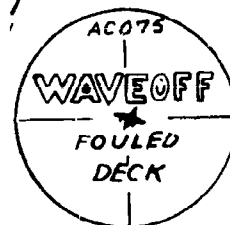
AIRCRAFT ON GLIDE SLOPE
AND ON COURSE



TRANSITION TO TV GUIDANCE



APPROACHING TOUCHDOWN ON COURSE
(WINDSHIELD USED AS CENTER-
LINE REFERENCE MARK)



POSSIBLE USE
OF TV AS
DATA LINK

Figure A-7. CILS Display

Since the PLAT image normally would be more accurate than the PEGS symbol position on the heads-up display, the pilot could switch off the PEGS symbol as soon as he had a suitable PLAT TV image on the display; subsequently, he would control the aircraft to keep its image lined up on the reference marks. The response of the aircraft to any control action would be shown instantly and continuously on the display in terms of its deviation from the desired course. The TV image would increase in size and detail as the aircraft approached the touchdown point.

The basic TV system could also be used as a ground-to-air data link to furnish pertinent approach or warning data, as shown in figure A-7.

To provide the most usable display in all types of day and night weather conditions, the display brightness would be adjustable by the pilot and would be controlled automatically (for any manual setting) by means of a photoelectric (light meter) sensor. Even more important, the positive/negative polarity of the TV picture could be switched instantly by the pilot to provide a bright image on a dark background or the reverse.

As the normal working range of the PLAT portion of the system would seldom exceed five miles, only a very low power would be required for the TV ship-board transmitter. This power could also be beamed directionally to cover only the final approach area.

6. H/E Compensation

The ultimate objective of any carrier landing system is to supply guidance for bringing the tail hook of the aircraft down a path where it will engage one of the cross-deck wires. However, the optical path, while parallel to the tail hook path in space, is offset from the tail hook path by the hook-to-eye (H/E) distance. This distance is different for different types of aircraft and must be compensated for to produce the correct touchdown point for the tail hook.

Two possible methods appear feasible for compensating the CILS approach path for different H/E distances of different aircraft. One method would be to use different camera locations for different aircraft types with the pilot lining up some fixed reference on the aircraft (such as the windshield) with the cross hairs on the display during the final portion of the approach.

The other method would be to utilize one camera, but different predesignated points (such as the cockpit on one, the wing tips on another), for lineup with the TV reference marks. It is possible that a combination of the two methods would be practical to give the widest range of adaptability for various aircraft types. The use of low-light-level TV cameras should facilitate the use of this procedure at night.

7. Operational Advantages

CILS would offer several improvements over the present FLOLS installation used on U.S. Navy aircraft carriers:

- a. CILS would provide precise glide slope displacement data over a wider vertical area of coverage all the way down the approach to touchdown.
- b. CILS would provide directional guidance all the way down the approach to touchdown.
- c. CILS would provide greatly increased day and night range to secure two important advantages: (1) it would increase safety by permitting interception at a much higher altitude and (2) this, in turn, should increase approach success by giving the pilot a longer time to become stabilized on the glide slope at final approach speed.
- d. CILS would provide the pilot instantly and continuously with an indication of how any control action is affecting the alignment of the aircraft on the desired approach course.

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APPENDIX C

ACKNOWLEDGMENTS

The present work was conducted in 1963 and early 1964, under Contract No. N156-44303, issued by the Naval Air Engineering Center, Philadelphia, Pennsylvania. The assistance of the following persons, in providing the necessary background information, is gratefully acknowledged:

Capt. D. K. Weitzenfeld, Cdr. Richard Hall, R. J. Cox, M. Giordano, and Max Doroff of the Naval Air Engineering Laboratories (Ships Installations) at Philadelphia

Cdr. J. T. Parady and LCDR. T. Porter of the Bureau of Naval Weapons, RSSH-5, Washington

T. S. Momiyama, J. Jennings, and LCDR. R. S. Chew of the Naval Air Test Center, Patuxent

LCDR. J. A. Mulligan, of NTDDPA, Washington

G. E. Hart of the Security Systems and Avigation Branch, Naval Research Laboratories, Washington

A. W. Baldwin, C. L. Tipton and Miss B. L. Perry, of the Engineering Psychology Branch, Naval Research Laboratories, Washington

Charles Douglas, of the Bureau of Standards, Washington

H. M. Ferguson, G. D. Bachelor, D. T. Hine, and Messrs. Stevens and Mawwaring of the G.E.C. Hirst Research Centre, North Wembley, Middlesex, England

R. L. Paugh, of General Electric, Nela Park, Cleveland

R. Egan, of Structural Electric Products Corp., Windsor Locks, Conn.