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The Depth of Flash Optical Landing System

RUTH H. SHIELDS

Engineering Psychology Branch
Applications Research Division

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ABSTRACT

The Depth of Flash Optical Landing System is an optical landing aid which projects a positive glide-slope indication to the approaching pilot, enabling him to achieve highly accurate vertical control of his aircraft on the final landing approach. The signal gives accurate glide path information to a range limited only by the intensity of the light source and atmospheric conditions.

Coding of the signal is by the color and depth of flash of a projected light source near the desired point of touchdown. Color coding provides high, low, and on-glide-slope information, while a gradually increasing flashing characteristic warns the pilot of increasing error from the prescribed glide path. On approaching the signal source, the pilot is guided onto the optimum path by correction of his altitude error in accordance with the signal received.

Two unique design principles are featured in the Depth of Flash Optical Landing System. First, the backward projector principle causes the pilot to see only that color which is projected to his eye. The light projected to the area directly above the prescribed glide path is steady green, that below it is steady red, and the 0.2-degree-wide glide path is steady white. Second, the defocused shadow bar method introduces a flashing characteristic, gradually increasing as a function of angular error. As error increases beyond certain angular limits, the flashing characteristic is perceived in the red or green signal, first as a slight pulsation and then as a more and more noticeable flash.

The Depth of Flash Optical Landing System is currently being evaluated under a Naval Air Systems Command program.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

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THE DEPTH OF FLASH OPTICAL LANDING SYSTEM

INTRODUCTION

Under the sponsorship of the Naval Air Systems Command (Formerly Bureau of Naval Weapons) the Engineering Psychology Branch at the Naval Research Laboratory is pursuing a program of development of visual landing aids to improve the accuracy and safety of nighttime carrier landings. Under this program several devices (1-4) have been developed or tested, all of which have been demonstrated to improve the accuracy with which the pilot acquires and holds the glide path to touchdown. One of the devices tested, the Depth of Flash Optical Landing System, is described in this report.

The Depth of Flash Optical Landing System was originally an independent development by three members of the Engineering Psychology Branch, intended as a simple and inexpensive glide path indicator and acquisition aid for use at small general-aviation airports. The outstanding performance of the experimental unit resulted in its being brought to the attention of the Naval Air Systems Command and the Naval Support Forces Antarctica. The latter had communicated their need for a visual landing aid for use in a unique polar weather condition called "whiteout," which occurs when extreme diffusion of light upon the totally white terrain blots out all shadow definition. Both surface and horizon become obscured, causing pilots to experience a dangerous loss of depth perception.

Among the available landing aids considered to fill this need were the Mirror/Fresnel Lens Optical Landing System now in use on Navy carriers, and the Rainbow Optical Landing System recently developed at the Naval Research Laboratory. Particular emphasis was placed upon the requirement for simplicity of operation and ease of interpretation of the signal provided. The Rainbow System developers at NRL, contacted for advice on the problem, suggested that the Depth of Flash Optical Landing System might be applicable to this special need. Subsequently, the NavAirSysCom, at the request of Naval Support Forces, Antarctica, sponsored the building of a weatherproofed experimental unit for testing at Williams Field, McMurdo Station, Antarctica.

Also under Naval Air System Command sponsorship, a second unit has been built and evaluated by the Naval Air Test Center, Patuxent River, Md., particularly concerning its potential for fleet use aboard carriers. Further evaluation at sea has been recommended. In addition, it is anticipated that, in keeping with its original development for small airport use, the system may prove to be an effective and easily transportable aid for land-based military aircraft in forward areas where facilities for installation of more complex equipment are limited.

It is the purpose of this report to provide a detailed description of the "Depth of Flash" landing system, discussing both its operational use and the concepts involved in its design.

THEORY OF OPERATION

Simple Three-Color Projection as a Part of the System

To illustrate the "backward projector" principle, which constitutes part of the basis of the Depth of Flash Landing System, consider a simple three-color projector slide as shown

in Fig. 1. A qualitative, or "high, low, and on-glide-slope" signal can be provided by a projector focused at optical infinity, containing such a slide. The projector, located adjacent to the touchdown point, can be directed toward the approaching aircraft along the line of the desired glide slope. The narrow yellow strip* in the center of the slide represents the glide slope; green is projected to the portion of the visual field above the glide slope, and red below it.

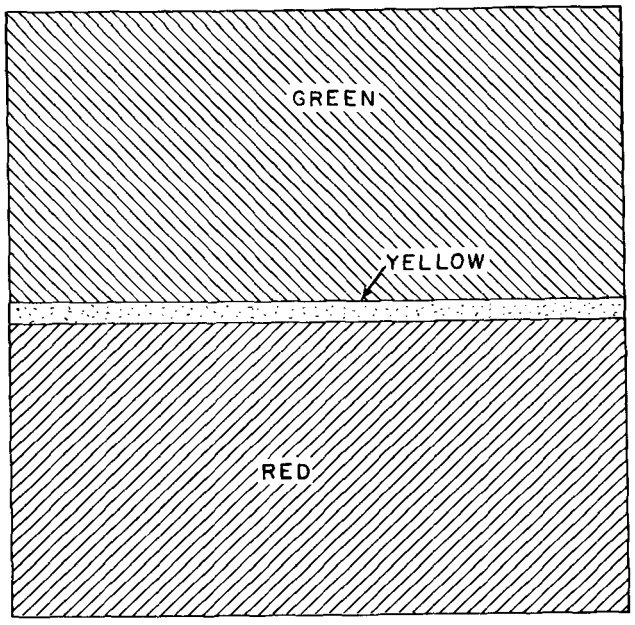

Fig. 1 - Projected image of a three-color slide

The pilot, looking toward the projector, will see only one color at a time, determined by his vertical position in the visual field (Fig. 2).

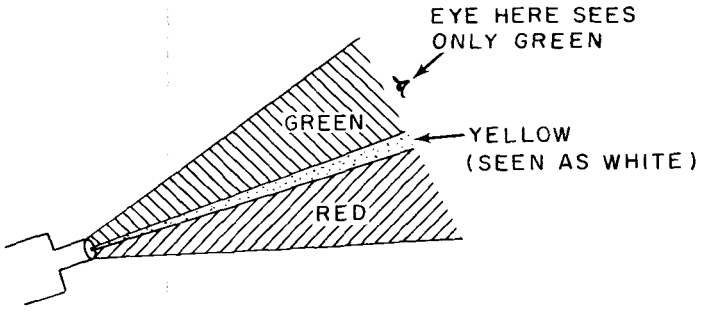

Fig. 2 - Operation of the "backward projection" principle

*Light projected through the yellow strip appears white to the approaching pilot and will be referred to as a white signal.

Depth of Flash Coding in the System

The Depth of Flash Optical Landing System (DFOLS) provides the high, low, on-glide-path information as described above, and in addition is designed so that at the upper and lower extremes the color-coded light is flashing vigorously, while the light projected near the center of the pattern is constant in intensity. The signal command is thus further coded by depth of flash; i.e., an increasing error from glide slope causes a gradual change of character of the light seen by the pilot from steady, through pulsating, to more and more deeply flashing (Fig. 3).

Combination of the color coding and flash coding of the system produces an easily interpreted signal command, always appropriate to the vertical position of the aircraft in the visual field. If the pilot making his approach is, for example, significantly high above glide path, a green signal light will be seen, flashing completely on and off, or with a maximum "depth" of flash. As he corrects the vertical error and approaches the glide path, the "depth" of the flash reduces; perceptually the light appears to lose its flashing quality, becomes merely pulsating, and then appears to "steady out." Just prior to entering the on-glide-path position, the pilot receives a steady (nonflashing) green signal which changes to steady white when his error from the optimum glide path is within a prescribed angular tolerance. If he then deviates slightly from glide path on the low side, he will see steady red; if he descends further, the signal will appear to lose its steady characteristic and become first a pulsating red and then, as he approaches a position dangerously below glide path, a deeply flashing red.

The system is designed to provide a white "on-glide-slope" indication having an angular dimension of 0.2 degree. Thus the linear vertical dimensions of the indicated glide path decrease as the aircraft approaches touchdown (Fig. 4). At 2 miles, for instance, the boundaries of the prescribed glide path are approximately 37 feet apart vertically, while at 1/2 mile this figure is reduced to about 9-1/4 feet. The angular dimensions of the steady red and steady green signals can be adjusted to cover a large or a small area. In the experimental unit these angular dimensions are approximately 0.2 degree. That is to say, the flashing characteristic will first become evident when error is in excess of 0.2 degree from the boundary of the white glide path indication. The total visual field in which the experimental unit can be used effectively is 12 degrees vertically and 20 degrees laterally. An alternate design of the DFOLS unit incorporates a wider field of view, 20 degrees vertically and 30 degrees laterally.

The flashing characteristic of the DFOLS signal is coded in depth rather than in maximum intensity. Although the flashing characteristic "increases" as a function of error, the general maximum brightness of the signal is unaffected by error, insuring that the signal source will present an approximately uniform average brilliance at all vertical points within the pattern at any given range. To the human eye the signal will appear to be diminished periodically by varying amounts. The "depth of flash" may be defined as the percentage decrease from the high to the low intensity noted in any constantly flashing light. The light source may be alternating from full intensity to no intensity (on-off), which is designated 100% depth of flash. Or it may vary between full intensity and an intensity equal to one-fourth of full intensity, designated 75% depth of flash. Similarly, a steady light (which can be thought of as alternating from full intensity to full intensity) will be exhibiting a 0% depth of flash. Table 1 indicates a scale of relative intensities which can be used to produce a gradually diminishing depth of flash from 100% flashing at the outer extremes to a steady, nonflashing light near glide path.

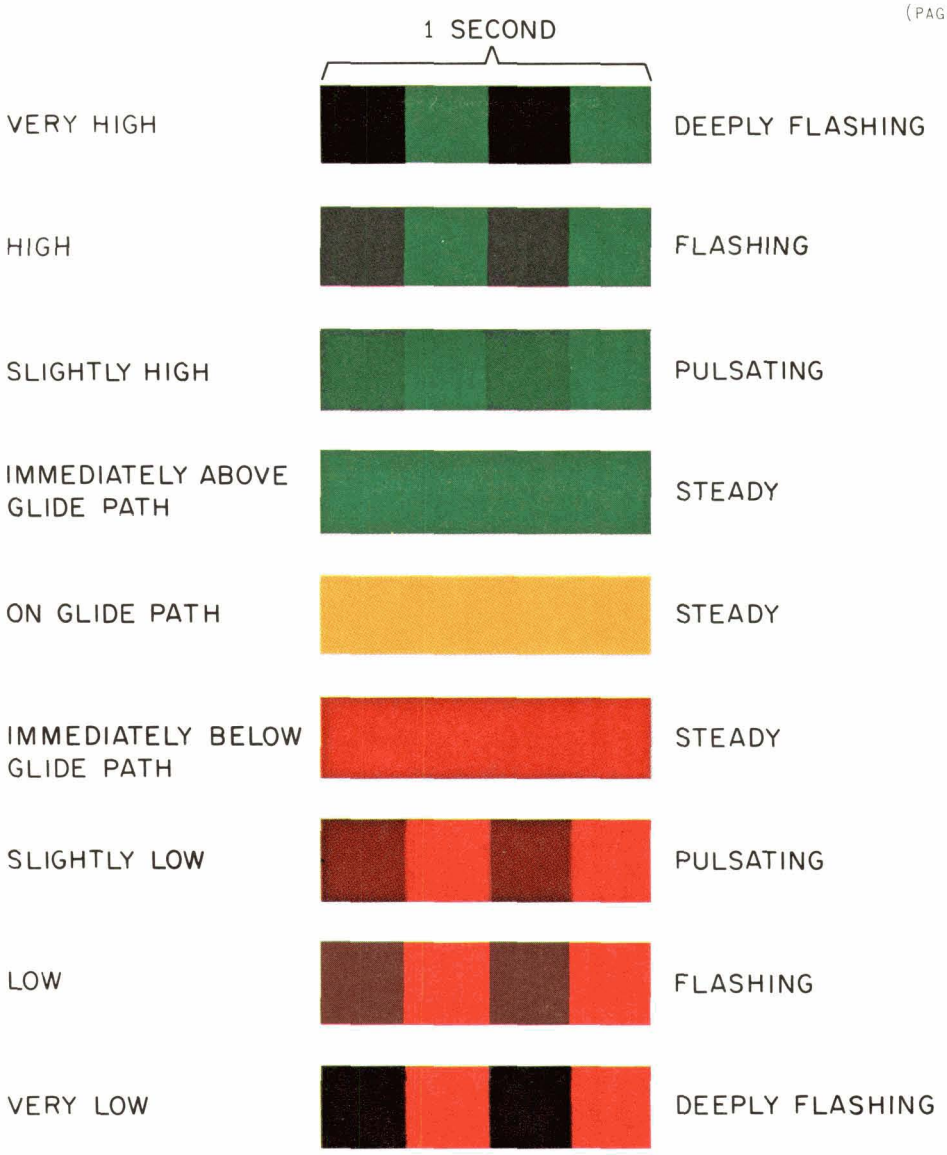

Fig. 3 - Signal received by the pilot (during 1 second) as a function of his vertical position relative to the glide path

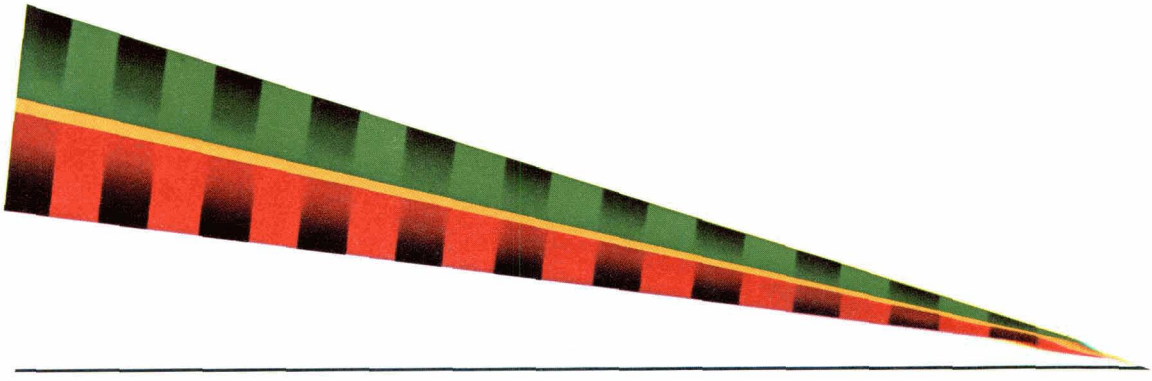

Fig. 4 - Depth of flash profile

Table 1
Depth of Flash Coding

Error From Glide Path	Low Intensity	High Intensity	Defined Depth of Flash
Large	0.00	1.00	100%
Increasing Error	0.25	1.00	75%
Increasing Error	0.50	1.00	50%
Increasing Error	0.75	1.00	25%
Minimal	1.00	1.00	0%

EXPERIMENTAL UNIT DESIGN

Several methods were considered for providing a graduated depth of flash proportional to angular error. The method chosen for the initial experimental unit uses two projectors having overlapping images, one projecting a steady light pattern and the other a pattern which is flashing at a constant frequency. The dual-projector method was chosen primarily for simplicity and reliability, since it requires few moving parts.

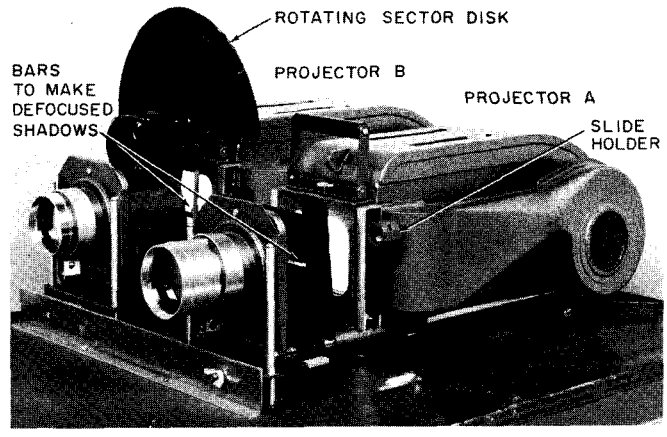

Fig. 5 - Experimental DFOLS Unit

The DFOLS signal is produced by the unit shown in Fig. 5, which consists primarily of two slide projectors, two stationary slides, and a rotating sector disk in the light path of one of the projectors (B) permitting that slide to be projected only 50% of the time.* Since the two projectors are in close proximity to one another, they appear as a single light source to the approaching pilot. The projectors are firmly affixed to a common chassis, the angle of which can be adjusted to provide any desired glide path angle. They contain identical slides which project green to the upper field, red to the lower field, and yellow to a narrow horizontal section in the center (Fig. 1).

*The duty cycle is a parameter which can be varied. A 25% duty cycle has also been experimentally tested.

By blanking out the center portion of the slide contained in the flashing projector B, it is possible to provide a constant signal from projector A in the area encompassed by the yellow glide path and a narrow band above and below it. The flashing projector B, then, intermittently adds its intensity to that of projector A only in the areas considerably above or below the ideal approach path. To achieve a gradual increase in contrast between the intensity of constant projector A and the periodic combined intensities (A + B), and to restrict the maximum intensity of the signal, the upper and lower portions of the slide contained in constant projector A must also be blanked out as shown in Table 2 and in Fig. 6.

Table 2
Breakdown of the Individual Slide Intensities Which Provide the "Depth of Flash" Coding. The Flashing Characteristic, When Present in the Signal, is Produced by Alternating Between the Intensity of Projector A Alone and the Sum of the Intensities of Projectors A and B.

Color	Error (degrees)	Intensity of Constant Projector A (Low Intensity of Flash)	Intensity of Flashing Projector B	Sum of Intensities of Projectors A and B (High Intensity of Flash)	Depth of Flash
Green (above glide path)	+6.0	0.00	1.00	1.00	100%
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	+1.0	0.00	1.00	1.00	100%
	+0.83	0.25	0.75	1.00	75%
	+0.65	0.50	0.50	1.00	50%
	+0.48	0.75	0.25	1.00	25%
	+0.3	1.00	0.00	1.00	0%
White (on glide path)	+0.1	1.00	0.00	1.00	0%
	-0.1	1.00	0.00	1.00	0%
Red (below glide path)	-0.3	1.00	0.00	1.00	0%
	-0.48	0.75	0.25	1.00	25%
	-0.65	0.50	0.50	1.00	50%
	-0.83	0.25	0.75	1.00	75%
	-1.0	0.00	1.00	1.00	100%
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	-6.0	0.00	1.00	1.00	100%

The constantly projected slide is most transmissive in the center portion, whereas the intermittently projected slide is most transmissive at the upper and lower extremes. Such an effect can be achieved by superimposing appropriately graduated neutral density filters over the slides. In the DFOLS unit, however, the effect is accomplished by use of opaque bars placed in close proximity to the slides, but out of the focal plane of the projection system. The bars fully obscure light from certain areas, and provide a gradually lessening shadow effect into areas where full transmission is desired. As the intensity of projector A decreases with error, then, the intensity of flashing projector B increases, i.e., projector B adds more and more as projector A provides less and less, thereby

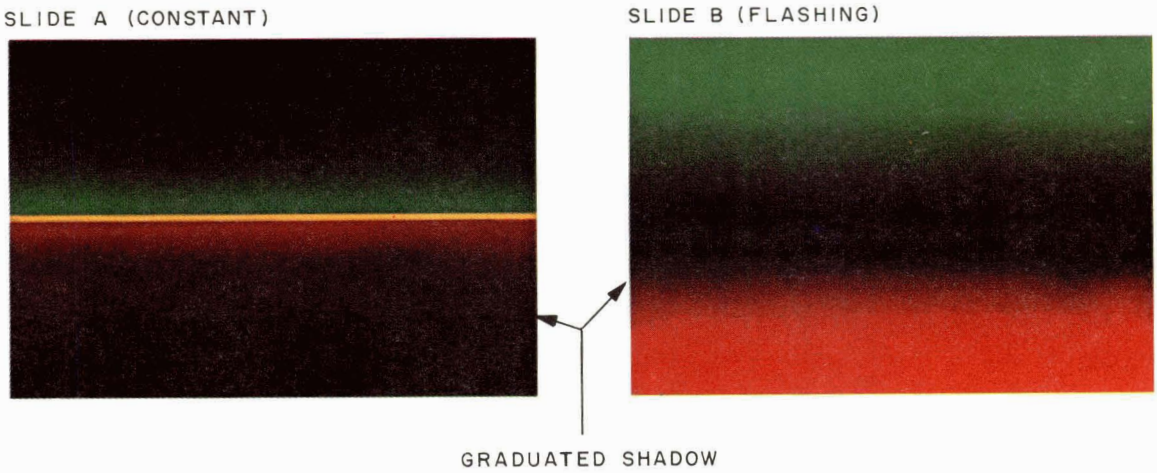

Fig. 6 - Projected images from projectors A and B

producing the complete on-off flashes at high and low extremes. The transmissiveness of the two slides must be regulated in this manner so that the combined signal will pres an approximately uniform brilliance at all vertical points within the pattern.

The defocused shadow bar method provides a complete range of variability of the depth of flash. Theoretically, therefore, a constant rate of change from near glide path to maximum error could be programmed. However, experimentation and flight testing determined that the optimum pattern placed the largest variation near the glide path. Figure 7 shows a curve of increasing depth of flash derived from figures found in Table

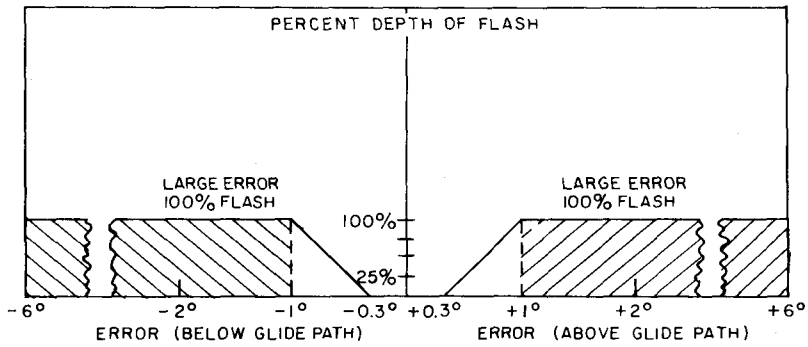

Fig. 7 - Percent depth of flash curve

Note that large portions of the upper and lower extremes of the projected image (areas of large error) are permitted to flash with a 100% depth of flash. The most rapid change in depth of flash in response to correction of altitude error occurs close to glide path. This pattern gives the pilot greater sensitivity when accuracy is most critical and enables him to adjust his rate of descent appropriately, so as to avoid overshooting the glide path and making resultant oscillatory corrections.

No electronic sensors are required in the aircraft, and no data link is necessary between the pilot and the ground. Further, it should be noted that the color coding and flash coding of the DFOLS cause interpretation of its signal command to be relatively independent of range to touchdown. At any range from which the signal can be detected, it can be categorized as to color and flashing or nonflashing character. The usable range of the system then is limited only by the intensity of the light source and by conditions of visibility.

One-thousand-watt projection lamps are needed for daytime use of the unit to provide an acquisition range of 3.5 miles. In nighttime operations, the range is increased to more than 20 miles; 500-watt projection lamps provide a usable signal under these conditions. The flash rate is constant at 2 per second for the selected duty cycle.

SUMMARY

The Depth of Flash Optical Landing System is being evaluated for carrier use under a Naval Air Systems Command program. It is anticipated that it may increase the safety of flight operations under whiteout conditions in Antarctica by providing a positive glide-slope indication to the pilot to counteract the lack of normal cues in the visual environment.

The DFOLS is color coded to provide a high, low, or on-glide-path indication, and has the additional feature of presenting the pilot with knowledge of the relative magnitude of his error from glide path by a changing depth of flash signal. The graduated depth of flash feature is accomplished through the use of shadow bars in combination with two optical projectors placed side by side. A complete range of variability can be achieved by adjusting the position, size, and defocusing of the shadow bars.

The designated glide path in the experimental unit is such that the pilot approaching within its tolerance is ±0.1 degree from the ideal approach path. At a 1/2-mile range this represents a deviation of no more than about ±5 ft. Because the glide path indication is flanked by a positive indication of high or low deviation (green light for the high signal and red for low), pilots flying the system have expressed the opinion that this extremely precise glide-path approach can be readily maintained.

ACKNOWLEDGMENTS

An application for a patent on the Depth of Flash Optical Landing System has been filed by the joint inventors, Mr. Henry P. Birmingham, Mr. Alan W. Baldwin, and Miss Barbour Lee Perry. The author wishes to express appreciation to each of them for valuable suggestions offered with respect to preparation of this report.

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13. ABSTRACT

The Depth of Flash Optical Landing System is an optical landing aid which projects a positive glide-slope indication to the approaching pilot, enabling him to achieve highly accurate vertical control of his aircraft on the final landing approach. The signal gives accurate glide path information to a range limited only by the intensity of the light source and atmospheric conditions.

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Two unique design principles are featured in the Depth of Flash Optical Landing System. First, the backward projector principle causes the pilot to see only that color which is projected to his eye. The light projected to the area directly above the prescribed glide path is steady green, that below it is steady red, and the 0.2-degree-wide glide path is steady white. Second, the defocused shadow bar method introduces a flashing characteristic, gradually increasing as a function of angular error. As error increases beyond certain angular limits, the flashing characteristic is perceived in the red or green signal, first as a slight pulsation and then as a more and more noticeable flash.

The Depth of Flash Optical Landing System is currently being evaluated under a Naval Air Systems Command program.

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Carrier landings - Equipment						
Projected color display						
Aircraft landings						
Vehicular guidance system						
Airport landing systems						
Error sensitivity - Range independence						

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