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The Shadow Box Optical Landing System

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CONTENTS

ABSTRACT

A simple replacement for the Fresnel Lens Optical Landing System (FLOLS) was designed and built at NRL for use as a research tool in the experimental testing of various landing aids. Called the Shadow Box Optical Landing System (SBOLS), the new system projects a beam pattern without the use of lenses and is designed to permit parametric variation for experimental purposes. In comparison to the FLOLS, the SBOLS is quite inexpensive, easy to transport, and simple to maintain.

Experimental evaluation of two proposed landing systems, the Laterally Compounded Fresnel Lens Optical Landing System (LCFLOLS) and the Integrated Fresnel Rainbow Optical Landing System (IFROLS), both of which incorporate the FLOLS principle, was made feasible by the development of the SBOLS.

Because initial flights with the experimental SBOLS verified its apparent optical similarities to the FLOLS, installation of SBOLS units on every runway at various naval air stations is suggested. Carrier pilots could then make training, practice, and even routine landings with the present shipboard type of system.

PROBLEM STATUS

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

AUTHORIZATION

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THE SHADOW BOX OPTICAL LANDING SYSTEM

INTRODUCTION

Naval pilots land high-speed aircraft aboard carriers by using the Fresnel Lens Optical Landing System (FLOLS) as a visual display of angular error above or below a prescribed glide-path angle. This display, located on the deck of the ship, consists primarily of five lens cells stacked vertically between two horizontal rows of lights, called datum arms (Fig. 1). An elongated bar of light, known as the "meatball," appears to move up or down on the face of the cells as the aircraft moves above or below the prescribed glide path. Error from glide path is presented to the pilot as an apparent vertical displacement between the moving meatball and the stationary datum arms. A high meatball appears when the aircraft is high, and a low meatball is seen when the aircraft sinks below glide path. A "roger meatball"—in perfect alignment with the datum arms—is visible to the pilot only when his aircraft is on the desired glide path.

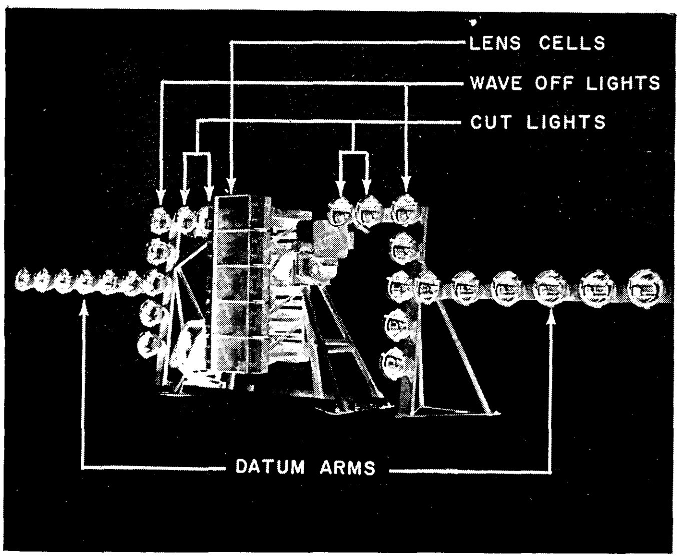


Fig. 1 - The Fresnel Lens Optical Landing System

Various improvements and modifications to the FLOLS are proposed from time to time, as are new landing systems which incorporate some features of the FLOLS into a new display. Accordingly, research and experimental testing and evaluation of modifications to the basic FLOLS continue even though the system has been in the fleet for a number of years.

In the operational unit, each of the five cells consists of three source lamps, a Fresnel lens, and lenticular lens which spreads the beam horizontally to encompass a field of 40 degrees without affecting the vertical dimensions or characteristics of the beam. The cells, which are ten inches high, are oriented at an angle of 18 min to each other. A virtual image is formed 150 ft behind the assembly.

Temperature changes within the cells alter both the dimensions and the density of the plastic Fresnel lenses, causing, in turn, variations in their effective focal length. Variable focal length results in variable image size, "jerky" image motion between cell center and transition line, and altered vertical field of view. To minimize these effects, temperature control is maintained to relatively close tolerances (1).

The complexity of system design and maintenance, the bulk and expense of the system, and the fact that parametric variation cannot be accomplished readily are deterrents to the acquisition and use of a FLOLS for research purposes.

THE SHADOW BOX OPTICAL LANDING SYSTEM

The Shadow Box Optical Landing System (SBOLS) is a simple indicator designed to exhibit effectively the same properties as the FLOLS but by means of an extremely simplified optical design and construction. The system was conceived and built at NRL as an experimental tool for use in the empirical evaluation of various modifications suggested for the FLOLS. Initial flights with the experimental unit verified its functional similarity in appearance to the FLOLS. This fact, together with its low cost, portability, and simplified design, which readily permits parametric variation, suggests the worth of the system as an experimental substitution for the operational system.

SYSTEM DESIGN

The SBOLS simulates the FLOLS by means of a shadow-box type of projection system which projects a beam pattern without the use of lenses. This projection is accomplished by means of a bulb plate on which are mounted an odd number of thin-filament bulbs, effectively point sources of light, and a slot plate, both mounted in a rigid housing (Fig. 2). Baffling must be included in the unit to insure that the rays from each light can pass only through its corresponding slot. Such a unit behaves like a lens-projection system, because the light source which the pilot sees is a function of the position of his eye in the beam pattern. He will see the seventh light, for instance, when and only when his eye is in alignment with the seventh light and the seventh slot. If his eye is in a higher position, so as to be aligned with the third slot and third bulb, he will see that source. (Since each slot is slightly wider than the bulb filaments, each "beam" has a finite angular width.)

Because of the dimensions of the display unit, a pilot is not aware of observing different sources as he moves up or down in the beam pattern. It appears that a single light is moving up or down on the face of the slot plate, just as it appears when he watches the meatball move on the FLOLS as he goes above or below glide path.

The apparent movement of the SBOLS meatball can be made to correspond, or if desired, to be opposite to the vertical motion of the aircraft. A unit in which meatball motion is in the same direction as aircraft vertical motion (similar to the FLOLS) exhibits a virtual image to the pilot and is call the "forward unit;" conversely, a unit on which the meatball reacts in the opposite direction to aircraft motion exhibits a real image to the pilot and is called the "backward unit."

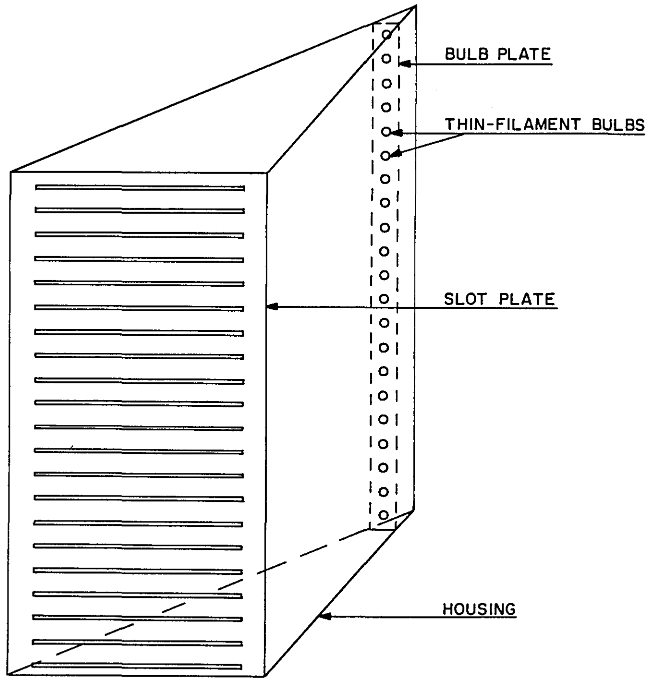


Fig. 2 - The Shadow Box Optical Landing System

The forwardness or backwardness of the SBOLS unit is determined by the relative spacing of the slots on the slot plate. The bulb mountings are the same for both unit types. For the forward unit, each slot is placed slightly farther from the centerline reference than is its associated bulb. For the backward unit, the reverse is true; i.e., each slot is located slightly closer to the centerline reference than is its partner lamp.

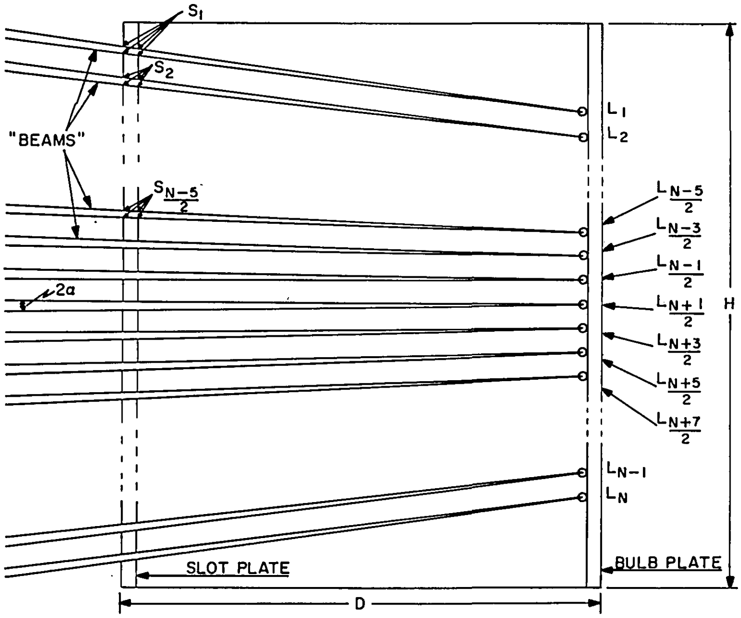
Figures 3a and 3b are schematic drawings showing cutaway views of a forward unit. The scale is greatly enlarged for easier viewing. The center light of N lights (where N is an odd number) is represented by $L_{(N+1)/2}$; L_n is the nth light as measured from the top of the unit, and S_{c_n} is the position of the center of the nth slot as measured from the top of the unit. In the drawing, α is the half angular width of each individual beam, and δ is the angular separation between adjacent beams. This is to say that the angular orientation with respect to the horizontal for the beams next to the center beam is δ. That for the adjacent beams above and below is 2δ, and so on. The orientation of the outer beams with respect to a horizontal reference is $\delta(N-1)/2$. These angles are measured toward the center reference for the backward unit and away from it for the forward unit. Angle θ represents the total angular field of view of the unit, H is the height of the slot plate, and D is the unit's total depth.

Equations can be written for L_n and S_{c_n} for the forward and the backward unit.

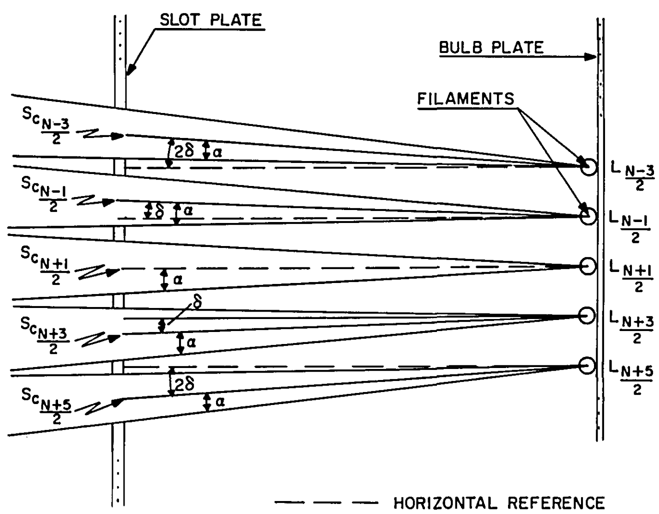
On the bulb plate,

$$L_n = \left(\frac{2n-1}{2}\right)\left(\frac{H}{N}\right). \tag{1}$$

It should be noted that, so long as the number of slots is unchanged, the same bulb plate is compatible with both backward and forward units for various values of α, δ, and θ.



(a) Cutaway view



(b) Enlarged center section

Fig. 3 - The SBOLS forward unit

For the forward unit, the position of the center of the nth slot is

$$S_{c_n} = L_n + \left(n - \frac{N+1}{2}\right) D\delta, \qquad (2)$$

and for the backward unit,

$$S_{c_n} = L_n - \left(n - \frac{N+1}{2}\right) D\delta. \qquad (3)$$

The total vertical height of each slot is, of course, $2D\alpha$.

The first experimental unit was built to correspond roughly to the dimensions of the standard FLOLS. It has a total angular field of ±0.75 degree and a vertical display height of 4 ft. Its focal length is therefore 150 ft. The unit has N = 21 bulbs, $\alpha = 0.15$ degree, $\delta = 0.075$ degree, and D was chosen to be 47.7465 ft so that the slot height would be a standard size of 0.25 in.

Because the "beams" originating from each bulb-slot combination are only slightly divergent, the viewer's eye will generally be within more than one beam, which means that he will see more than one source. However, due to the close proximity of the slots to each other, and the relatively long viewing range, when several adjacent slots are illuminated with respect to the pilot's eye, the multiple images will blend together and appear as one slightly elongated meatball (Fig. 4).

For the forward unit, it can be shown that the pilot's eye can never be within more than four beams simultaneously, as long as $\alpha \leq 2\delta$. The maximum number of lights visible, even at infinite range, is four. As range decreases, this number also decreases. Conversely, for the backward unit, as long as the aircraft is beyond the focal point, the pilot will always see at least four lights, and at increasingly close range the size of the meatball will grow as more and more lights become visible. When the meatball becomes noticeably larger, as it does at very close range, the pilot can treat the center of the image as the zero reference point for true meatball indication. In early flights the variable apparent size of the meatball did not prove to be a problem—even for the backward unit.

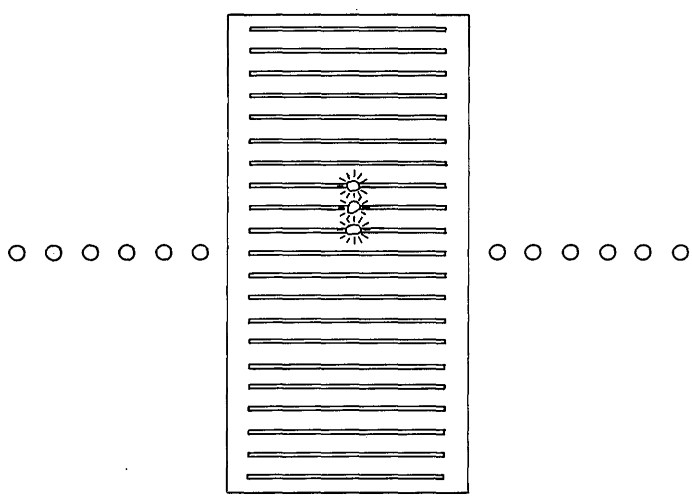


Fig. 4 - The SBOLS (forward unit) indicating "slightly high"

THE SBOLS AS AN EXPERIMENTAL TOOL

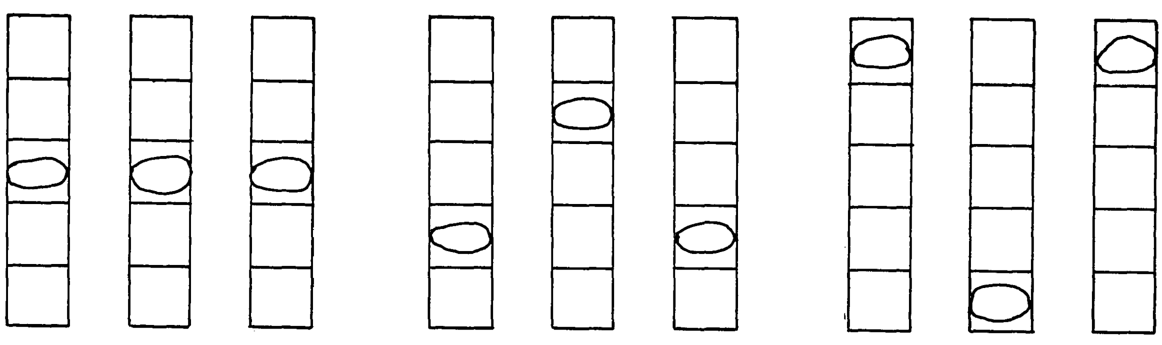
The Laterally Compounded Fresnel Lens Optical Landing System

The Laterally Compounded Fresnel Lens Optical Landing System, as first conceived, would incorporate three Fresnel lens units. On one unit, unchanged except for the removal of the datum arms, the pilot would observe the standard virtual image moving up and down as he moved his eye up and down in the projected beam. Two converted units, displaying the oppositely moving real images, would be located on either side of the standard unit.

If the aircraft is on glide path, the pilot would see all three meatballs in alignment across the center of the display (Fig. 5a). If the aircraft should move above glide path, however, the inner meatball would move up, and the outer two meatballs down (Fig. 5b); conversely, if the aircraft should sink below glide path, the inner meatball will move down and the two outer meatballs up (Fig. 5c). Comparison of the error indication presented by such a display with that presented for the same error by the standard FLOLS makes immediately obvious the increased sensitivity obtainable in the LCFLOLS. The apparent displacement between the center LCFLOLS meatball and its adjacent reference lights, i.e., the outer meatballs, is twice the size of that generated in the FLOLS between the meatball and the stationary datum arms. Detection of maximal angular error becomes, then, theoretically possible at twice the range from touchdown. Comparable sensitivity of the error indication at the pilot's eye to altitude error from glide path is attained at only a 40-percent greater range, however, since sensitivity is inversely proportional to the square of range (for a detailed derivation of this relationship, see Ref. 2). The minor improvement which would result from the costly operation of modifying two FLOLS units (and then tripling the total system cost due to the additional two units) was not considered worthwhile. Fabrication of the system with SBOLS units would be quite simple and straightforward, however, and could be considered worthwhile to obtain the attendant 40-percent increase in effective range.

The Integrated Fresnel Rainbow Optical Landing System

The SBOLS demonstrated its utility in the experimental testing and eventual determination of the limited usefulness of a proposed system called the Integrated Fresnel Rainbow Optical Landing System (IFROLS). This system, as conceived, consists of the



(a) Indicating "on-glide-path" (b) Indicating "high" (c) Indicating "very low"

Fig. 5 - The LCFLOLS

combination of two separate systems. The manner of combination is such as to produce more complete guidance information than is inherent in either system alone.

The IFROLS, as its name suggests, is essentially a combination of a standard Rainbow unit (3) and two modified Fresnel lens units.* The standard Rainbow system consists of a stationary source of colored light which appears to the pilot as a single point source located adjacent to the desired touchdown spot. This light changes color sequentially in response to errors in the aircraft's rate of descent to the glide path. A repetitive red-white-blue sequence, for instance, indicates insufficient rate of descent for acquiring glide path optimally, while the reverse blue-white-red warns of excessive sink rate. A constant color indicates optimum sink-rate adjustment, and steady green is the on-glide-path signal. This system displays sink-rate-error information as based on both aircraft position and aircraft rate of descent, yet it does not display any position information (or hi-lo error) to the pilot. Absence of this information has been cited as a primary problem by pilots evaluating the ROLS.

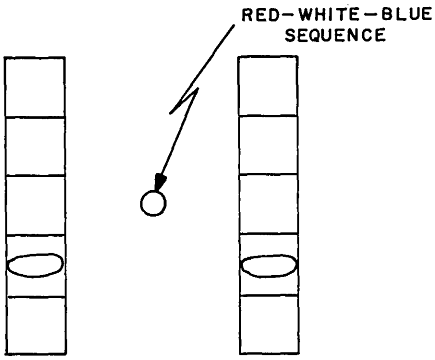
The missing hi-lo indication can be supplied, however, by the addition of two "backward" Fresnel lens units, one on either side of the Rainbow, adjusted so that their horizontal centerlines are exactly aligned with the Rainbow's green glide-path beam. The Fresnel units thus become the "datum arms" of the IFROLS, with which the relative position of the "Rainbow meatball" is determined. Although the image movement is actually in the Fresnel units, thus producing moving datum arms, the system gives the illusion of the standard FLOLS with a "high meatball" for error above glide path, actually displayed by low datum arms and stationary meatball (Fig. 6a), and a "low meatball" for error below glide path, displayed by high reference arms and stationary meatball (Fig. 6b).

Simultaneously, the Rainbow meatball is projecting its sequencing colors to inform the pilot of any discrepancies in his rate of descent for acquiring the glide path. The color sequence indicating insufficient rate of descent is shown in Fig. 6a when the aircraft is high. A steady blue color is shown in Fig. 6b, indicating that the aircraft is low but that the pilot has adjusted rate of descent for optimal acquisition of glide path. Figure 6c shows a green, roger meatball when both components indicate that the aircraft is on the correct glide path.

The necessary modifications to the Fresnel lens units in addition to their initial expense would have been prohibitive to an evaluation of the IFROLS under this project. However, a simple SBOLS unit, constructed and flown experimentally with a Rainbow unit, proved to be entirely adequate for evaluating the concept of the IFROLS. On the basis of these tests with the SBOLS, it was decided that further development of the IFROLS was not warranted. This decision was based on the fact that the pilot flying the IFROLS was unable to detect any relative motion of the Rainbow meatball and the Shadow box datum arms as long as he responded to the color-sequenced rate commands of the system, due to the highly precise approaches resulting from use of the Rainbow indication. At very long range, for instance, it is predictable that the size and dimensions of the SBOLS (in this case identical to those of the FLOLS) preclude discrimination of error indications. Following the color-sequenced rate commands, the pilot decreases error from glide path as range decreases. As a result, by the time the aircraft is within the useful range of the SBOLS (about one mile), there is unlikely to be very much sufficiently large deviation from the glide path as to be observable by meatball displacement.

This is due, of course, to the sensitivities inherent in the two component systems. The on-glide-path indication of the ROLS is ±0.1 degree, which corresponds to the center 2/15ths

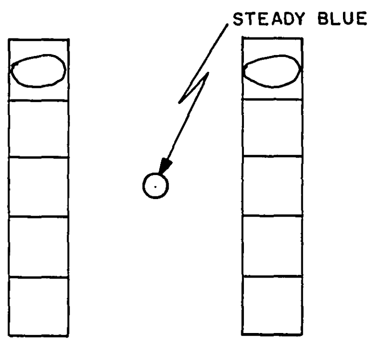
*The IFROLS was conceived prior to the invention of two other point-source type landing displays, the Depth of Flash Optical Landing System (4) and the Altitude Rate Command system (5). The principle of the IFROLS is equally applicable to such a system incorporating any point-source display as the "meatball."



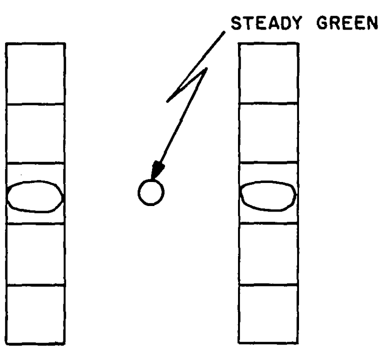
6a

(a) Indicating "high, insufficient sink rate"

(b) Indicating "low, optimum correction rate"



6b



6c

(c) Indicating "on-glide-path"

Fig. 6 - The IFROLS

of the SBOLS (and the center 2/3rds of the center cell of the FLOLS), an area smaller than the size of the image at most ranges. The SBOLS can be made more sensitive in order to exhibit more image movement only by increasing its size, which would be undesirable for shipboard operation, or by decreasing its total angular field, which would further limit its utility when the aircraft is far from the glide path. This experimental determination of the limited usefulness of the IFROLS concept served a useful purpose, however, for it demonstrated that the accuracy achievable with the narrow-glide-path Rainbow system generally results in error below the threshold of detectability in the FLOLS.

CONCLUSIONS

In preliminary evaluation flights, the performance of the SBOLS unit appeared to be quite satisfactory. Both its general appearance and optical characteristics are very similar to those of the FLOLS. It is greatly simplified, however, in construction and maintainability, since, for example, its design characteristics do not place rigorous demands on temperature control, and also since operating power requirements are greatly reduced. For these reasons, and also because of the feasibility of parametric variations, the experimental unit proved to be quite satisfactory for use as a simple research tool to simulate the FLOLS.

RECOMMENDATION

Because initial flights with the experimental SBOLS verified its apparent optical similarities to the FLOLS, it is suggested that the new system could be utilized at various naval air stations to provide carrier pilots with a model of the currently used operational system to use as a training and/or field-practice aid. The simplicity and low cost of the SBOLS would make it feasible to install one on every runway of many airfields, so that even routine landings can be made with a system such as is now used aboard ship.

ACKNOWLEDGMENT

The Shadow Box Optical Landing System is the joint invention of Mr. H. P. Birmingham, Mr. A. W. Baldwin, and the author.

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13. ABSTRACT

A simple replacement for the Fresnel Lens Optical Landing System (FLOLS) was designed and built at NRL for use as a research tool in the experimental testing of various landing aids. Called the Shadow Box Optical Landing System (SBOLS), the new system projects a beam pattern without the use of lenses and is designed to permit parametric variation for experimental purposes. In comparison to the FLOLS, the SBOLS is quite inexpensive, easy to transport, and simple to maintain.

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