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The Altitude Rate Command System

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ABSTRACT

A visual landing aid designed to increase landing accuracy and thus reduce accident rates, has been developed. Called the Altitude Rate Command (ARC) system, it provides highly sensitive rate-of-descent error information to approaching aircraft. The information is encoded as a cyclic sequencing of the intensity of a single light. The pilot interprets a repetitive increasing of intensity as a command to increase power so as to decrease his sink rate. Conversely, a decreasing sequence indicates the need to reduce power in order to increase rate of descent.

In addition, binary hi-lo information is provided by color coding of the sequencing light: amber signifies "on glide path," green signifies high, and red warns of the potentially dangerous low condition.

The introduction of intensity sequencing, rather than the color sequencing of the similar Rainbow Optical Landing System, to encode error rate permits increased information rate and minimum interpretation time, which thus increase the effectiveness of the rate display.

PROBLEM STATUS

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

AUTHORIZATION

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THE ALTITUDE RATE COMMAND SYSTEM

INTRODUCTION

Reduction of the landing accident rate is of primary concern in the shipboard operation of high-performance aircraft. Accordingly, the Naval Air Systems Command is sponsoring research directed toward this end. The Engineering Psychology Branch of the Naval Research Laboratory, as part of this program, performed an analysis of the present landing configuration which pinpointed the sources of system inaccuracy in the use of the present glide-path error indicator. Believing that such system inaccuracy is responsible for many landing accidents, the Branch then developed new concepts in aircraft landing displays and applied these to the design of unique optical landing aids.

The analysis of the present landing system revealed that system inaccuracy originates in (a) inadequate sensitivity of the glide-path error display and (b) the absence of an error rate signal, or of an error signal from which the necessary rate information can be derived by the pilot. The Rainbow Optical Landing System (ROLS) was designed and built at NRL to correct these deficiencies by providing highly sensitive information regarding the appropriateness of aircraft rate of descent for acquiring and maintaining the desired glide path (1,2). The Altitude Rate Command (ARC) system is an outgrowth of the ROLS; it provides the same necessary error rate information as the ROLS but by an improved system of error encoding for greater ease of detection and interpretation and in addition provides hi-lo information.

These visual landing aids are simple projection systems in which a precisely patterned beam is projected toward the approaching aircraft. Its pilot, flying into the beam and looking directly into the projection lens, sees only a single point of light adjacent to the desired touchdown point. The apparent characteristics of this light vary as a function of the position and motion of the aircraft (and therefore of the pilot's eye) relative to the projected beam pattern. The pilot thus receives error information without the requirement for any electrical or mechanical sensors either in the aircraft or on the ground and without any data link required between the aircraft and the display.

BACKGROUND–THE RAINBOW OPTICAL LANDING SYSTEM

The ARC system is quite similar to the ROLS in design and in the type of information which each presents to the pilot. The primary difference between the two is the form of error signal encoding. Because of their similarities it is helpful to consider the pertinent characteristics of the ROLS as a preface to a discussion of the new system.

To display high-gain sink-rate error information, the ROLS uses a tricolor, dynamic, projected beam of light. The error information is encoded in the form of a sequential ordering of three colors–red, white, and blue–which appear, one at a time, to the pilot. He is instructed to interpret the sequence red-white-blue-... as an indication to increase sink rate, that is, to reduce power, and the reverse sequence blue-white-red-... as an indication to add power so as to lessen the rate of descent. Sequence deceleration indicates the proper type of sink rate correction, sequence acceleration denotes the wrong type of rate correction, and sequence reversal signifies overcorrection. A steady green color indicates that the aircraft is on the glide path, and any steady color other than green (zero sequence) indicates

that the aircraft is not on the glide path but is descending so as to acquire the glide path asymptotically.

An experimental Rainbow unit was built for use in evaluating (a) the landing accuracy, or system performance, which could be achieved by pilots flying an error rate display and (b) the use of color sequencing as a means of encoding the information.

Once the pilots become familiar with the encoding system, the sequencing colors of the ROLS have been found to provide a definite, unambiguous indication of sink-rate error. The colors are programmed to pass by any given stationary point at the rate of three colors in 2 seconds. The actual observed sequence rate depends, of course, on the interaction between aircraft sink rate and beam rate and can therefore be faster or slower than the programmed rate. With practice, many pilots become able to determine the sequence upon seeing only two colors, thus being able to initiate sink-rate corrections quite rapidly.

In preliminary tests landing accuracy has been found to be very satisfactory. Although the glide-path beamwidth on the experimental unit is only ±0.1 degree, most pilots are able to maintain their aircraft within the green during the major portion of the approach. Film taken from the ground of an aircraft flying the ROLS reveals a smooth acquisition of the glide path and very little deviation from it. The Rainbow beam has been located and used at quite long ranges–up to about 3-1/2 or 4 miles in bright sunlight and over 20 miles at night. These long beam-acquisition ranges allow for early glide-path acquisition and also for "getting set up early" so as to maintain the glide path, a feature which is believed to contribute materially to successful landings.

Figure 1 shows the idealized approach path, relative to the moving deck of the carrier, of an aircraft, whose pilot is flying the ROLS. This graph assumes acquisition of a beam at a range of 2 miles and perfect response thereafter so that the aircraft always remains within a single color until intercepting glide path. Note the asymptotic approach to the glide path and the absence of overshoots, oscillations, or glide-path hunting maneuvers.

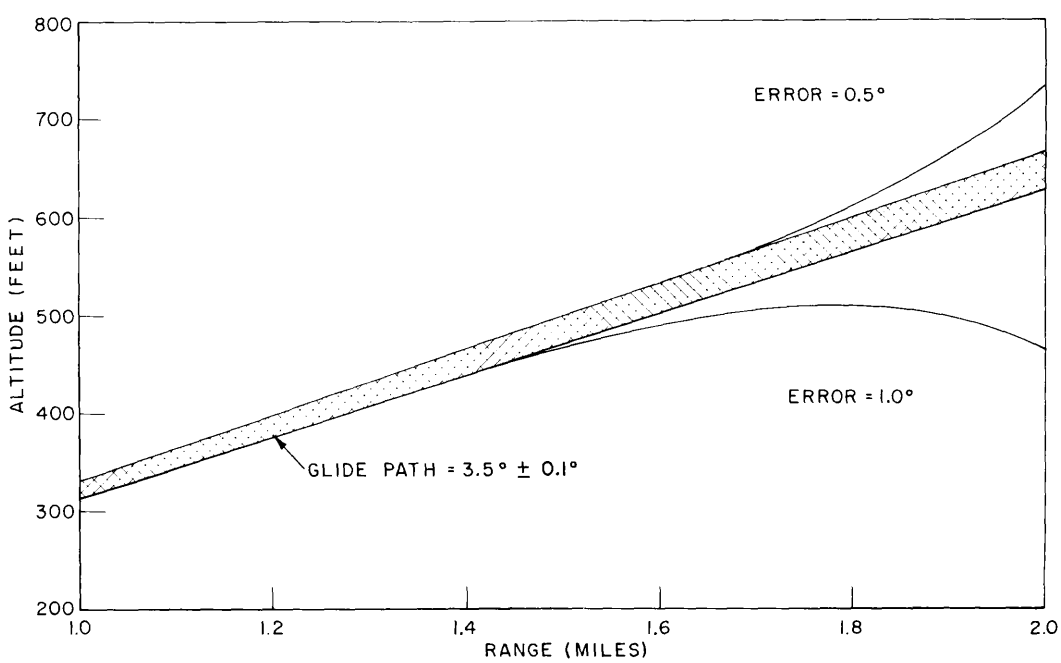

Fig. 1 - Aircraft idealized approach paths made with the Rainbow Optical Landing System

Although the ROLS, both theoretically and in practice, gives rise to very satisfactory system performance, it was felt that certain improvements to the system would be desirable. For example, the sequenced signal should be easy to distinguish at all points within the beam pattern. In the areas of the projected pattern where the observed signal is least sensitive to aircraft sink rate, the sequence rate must be sufficient for the pilot to initiate corrective actions promptly. However, in those areas where the observed signal is most sensitive to variations in aircraft sink rate, the sequence must never become so fast as to result in confusion or misreading.

It should be remembered that the ROLS does not furnish pilots with an indication of whether they are above or below the glide path. Rather, it provides a color sequenced indication of the correction they must make in sink rate in order to approach the glide path from above or below along an asymptotic approach. It is often suggested that hi-lo information in addition to sink rate error information would be beneficial. Hi-lo information means a qualitative, binary type of altitude error information. Theoretically this information is not required, for the ROLS rate signals are always appropriate to the present position of the aircraft, even though this position is not displayed to the pilot. However, when the aircraft has been on the glide path and gets off, perhaps due to a wind gust, the pilot wants to know immediately whether he went off high or low, without waiting to determine a sequence and set up a new rate of descent. It would seem that hi-lo information would be very useful in making the small corrections necessary to maintain glide path, whereas rate information is more appropriate to the initial, smooth acquisition of the glide path. With these improvements in mind, a new landing system has been designed. It retains the advantages of the high-precision, high-accuracy, asymptotic approaches generated by the Rainbow, but it also incorporates some of the desired improvements in signal encoding.

ALTITUDE RATE COMMAND SYSTEM

Theory of Operation

The new landing system is called the Altitude Rate Command (ARC) system. It is quite similar to the ROLS; however, the sequencing colors of the Rainbow have been replaced by a sequencing of different levels of intensity in the ARC system. The pilots are told to interpret the intensity sequencing as follows: When the light gradually becomes brighter, in a cyclic or repetitive manner, add power so as to decrease sink rate (corresponding to the blue-white-red Rainbow sequence); when the reverse sequence appears, that is, when the light grows gradually dimmer in a cyclic or repetitive manner, reduce power so as to increase rate of descent (corresponding to red-white-blue Rainbow sequence). Sequence deceleration indicates that the proper type correction was made. A steady light of constant intensity, or a zeroed sequence, denotes the optimum sink-rate correction. Sequence reversal indicates overcorrection, and sequence acceleration warns of correction of the wrong polarity. The sink-rate error information is presented to the pilot in the form of a repetitive, sequential ordering of increasing or decreasing levels of intensity.

The ARC glide path is indicated by an amber beam. Furthermore, since color is no longer used in the sequencing code to provide sink-rate error information, it becomes available for encoding another type of information–namely, hi-lo. The portion of the projected pattern below glide path is red, and that above it is green. (It has been found that the intensity sequencing of both red and green lights is equally as noticeable and distinguishable as that of white light.) To summarize, then, the pilots receive from the ARC system color-coded hi-lo information together with rate-of-descent error information which is intensity-sequence-coded.

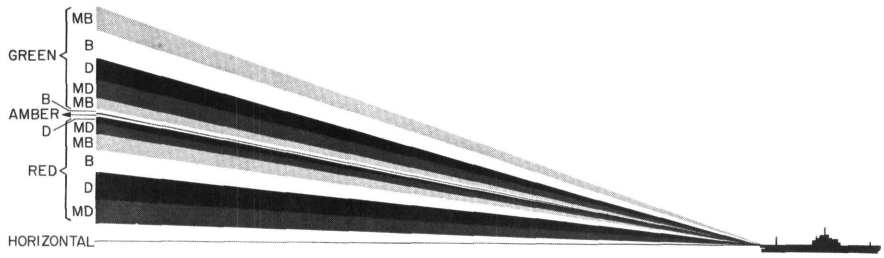

Fig. 2 - The profile of the Altitude Rate Command System

Figure 2 shows a beam pattern which will generate such error signals for incoming pilots. This schematic shows the projected pattern at a single instant in time. Actually the pattern is continually changing as the bands of light converge about the glide path. The apparent intensity and color of the light which the pilot sees at any moment depends, of course, on the position of his eye relative to the beam. This is because the projected beam pattern is focused precisely at optical infinity, so that the viewer's eye is always in the image plane. Therefore, all of the light striking the eye emanates from a single point on the transparency. Thus the characteristics of the light viewed depend on those of the point on the slide which is aligned with the eye and the objective lens.

In Fig. 2, the narrow glide-path beam is designated amber, the area above the glide path is green and that below it is red. Four different levels of intensity are shown. If a pilot is in straight and level flight above the glide path, the bands appear to move down past his eye. The resulting sequence which he sees then is bright (B), medium bright (MB), medium dark (MD), dark (D), ...This sequence repeats until he follows the command to decrease power so as to increase sink rate. As his aircraft begins to sink more rapidly he will observe that the sequencing slows down and, if he makes exactly the right correction, stops altogether so that he sees a light of constant intensity. If he overcorrects, however, and begins to descend too rapidly, he flies down through the moving bands and sees an apparent reversal of the sequence. The light sequence is D, MD, MB, B, ..., telling him to add power so as to reduce his sink rate. It becomes apparent then that a pilot can see a green light, telling him he is above glide path, which is sequencing such as to tell him to add power to decrease his rate of descent so as to avoid overshooting the glide path. If overshoot should occur, however, the light will become amber as the aircraft intercepts the glide path beam, turning to red as it goes below. At the same time, the intensity sequencing will resume to provide information appropriate to setting up the correct rate of descent (or climb, as the case may be) to acquire and maintain the glide path.

The movement of the beams toward the glide path is exponential in nature, which means that beam rate at any given angular position is always proportional to the angular distance remaining to the glide path. The aircraft flying within any single intensity band, then, must make large sink-rate corrections when far from glide path and smaller and smaller ones as it nears the glide path. When the aircraft intercepts the amber beam from along such an approach its rate of descent is appropriate to maintain glide path.

Experimental Unit Design

The ARC system will use essentially the same equipment to project its beam pattern as does the ROLS. The primary difference between the two will be the transparency through which the pattern is projected into space. The unit consists of a modified slide projector

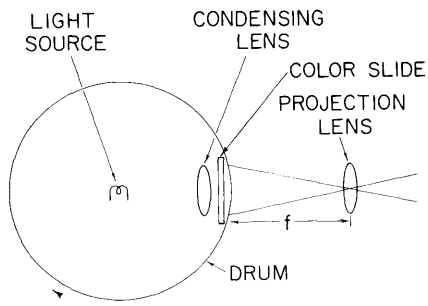

Fig. 3a - Schematic diagram of the ARC experimental unit

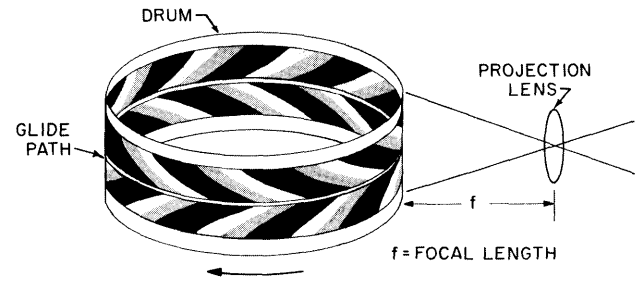

Fig. 3b - An ARC drum pattern

and a rotating drum on which is superimposed a patterned transparency. Figure 3a shows a schematic representation of the experimental unit. The optics consist of standard condensing and objective lenses. The rotating drum serves as the slide, or object, for projection. Its rotation, together with the pattern superimposed upon it, gives rise to the beam moving in space.

The transparency (Fig. 3b) consists of a series of exponential bands which converge about a fixed-width glide-path band. These bands can be defined in terms of their transmission characteristic. The bright band (B) is 100% transmissive, the medium bright band (MB) is 50% transmissive, the medium dark band (MD) is 25% transmissive, and the dark band (D) is 12.5% transmissive. Early tests indicate that these 50% attenuations between successive bands, resulting in an 8 to 1 difference between the greatest and the least, will result in a sequence with easily sensed gradations and obvious bounds.

The basic information rate of the ARC system will be higher than that of the ROLS, but the sequence repetition rate is the same. This is to say that the four levels of brightness will pass any stationary point within the pattern in the same amount of time as would three Rainbow colors. The direction or order of the sequence is therefore established sooner, permitting the pilot to initiate corrective actions more readily than he can with the ROLS. Also, intensity sequencing has a built-in redundancy feature which the color sequencing of the ROLS lacks and which should facilitate discrimination and interpretation as well as reduce the learning time. The change from B to MB is qualitatively the same as the subsequent changes from MB to MD and from MD to D. So the pilot receives three bits of information within each ARC sequence cycle, each telling him that the intensity is decreasing. The color sequencing of the ROLS, on the contrary, depends on the qualitative differences between the three colors. For this reason, the intensity sequencing should be more readable than the color sequencing at high-sequence rates such as when the aircraft has an error in rate very close to the glide path.

The time constant of the exponential bands determines the amount of time (and therefore the distance) it takes for an aircraft to acquire glide path from any given angular error (3). The shorter the time constant, the quicker the acquisition of the glide path and the longer time remaining before touchdown for getting the aircraft properly trimmed, but also, the greater changes in vertical rate necessary. However, the longer the time constant, the more sensitive the system becomes to rate changes, or the more damping there is in the overall system. Further, the longer the time constant, and thus the greater the sensitivity to rate, the higher the sequencing rate when the aircraft is close to glide path but with an error in rate. These were the determining factors in the selection of the "best" time constant for the ROLS. However, because of the advantages of intensity sequencing, which permit better determination of sequence characteristics due to redundant bits of information, higher sequence rates can be tolerated in the ARC system, and

therefore longer time constants and more reasonable rate changes are feasible. A time constant of 10 sec has been selected for the experimental ARC system. (A 6-sec time constant was used for the ROLS (3).)

A drum pattern for an experimental ARC unit is being designed according to the design equations used for the ROLS pattern (2). Attenuation of the different brightness levels is achieved on the transparency by the use of vertical screening in which the ratio of clear area to opaque area is varied so as to achieve the desired percentage of transmission in each band. The screening is of such dimensions that the resultant flicker is considerably above that detectable by the human eye. This method of fabricating the pattern makes feasible the required high precision of the exponential bands and of the brightness levels. Red, amber, and green filters, selected to correspond with the characteristics of the human eye, are used in a slide located in front of the drum.

SUMMARY

The experimental ARC unit is under development for evaluating the contributions of intensity-sequence-encoded rate error information to landing accuracy. Analysis of the landing configuration indicates the necessity of a lead term, or derivative information, for a stable accurate approach to the glide path. The provision of such lead information serves to compensate for the lags inherent in the man-machine system. In order to be effective, however, the lead information must be presented in a manner such that its discrimination and interpretation do not introduce further time lags which would tend to nullify the benefits of the lead. In regard to this requirement, intensity sequencing would seem to be a decided improvement over color sequencing as a means of encoding error information, since the usable sequence rate is higher. This is attributed to the inherent internal redundancy of the intensity sequencing, in contrast to the qualitative differences of the color sequencing. Higher sequence rates permit longer time constants and therefore lesser vertical rates required of the aircraft.

The use of intensity sequencing to encode rate error releases color for encoding hi-lo error. This information is desired by most pilots and should facilitate the quick reacquisition of glide path resulting from small errors in aircraft trim or from wind gusts. The ARC system provides the highly sensitive, rate-of-descent error information, at high information rates, together with instant hi-lo information, which both theory and experience suggest can contribute to an effective reduction of accidents.

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