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HEAD-UP DISPLAY IN THE NON-PRECISION APPROACH

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SUMMARY

This paper deals with the problem of head-up guidance for an aircraft making an instrument approach without glide-slope information. Requirements for path control are considered for each section of the approach profile and a head-up display is developed to meet these needs.

The display is an unreferenced flight director which is modified by adding a ground-referenced symbol as an alternative guidance component. The director is used for holding altitude in the first segment and for descent at a controlled rate in the second segment. It is used in the third segment to maintain the minimum descent altitude while assessing the approach situation. This is done by means of occasional, brief changes to the referenced symbol. In the final segment a visual approach is made with the referenced symbol used continuously for path control.

The display is investigated experimentally in simulated approaches made by three pilots. The results show a fair agreement between objective and subjective estimates of the quality of landing decisions.

INTRODUCTION

The Head-Up Display[1] (HUD) has been used in real flight for two kinds of landing approach, each having its own characteristic guidance information. It has been used for the instrument approach with guidance derived from a source external to the aircraft (the Instrument Landing System or ILS) and with symbols which could be used without seeing the runway (ref. 2). It has been used for a visual approach in which an external source was not assumed and

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[1]Head-Up Display (ref. 1) - A format of symbols providing guidance and support information which is presented in the head-up mode. The format is conveniently generated by electronic means, such as a cathode-ray tube, together with symbol forming and control equipment. The head-up mode is efficiently achieved by means of a reflecting collimator in which an image of the display is formed at infinity and superimposed on the external scene by a partial reflector. (Reflecting collimators are also used in weapon sights and these are sometimes loosely described as examples of the Head-Up Display.)

guidance symbols were used in conjunction with a directly viewed runway (ref. 3). But it does not appear to have been used for the Non-Precision Approach (NPA). The reason for this may be found to lie in the different information characteristics of NPA.

In the normal instrument approach the ILS provides lateral guidance by means of the localizer and vertical guidance by means of the glide slope. These facilities enable the approach to be made with precision. In the NPA, the ILS glide slope is not available and the vertical profile must be established by other means if the approach is to be made under instrument flight conditions.

As an illustration of the NPA suppose an aircraft to be making an approach in cloud through point F in figure 1 which is the Final Approach Fix designated by an airport approach chart. A descent may be made at a chosen rate of change of height from F to M, which is at the Minimum Descent Altitude (MDA) or the lowest altitude to which a descent may be made without glide slope and without visual contact. The approach may then be continued in level flight and if the runway has been sighted the final approach may be made visually. This will be from a point G which is estimated by the pilot to lie on the glide slope through the touchdown zone at T. The resulting approach may not be precisely defined, however, because the horizontal position of M is affected by wind (which is only known approximately during the descent from F) and because G is only estimated visually (in the absence of approach aids).

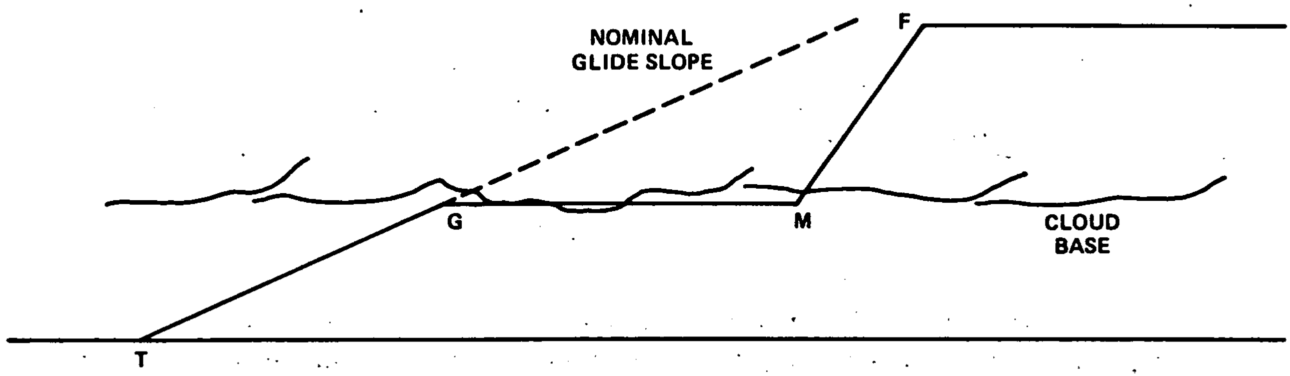

Figure 1.- Non-precision approach profile.

In order that HUD can be used in the NPA it is evidently sufficient if it gives the information needed for each segment of the profile of figure 1. It must then provide for level flight in cloud in the first segment. It must allow descent in cloud at a selected rate of change of height. In the third segment it must again allow for level flight but in either good or bad visibility. Finally it must support a visual approach if the runway is sighted from a suitable position. In all segments it must provide information for holding a given course and at all times the information must be of requisite quality (for it is axiomatic that a display can be no better than the information which it presents). It is, of course, implicit that all of these requirements are subordinate to the ultimate purpose of judging whether or not to continue the approach.

This paper describes a form of HUD which has been developed for use in the NPA. It is derived from visual and instrument approach displays which are combined in a manner allowing operation in all of the flight segments which have been described. The new display has been used for non-precision approaches by a small number of pilots in simulated flight.

NPA HEAD-UP DISPLAY

Guidance Components

The guidance components of the display were drawn from symbol formats investigated in detail in earlier work (ref. 4). These included what was called an unreferenced flight director or Type 1 display and a referenced flight path or Type 2 display. The guidance information of the Type 1 display was "processed" in the sense of incorporating signals originating in several data sources. This information was presented in the general framework of the external world but without being referred to a particular origin such as the aim point on the ground. In the Type 2 display the guidance information was drawn from individual sources and was processed only in the sense of securing the stability of a symbol in relation to its true position. This information was presented in and referred to the framework of the external world. (Another kind of display in the earlier work was the referenced flight director or Type 3 format, but this was not relevant to the present investigation.)

Instrument flight guidance— The guidance components used during instrument flight conditions were drawn from a format previously described as H11 (ref. 4) which was an example of a Type 1 display. These components are shown in figure 2 where double lines are used to represent symbols (the same convention is also used in succeeding display diagrams). The essential parts were a fixed aircraft circle (having stub wings) and a moving director dot.

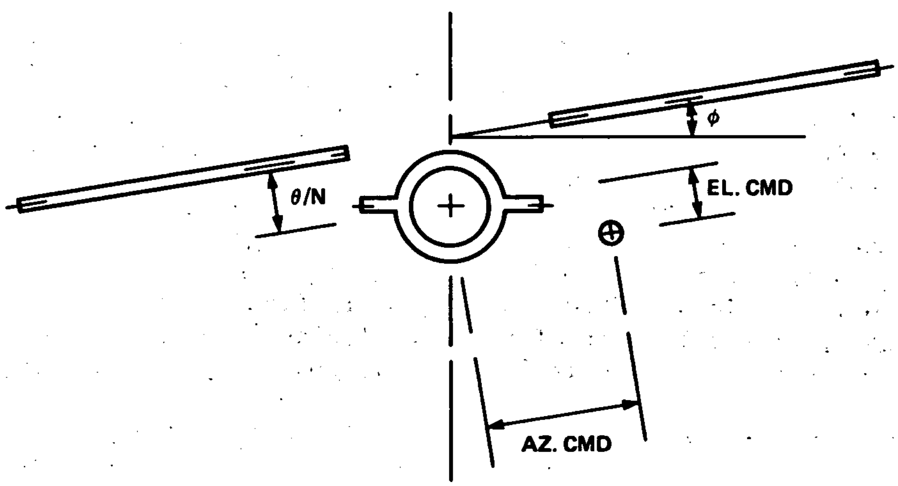

Figure 2.- Guidance components of unreferenced flight director (Type 1) display.

These parts together made the flight director and were functional for any relative position of the aircraft and the external world. The dot nevertheless moved in the coordinate framework of the external world so that the display was conformal for motion. The director was supported by an horizon bar (having a central gap) which was always parallel to the external horizon but moved in elevation at a reduced scale. These symbols were similar to the basic components of the conventional attitude director indicator (ADI).

The flight director dot was augmented with a device intended to reduce fixation, which is shown in figure 3. It comprised a stack of crossbars each parallel with the horizon. The lowest crossbar had its center always at the same distance from the display center and thus swept out an arc during changes in bank angle. All of the crossbars were contained within a triangle based on the lowest member and terminating in the dot. The form of the triangle changed during movements of the director dot and because it covered a large area it enabled the dot to be seen without looking directly at it. Without the device it would be necessary, of course, to follow the dot continuously to achieve consistent tracking and this could result in fixation (in the psychological sense).

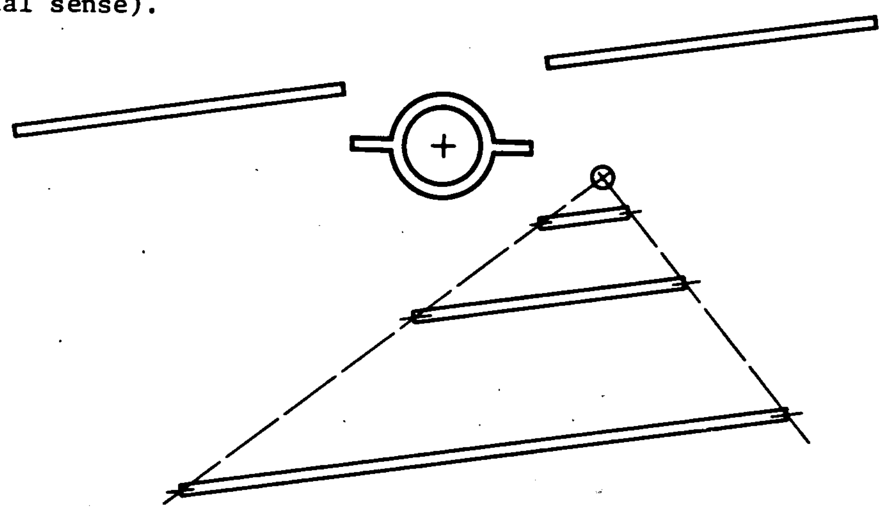

Figure 3.- Unreferenced director adapted to reduce fixation.

Visual approach guidance— The guidance component used during a visual approach was derived from elements of a format previously described as H21 (ref. 4) which was an example of a Type 2 display. In that format the guiding components were a flightpath symbol (γ) and a fixed depression symbol (γ_K). The former showed the direction of flight in relation to the outside world and the latter showed the position of the aircraft in relation to a (selected or desired) path which was depressed by a constant angle (γ_K) from the horizon. These symbols were in the form of a circle and a dashed line, respectively, and their positions in the format are shown in figure 4 by single lines since they were not necessarily part of the new display. The runway and the true horizon are also shown by single lines, as belonging to the external scene.

In the situation presented in figure 4 the flightpath circle lies beyond the runway aim point in the touchdown zone and the fixed depression line is offset below the aim point. The meaning in this case is that the aircraft is

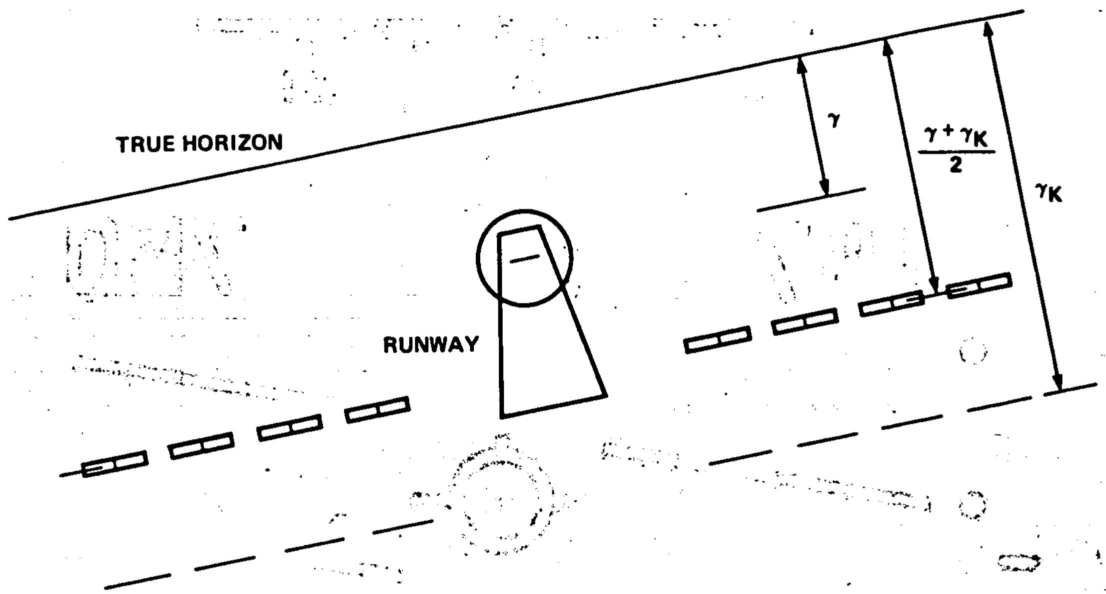

Figure 4.- Guidance components of referenced flightpath (Type 2) display.

being flown beyond aim to compensate for a position below the desired path. The pilot's task is to balance the two symbols so as to reduce the offset at a convenient rate. The task can be made easier by combining the signals which drive them. This can be done by simple addition as in the "delta gamma" method of Bateman (ref. 5). Or they may be combined by the more sophisticated method of "compensation" due to Lowe (ref. 6). In the present display the two signals were simply added in equal proportions and a single symbol was placed in a position midway between the flightpath and fixed depression symbols. The symbol was also a dashed line but with crosshatching to distinguish it from a fixed depression symbol. The pilot's task was generally to hold this combined symbol on aim to reduce offset from the desired path.

Combined guidance— For NPA operation the two kinds of guidance component (flight director and dashed line) were made available in the same display format. It was not advisable to show both at the same time because of the interference resulting from the different motion characteristics of their individual framework (referenced, unreferenced). It was arranged instead that each kind of guidance component could be selected alternately by means of a thumbswitch. An additional switch was provided for the purpose of changing the mode of operation of the dashed line. This line could either be used in the delta gamma mode, as described above, or it could be used simply as a fixed depression symbol.

The complete display format is shown in figure 5 which also includes peripheral and support components. The guidance components occupied the central zone except for occasional excursions of the dashed line during changes of attitude. The only other central component was a speed error "worm" appearing above or below the aircraft circle to indicate positive or negative errors, respectively. Digital readouts of airspeed and radio altitude were placed above center to the left and right, respectively. These components were sufficiently far out to force the pilot to scan, which would thus reduce any fixation tendency. Corresponding positions below center were used mainly for discrete messages. A square box could be shown intermittently

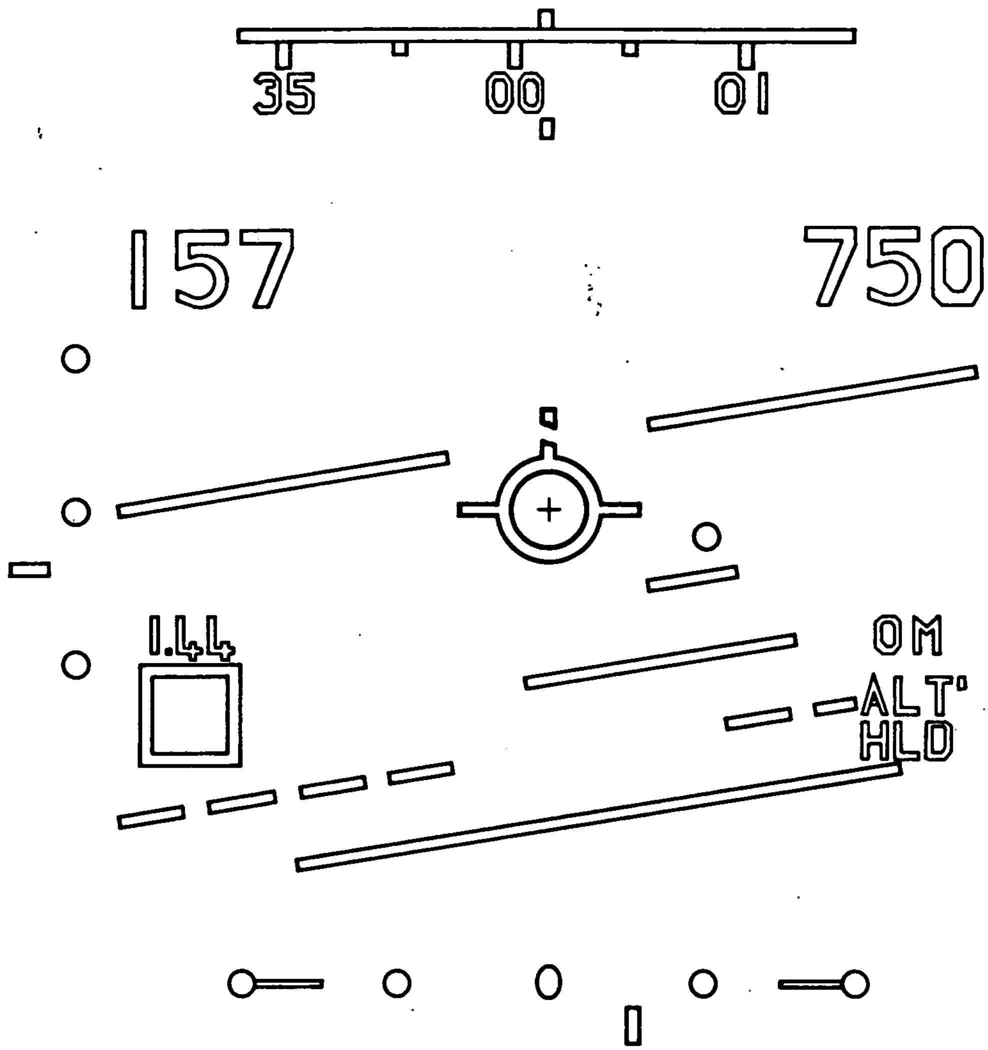

Figure 5.- Head-Up Display for Non-Precision Approach.

at the left as a master warning symbol and above this was a digital readout of engine pressure ratio. The mode of flight (such as Altitude Hold) was shown at the right and the passage of marker beacons was indicated for short periods by acronyms (OM, MM, IM) which appeared above the mode annunciator.

The outer regions of the format were occupied by scales. The heading scale was at the top and this was in the form of a tape moving past a fixed lubber line and within an invisible window. An ILS localizer scale was placed below. This was conventional in position and movement but it had a pair of tapes of changing length added to show permissible deviations from the approach path. An ILS glide-slope scale was not normally shown but could be made to appear (on the right-hand side) if the display were to be used for a full ILS approach. A scale on the left-hand side was used to show vertical speed.

Driving Signals

Segment 1— The first segment of the non-precision approach was to be flown in an Altitude Hold mode (as would be shown by the mode annunciator). The flight director symbol would be driven by the ILS localizer for course guidance and by a vertical control law designed to maintain a constant radio altitude. This segment would be flown essentially in the same manner as in the NPA wihtout HUD. It would be flown with equivalent accuracy since the head-up director is as accurate as a conventional attitude director indicator (ref. 4). By choosing an altitude of 1385 ft for this segment the aircraft would intercept a three-degree approach path at the Outer Marker and this would be used as the Final Approach Fix.

Segment 2— In the second segment the aircraft would continue to be flown by means of the HUD flight director but in a Height Rate mode. This would be announced by the discrete HT RTE. Lateral guidance would again be based on the ILS localizer but for vertical guidance the control law would be designed to generate a selected rate of descent by comparing actual and selected rates. This operation would be equivalent to making a descent on conventional instruments but with a director used in place of a vertical speed indicator. It should therefore be at least as accurate as the conventional operation and possibly more so. The selected rate of change of height would be either 720 (for a 3° path at a nominal approach speed) or 1000 ft/min.

Segment 3— The third flight segment would also be flown in the Altitude Hold mode with ALT HLD again annunciated. As before the guidance signals would be derived from localizer and radio altitude inputs. This operation would also resemble the corresponding part of a conventional NPA but the difference would be that the pilot could momentarily interrupt the director guidance by switching to the visual approach method. For this the guidance component (dashed line) would be used as a fixed depression symbol and it would show aircraft position in relation to the three-degree path (or a path inclined at some other selected angle). At this time the mode annunciator would show HI LO. After this brief interruption flight would continue by director with further interruptions as required until the depression symbol showed the selected path to have been reached. The fixed depression angle would be derived from a high-quality source of pitch attitude and would allow position to be determined more accurately than in the conventional operation.

Segment 4— In the final (visual approach) segment only the dashed line would be used for guidance. The Altitude Hold mode would be cancelled and the annunciator would show either HI LO or DEL GAM depending on the drive selected for the dashed line. The delta gamma mode would normally be used since the visual approach would be made from a position on the selected path. The pilot would hold the dashed line on the touchdown zone and he would make occasional brief changes to the fixed depression mode to check offsets due to wind shear. The accuracy of the vertical profile would depend not only on the source of pitch attitude information but also on the computation of flightpath angle. It would probably be better than in an unaided visual approach (ref. 3). The accuracy of the lateral path would be the same as in an unaided visual approach because both would be achieved simply by observing the runway.

Go-Around— In the event of needing to break off the approach at any time the Go-Around mode would be selected. The annunciator would then show GO ARD. The flight director display component would be used and the director control law would generate a rate of climb of 1000 ft/min.

Operational Procedure

The operational procedure used in the simulated non-precision approaches is illustrated in figure 6 for the case of a successful visual acquisition. The figure shows the approach profile and in the space below there are two rows of entries for the actions taken by the captain and first officer. The approach is divided into the same four segments which have already been considered.

Before the start of the run the first officer would use a selector switch to set the height rate to be used eventually in the descent and he would call this value. He would set Altitude Hold on the mode selector and call that it had been engaged. He would also call the Minimum Descent Altitude. The approach would then be started with the captain flying the director in Altitude Hold. This would continue until the OM discrete appeared which the first officer would confirm by calling "Outer Marker." The first officer would then set Height Rate on the mode selector and at the same time call "Descent."

The captain would start the descent by adjusting power and flying the flight director in the Height Rate mode. On reaching a height 100 ft above the Minimum Descent Altitude the first officer would call "100 Above" and almost immedicately set and call the Altitude Hold mode (nominally at 50 ft above MDA). The first officer would also call "Minimum Altitude" at the MDA. By this time the aircraft would have descended below cloud and it would have reached a position short of the selected approach profile if a high rate of descent had been used and if the wind had been fairly normal. The captain would then fly the director in Altitude Hold after adjusting power. At intervals he would use his thumbswitch to select the dashed line in the HI LO mode and check aircraft position relative to the selected path.

When the aircraft reached the selected approach path the captain would engage the Delta Gamma mode for the dashed line and call this action. On hearing "Delta Gamma" the first officer would use the mode selector to disengage Altitude Hold. He would announce this change to let the captain know that the Go-Around mode could be used at any time (this was necessary because of limitations in the switching logic available in the experimental equipment). Meanwhile the captain would adjust power and fly the visual approach by holding the dashed (and crosshatched) line on aim with occasional position checks by reverting to the HI LO mode.

In the event that the ground had not been sighted during (or before) flight at the Minimum Descent Altitude the captain would continue for an interval of time calculated to take him no further than runway threshold and make a go-around. He would also use the Go-Around mode if the aircraft broke cloud at a position beyond the selected approach path because of an unexpected tailwind.

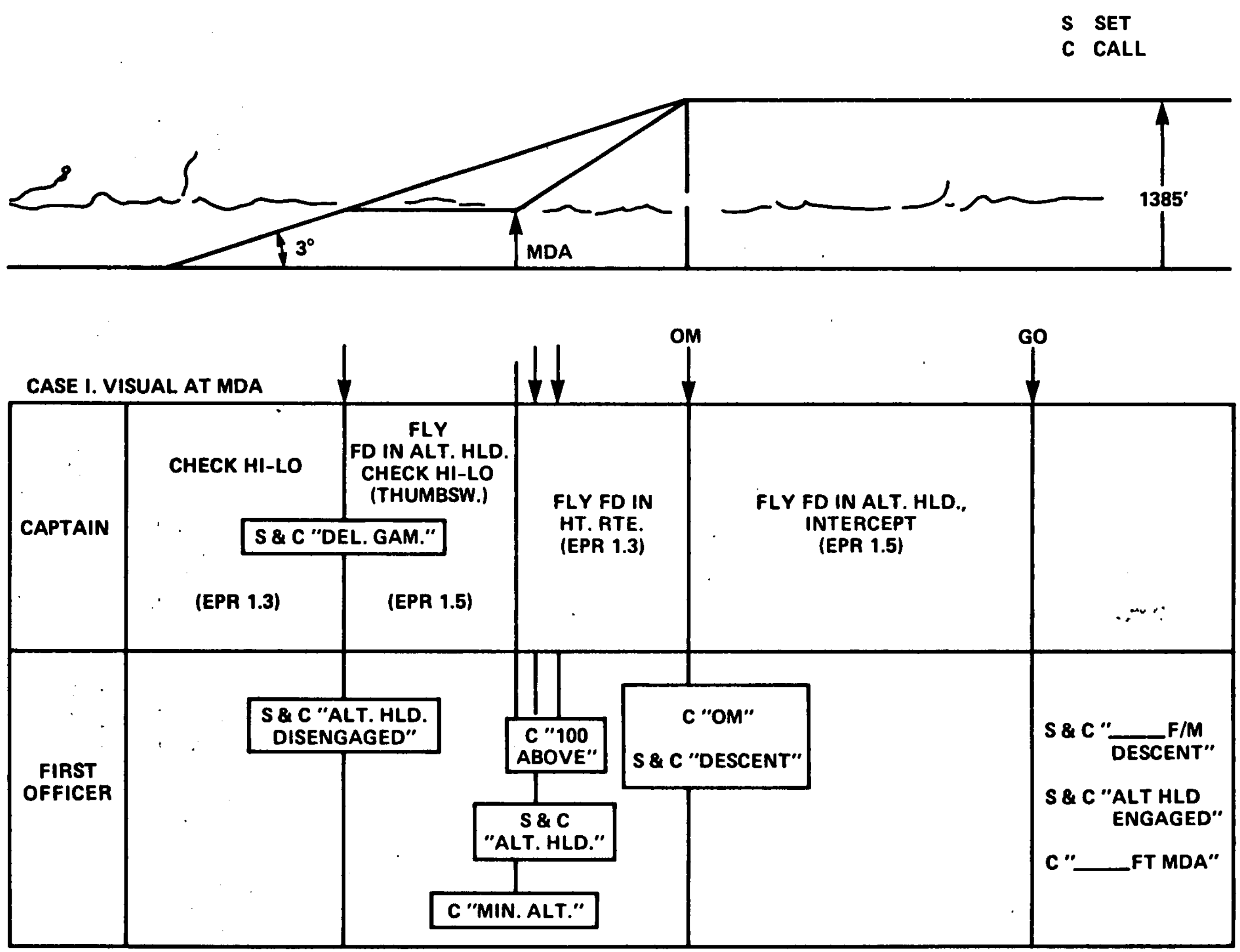

Figure 6.- Operational procedure for simulated non-precision approach.

EXPERIMENTAL INVESTIGATION

Aim

Experimental work was carried out in a simulator to determine whether the new display could be used in the manner intended. To this end it was necessary to show that the display enabled the approach to be made with sufficient accuracy under the condition of a failed glide slope. This meant that the runway centerline should be held within acceptable ILS limits and that the aircraft should break cloud in a position suitable for completing the approach or for going around in safety. Perhaps the most important issue was whether the display enabled the pilot to make the right decision, namely, to go around or to land.

Method

The experimental method was based on using a computer-generated display which was superimposed on a simulated forward view and presented by a large collimating lens in a cab similar to a jet transport cockpit. The visual scene and the display were driven by a simulation of the dynamics of a medium-sized jet transport in response to inputs from the normal cockpit controls. The equipment was essentially the same as used in the previous study of display formats (ref. 4) but it had been modified to provide the new mode switching facilities.

Subjects

Three subjects were used in the experimental program. Two were pilots holding commercial licenses and having experience as first officer of 1500 and 7500 hr. Both of these pilots had taken part in the previous investigation (S20, 22, ref. 4). The other subject (S40) was an experimental test pilot of considerable experience who had not taken part in the previous study.

Experimental Procedure

The briefing material used in the earlier work was presented to S40 to give him the same general understanding of the basic HUD formats (ref. 4) as the other subjects. All were then briefed on the way the new display had been derived and on the supporting elements. The operational procedure for the four segments of the NPA was outlined with the help of figure 6. The mode annunciator was explained in detail as were the switching arrangements for changing the display format and the dashed line drive.

It was then pointed out that the aircraft might be found on breakout in a position making landing difficult. Combinations of wind shear and crosswind would be used. The approach might start with a lateral offset and turbulence would be added on some runs. It was thus intended that the pilot might find himself well off a desirable approach path so that he would be confronted with the necessity of deciding whether to continue or go around. It was explained that the interest would lie in the nature of, and the reason for the pilot's decision. This information would be related subsequently to the approach situation.

The experimental session was conducted according to the schedule of table 1. Preliminary runs (1-6) were used to recall, or familiarize the pilot with, characteristics of the display when used as a flight director in the full ILS approach. These approaches were without initial offset but with the degree of difficulty increased progressively by adding mild turbulence and then crosswind. No shear was used and the breakout was always at 600 ft with no decision height given.

The glide slope was then failed for the NPA training runs (7-14) which were conducted with height rates of 720 or 1000 ft/min in the second segment of the approach (descent to MDA). Offsets of ±1000 ft were used with crosswinds of 0 or ±10 knots. The degree of difficulty was increased by adding mild then light turbulence and by introducing wind shear. The shears were selected from a repertoire used in earlier work (W31-39, ref. 4). They had the characteristics of a fairly severe decrease in headwind and an increase in downdraft which occurred together in a 200-ft height band. Breakout height was also decreased and on run 12 a decision height was given which was above breakout. This condition was intended to give experience in using a Go-Around mode.

The data runs were similar to the latter runs of the NPA training with various combinations of offset, crosswind, and turbulence. Each approach was made with a different wind shear, however, and breakout was either at 300 or 600 ft. The decision height was usually at breakout but on runs 17 and 20 it was above breakout. The selected height rate was the same for all runs made by one subject but was varied between subjects. The runway visual range was 12,000 ft for all runs.

No attempt was made to randomize the order of runs because of the limited number of subjects and the random nature of the schedule. Subjects were expected to fly the approaches as well as possible but were told to land only if conditions were favorable. The entire session lasted somewhat less than 2 hr with a short break taken before the data runs.

The chief experimental observation was of the decision whether or not to land. In the event of a go-around the height for taking this action was noted. After each run the pilot was asked if he felt he had made a good decision and whether he had other comments to make. General comments were sought on the adequacy of the operational procedure and the sufficiency of information. In addition to these observations recordings were made of lateral tracking errors in four successive height bands of 300 ft, from 1200 ft down.

TABLE 1.- RUN SCHEDULE FOR NON-PRECISION APPROACH

Run	Height rate, ft/min	Glide slope	Offset, ft	Crosswind, knot	Shear	Turbulence, ft/s	Breakout, ft	Decision height, ft
				ILS Training				
1	-	On	-	-	-	-	600	-
2	-	On	-	-	-	1.5	600	-
3	-	On	-	10	-	1.5	600	-
4-6		Repeat previous runs if necessary						
				NPA Training				
7	720	Off	1000	-	-	-	600	-
8	720	Off	1000	10	-	-	600	
9	720	Off	1000	10	-	1.5	600	-
10	720	Off	-1000	10	32	1.5	600	-
11	1000	Off	-1000	-10	32	3.0	400	-
12	1000	Off	1000	-10	35	3.0	400	500
13-14		Repeat previous runs if necessary						
				Experimental Data				
15	As given	Off	1000	-	31	-	600	
16		Off	-	10	34	1.5	300	
17		Off	-1000	-	37	3.0	300	400
18		Off	-1000	-10	32	1.5	600	
19		Off	1000	-10	35	3.0	600	
20		Off	-	-	38	-	300	450
21		Off	1000	10	33	3.0	300	
22		Off	-1000	-	36	-	600	
23		Off	-1000	10	39	1.5	300	

Notes: RVR 12,000 ft for all runs.
Turbulence values were rms.
Decision heights given when different from breakout.

RESULTS

All subjects completed the schedule of data runs with each approach comprising the four segments of the NPA. The experimental results are summarized in table 2 for each of the three subjects, with the selected rate of descent shown for each of them. The decision to land or go around is given for each run. In the case of a landing the coordinates of the touchdown point are given, the first entry being the distance from threshold (in ft) and the second the lateral offset from the centerline (in ft). These values are averages for the left and right gear. They are followed by the sink rate (in ft/s). This value is marked by a superscript in the case of a landing on one gear and then the value shown is the larger of the rates for the two gears. In the event of a go-around the height shown is that at which this action was initiated. The table also includes estimates made by subjects of the quality of their own decisions. These are shown in parenthesis as good (G) or only marginally good (M).

TABLE 2.- LAND OR GO-AROUND DECISIONS IN NON-PRECISION APPROACHES BY THREE SUBJECTS

(Touchdown Point Coordinates (ft) and Sink Rate (ft/s), or Go-Around Height (ft); Subjective Quality of Decision in parenthesis, G-good, M-marginal.)

Run	S20 720 ft/min	S22 1000 ft/min	S40 720 ft/min
15	Land (G) 298,-15; 9.9*	Land (G) 726, -2; 1.0*	Go-Around (-) circa 500
16	Land (G) 632, 0; 0	Land (G) 458,-25; 8.6*	Land (M) 1698, 6; 3.4*
17	Go-Around (G) 400	Go-Around (G) 350	Land (-) 85,-20; 9.3*
18	Land (G) 518, 37; 1.2	Land (G) 117,-11; 5.1	Land (M) 728, 39; 8.6
19	Land (G) 360, 51; 5.7*	Land (G) 431,-10; 8.4	Land (G) 494, 47;11.2*
20	Go-Around (G) 450	Go-Around (G) 420	Land (-) 304,-12;11.3*
21	Go-Around (G) 300	Go-Around (G) 200	Land (-) 174, -7;12.7*
22	Land (G) 898, 6; 0.6	Land (G) 703,-15; 8.2	Land (-) 210,-22; 8.5
23	Land (G) 1294,-18; 2.6	Land (G) 222, 5; 3.4*	Go-Around (-) circa zero

*Landed on one gear.

The subjective estimates of decision quality were then compared with objective estimates, as shown in table 3. If in the case of a landing decision the aircraft touched down at a point more than 500 ft beyond runway threshold with a lateral offset less than 40 ft from the runway centerline and a sink rate not exceeding 4 ft/s the pilot was considered to have made a good decision because he was able to effect an acceptable landing. Decisions to go around were, of course, good if breakout was below the Minimum Decision Altitude (runs 17, 20). Other go-around decisions were assessed on the basis of the situation at or just before the time of taking this action. Thus on run 21 the records showed that subject 20 broke out at 300 ft (MDA = 300 ft) at a point 1764 ft short of threshold instead of at a point about 5000 ft short (for an ideal approach) and while he was carrying a speed of 149 knots (or 14 knots above reference speed). The judgment to go around was therefore sound. On the same run S22 was 1426 ft short of threshold and had a lateral offset of 83 ft. His decision to go around was therefore also sound. In the case of run 15 for S40 the decision to go around was based on being too high at the 600-ft breakout where the distance to threshold was 7969 ft, which should correspond ideally with a height of about 400 ft. On run 23 the same pilot was 13 ft short of the runway at a height of 25 ft instead of being at a point beyond threshold. Both of these judgments were thus sound.

TABLE 3.- COMPARISON OF ESTIMATES OF QUALITY OF DECISIONS TO LAND OR GO-AROUND BY THREE PILOTS

Run	S20			S22			S40		
	L/GA	Sub	Ob	L/GA	Sub	Ob	L/GA	Sub	Ob
15	L	G	NG	L	G	G	GA	-	G
16	L	G	G	L	G	NG	L	M	G
17	GA	G	G	GA	G	G	L	-	NG
18	L	G	G	L	G	NG	L	M	NG
19	L	G	NG	L	G	NG	L	G	NG
20	GA	G	G	GA	G	G	L	-	NG
21	GA	G	G	GA	G	G	L	-	NG
22	L	G	G	L	G	NG	L	-	NG
23	L	G	G	L	G	NG	GA	-	G
Summary of Estimates									
Similar	7			4			1		
Dissimilar	2			5			2		

Legend, L - land; GA - go-around; Sub - subjective estimate; Ob - objective estimate; G - good decision, NG - not good decision.

The comparison of subjective and objective estimates is shown in the last part of table 3 where the numbers of similar and dissimilar estimates are given for each subject. Both S20 and S22 considered all their decisions to have been good and these judgments agreed with objective assessments in seven out of nine cases for S20 and in four out of nine for S22. S40 made only three estimates of decision quality and only one of these agreed with the objective evaluation.

The information provided by the display was considered to be sufficient by all subjects. It was noted by S22, however, that it was at first difficult to line up the dashed line with the touchdown zone in the presence of crosswind. On the other hand he found the offset of the flight director symbol useful in this condition because it made the decrab maneuver easier. S40 said he would have liked to have had thrust demand information in the display and he made the incidental comment that the speed error "worm" was preferable to the digital speed readout in turbulence.

The operational procedure was considered acceptable by S20, 22 with the following reservations. S20 made one mistake in using the thumbswitch but this he was able to correct immediately. S22 said that Altitude Hold should be disconnected automatically. S40 did not comment on the procedure except to say that the change from one flight mode to another came at a very difficult moment.

Lateral tracking errors for the three subjects are shown in table 4 as means and standard deviations of the localizer error (in deg). Results are given for three flight sections covering the first three height bands. Complete results were not available for the lowest height band on account of the go-arounds. Means were generally in the range from 0.02 to 0.075 degree but there was a much larger value (0.248) for the first segment of approaches by S22. The grand mean was 0.069 degree.

TABLE 4.- LATERAL TRACKING ERROR FOR THREE SUBJECTS

(Mean and standard deviation, SD, of localizer error in degrees for three flight segments of nine non-precision approaches)

Subjects	Height band, ft		
	1200-900	900-600	600-300
S20			
Mean	0.0318	0.0218	0.0670
SD	.0183	.0078	.0544
S22			
Mean	.2476	.0259	.0647
SD	.1315	.0183	.0560
S40			
Mean	.0470	.0433	.0753
SD	.0184	.0228	.0592
Grand Mean	.0694		

DISCUSSION

The experimental results showed that the display could be used in the Non-Precision Approach by means of an operational procedure defining the actions to be taken by the flight crew. Subjects were able to fly the aircraft in each of the four flight segments and arrive at a position at which approach decisions could be made. They were then able to complete the approach or go around.

The approach profile was thus satisfactory during the first three flight segments. The final visual approach was also acceptable, at least for a fair proportion of the runs made by S20, as shown by the objective estimates of decisions presented in table 3. (It will be realized, of course, that the environmental conditions were deliberately made severe in these approaches, and that better accuracy would be expected in better conditions.) The lateral accuracy was also sufficient. A mean tracking error of 0.069 degree compared favorably with a value of about 0.05 degree obtained in earlier work (ref. 2), while both of these values were within Category II autopilot limits. All of these results were obtained, however, with data sources assumed to be perfect, and this investigation did not take into account the effects of errors arising in real flight conditions.

The quality of the decision whether or not to land was obviously a matter of the first importance. Unfortunately, it was not possible to form a definite conclusion on this issue from the limited data provided by a few subjects using equipment in an early stage of development. But the results do give some idea of the capabilities of the display system and they at least pave the way for a more extensive investigation with improved facilities.

The approach scenario had been designed to exercise both skill and judgment. By combining shear, crosswind, and turbulence the breakout usually occurred under difficult circumstances and there was also an interaction with the permissible height for making a decision (MDA). It was therefore appropriate to find a fairly high frequency of go-arounds (8 out of 27 (table 2), or 30%). There was a marked difference between subjects, however, in the distribution of go-arounds. On the one hand S20, 22 went around on both occasions when required to do so by regulations and on one occasion when conditions were the most difficult because of breaking out low in moderate turbulence and crosswind (run 21). On the other hand S40 landed on all three of these occasions but went around in relatively easy conditions of a high breakout and neither turbulence nor crosswind (run 15). This difference may reflect the backgrounds of subjects and it should perhaps influence the choice of subjects for future work.

Considering only the results of S20, 22 it appears that there was a measure of agreement between subjective and objective judgments of the quality of decisions. For S20 the agreement was very good with discrepancies in only two out of nine cases (22%). For S22 there was a greater disparity with disagreements in five out of nine cases (56%). These figures were, of course, based on arbitary landing criteria and the agreement would have been closer if the tolerances had been relaxed.

Except for some difficulty in lining up in a crosswind and a possible need for more detailed thrust data the display appeared to provide adequate information to subjects. The mode changing problems encountered by one subject suggest that the operational procedure used was not fully satisfactory. In an improved arrangement the switching between modes and between display formats would be organized to conform more closely with workload requirements. Improvements might also be made to provide better crosswind operation and additional thrust control.

CONCLUSIONS

1. Assuming data sources of sufficient accuracy, and on the basis of limited tests, it appeared possible to adapt the Head-Up Display for use in the Non-Precision Approach.

2. Further work is needed in refining the method of changing the display during transition between instrument and visual flight in the head-up mode.

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16. Abstract

This paper deals with the problem of head-up guidance for an aircraft making an instrument approach without glide-slope information. Requirements for path control are considered for each section of the approach profile and a head-up display is developed to meet these needs.

The display is an unreferenced flight director which is modified by adding a ground-referenced symbol as an alternative guidance component. The director is used for holding altitude in the first segment and for descent at a controlled rate in the second segment. It is used in the third segment to maintain the minimum decision altitude while assessing the approach situation. This is done by means of occasional, brief changes to the referenced symbol. In the final segment a visual approach is made with the referenced symbol used continuously for path control.

The display is investigated experimentally in simulated approaches made by three pilots. The results show a fair agreement between objective and subjective estimates of the quality of landing decisions.

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