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SIMULATION STUDIES OF AIR TRANSPORT OPERATIONAL PROBLEMS

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SUMMARY

An experimental evaluation of the monitored approach procedure for conducting low visibility instrument approaches is described. Four airline crews each flew 16 approaches using the monitored procedure and 16 using a modified "standard" procedure in a DC-10 simulator under various conditions of visibility, wind shear and turbulence, and radar vectoring scenarios.

In terms of system measures of aircrew performance, no major differences were found. Pilot opinion data indicate that there are some desirable characteristics of the monitored procedure, particularly with reference to the increased role of the flight engineer in conducting low visibility approaches. Rationale for developing approach procedures is discussed.

INTRODUCTION

The research described in this paper grew out of some of the concerns expressed by airline pilots during the preliminary pilot interview studies mentioned in the previous paper (ref. 1). Specifically, many pilots felt that the approach procedures they were using were less than optimal with regard to two major items: (a) the integration of all three cockpit crewmembers into the approach procedure; and (b) the callouts required of the various crewmembers during an approach.

The critical demands placed upon pilots during the last one or two hundred feet of an approach are well known. Many accidents have occurred during this critical phase of flight, and in many of these it appears that one of the major contributing factors was the inadequate or inappropriate design of approach procedures, including crew integration and callouts. In many cases sufficient information to prevent the impending disaster was present within the cockpit, yet the crew failed to utilize this information. Once the flying pilot has changed to flight by visual reference, deviations from the desired flight path might not be readily discernible from outside visual cues. These deviations will, however, invariably show up on the cockpit instrumentation; increased sink rate, deviations below glide slope, or low airspeed — all so-called killer items — will be displayed inside the cockpit. It is necessary that this information be transferred to the flying pilot if an accident is to be prevented.

There are two ways of performing this task: (a) the physical environment can be modified, making the information available in the pilot's visual field via the use of VASI or a Head-Up display, for example; or, (b) the operational environment can be modified by using autoland or by the adoption of new callouts and monitoring procedures.

Figure 1 illustrates the relationship between the present experiment and the epidemiological model described in the previous paper by Billings et al. (ref. 1). The primary interest was in the effects of manipulation of the operational environment, specifically low visibility approach procedures, upon aircrew and aircraft performance.

Although approach procedures used by airlines vary widely, it is possible to discern two basic philosophies which have been used to structure these procedures. One of these, the standard procedure, is basically this: one pilot is responsible for flying the approach and landing, or missed approach if that should be necessary, and the other crewmembers are assigned monitoring and callout duties. The decision to land or to go around is made by the flying pilot on the basis of his assessment of the visual situation following the transition from heads-down flying. Variations of this basic procedure are used by virtually all U.S. air carriers.

One alternative to the standard procedure is one called the monitored approach by several of the foreign carriers who have developed these techniques. Basically, using this procedure, one pilot, usually the copilot, is responsible for flying the heads-down portion of the approach; the other pilot is responsible for monitoring this portion of the approach and is the individual who decides whether the outside visual cues are sufficient for the landing. If they are, this pilot, who is usually the captain, takes physical control of the aircraft and proceeds with the landing. At the transition, the copilot assumes responsibility for monitoring the remainder of the approach and landing, remaining head down until sometime during the landing roll.

Intuitively, this monitored approach procedure has some appealing features, particularly in the way the transition from instrument reference to visual reference flight is made. The captain is given sufficient time to assess the visual situation and reach a decision and can do so without the additional burden of flying the aircraft. Furthermore, more emphasis is placed upon continuous monitoring of the critical final portion of the approach and landing. However, there are also some characteristics of this procedure which appear to be less desirable, particularly those having to do with the physical transfer of aircraft control at very low altitudes.

In attempting to resolve these and other issues, it soon became apparent that there is little, if any, objective data pertaining to the relative effectiveness of these two basic philosophies for conducting low visibility approaches. On the basis of the accumulated operational experience of those carriers who have used the monitored procedure, it can be concluded that the idea has considerable merit. However, because of the fundamental importance of approach procedures for the safety of aircraft operations, decisions to utilize this approach, or any other for that matter, should be based on more rigorous, objective performance data obtained from line pilots operating under a wide variety of realistic conditions.

In summary, the major objective of the experiment was to compare aircraft and aircrew performance during low visibility approaches using either the standard or the monitored approach procedure. A secondary objective was to develop full mission simulation research techniques for use in other research.

METHOD

Development of Approach Procedures

Because the carrier who participated in the study used a variant of the standard procedure, it was necessary to develop a modified standard procedure in order to control for the possible effects of crew familiarity with the standard procedure. To accomplish this, the approach procedures and callouts used by another U.S. carrier were used. This set of procedures was sufficiently different from those used by the participating carrier, that the likelihood that familiarity influenced the results of this study is minimal. This set of procedures is summarized in figure 2.

Two major criteria were used during the development of the monitored procedure which was used in this experiment: (a) the flight engineer should be fully and completely integrated into the approach procedure; and, (b) there should always be a clear-cut division of responsibilities — pilot flying, primary monitor, and backup monitor — as shown in figure 3. In other words, at any given point during an approach, each crewmember should be assigned one of these three functions, and whenever there is a change in one crewmember's function, there should be a corresponding, compensatory change in another crewmember's function. Thus, for example, when the flight engineer calls out, "Approaching minimums," the captain verbally acknowledges this callout and changes to outside visual reference. Simultaneously, the flight engineer assumes the primary monitoring duties inside the cockpit, and the first officer continues to function as the flying pilot. When the captain announces, "Land," the first officer now assumes primary monitor duties, the flight engineer resumes his role of back-up monitor, and of course, the captain becomes the pilot flying.

Callouts were constructed with regard to the three major functions which callouts can perform: (a) they serve to transmit information about the state of the aircraft; (b) they serve to check for subtle pilot incapacitation — if a pilot misses a callout, or fails to acknowledge one, the other pilots should check to make sure the quiet one is still with them; and finally, (c) callouts can be used to help enforce heads-down discipline. If we want to maximize the probability that a pilot will remain on the instruments during the last stages of an approach, we can assign him specific callout duties during that period of time.

Missed approaches were automatic; if the captain had not taken control of the aircraft when it reached the missed approach point, the first officer initiated the missed approach procedure, and the captain came back inside the cockpit to resume the role of primary monitor. If it became necessary to go around after the captain had decided to land, the captain called out, "Missed approach," and the first officer resumed control of the aircraft and announced, "I have the airplane." This procedure was chosen because it was reasoned that the first officer, being continuously heads down, was in the best position to assume rapid and precise control of the aircraft.

Figure 4 shows the work sheet which was provided to the flight engineer when using the monitored procedure. Before each approach was begun, the flight engineer was given an approach plate by the pilot so that he could determine the information shown on the worksheet. This information was used subsequently by the flight engineer for cross checking and for callouts. In addition, the flight engineer was assigned very specific monitoring duties and guidelines for calling out deviations from the desired flight profile.

Subjects

Because the study involved training airline pilot subjects on the use of an approach procedure which was not the approved procedure used by their company, training pilots, rather than line pilots, were used for this experiment. It was felt unwise to risk the possibility of training someone to the point where, if he were by chance to fly an actual low visibility approach shortly after his participation in this study, he might revert to the experimental procedures rather than use the approved procedure.

Eight current instructor pilots and four current flight engineer instructors served as subjects for this experiment. These instructors were assigned to one of four crews. The flight experience of each of the subject pilots is summarized in table I.

Simulation Facilities

The simulator used for this experiment was a DC-10 simulator equipped with a six-degree-of-freedom motion platform and a TV, model-terrain-board visual system. Modifications were made to the simulation software to allow control of the experimental conditions from the instructor's CRT display and control panel located in the cockpit, and to allow real-time recording of simulator data on digital magnetic tape. Additionally, provisions were made for recording communications, cockpit voice, and observer comments. Experimental sessions, each four hours long, were integrated into the normal simulator training schedule.

Simulator Scenarios and Experimental Design

Since one of the primary areas of concern with the monitored procedure centers around the question of transfer of control of the aircraft at low altitudes, only hand-flown approaches were used. Autopilot use and its interaction with approach procedures is a separate question which was not addressed in this study.

Possible interactions between the kind of approach and the approach procedures were also of interest. Therefore both non-directional beacon (NDB) and instrument landing system (ILS) approaches were flown. All ILS approaches were flown using the Flight Director and manual throttles. All NDB approaches were flown using raw data only.

Each crew flew a total of 32 approaches during the data collection phase of the experiment, sixteen using the monitored approach procedure, and sixteen using the standard procedure.

Since one of the characteristics of a good set of approach procedures is to better enable crews to cope with difficult operational situations, the effects of a variable called "Stress and Workload" on crew performance were evaluated. To accomplish this, radar vectoring techniques, wind shear, and turbulence were used to generate high and low stress and workload conditions. The low workload condition involved no turbulence, no wind shear, a five-knot crosswind from either the right or left, and radar vectoring service that was nearly ideal -- timely, accurate, and such that the aircraft would intercept the final approach course well outside the final approach fix at the proper altitude and airspeed. In contrast, the high workload condition involved a forty-knot head or tail wind which sheared to a direct crosswind of ten knots by 61 m (200 ft) above ground level (AGL), some turbulence, and radar vectoring of the kind too often encountered in the real world — late descent clearances, late turn-ons, and delayed speed reductions. These vectoring scenarios were chosen such that, if flown precisely, the aircraft would intercept the glide slope and final approach course right at the final approach fix (FAF) for the ILS approaches, and 1.6 km (1 mi) outside the final approach fix for the NDB approaches. These were difficult scenarios to fly, and they were chosen deliberately because instructor pilots are extremely proficient simulator pilots and it was necessary to ensure that there was ample opportunity for deviations from profile to develop.

Each approach (as shown in fig. 5) was begun from identical conditions: downwind heading, 1542 m (5000 ft) AGL, 250 knots, and with the aircraft in a clean configuration from a position 16 km (10 mi) abeam (either right or left) of the final approach fix. After a preliminary briefing during which the approach location and type were specified, the simulator was released, and the Experiment Controller, a qualified DC-10 instructor pilot who worked with us for the duration of the study, proceeded to give radar vectors according to the preselected scenario. Standard company operating procedures, including checklists, were used for all approaches.

An approach was terminated during the landing rollout, or upon reaching 150 m (500 ft) AGL during the missed approach. For half of the approaches, the simulated visibility was set to zero (below minimums). For the remaining half, the visibility was set at the appropriate minimums for the approach type. Daylight conditions were simulated in all circumstances.

Two crews flew the monitored approach procedures first, followed by the standard procedure. The order was reversed for the remaining two crews.

Data collection was proceeded by a 2-hr ground school session during which two crews were briefed regarding the approach procedures they were about to fly. Following ground school, the pilots were given a 1-hr, 15-min simulator training session during which 4 ILS and 4 NDB approaches were flown utilizing the appropriate set of procedures. The entire sequence of ground school, simulator training, and data collection was repeated for the alternate set of approach procedures. Upon completion of the last data collection run, an extensive debriefing session was held during which comments, observations, and suggestions of the pilots were sought.

RESULTS

For the purposes of analyzing the tracking data recorded during this study, each approach is arbitrarily divided into two segments. The initial approach segment is that portion of the approach between the Final Approach Fix and a point 10 sec prior to reaching the missed approach point. The remainder of an approach to a landing is termed the final approach segment. Landings and missed approaches were analyzed separately from the initial approach data. This division was necessary to enable the analysis to focus clearly upon the critical last 100 m of an approach. For all practical purposes, there is little difference between the two kinds of approach procedures prior to the missed approach point. It is at the point where the control of the aircraft is transferred from one pilot to the other that major differences would be most likely to appear. ILS and NDB approaches were analyzed separately.

Initial Approach Segment

Tracking data were transformed into rms lateral error, rms glide-slope error, and airspeed variability measures, and were subjected to an Analysis of Variance. As expected, the stress and workload variable did significantly affect airspeed, localizer and glide-slope tracking for the ILS approaches, and lateral course error and airspeed control for the NDB approaches. No other factor, including the set of approach procedures used, produced any significant differences in aircraft performance.

Final Segment

One measure, lateral error during NDB approaches, was significantly different as a function of approach procedure — lateral tracking was more variable using the monitored procedure. This was one of only two instances where the approach procedure variable resulted in a significant difference in performance.

Landing Data

Landings were analyzed using lateral and longitudinal error and sink rate at touchdown as measures of landing performance. There were no significant differences observed for any landing measures.

Missed Approach Data

Missed approach performance was evaluated using peak deviation below MDA/DH (where MDA is minimum descent altitude and DH is decision height), and the square of peak deviation to give emphasis to the larger and presumably more dangerous deviations. In addition, the time integral of total flight path below MDA/DH was analyzed. The average peak deviation below MDA for NDB approaches was significantly larger using the monitored approach procedure. No other significant differences were observed.

Debriefing Interview Results

Pilot reaction during the training sessions to the monitored procedure was largely negative, and virtually all subjects expressed concern about the transfer of control of the aircraft. These negative attitudes were modified after the subjects had experience with the experimental set of procedures; however, it is still necessary to characterize the prevailing attitude as "concerned." Most pilots, however, did concede that there were some positive benefits to using the experimental procedure, particularly in reference to the increased monitoring discipline achieved with this procedure.

There was universal acclaim from the subjects for the increased emphasis on involving the flight engineer in the approach. It was the concensus that this one aspect of the experimental procedure was by far the most important and valuable.

DISCUSSION AND CONCLUSIONS

In some ways the lack of major significant difference between the two procedures was a disappointing outcome. However, in retrospect, there are some encouraging aspects as well.

First, with respect to the question of the superiority of one set of procedures over another, it is necessary to conclude on the basis of results obtained here, that crews can perform equally well using either set of procedures. There is no clear-cut reason to select one set of procedures over another on the basis of system performance measures used in this experiment. Put another way, the choice of which of the basic approach procedures to be used should be based upon other factors. Particularly important here is the accumulated experience of a company with one set of procedures; the difficulties encountered in changing from one set of procedures to another may far outweigh the potential advantages obtained by adopting an alternate set of procedures.

Another conclusion is that regardless of which basic approach procedure is used, it is important that the flight engineer be fully integrated into the approach. The callouts and monitoring duties which were assigned the flight engineer are largely independent of the approach procedure adopted. Although not directly supported by the tracking data obtained in this study, there is little doubt that this is the most important single consideration in the development of low visibility approach procedures.

And finally, we can conclude that simulator evaluations of approach procedures are feasible.

In summary, this first experiment was a preliminary attempt to assess the effects of selected operational factors on pilot performance, in this case with largely negative results. In a second study, the experience accumulated during this first study was used to refine procedures and techniques in an attempt to understand how certain perturbations in the operational environment can affect aircrew behavior. The preliminary results are highly encouraging, and it is intended to pursue the leads generated by those data in an attempt to see if techniques can be developed which will help airline pilots to cope with such disturbances.

REFERENCE

1. Billings, C. E.; Lauber, J. K.; Cooper, G. E.; and Ruffell-Smith, H. P.: Retrospective Studies of Operating Problems in Air Transport. Aircraft Safety and Operating Problems, NASA SP-416, 1976. (Paper no. 33 of this compilation.)

TABLE I.- PILOT DATA

CREW	SUBJECT	TOTAL TIME	DC-10
	1	9000 hr	600 hrs
A	2	14000	400
	3	1500	400
	4	14000	400
B	5	13000	400
	6	6000	700
	7	9000	600
C	8	11000	400
	9	15000	300
	10	7600	500
D	11	6000	500
	12	6900	(2.5 yr)

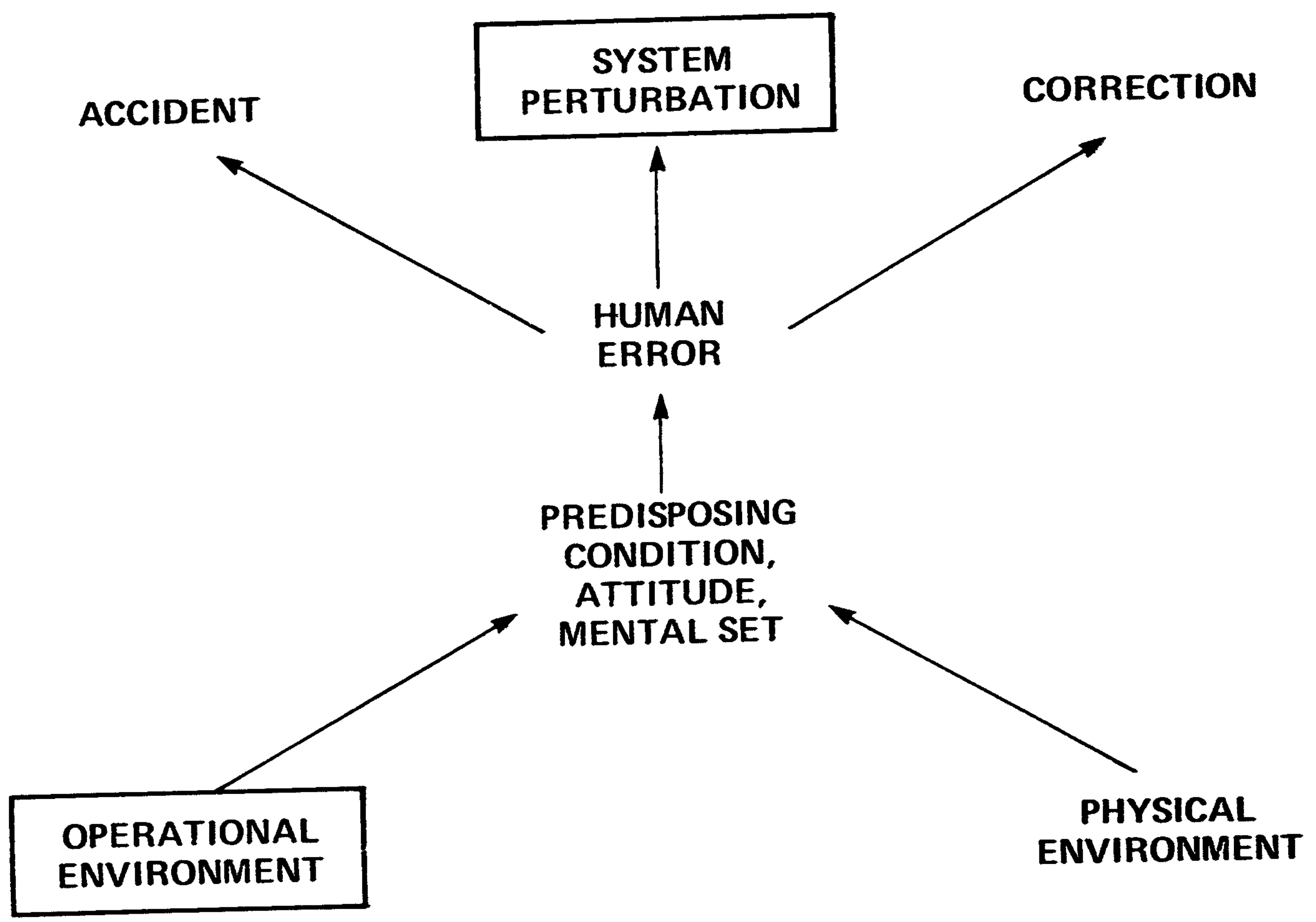

Figure 1.- Epidemiological model.

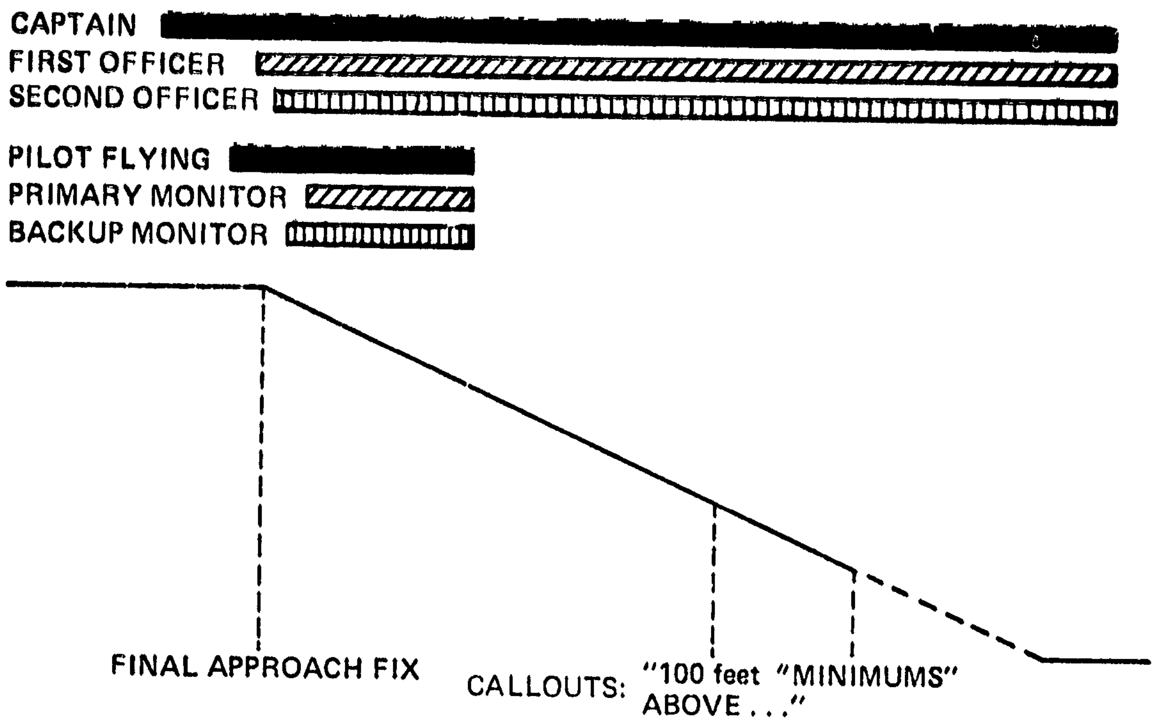

Figure 2.- Standard approach procedure.

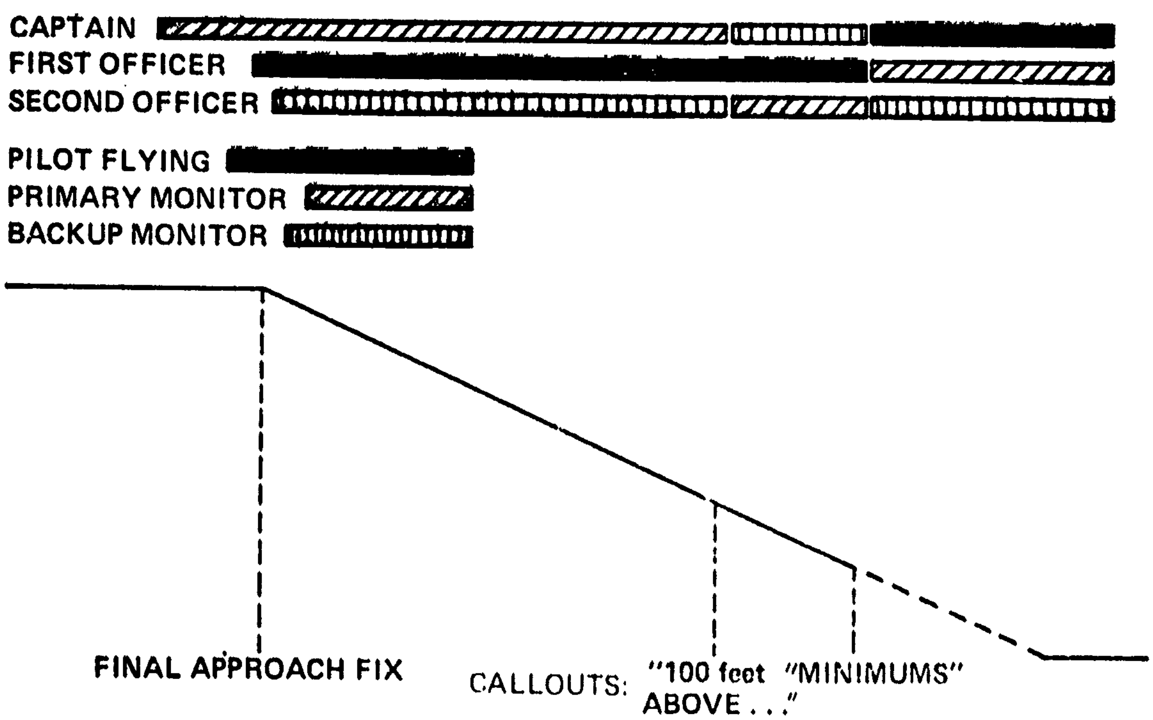

Figure 3.- Monitored approach procedure.

FAF ______________________________ feet MSL

1000′ ______________________________ feet MSL

MDA/DH ______________________________ feet MSL

TIME ______________________________ min:sec

Figure 4.- Flight engineer's worksheet.

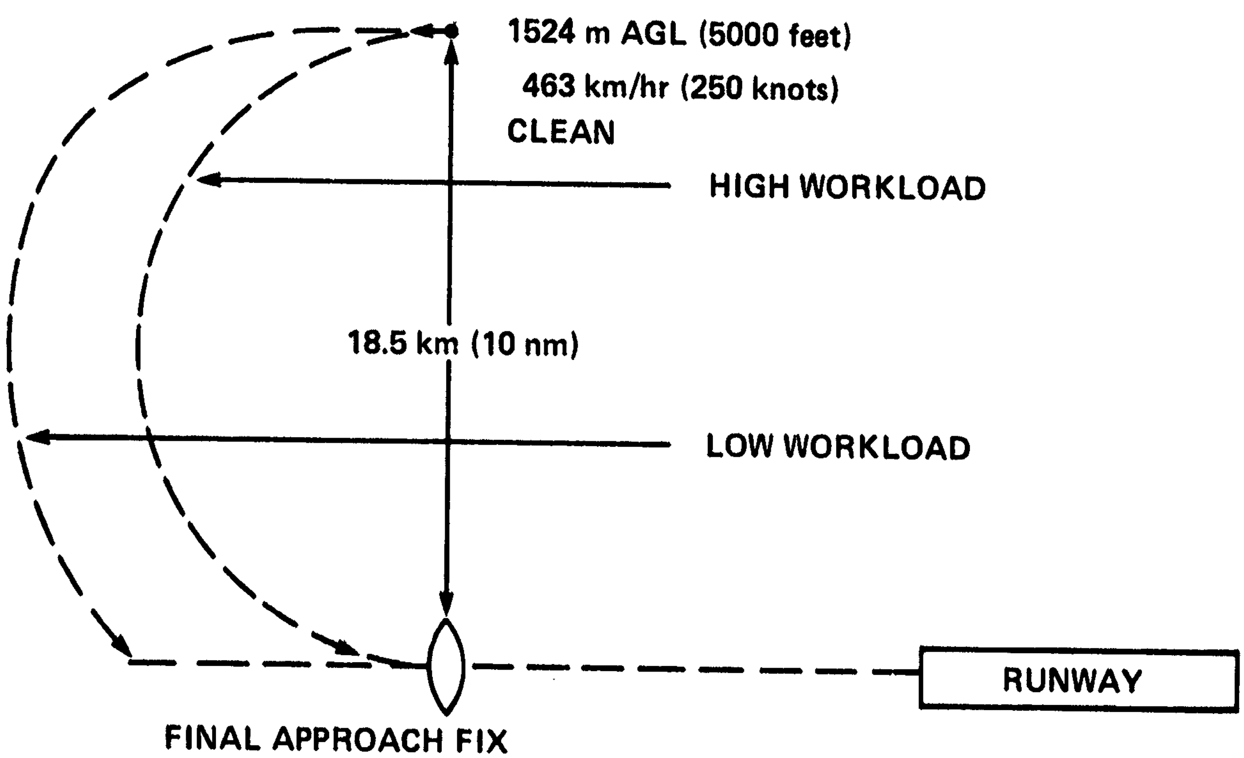

Figure 5.- Approach profile.