TR56-68-26 (U)

[redacted]

CR 73302
Available to the Public

SST FLIGHT MANAGEMENT SIMULATION STUDIES: EXPERIMENTAL PLAN AND PROCEDURES FOR THE INITIAL STUDY (PROJECT I)

FINAL REPORT

December 1968

Prepared for

Man-Machine Integration Branch
National Aeronautics and Space Administration
Moffett Field, California

Principal Investigator:

Walter B. Gartner

NASA Technical Monitor:

Charles C. Kubokawa

Project Staff:

Harry L. White
James L. Costanza
William J. Ereneta
Vincent R. Donohue

SERENDIPITY, INC.

199 First Street
Los Altos, California 94022

FOREWORD

In earlier research efforts, the critical importance of effective flight management task performance in the successful accomplishment of low visibility approach and landing operations in civil jet transport aircraft was established. Flight management tasks were distinguished as being concerned with assessing the ongoing flight situation, judging the significance of aircraft and subsystem operating states, and with formulating and resolving action decision problems arising out of these assessments. Subsequent analysis of pilot information processing associated with the performance of these tasks indicated that the pilot's effectiveness in satisfying certain flight management task requirements, using flight instrumentation assumed to be available in a baseline low visibility landing system for the SST, is in serious doubt.

Arguments regarding the character of these anticipated problems in flight management task performance were developed and pertinent flight test and simulation research data in support of these arguments has been cited. However, carefully planned empirical studies of these issues have not been conducted. Empirical verification of problem areas is recommended before solution concepts, in terms of system design changes and/or flight crew qualification procedures, are sought.

The simulation research study delineated in this document is the first of a series of projects which will be designed to distinguish empirically verified problems in supporting flight management task performance and, subsequently, to develop and test solution concepts. Subject pilots will be exercised in the performance of suspect tasks, under simulated Category II approach conditions, and data will be taken on the accuracy and timeliness of selected estimates and judgments of the flight situation. The results of this initial study are expected to identify requirements, if any, for improved support of the flight management tasks examined and to provide baseline pilot performance data against which changes in flight instrumentation and/or operating procedures can subsequently be evaluated.

CONTENTS

Page

FIGURES

TABLES

INTRODUCTION

This report is intended to serve as a detailed guide for the execution of a simulation research project concerned with flight management activities during SST low visibility approach and landing operations. The material provided in this document was developed under a supplemental agreement to contract number NAS2-4406. A summary of the previous work performed under this contract is presented in reference 1 and provides the context and point of departure for the current effort.

A major goal of the earlier studies was to identify specific research issues within the problem area of interest which could be investigated using the jet transport simulation facilities at the Ames Research Center. In the final phase of the previous effort general research objectives were established for an ongoing program of simulation studies and an initial project to examine selected problem areas was planned and recommended. The effort reported in this document was directed toward the preparation of detailed procedures for implementing this initial study and to the definition of additional simulation facility requirements.

The specific objectives and general structure of the initial study are presented in the next section of this report. Detailed design features and capabilities of the transport simulator, visual attachment, and data recording equipment selected to carry out the study are then outlined in the following section. Facility requirements were coordinated with cognizant personnel of the Simulation Experiments Branch at Ames and efforts to prepare the facility as described are now in progress. The experimental design developed to provide the basic framework for the study and to define data collection and analysis requirements is delineated in a subsequent section. The last section in the body of the report presents the detailed procedures for preparing subject-pilots, for executing the experimental run series, and for recording and processing subject performance data.

Additional material required for implementing the initial study is discussed in the body of the report and attached in Appendices B through E. A complete schedule of simulator runs and a specification of the conditions to be represented on each run is presented in Appendix B. Appendix C is a subject orientation booklet with recording forms attached for obtaining background data. The orientation booklet introduces the subjects to the study, identifies the equipment and operating conditions represented in the scheduled simulation series, and outlines the tasks subjects will be asked to perform. Appendix D establishes the content and format of intercom messages transmitted by the experimenter in simulating the communication activities of the First Officer. A subject debriefing questionnaire, designed to explore the subject's attitudes and opinions regarding the issues examined in the study, is reproduced in Appendix E.

As indicated earlier, this report was prepared for use by project personnel at Ames in the actual set-up and conduct of the initial study. The scope and specificity of the delineation of procedures and of the documentation of supporting materials is thus expected to guide the day-to-day activities of these personnel in the execution of the study. For this reason, general distribution of this report to individuals and/or organizations not directly concerned with the program at Ames is not recommended.

STUDY OBJECTIVES AND GENERAL PROCEDURE

The simulation study outlined in this document is the first of a proposed series of SST flight management studies concerned with approach and landing operations under highly restricted visibility conditions. The broad objectives of these studies are to provide an empirical assessment of the extent to which the flight management activities of command pilots are adequately supported by flight deck instrumentation and crew procedures projected for low visibility approach and landing systems in jet transport aircraft and, subsequently, to develop and test solution concepts for empirically verified problems in this area. In this first study, potential problems in judging an approach to Category II minimums and in achieving successful landings from various flight path offset situations at the 100 foot decision height will be examined.

The specific objectives of this first study are outlined below and a brief characterization of the procedures which will be used to achieve these objectives is provided. For a more complete discussion of the study context, i.e., flight management activities during SST approach and landing operations, the reader is referred to the documentation of background studies (2) (3) (4). These documents present the potential problems identified in regard to how well flight management task performance is expected to be supported in a baseline SST landing system and spell out the general objectives and plan adopted for the initial simulation study.

Objectives of the Initial Simulation Study

Fourteen potential problem areas were distinguished as a result of the analysis carried out in the background studies just cited. Insofar as support for flight management activities is concerned, each of these problem areas represents a possible inadequacy in the SST landing system design features and/or operational procedures assumed as the reference system in the analysis. Despite active and increasingly extensive research and development programs in support of low visibility landing systems, the issues raised in these problem statements remain largely unresolved.

In the initial simulation study defined in this report, selected issues from these fourteen problem areas will be examined. Potential flight management problems associated with judging the success of an approach to the authorized minimum decision height (100 feet) under Category II operating conditions (1200 feet runway visual range) were selected for investigation at this time. For the reader's convenience, the discussion of these selected problems, as they were originally developed in an earlier report (3), are attached to this document as Appendix A.

Two major considerations influenced the selection of these problems for the first study. First, it was decided that problems peculiar to Category II operating conditions, and preferably those applicable to current subsonic jet transport operations as well as to the SST, were to be considered early in the program. A number of system configurations have already been certified for Category II operations and data on potential operating problems, if any, should be made available as soon as possible if it can be expected to affect the development and use of these systems. Further, data pertinent to Category II operations can be expected to be a significant factor in the subsequent derivation of Category III system design concepts and operating criteria which are not yet formally specified.

The second consideration is that it is desirable, for initial investigations, to select problems which can be examined without imposing extensive demands on simulation equipment capability. At the time this study was planned, full capability for simulating SST aircraft dynamics, advanced flight deck instrumentation (such as the Electronic Attitude-Director Indicator), external visual effects and environmental conditions peculiar to both Category II and III operations, etc., were not available in Ames simulation facilities. This is understandable, since comprehensive requirements for simulation studies in this area have not previously been defined. Beginning with this study, however, the additional capabilities required can be built up as they are needed and this development can be guided by experience gained with the more austere facilities.

These general constraints were satisfied by selecting potential flight management problems associated with judging Category II approach success as the focus of initial study efforts. In the baseline Low Visibility Landing System (LVLS), pilot tasks associated with this flight management activity are performed, primarily, by reference to conventional flight instruments. Representation of SST-peculiar aircraft dynamics and flight deck design concepts in the simulation is, of course, desirable, but it is not considered essential to the derivation of useful data in the simulation study. The results of this initial study will therefore be applicable to Category II operations and to appropriately equipped subsonic jet transports as well as to the baseline SST system. At the same time, minimum demands will be imposed on the simulation facility, since no complex display of extra-cockpit visual cues is required and no advanced display concepts need be represented in initial simulation sequences.

The general objective of the initial study, then, is to exercise subject-pilots in the performance of selected approach assessment tasks under nominal Category II operating conditions and to obtain data on how well they are supported in the performance of these tasks by the information availability and flight deck display characteristics assumed for the baseline SST landing system. More specifically, the objectives of this simulation exercise are:

1. To determine the accuracy of the command pilot's estimates of relative altitude (i.e., the aircraft's height above the intended touchdown point on the runway) during the approach, especially the accuracy of his estimate of arrival at the authorized 100 foot decision height;

2. To determine the accuracy of pilot estimates of cross-track position (i. e., lateral deviation from the localizer course) and the accuracy of his judgments of the aircraft's direction of flight relative to the runway;

3. To determine the effects of three different pilot operating procedures and three alternate flight control modes on the accuracy of these flight progress judgments; and

4. To determine the effects of various flight path offset conditions which can occur at the decision height on the success of manually controlled landing maneuvers.

Analyses of the data recorded during these simulation runs is expected to provide an estimate of the number and type of errors in pilot judgment which may be expected to occur under the conditions represented and the interpretation of these results will be addressed to the practical significance of such errors. Study results are expected to support subsequent simulation research projects by distinguishing the particular components of the flight management tasks on which difficulties are expected, if any, and by providing baseline performance data against which various system design changes, revisions in operating procedures, performance under different task conditions, etc., can subsequently be assessed.

The occurrence of significant errors in pilot judgment during these simulation exercises would tend to confirm the arguments outlined in Appendix A and, with respect to the support given to flight management activities, would therefore indicate inadequacies in the system design features and/or operational procedures assumed in the underlying analysis. To the extent that comparable system design features and procedures are also characteristic of low visibility landing systems under development or currently being certified for other jet transport aircraft, study results will be applicable outside of the SST context.

General Procedure

In terms of the requirements for establishing the conditions under which the performance of flight management tasks will be examined in the study and for fully exploiting the simulation exercise to obtain additional data pertinent to related issues, the specific objectives of the study can be further elaborated by reference to the structure of the study as schematized in Figure 1. Each run in the simulator will represent the execution of an approach and landing sequence beginning with the aircraft at approximately ten nautical miles from the runway, stabilized on the assigned localizer course, and maintaining an assigned initial approach altitude. This sequence ends with the aircraft on the runway decelerating to a nominal turn-off speed or with the subject-pilot's decision to reject the approach and initiate a go-around. During these simulated flight sequences, subjects will perform specified flight management tasks, responding to simulated information inputs representing the ongoing flight situation as they would be available to command pilots in the projected SST operational environment. The intent here is to impose the same information processing demands on subjects in the simulation as those associated with the performance of specified tasks in the operational situation. To accomplish this objective, both the information provided and the display characteristics (display-referent relationships) must match their assumed counterparts in the baseline SST system.

On each run, data on subject performance will be recorded as indicated by the subject outputs shown in Figure 1. At the same time, data will be recorded on the "actual" position and behavior of the aircraft as represented in the simulation sequence and, where appropriate, on the corresponding display of flight situation parameters which, presumably, will serve as the immediate basis for subject judgments. Objective data on the simulated flight situation (e. g., actual aircraft track) and on subject pilot judgments (e. g., estimates of cross-track position) will be used to derive accuracy and/or error scores for determining how well the specified flight management tasks were performed. In addition, subjective data obtained in debriefing sessions (e. g., subjects' reports of how judgments were made and appraisals

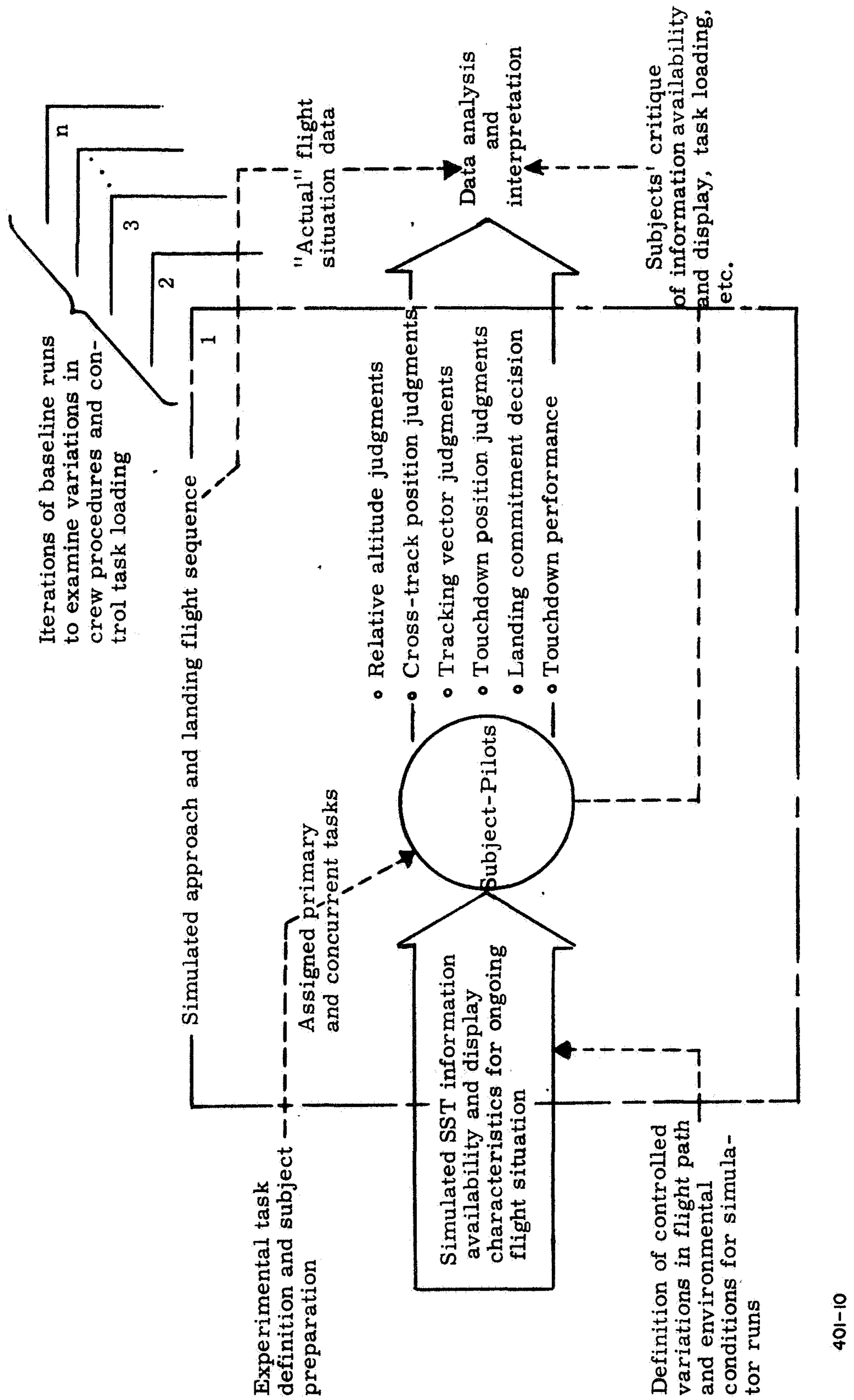


Figure 1. Schematic Representation of the Overall Structure of the Simulation Study.

of flight instruments) will be available to support the interpretation of objective performance data.

Notice that simulated information inputs, subject task assignments, and the data taken will be held constant on all baseline simulator runs. Controlled variations in the flight path actually followed (e. g., ILS deviation, actual lateral and vertical offset position at the decision height, etc.) and environmental conditions (e. g., terrain profiles approaching the decision height, wind conditions, runway visibility, etc.) will be represented in the information inputs in order to include a number of different flight situations for subjects to respond to. A systematic assignment of these variable conditions to simulation runs has been worked out to ensure an appropriate sampling of conditions of interest.

In order to exploit this basic experimental situation to obtain additional data, the study is also designed to examine the effects of alternative crew procedures and control task loadings on flight management task performance and to examine landing performance from various flight path offset conditions at the decision height. Variations in crew procedures can be distinguished by citing differences in the pre-arranged assignment of specific monitoring and/or control duties to the Captain and First Officer. It is reasonable to assume that flight management performance would be differently affected by such variations, since the immediate bases for making the approach success judgments, in terms of information available and display modes, will not be the same when alternative crew procedures are adopted. Alternative flight control modes (i. e., fully automatic, split-axis control, and fully manual) will be examined to disclose the effects, if any, of differences in task loading on the Captain. When manual control is assumed for one or more axes, the Captain can be expected to have less time and attention to apply to flight management tasks, per se.

Baseline runs will be conducted with a fully-coupled automatic flight control mode simulated and, somewhat arbitrarily, adopting a crew procedure wherein the Captain exercises complete control of the approach to the decision height. As the aircraft approaches the decision height, the Captain has the option of looking up to assess the adequacy of external visual reference at any time. Based on this assessment and, at his discretion, on the additional cross-checking of flight instruments, he would then resolve the landing commitment decision and either abort the approach or assume manual control to complete the landing maneuver. As indicated in Figure 1, iterations of the baseline scheme will be carried out to examine the effects of alternative flight control modes and crew procedures. The structure of the study, as schematized, will be essentially unchanged in these iterations, but in each of the iterations a different combination of control mode and crew procedure will govern the subject's task orientation and the simulation of the flight sequence.

On the basis of the foregoing discussion, the specific objectives of the simulation sequence delineated in this planning document may be summarized as follows:

1. To represent the actual behavior of heavy jet transport aircraft during the approach and landing flight sequence, in terms of the attitudes, velocities, and flight paths which may be expected to result from both programmed and manual flight control inputs.

2. To represent the flight environment appropriate to an approach and landing under Category II conditions, including the runway and its surrounds, approach lighting, the ILS,

runway visibility and surface winds appropriate to Category II conditions, and irregularities in terrain elevation approaching the runway.

3. To represent the information expected to be available to an SST command pilot during Category II approach and landing operations and the manner in which it is displayed or otherwise input to the pilot in the baseline SST low visibility landing system.

4. To select and prepare subject-pilots to perform the suspect flight management tasks on the basis of this representation of SST information availability and display characteristics.

5. To obtain and process data on subject-pilot performance of assigned tasks which can be used to assess the accuracy and timeliness of task performance under the conditions of interest.

6. To design and implement data collection and analysis procedures so that the effects of alternate control task loadings and operating procedures on task performance can be assessed.

7. To interpret the practical significance of subject-pilot performance data and identify the implications, if any, for the design of flight deck instrumentation and/or operating procedures for low visibility landing systems.

APPARATUS

The simulation facility to be used for the study is the Ames Research Center fixed-base transport simulator (S. 05) equipped with a closed-circuit, color television visual display attachment (VFA-4). Engineering modifications to this facility are currently being carried out to ensure that the simulation of key flight path control functions and flight deck instrumentation is appropriate to the requirements of the flight management study. The principal components of the facility and a generalized representation of signal flow are schematized in Figure 2. The symbology used to represent signal flow is decoded in Table 1.

The principal components of the facility are: (1) the crew compartment, (2) the analog computation of aircraft equations of motion and display functions, (3) the extra-cockpit visual display system, and (4) data recording equipment. A brief characterization of the design features and functional capabilities of each of these components is delineated below. Emphasis here has been given to the identification of the means selected for meeting various study requirements rather than providing a detailed description of the mechanization of simulation functions.

Crew Compartment

The crew compartment is a conventional transport-type cab mounted on a stationary raised platform. Two forward facing seats are installed with a control pedestal in the usual location between the

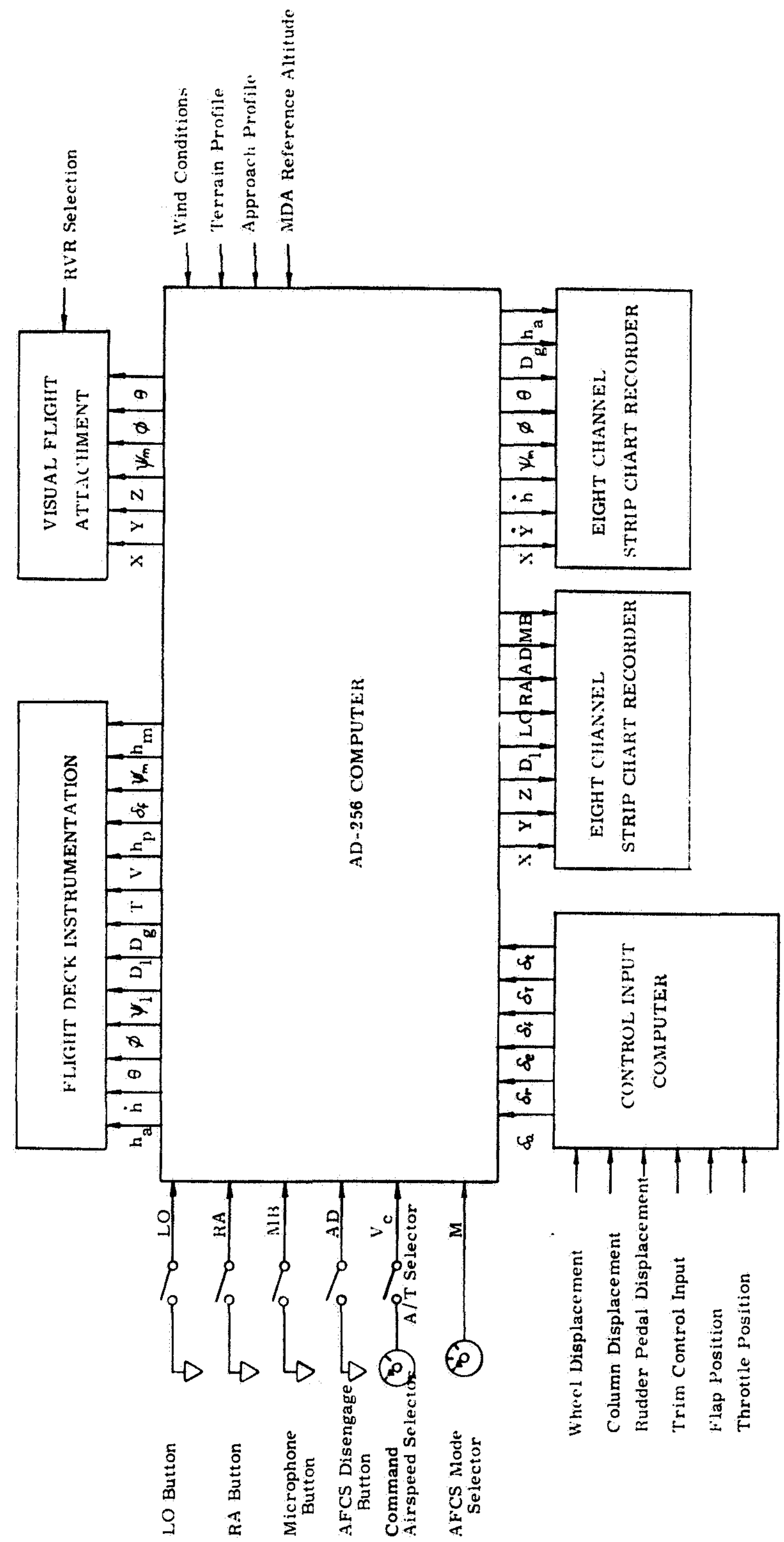


Figure 2. Schematic Representation of Simulation Facility.

TABLE 1. Interpretation of Symbology Used in Figure 2.

AD	Automatic flight control system (AFCS) disengage signal
LO	Lateral offset (LO) button depressed/released signal
RA	Relative altitude (RA) button depressed signal
M	AFCS mode selection
MB	Microphone button depressed signal
V_c	Command airspeed
δ_a	Aileron control input signal
δ_e	Elevator control input signal
δ_r	Rudder control input signal
δ_f	Flap position input signal
δ_T	Throttle position
δ_t	Trim control
θ	Pitch attitude
ϕ	Roll attitude
T	Thrust index
V	Indicated (Equivalent) Air Speed
$\dot{h}$	Vertical velocity
h_p	Pressure altitude
h_a	Absolute altitude
h_m	Minimum Decision Altitude (MDA) alert signal
ψ_m	Heading
X	X coordinate of aircraft position (Distance from runway/glide slope intersection along extended runway centerline)
Y	Y coordinate of aircraft position (Lateral offset from extended runway centerline)
Z	Z coordinate of aircraft position (Height above runway elevation)
$\dot{Y}$	Cross-track velocity (rate of change in Y)
ψ_l	Localizer course
D_l	Localizer deviation
D_g	Glide slope deviation
A/T	Autothrottle
MDA	Minimum decision altitude

seats. Functional control columns and rudder pedals are available at both crew stations, but complete instrumentation is provided only at the Captain's station on the left side. This left seat will serve as the subject-pilot's station.

Flight instruments and controls available to the subject are identified and located on the station configuration drawing prepared as Figure 3. No attempt was made to reproduce a particular SST flight deck configuration. The requirements of the study are met by providing the same information as that available in the projected baseline SST landing system for the approach and landing task and by employing functionally equivalent displays, i.e., instrumentation that imposes the same kind of information processing requirements on the pilot. In general, only those controls and instruments which directly support the selected experimental tasks are provided. For this reason, complete engine instrumentation and system status/warning displays are not installed.

Primary flight situation/director information is provided by the Collins FD-109 Integrated Flight System operating in the approach mode (mode selector set to GS AUTO) and equipped with expanded scale localizer deviation and rising runway (absolute altitude) indicator elements. Display elements of the Flight Director Indicator (FDI) and Course Indicator (CI), the principal display units of the FD-109 system, are identified in Figure 4. The details of other subject-station flight instruments and controls are also shown in Figure 4. Subject utilization of these controls and displays during the simulation sequence will be covered in a subsequent section on procedures.

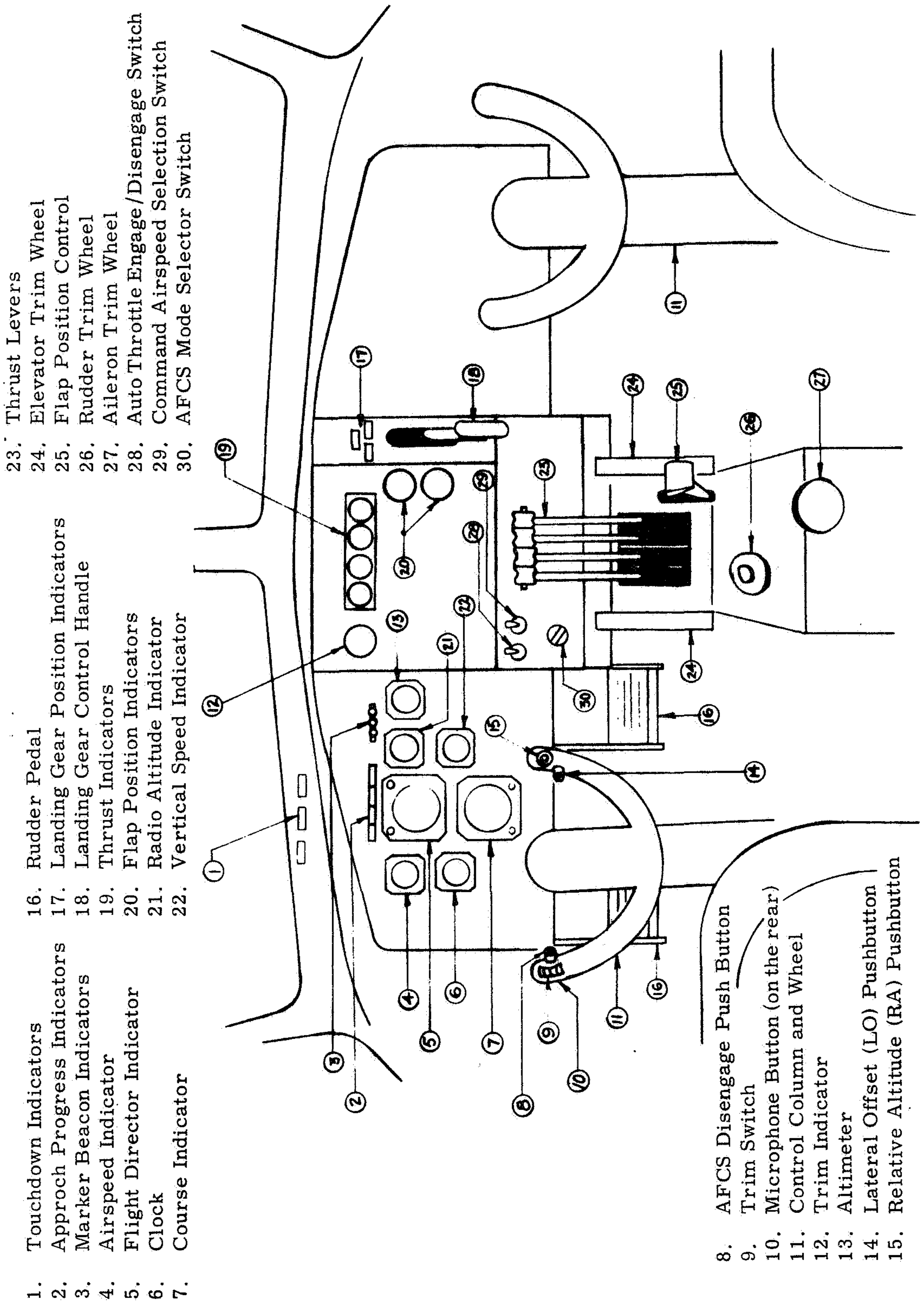


Figure 3. Flight Instruments and Controls Provided at the Subject-Pilot's Station

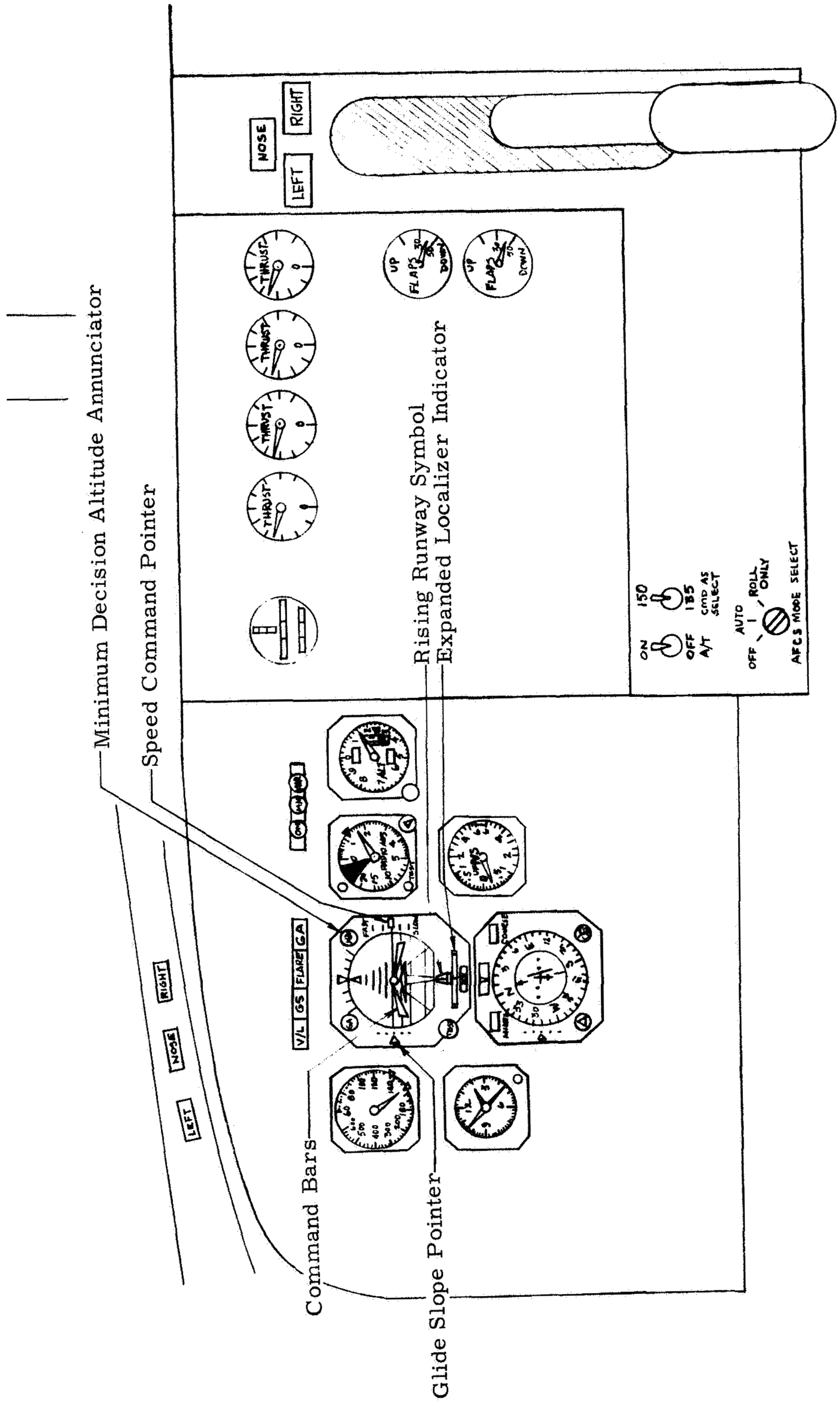


Figure 4. Flight Instrument Details.

An experimenter will occupy a high stool located behind and slightly off-center to the right of the subject-pilot's seat. This position will allow the experimenter to observe the subject's behavior during simulator runs and to monitor the flight instruments and external visual display available to the subject. No controls or displays are required at this location. However, the experimenter will be equipped with a headset and microphone in order to communicate to both the subject and to simulation facility operators via an intercom system. Since no communication with the facility operators will routinely be necessary during data collection runs, no communication channel or station selector is required.

Analog Computation

Analog computation is used to solve the three-degree-of-freedom equations of motion and to generate the drive signals for flight instruments and the visual flight attachment. A DC-8 airplane is currently represented in the aerodynamic simulation and all aerodynamic control and aircraft configuration effects occurring in routine approach and landing operations are included. Ground effect is also computed. Consideration is being given to re-programming the computer to represent B-2707 aircraft dynamics, however, up-to-date aerodynamic data is not available from Boeing at the present time and its subsequent availability is currently uncertain due to the major redesign effort now in progress on the B-2707 airplane.

The computation of earth-referenced flight situation quantities (e.g., flight path coordinates, ILS deviation, absolute altitude, etc.) is based on a representation of an approach to runway 1R at Dulles International Airport and on selected variations in environmental conditions. A glide slope angle of 2.5^{o} and localizer course angle of 3.2^{o} is used. The glide slope beam originates 1,000 feet down the runway from the approach end and the localizer beam originates 1,000 feet beyond the far end of the 11,500 foot runway and is aligned with the 006^{o} runway heading. Three marker beacons, the Inner Marker (IM), Middle Marker (MM), and Outer Marker (OM), are positioned at 2,240 feet, 4,600 feet, and 25,900 feet, respectively, from the glide slope intersection with the runway (X = 0). The effects of three alternate wind conditions, selected prior to the start of each run, are computed: (1) a 15-knot left quartering headwind, (2) a right quartering headwind at the same speed, and (3) a 10-knot tailwind.

Programmed Flight Path Control

Basic computations are driven, as they typically are in piloted flight simulators, by manual control inputs from the subject-pilot (i.e., by δ_a, δ_e, δ_r, δ_T, and δ_f in Figure 2). To fully represent the conditions of interest in the present study, however, it was necessary to add an "automatic" flight path control mode and then to further modify this operating mode to provide for "split-axis" control. In the fully automatic mode, values for flight path defining parameters Y (lateral deviation from the runway centerline extended) and Z (height above the runway) are programmed on diode function generators as functions of X (distance from the glide slope intersection with the runway) for nine different approach profiles (see Figure 5) and used to control aircraft position. In effect, the computer then acts as a controller. Y and Z inputs available from the diode function generators for a designated profile are combined with "actual" aircraft position coordinates to generate error signals which are in turn used to generate control inputs corresponding to the manual control inputs (δ_a, δ_e, and δ_r) which would be necessary to follow the selected profile. The subject-pilot is thus relieved of the manual flight control task, as he would be using the autopilot - ILS coupler in the actual airplane.

In the split-axis mode, the pilot retains manual control of the pitch axis (i.e., he generates δ_e) while roll axis control (δ_a and δ_r) is derived from programmed values of the Y function. When this mode is selected, the vertical component of the flight path and associated display functions are governed by δ_e rather than programmed values of Z. The automatic and split-axis modes are selected by placing the AFCS MODE SELECT control in the crew compartment (see Figure 4) in the AUTO (automatic) or ROLL ONLY (split-axis) positions. Depression of the AFCS DISENGAGE switch located on the left side of the subject-pilot's control wheel returns the computer to the full manual mode wherein the computations are again derived by manual control inputs from the pilot.

Autothrottle

Automatic control of subject-selected command airspeeds is also included in the simulation. When the A/T selector (Figure 4) is in the ON position, the basic computation of indicated airspeed (V) on the basis of δ_T and aerodynamic forces is interrupted. A simplified autothrottle function is then simulated by maintaining V within ± 5 knots of

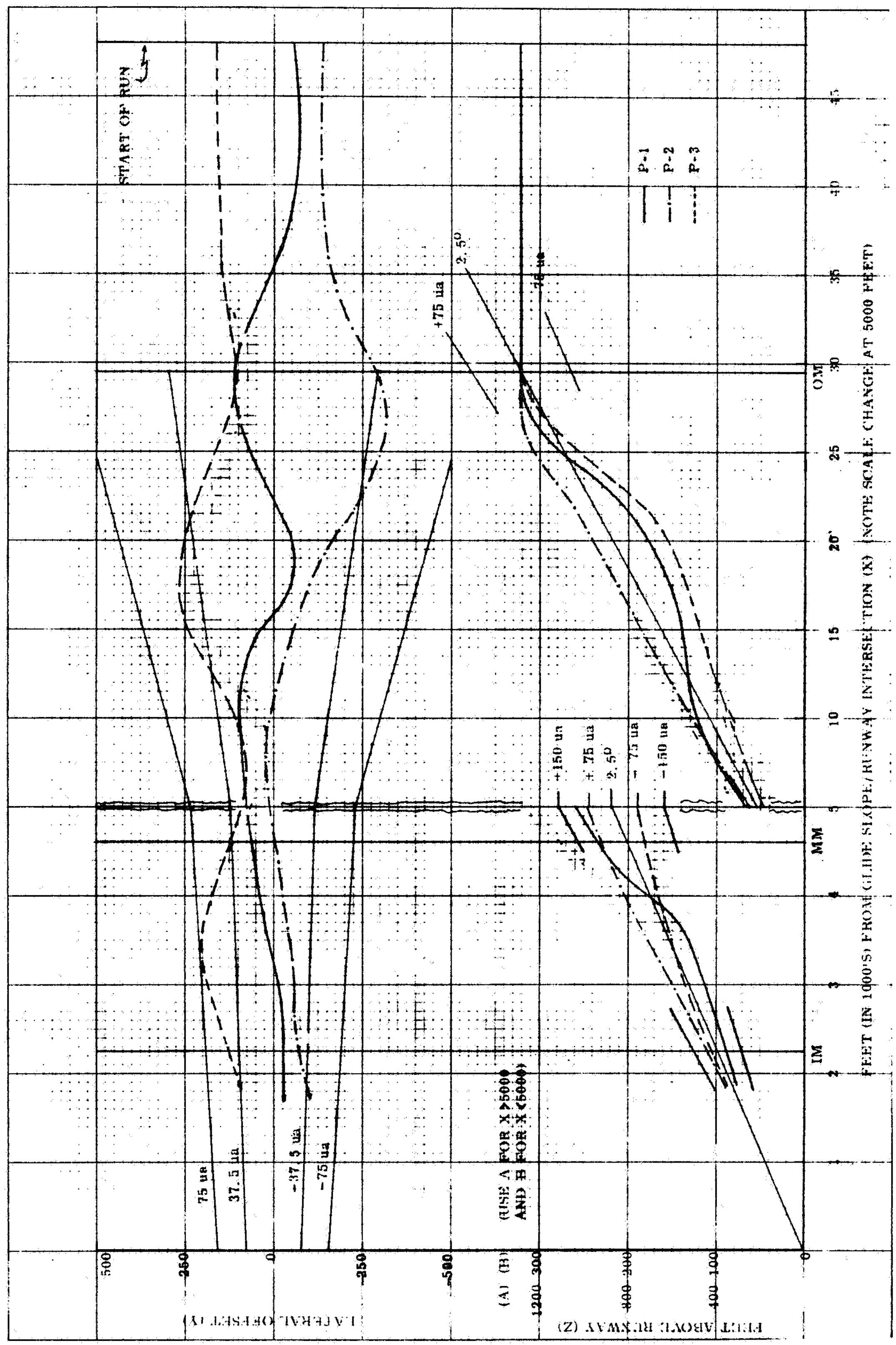


Figure 5. Programmed Approach Profiles Utilized in the Simulation Study.

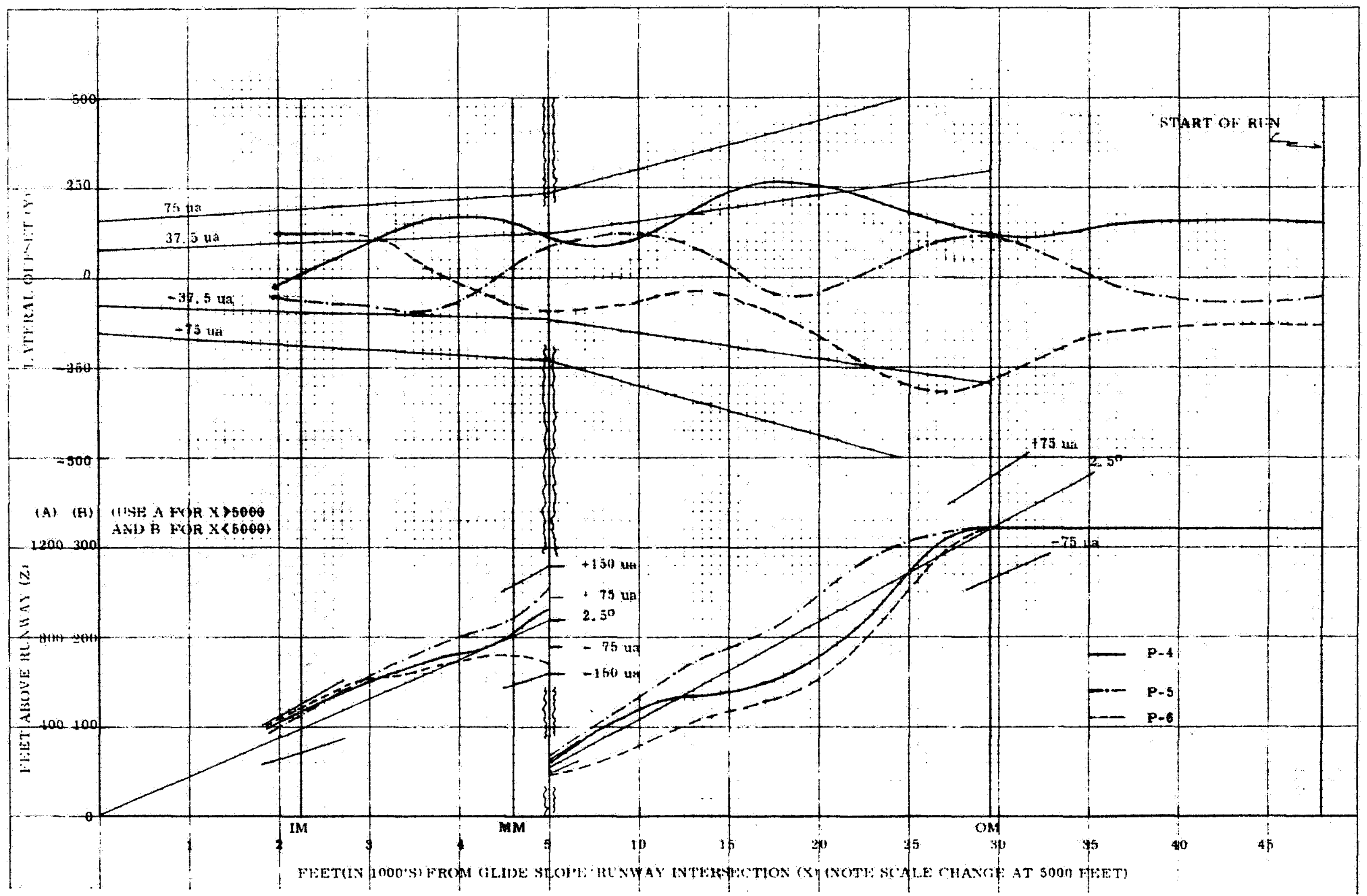


Figure 5. Programmed Approach Profiles Utilized in the Simulation Study (continued)

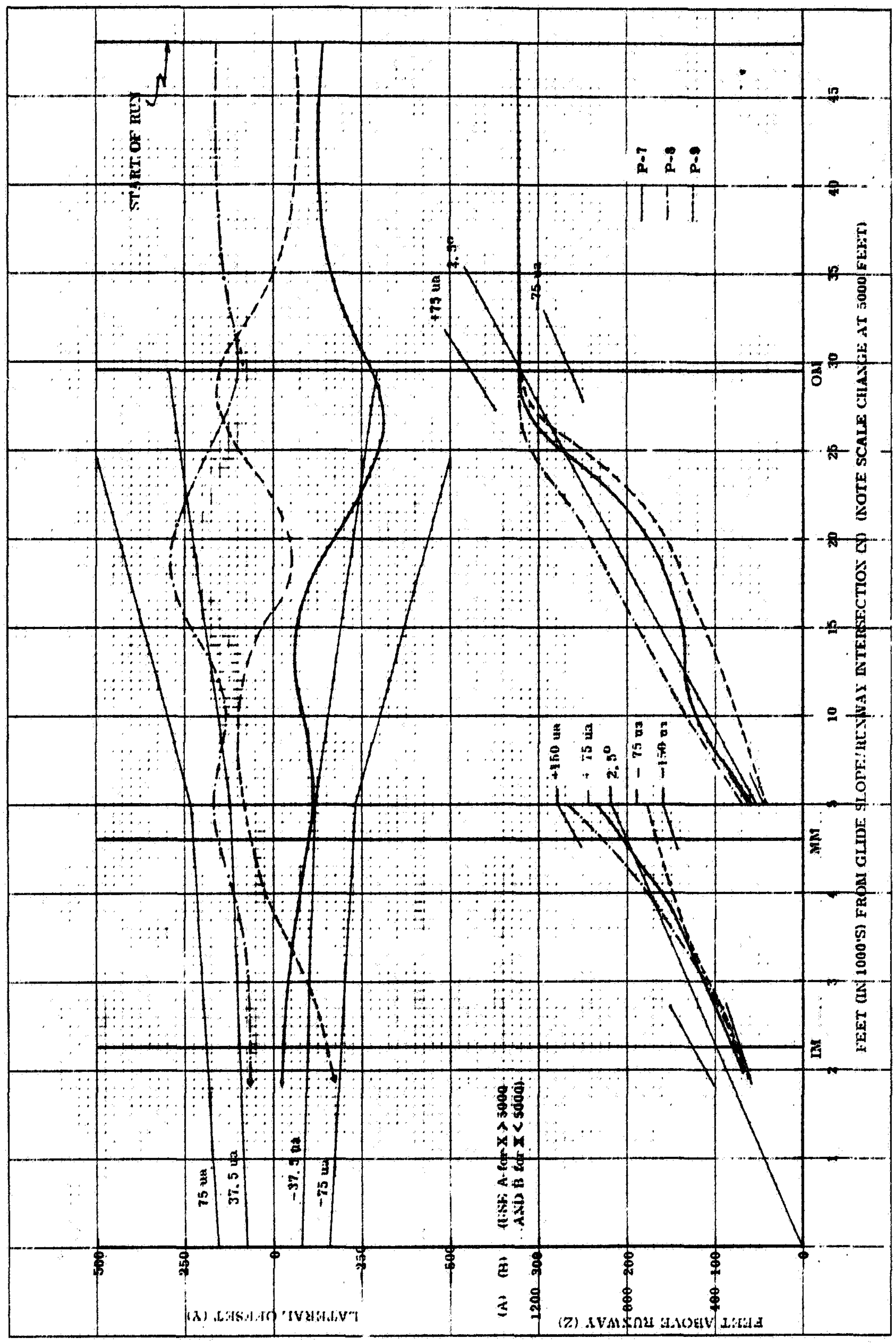


Figure 5. Programmed Approach Profiles Utilized in The Simulation Study (concluded).

the subject-selected command airspeed (V_c). Only two command airspeeds are used in the problem: an initial approach speed of 150 knots at the beginning of the run and a change to a final approach speed of 135 knots when X is approximately 36,000 feet, i.e., when the aircraft is one dot below the glide slope. The airspeed change is commanded by the subject using the CMD A/S SELECT control (Figure 4).

Depression of the AFCS DISENGAGE switch also terminates the simulation of autothrottle function and V is again computed on the basis of throttle position and aerodynamic factors. To minimize the transition problems when the autothrottle function is terminated, the throttles will be positioned prior to initiation of runs on which the A/T feature is used such that computed V for conditions at the decision height will not differ excessively from the 135 knot command airspeed.

Flight Instruments

The simulation of the primary flight deck display functions (i.e., θ, ϕ, Ψ_m, h_p, $\dot{h}$, V, D_l, and D_g) is a straightforward product of the solution of aerodynamic equations and the application of computer outputs, via suitable buffering and scaling amplifiers and synchro converter, to the instruments at the subject's station. Special mention must be made, however, of the simulation of flight director commands, expanded localizer deviation, radio altitude, and minimum altitude indications. Flight director pitch and roll commands are computed by the 562R-1E steering computer component of the FD-109 system such that a full-scale deflection (one dot) on the expanded localizer deviation indicator (Figure 4) corresponds to a D_l proportional to a 20 micro-amp deviation signal from the localizer receiver. The steering computer is also designed to automatically change the glide slope input (D_g) gain when activated by a preset radio altitude trip point. In the present study, this trip point will be set at Z = 200 feet. Below this altitude, displayed D_g will be consistently proportional to glide slope displacement in feet (one dot = 12 feet) rather than to angular deviation.

Radio altitude (h_a) is derived in the simulation computer by summing Z and the programmed values of terrain elevation (h_t). Three different approach terrain profiles (see Figure 6) are programmed on diode function generators as functions of X to represent the variations in this environmental condition which are of interest in the study. A minimum decision altitude (MDA) trip signal (h_m) is provided by a comparator matching an h_a input with a preset voltage representing the MDA, i.e., that h_a which corresponds to a Z of 100 feet at the Inner Marker. This preset MDA reference will be different for each of the terrain profiles used in the problem.

The h_m signal is used to illuminate the MDA light on the Flight Director Indicator. Another MDA trip signal is generated by comparing h_a to a preset signal representing an h_a which is 50 feet higher than the MDA. This second signal is used to initiate an audio tone warning applied to the subject's headset. Onset of the tone occurs at 50 feet above the preset altitude, increases in volume as the aircraft descends, and terminates abruptly when the h_m signal is generated.

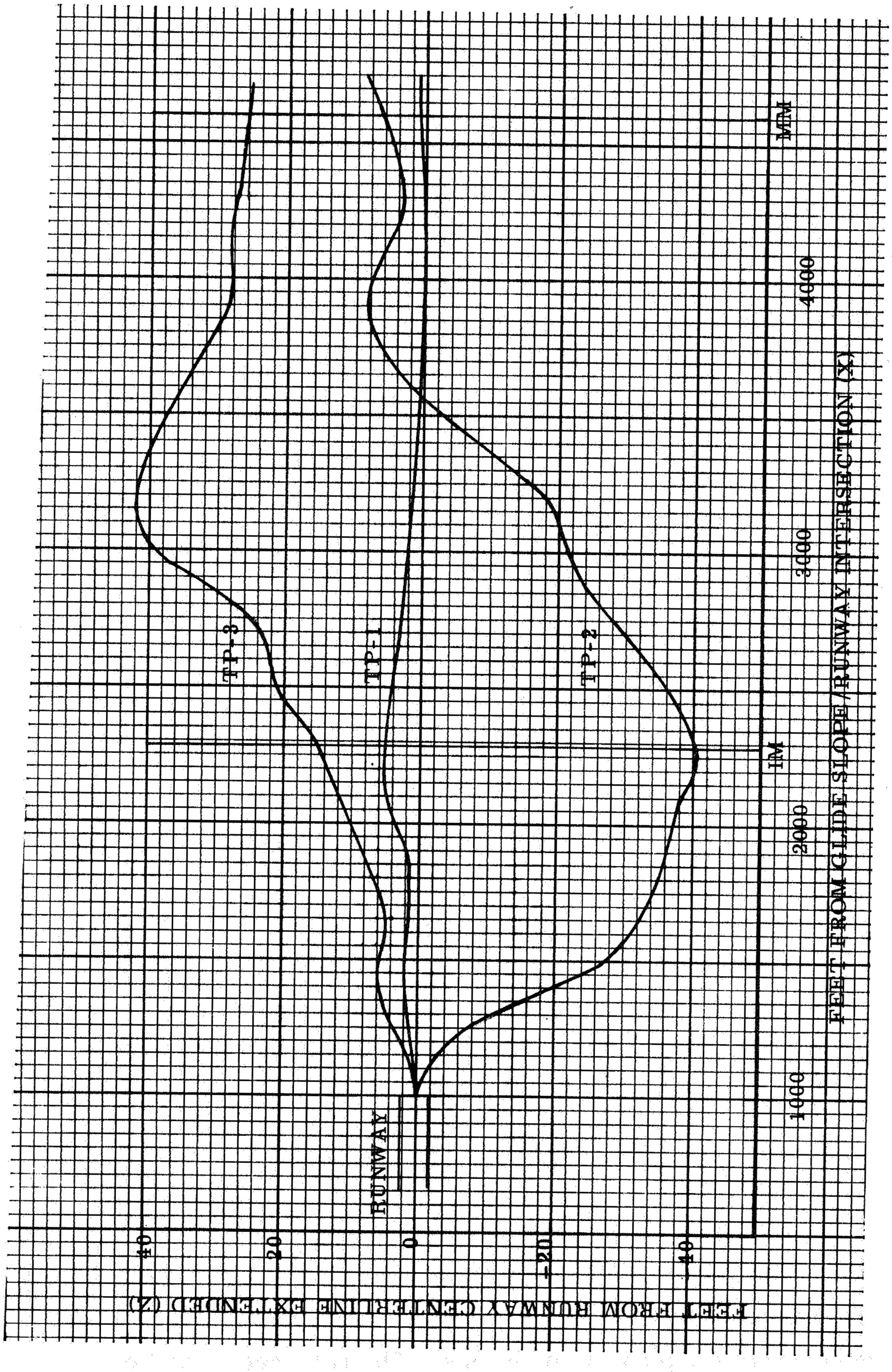


Figure 6. Programmed Approach Terrain Profiles Utilized in the Simulation Study.

Visual Flight Attachment

The Visual Flight Attachment (VFA), designed and constructed by General Precision Systems, Ltd., is comprised of a moving-belt type terrain model, a closed-circuit TV camera and optical attachment, a TV projection system and direct view monitors, and various rack mounted control equipment. Operation of the VFA is controlled by signal inputs from the simulation computer. Relative movements of the camera, optical attachment, and terrain model associated with the X, Y, and Z axes and aircraft attitude produce changes in the displayed picture. These movements are produced by electronic servo systems controlled by corresponding drive signals from the simulation computer.

On all runs in the present study, the descent to the decision region ($100 < Z < 200$ feet) will be conducted with the external visual scene obscured to represent an "in-cloud" condition. The fade-in of visual cues will begin at a point in the decision region and with the degree of obscuration appropriate to the selected runway visual range (RVR) conditions. A RVR of either 1,200 or 1,600 feet will be selected by the VFA operator prior to each run. Subject-pilots will execute the landing maneuver by reference to the visual display on every run.

Data Recording Equipment

Objective recording of flight situation data and subject response events required for the subsequent assessment and interpretation of flight management task performance will be accomplished on two eight-channel strip chart recorders. The parameters and events to be recorded on each of these devices are identified in Figure 2 (symbols are decoded in Table 1). In order to record subject response events, the following controls and/or control design features were added to the subject's station (see Figure 3):

1. A push-on-release-off type pushbutton labelled LO, located on the inside of the inboard horn of the control wheel. When this button is depressed, a continuous voltage level change is recorded until the button is released.

2. A momentary contact type pushbutton, labelled RA, located on the front of the inboard horn of the control wheel. A discrete voltage level change is recorded each time this button is depressed.

3. A discrete voltage level change is recorded each time the subject's microphone button (located on the rear of the outboard horn of the control wheel) is depressed.

4. A discrete voltage level change is recorded each time the AFCS DISENGAGE button (on the inside of the outboard horn of the control wheel) is depressed.

Subject utilization of these controls during the simulation sequence, and the interpretation of recorded events will be covered in a subsequent section on procedures.

EXPERIMENTAL DESIGN

Basic Structure

The design of the study is best understood as a composite structure comprised of three separate and distinguishable component experiments which can all be carried out within the context of the same set of simulated approach and landing sequences. Its basic structure, as schematized earlier in Figure 1, is simply a testing sequence wherein a number of subject-pilots are exposed to controlled variations in aircraft behavior and data is taken on their performance of specified flight management tasks. All of the runs in this test series are made under the same baseline conditions of information availability and display, operational procedure, and control task loading.

The testing sequence can be seen as the first component of the study. Performance data obtained on elements of the approach success judgment will be interpreted with reference to external criteria of accuracy, timeliness, appropriateness, etc. For example, the accuracy of lateral offset judgments will be assessed by comparing subject estimates of this parameter value with the "actual" position of the aircraft at selected points in the simulation sequence. The average magnitude and variability of these "error" scores, taken on all subjects over all controlled variations in flight path and environmental conditions, will then be interpreted with regard to the practical significance of errors as great as those reflected in the data and/or the proportion of runs on which errors in judgment were indicated. The data obtained is expected to reveal differences, if any, in the effects of flight profile variations on subject performance, but no rigorous statistical comparisons are considered necessary and provisions for making such comparisons are not required for the basic test series.

Iterations of this test series will be carried out, however, in order to examine the effects of differences in crew procedures and control task loading on flight management task performance. This examination does entail a statistical assessment of differences in flight management performance under alternative conditions and may be construed as the second experiment in the composite design. Including baseline conditions, three alternate operational procedures and three alternate control task loadings were distinguished to define the levels of these experimental variables. A three-by-three factorial design with repeated measures on one factor (Ref. 5, p. 298) was adopted for carrying out this part of the experiment and will provide the detailed basis for scheduling subject exposure to run variations and experimental conditions for all components of the study. This design is schematized in Figure 7.

Twelve subjects are required to carry out this design and will be randomly assigned to three experimental groups comprised of four subjects each. The four subjects in Group 1, using the "Cross-check" procedure, will complete nine approach and landing sequences under condition b_1, nine more under condition b_2, and, finally, nine runs under condition b_3. Group 2 will do the same thing using the "Head-down" procedure. The four subjects in Group 3 will complete only nine runs under condition a_3b_1. In the baseline SST landing system (with no head-up display) the "Head-up" procedure can be used only when the Captain is relieved of the manual flight control task in both axes, either by the autopilot or the First Officer; combining this operational procedure with split-axis or fully manual control would, therefore, be meaningless.

Primary data for the first component of the study will be provided by the results of running Group 1 under condition a_1b_1, the baseline condition. Additional data from subjects in Groups 2 and 3 when they are run under condition b_1 can also be used for the basic assessment of performance on suspect flight management tasks. In order to assess the joint and separate effects of alternative Control Task Loading (levels of Factor B)

FACTOR B

Control Task Loading

FACTOR A

Operational Procedure

	b_1 (Fully Automatic)	b_2 (Split Axis)	b_3 (Fully Manual)
a_1 (Cross-check)	Group 1 (n=4)	Group 1	Group 1
a_2 (Head-down)	Group 2 (n=4)	Group 2	Group 2
a_3 (Head-up)	Group 3 (n=4)		

Figure 7. Schematic Representation of the Experimental Design

and Operational Procedures (levels of Factor A), the factorial design was adopted. Using this design, comparisons between different levels of Factor A are confounded with differences between groups of subjects. However, the effects of Factor B and of interactions between A and B will be free of this confounding and the tests of these effects will be more sensitive than those on the effects of A.

The third experiment in the composite design is directed toward the problem of establishing appropriate lateral offset limits at the 100-foot decision height and to the issue of relating variations in the vertical flight situation to touchdown performance relative to longitudinal dispersion limits. As a consequence of exercising control over the flight paths followed by the simulated aircraft on most of the runs conducted for purposes of study components one and two, touchdown performance associated with a wide range of terminal conditions (i. e., vertical offset, lateral offset, and tracking vector at the decision height) will be examined. Subjects will be instructed to attempt the landing maneuver on all runs, even those on which the approach success and/or landing commitment decision is negative. For purposes of the experiment, subjects will be further instructed not to compromise on desired touchdown rate-of-descent in attempts to assure touchdown within established longitudinal limits nor to use control techniques that could not be used routinely under actual Category II flight conditions (e. g., the "duck-under" maneuver or the use of excessive roll rates and/or bank angles).

With respect to the lateral offset limit problem, this third experiment can be seen as a parametric study of the subject-pilot's ability and willingness to execute the side-step maneuver from various lateral offset positions at the decision height. The controlled flight profiles defined in Figure 5, will provide for an examination of lateral touchdown performance (in terms of both deviation from the runway centerline and cross-track velocity) as a function of the following values of lateral offset and tracking vector at the decision height:

a.	30 feet left/parallel	(Profile P-1)
b.	60 feet left/converging	(Profile P-5)
c.	150 feet left/diverging	(Profile P-9)
d.	10 feet right/diverging	(Profile P-4)
e.	65 feet right/parallel	(Profile P-8)
f.	130 feet right/converging	(Profile P-3)
g.	25 feet left/converging	(Profile P-7)
h.	70 feet left/diverging	(Profile P-2)
i.	125 feet right/parallel	(Profile P-6)

Data on landings made from lateral offset positions resulting from manually controlled approaches will also be available for analysis.

The examination of touchdown performance relative to longitudinal dispersion limits is included as an empirical test of the subject-pilot's ability to judge his anticipated touchdown position on the basis of vertical situation data available to him at the decision height. It is not primarily concerned with determining vertical offset positions from which a touchdown within these limits can be accomplished. In the analysis of the problem of assessing vertical flight path alignment (Appendix A), it was suggested that unacceptably long touchdowns -- possibly beyond the 3,000 foot touchdown zone -- could occur even with no significant vertical offset at the decision height. In order to test this in the simulation study, subject estimates of their ability to touchdown within the touchdown zone, made at the decision height, will be compared with actual touchdown performance in order to determine the degree of correspondence between the two.

Schedule of Subject Exposure to Run Variations
and Experimental Conditions

As indicated earlier, the twelve subjects made available for the simulation study will be randomly assigned to the three experimental groups. Membership in a group will determine the operational procedure to be used by a given subject on all runs. Group 1 will use the "Cross-check" procedure, Group 2 will be "Head-down", and Group 3 will go "Head-up". The details of these procedures are given in subsequent sections on subject preparation.

The order in which subjects in Groups 1 and 2 will be exposed to different levels of Control Task Loading will be counterbalanced so that differences in performance which may be reflected in the data will not be systematically biased by carry-over effects. These effects include such factors as fatigue and learning which may occur as earlier runs in a series are completed and "carry-over" to affect performance on subsequent runs.

The order of exposure to levels of Factor B will be as indicated below for subjects in both Group 1 and Group 2:

Subject	First Series	Second Series	Third Series
S_1 and S_5	b_1	b_2	b_3
S_2 and S_6	b_3	b_2	b_1
S_3 and S_7	b_1	b_3	b_2
S_4 and S_8	b_2	b_1	b_3

Each series will consist of nine approach and landing sequences (runs). Automatically controlled flight paths will be used under conditions b_1 and b_2 (see Figure 7) and variations in environmental conditions (i.e., terrain profile, winds, and RVR) will be applied on all run series. As indicated earlier, these variations in flight path and operating conditions were included to provide the subjects with a wider range of flight situations to judge. Variations in flight path and environmental conditions were combined to define nine basic run condition alternatives. One of these alternatives will be specified for each run. Definitions for these alternatives, designated A1, A2, A3, ... A9, are given in Table 2 by specifying the approach profile, wind vector, terrain profile, and RVR to be used on the designated run.

Table 2. Definition of Alternative Run Conditions

Alternative Designator	Approach Profile*	Wind Vector	Terrain Profile**	RVR (ft.)	Notes
A 1	P-1	calm	TP-1	1200	*Approach profiles are defined in Figure 5.
A 2	P-2	051°/15 kts	TP-2	1600	
A 3	P-3	321°/15 kts	TP-3	1200	
A 4	P-4	186°/10 kts	TP-1	1600	
A 5	P-5	calm	TP-2	1600	**Terrain profiles are defined in Figure 6.
A 6	P-6	051°/15 kts	TP-3	1200	
A 7	P-7	186°/10 kts	TP-1	1200	
A 8	P-8	321°/15 kts	TP-2	1600	
A 9	P-9	calm	TP-3	1200	

To further counterbalance carry-over effects and to preclude subject detection of commonalities in the flight situations he is exposed to from run to run, the order of subject exposure to run alternatives was randomized. A table of random numbers was used to generate the twelve run patterns given in Table 3. Cell entries identify the run condition alternative, as defined in Table 2, to be selected for each run in a series of nine runs. A given run pattern thus establishes the order in which these alternatives will be presented.

Table 3. Random Patterns of Run Alternatives

Pattern Designator	Order of Presentation in a Given Series								
	1	2	3	4	5	6	7	8	9
A	4	9	6	8	1	5	7	2	3
B	5	6	7	4	8	9	2	3	1
C	8	4	2	5	7	1	3	9	6
D	6	2	4	7	3	1	8	5	9
E	5	3	4	6	2	7	8	9	1
F	6	5	1	7	9	2	8	3	4
G	5	7	2	9	6	8	4	3	1
H	2	4	5	3	9	6	8	7	1
I	8	3	2	4	9	6	7	1	5
J	2	5	1	6	3	4	7	9	8
K	6	2	5	9	7	1	3	4	8

The foregoing can now be used to fully structure the study in terms of the total number of simulator runs required, subject assignments to particular run series, and the flight situation to be represented on each run. Each of the four subjects in Groups 1 and 2 will fly 36 runs: nine practice runs and 27 experimental. Subjects in Group 3 will fly 16 runs: seven practice and nine experimental. The total number of runs is thus 352, of which 252 will provide the data used in the analysis and interpretation of results.

A run schedule, listing all 352 runs in the simulator in the order in which they will be conducted, is attached to this document as Appendix B. A practice series and an experimental series will be completed on each of the 12 subjects in turn. Run conditions are specified for each run based on the adoption of one of the random patterns of run alternatives (Table 3) for the nine runs under each level of Factor B. The practice series was designed to assure coverage of all variations in flight path control mode and environmental conditions. This run schedule will be followed in running subjects and provides the necessary information for preparing the simulation facility for each run.

Performance Measures

Flight situation and subject response data will be recorded on each run to provide the basis for deriving five basic measures of flight management task performance and three measures of touchdown performance. These measures, together with attitude and opinion data obtained from subjects in debriefing interviews, will be used to derive additional indices of subject performance and criterion measures of the effects of the experimental variables. This treatment of the measurement data is covered in a later section on data analysis and interpretation procedures. In this section, coverage is restricted to the eight measures cited above and their definition in terms of the data to be obtained on each simulator run.

Task Performance Measures

The five measures of flight management task performance are:

1. Number of errors in judging lateral offset (Y) during the approach to 300 feet (relative altitude);

2. Number of errors in estimating relative altitude (Z) at $Z = 500$ feet, $Z = 200$ feet, and $Z = 100$ feet (decision height);

3. Accuracy and timeliness of decision height (DH) situation predictions;

4. Accuracy of lateral offset estimates at $Z = 150$ feet and at the DH; and

5. Number of errors in judging aircraft tracking vectors at $Z = 150$ feet and at the DH.

Definitions of these measures and a brief characterization of their derivation from data obtained during a simulation run are outlined below:

Errors in Judging Lateral Offset - Subjects will be instructed to assess lateral offset (Y) continuously during the approach to 300 feet and to depress and hold the lateral offset (LO) button (Figure 3) whenever they are confident that Y exceeds a value corresponding to a localizer deviation of 35 micro-amps on either side of the localizer course. When Y is judged to be within the 35 micro-amp deviation limits, the LO button is released. Depression of the LO button will be recorded as an event on the strip recorders and compared with recorded values of Y and D_1 to count errors. Allowing for lags in the subjects perceptual response, an error will be counted whenever $D_1 > 35$ micro-amps and the LO button is not depressed or when $D_1 < 35$ micro-amps and the LO button is depressed.

Errors in Estimating Relative Altitude - Response indicators of subject estimates of the aircraft's height above the intended touchdown zone on the runway (Z) will be obtained at three points in the approach. When the subject is confident that the aircraft is precisely at 500 feet (and later at 200 feet), he will depress and release the (relative altitude) RA button. When he is confident that the aircraft is precisely 100 feet above the runway (i.e., at the DH), he will depress the AFCS DISENGAGE (AD) button. Activation of the RA and AD pushbuttons is also recorded on event markers and will be compared with corresponding values of Z to count errors. At Z = 500 feet, an error will be counted when $|Z - Z_{est.}| > 50$ feet; at Z = 200 feet, $|Z - Z_{est.}| > 20$ feet constitutes an error; and at Z = 100 feet, $|Z - Z_{est.}| > 12$ feet will count as an error.

Accuracy and Timeliness of DH Situation Predictions - At any time between Middle Marker passage and arrival at the DH, and at their discretion, subjects may report their prediction of the aircraft's flight path offset situation on arrival at the DH. This report will be given verbally, using the intercom system, and will reflect the subject's go/no-go judgment that the aircraft will be "within" (go) or "outside" (no-go) specified offset limits in both the lateral (Y) and vertical (Z) components of the flight path. The accuracy of these predictions will be assessed by comparing reports as given with the actual offset situation at the DH using the runway centerline $\pm$ 50 feet as the offset limits on Y and a Z = 100 $\pm$ 12 feet when the aircraft is over the Inner Marker as the offset limits on Z. An error will be counted whenever a "go" prediction is reported and actual offsets exceed either of these limits or when a "no-go" report is given and actual offsets are within both limits. Instances of failure to report a prediction prior to arrival at the DH will also be counted and used in the interpretation of results, but will not be counted as errors.

The timeliness of DH situation predictions is also of interest and will be measured by determining the distance of the aircraft from the runway when the report is given. Depression of the subject's mike button will be recorded as an event mark on the strip recorders and compared with corresponding values of X to obtain this measure. Greater values of X represent more timely predictions.

Accuracy of Lateral Offset Estimates - Subjects will report quantitative estimates of their lateral offset from the extended runway centerline at two points in the approach: first at the onset of the audio tone warning (when Z = 150 feet) and then at the DH. These reports will be given verbally, via the intercom system, and will represent the subject's best estimate of Y, in feet, at the time of onset of the tone and at the time of arrival at the DH. Y estimates will be compared with actual values of Y at corresponding points in the run records to derive the accuracy measures.

Errors in Judging Tracking Vectors - When subjects report Y estimates at 150 feet and at the DH, they will include in their transmission a qualitative estimate of the alignment of the aircraft's tracking vector (ψ_T - direction of flight over the ground) with the extended runway centerline. Subjects will report ". . . . . tracking on (or parallel)", when no significant misalignment is perceived; ". . . . . track diverging", when the aircraft is judged to be moving away from the desired track; or ". . . . . track converging", when the aircraft is judged to be moving toward the desired track. Errors will be counted whenever these estimates fail to agree with tracking vectors indicated in the recorded plot of Y and of cross-track velocity ($\dot{Y}$). Errors at 150 feet and at the DH will be counted whenever ψ_T is reported as "ON" or "PARALLEL" when $\dot{Y} > 4$ fps, when ψ_T is reported as either "DIVERGING" or "CONVERGING" when $\dot{Y} < 4$ fps, or when the direction of the track is misrepresented.

Touchdown Performance Measures

The touchdown performance measures are (1) the number of lateral touchdown errors, (2) the number of longitudinal touchdown errors, and (3) vertical velocity ($\dot{h}$) at touchdown. Recorded values of X and Y at touchdown (Z = 0) will be compared with FAA established lateral and longitudinal touchdown dispersion limits (6). Lateral touchdown errors will be counted whenever the main gear touchdown point is determined to be in excess of 27 feet from the runway centerline on either side. Longitudinal touchdown errors will be counted whenever X at touchdown is not within +1,000 feet and -1,500 feet. Since X = 0 occurs at the glide slope intersection with the runway (GSX), X = +1,000 feet defines the actual runway threshold and a touchdown at X values greater than this would therefore constitute a short landing. An X value of -2,000 feet corresponds to the end of the 3,000 foot touchdown zone. Assuming a restriction in the pilot's forward visibility of approximately 125 feet in front of the aircraft when it is in the landing attitude, a main gear touchdown at or before the point where X = -1,500 feet is required to stay within longitudinal touchdown dispersion limits. These limits would assure a main gear touchdown point that will enable the pilot "..... to see at least four bars (on 100 foot centers) of the 3,000 foot touchdown zone lights at touchdown."

PROCEDURES

This section presents a detailed description of the procedures to be followed in preparing subjects for experimental runs, in executing the practice and experimental run series, and in collecting and analyzing the data obtained during these runs. The general plan, as indicated in Appendix B, is to complete a practice series and an experimental series on each subject in turn. Subjects will be oriented to their assigned pattern of simulator runs, briefed on the execution of experimental tasks, familiarized with the simulator, exercised on all scheduled runs, and debriefed on an individual basis. General procedures will be the same for each subject; however, the specific character of each run will be determined by the experimental design.

The basic presentation format adopted for the delineation of procedures is the simulation sequence description represented graphically in Figure 8 and discussed in the sub-sections which follow. Subject selection and preparation requirements are discussed first to establish the initial subject pilot qualifications expected and the preparation needed to assure a common understanding of experimental task requirements and of the conditions to be represented in the simulation. The execution of various run series in the simulator will then be covered in detail, following the sequence of activities defined in Figure 8. Finally, data analysis and interpretation procedures will be discussed to provide a clear description of how the data obtained in the simulation sequences will be processed and interpreted to resolve the issues raised in Appendix A.

Subject Selection and Preparation Requirements

As indicated in the preceding section, twelve subject-pilots are required to implement the experimental design adopted for the study. The aim of subject selection and preparation procedures is to ensure that subjects have comparable skills and knowledge pertinent to Category II approach and landing operations and that their subsequent performance of the experimental task can be taken as broadly representative of the behavior of SST command pilots in actual flight operations. While no attempt will be made to match subjects on specific characteristics or qualifications, their selection and preparation, together with the random assignment of subjects to the experimental groups, is expected to preclude any systematic bias in the results obtained on a given subject or group of subjects which can be attributed to differences in subject skills and knowledge.

To ensure comparable initial qualifications, pilots meeting the following requirements will be solicited to serve as subjects in the study:

1. Currently active line pilots engaged in scheduled commercial air carrier operations.

2. Possess an airline transport rating (ATR) and type rating in 4-engine turbojet aircraft.

3. Completed FAA approved Category II training program and certified by FAA Inspector or a Company Check Pilot as being qualified for Category II operations.

The last requirement cited will call for all subjects to be Captains, since pilots are not currently authorized to conduct Category II operations in turbojet aircraft unless they have had at least 300 hours as pilot-in-command in turbojet aircraft. It is anticipated that pilots meeting these requirements can be obtained for the study. If difficulties are experienced in recruiting subjects, the Category II certification requirement can be relaxed; however, completion of approved Category II training must be retained as a minimum requirement. A large number of First Officer pilots would then qualify as subjects. If a mix of Captain and First Officer-qualified subjects is used, the random assignment of subjects to experimental groups will be modified so that the proportion of Captains is the same in each group.

Subject preparation procedures will be concerned with the orientation of these pilots to their role in the simulation study and with establishing a common understanding of the assigned experimental tasks, the simulator, and the equipment and conditions represented in the scheduled simulation sequence. Orientation to the study will be accomplished in a designated briefing area by having the subjects read the booklet attached to this document as Appendix C. Operating Procedures outlined in this booklet will be amplified by the experimenter as necessary to clarify the procedures to be followed by subjects in different experimental groups; i.e., in order to follow "Cross-check", "Head-down", or "Head-up" procedures. As part of this orientation session, background data which may be of interest in the subsequent interpretation of study results will be recorded on each subject. The data recording form to be used for this purpose is attached to Appendix C.

After completing the orientation session the subject-pilot will be taken to the simulator and familiarized with the location and operation of all controls and displays he will use during the simulator runs. Subsequent events and activities will then follow the simulation sequence description schematized in Figure 8. To facilitate cross referencing, this figure is located at the end of the next section (page 52).

Execution of the Simulation Sequence

The format and symbology adopted for representing the simulation sequence in Figure 8 is derived from Operational Sequence Diagrams (OSD's), a graphic technique used to delineate operator task sequences and interactions with other personnel and/or system components. A sequence of events (Column 1), beginning with the arrival of a designated subject (S_i) in the briefing area and ending when this subject has completed his scheduled run series and is released, is used to "drive" the simulation sequence description. Run times (t) are referenced to the initiation of a given run (t=o) and coordinated with certain events. The activities and interactions of the subject-pilot (S), the experimenter (E), and simulation facility operators (O) are of interest in the sequence description and are represented symbolically in Columns 2, 3, and 4. The symbols distinguish different kinds of operator activity in accordance with the following key:

⇨ Communication activities; the letter D indicates direct voice communications and an I indicates those made via the intercom system.

▽ Extraction of information from storage media, such as documents and other reference material.

○ Observation or monitoring activities.

□ Control actions; i.e., manipulation of control devices is required in the activity.

⬡ Diagnosis or assessment activities; information processing activities concerned with establishing the character, value, or implications of an object/event of interest.

◇ Decisions; i.e., the resolution of some specified uncertainty.

The solid lines define the primary sequence of activities and simply indicate the general order in which the activities occur. Dotted lines into an open arrow head are used to indicate that the activity is ongoing; the solid arrow head indicates the termination of an ongoing activity. The numerals inside the activity symbols are used to identify the activity in the last column where a brief characterization of each activity is given.

Initial conditions assumed to be established prior to the scheduled time for conducting a run series are cited at the top of page 1 of Figure 8. The daily checkout of the simulation facility and determination of its operational readiness is not peculiar to the study and procedures for these preparation functions are not given in this document. The run schedule (Appendix B) will be reviewed and coordinated with the facility operators so that equipment-specific operating guides (e.g., specific program control positions, potentiometer settings, etc.) can be prepared when the computer re-programming and facility modifications are completed. At the start of the scheduled run series, then, the facility will be operational but not yet set up for any particular run, and operators who are checked out on the procedures to be followed will be at their assigned stations.

S_i's introduction to the study and briefing in the scheduled run series were covered in the foregoing section. This discussion will begin with S_i seated in the crew compartment and E's briefing on the procedures S_i is to follow in setting up the flight deck. It should be noted, however, that while S_i and E are engaged in the orientation session, O s stationed at the computer console and VFA control console are setting up the facility for the first scheduled run.

Set-up procedures performed at the computer console consist of diode function generator (DFG) selections, pot adjustments, and data recording equipment preparation. Three DFG's must be selected for each run when automatic flight path control is used: one DFG for establishing the terrain profiles to be represented and two for programming the flight path profile. Lateral offset (Y as a function of X) is programmed on one of the latter two DFG's and height (Z) is programmed on the other. Initial pot settings for aircraft position coordinates (X, Y, and Z) and heading (ψ_m) are then established for all runs and the initial airspeed (V) must be set when the run is manually controlled. The wind vector and minimum decision altitude specified for the run is also set at the pot panel. Strip chart recorders will then be tied-in to appropriate signal channels and the paper will be labeled with the date, time, run number, and subject number. Only one adjustment is needed at the VFA console. The visibility control pot must be set for the runway visual range (RVR) conditions specified for the run.

As indicated above, S_i will be thoroughly acquainted with the flight deck configuration and the operation of the controls and displays before initiating the run series. In addition, the first run in the practice series will be a demonstration run. After instructing S_i to set up the flight deck for run #1 (see Appendix C - Operating Procedures), E will ask O to initiate the demonstration run and, as the approach to the DH proceeds under programmed flight path control, E will talk-through the procedures to be followed by S_i in carrying out the experimental tasks. On the demonstration run only, O will stop the simulation at the DH and manually position the aircraft at various lateral offset (Y axis) and relative altitude (Z axis) positions. The offset positions to be used are listed below and will be called out by O as they are established:

Position	Y	Z
1	25' left	100'
2	60' left	120'
3	150' left	95'
4	10' right	75'
5	65' right	85'
6	135' right	120'

The demonstration run will be concluded by having O reposition the simulator to the appropriate offset position at 200' (over the Middle Marker) and re-starting the computations. S_i will then be exercised, again with E verbalizing the procedures to be followed, in transitioning from programmed flight path control to manual control at the DH and in executing the landing maneuver. After touchdown O will reposition the simulator for the second run in the practice series and establish the initial conditions specified in the run schedule.

The next six runs in the practice series will be accomplished by S_i without assistance from E and will be executed as if they were data collection runs. Note that recorders will be turned on for these runs so that learning effects across the practice series, if any, can be examined. The run sequence represented in Figure 8, beginning with E communication action #15 and ending with S_i control action #18, will be repeated until all remaining runs in the series scheduled for S_i are completed. Amplifying information on subject procedures is given in Appendix C and additional clarification of data recording procedures is given in the next sub-section. As indicated in Figure 8, material in Appendices B, C, and D will be used by E and O during the simulation sequences.

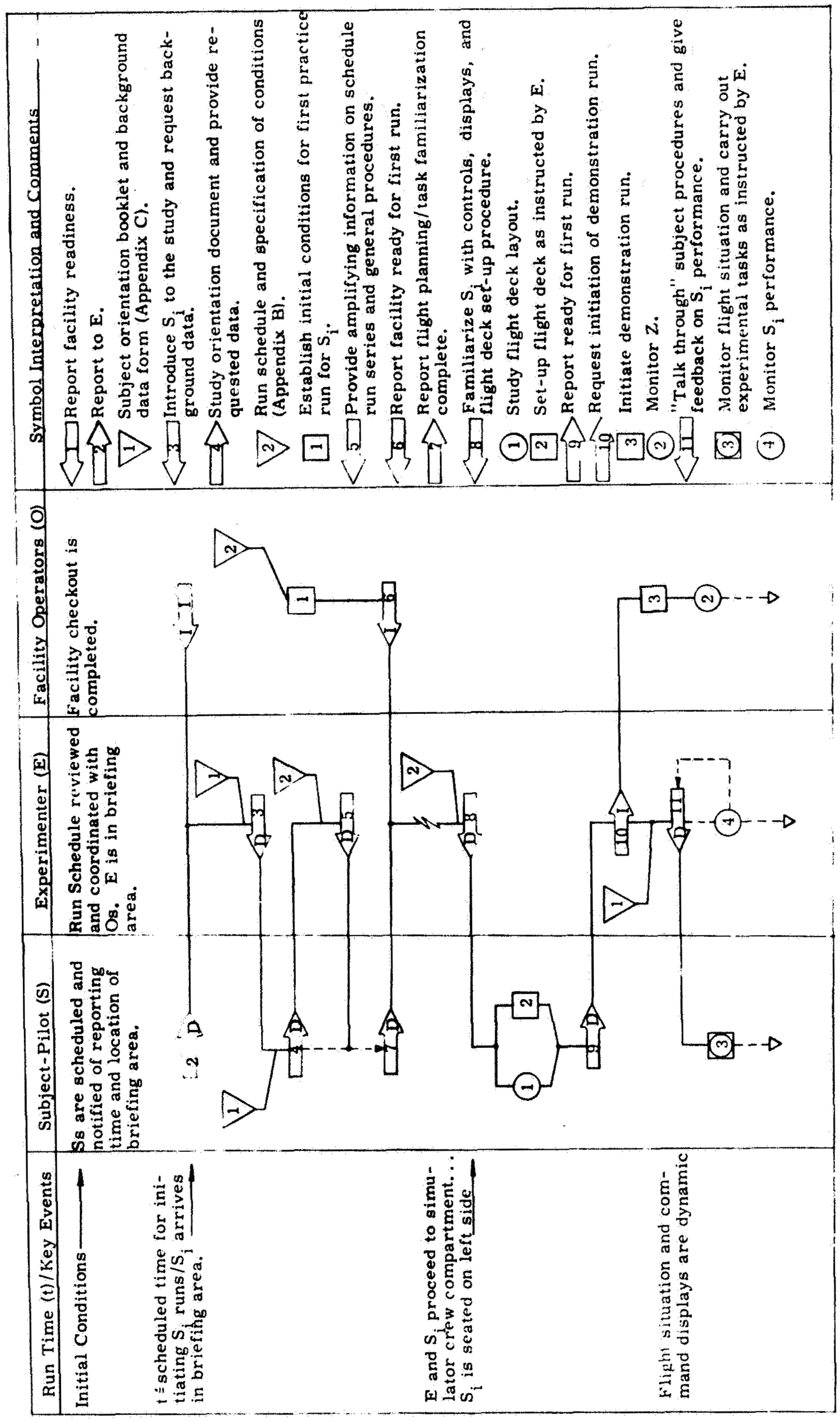


Figure 8. Simulation Sequence Description.

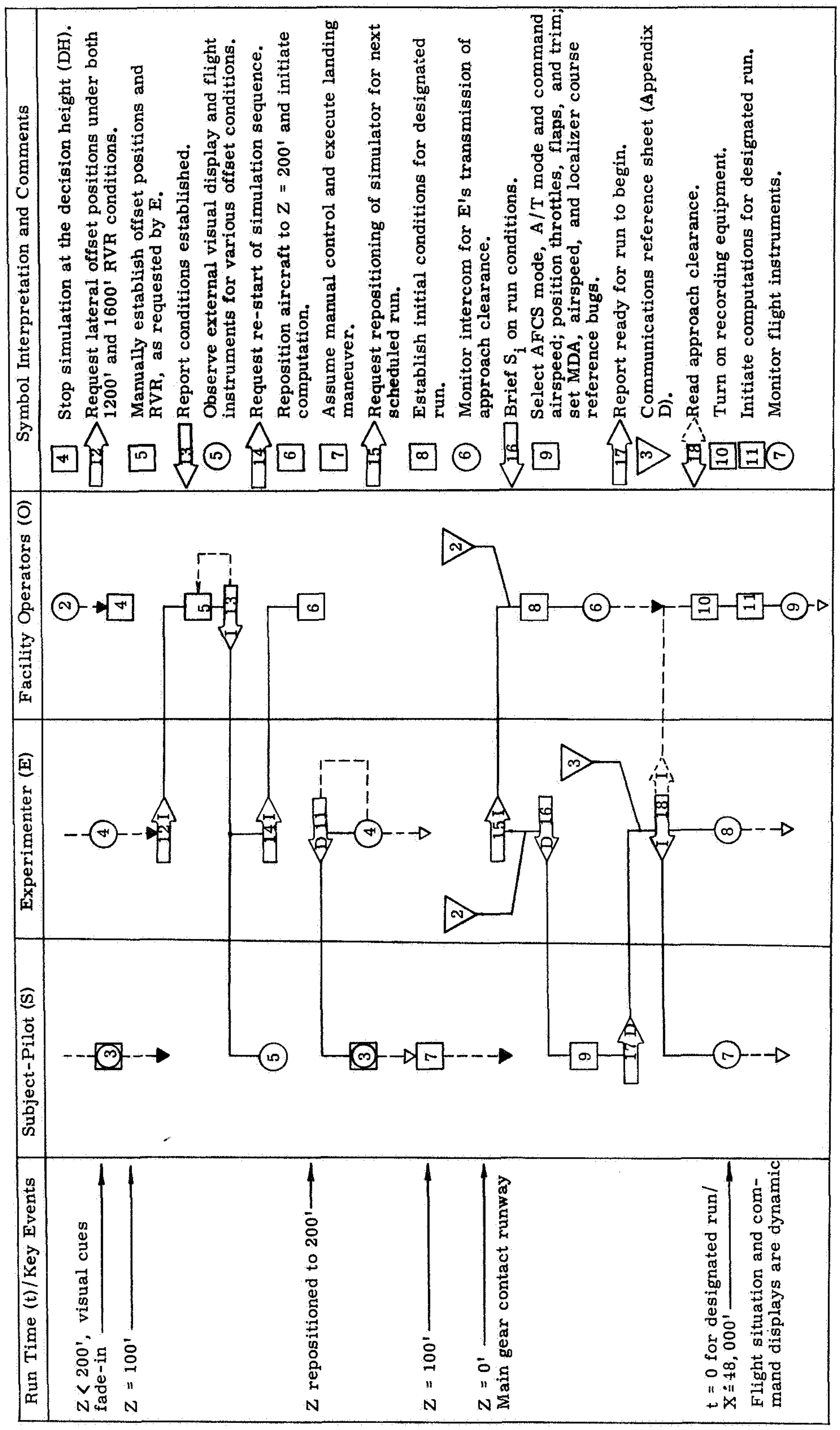


Figure 8. Simulation Sequence Description (continued)

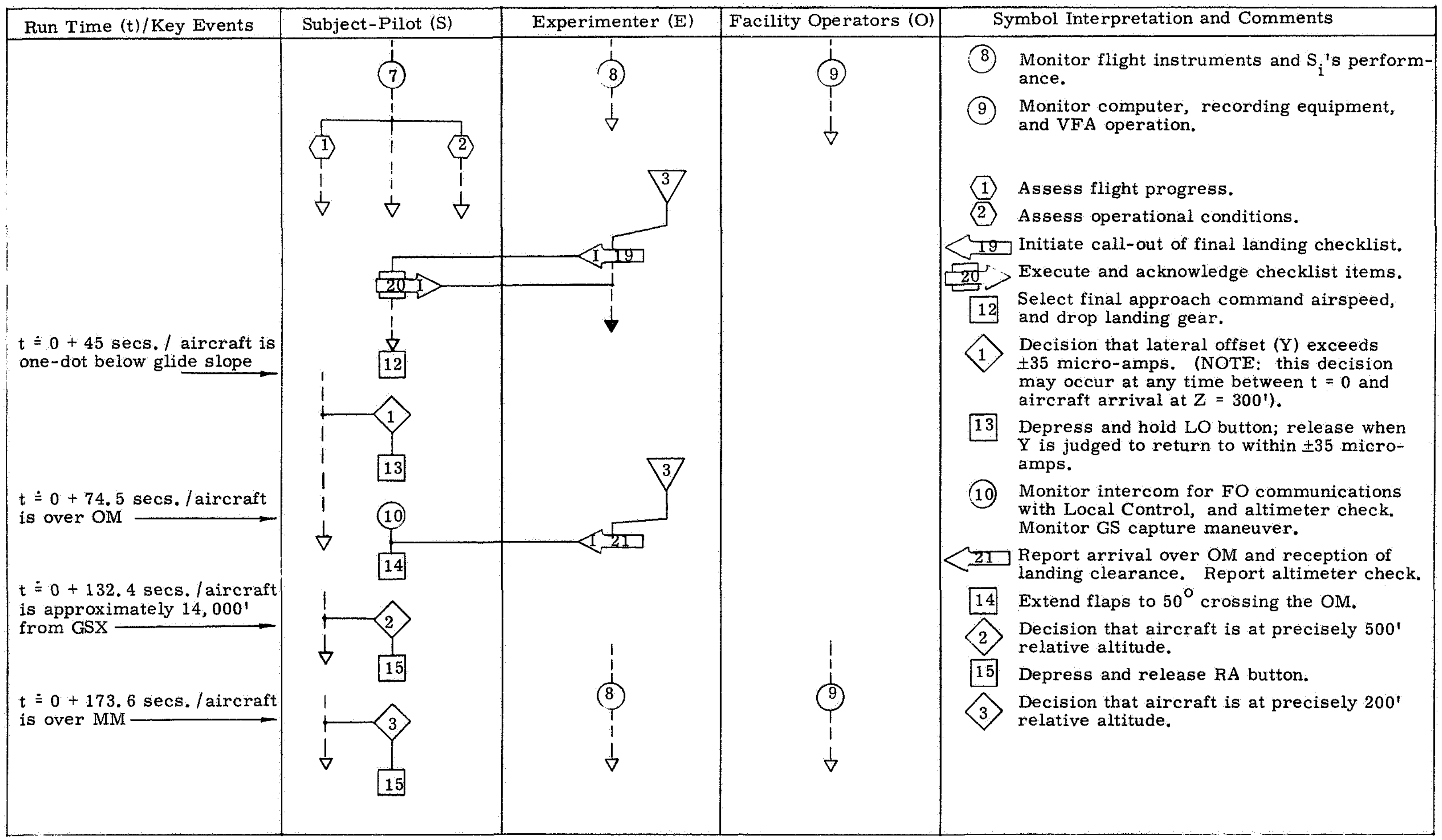


Figure 8. Simulation Sequence Description (continued)

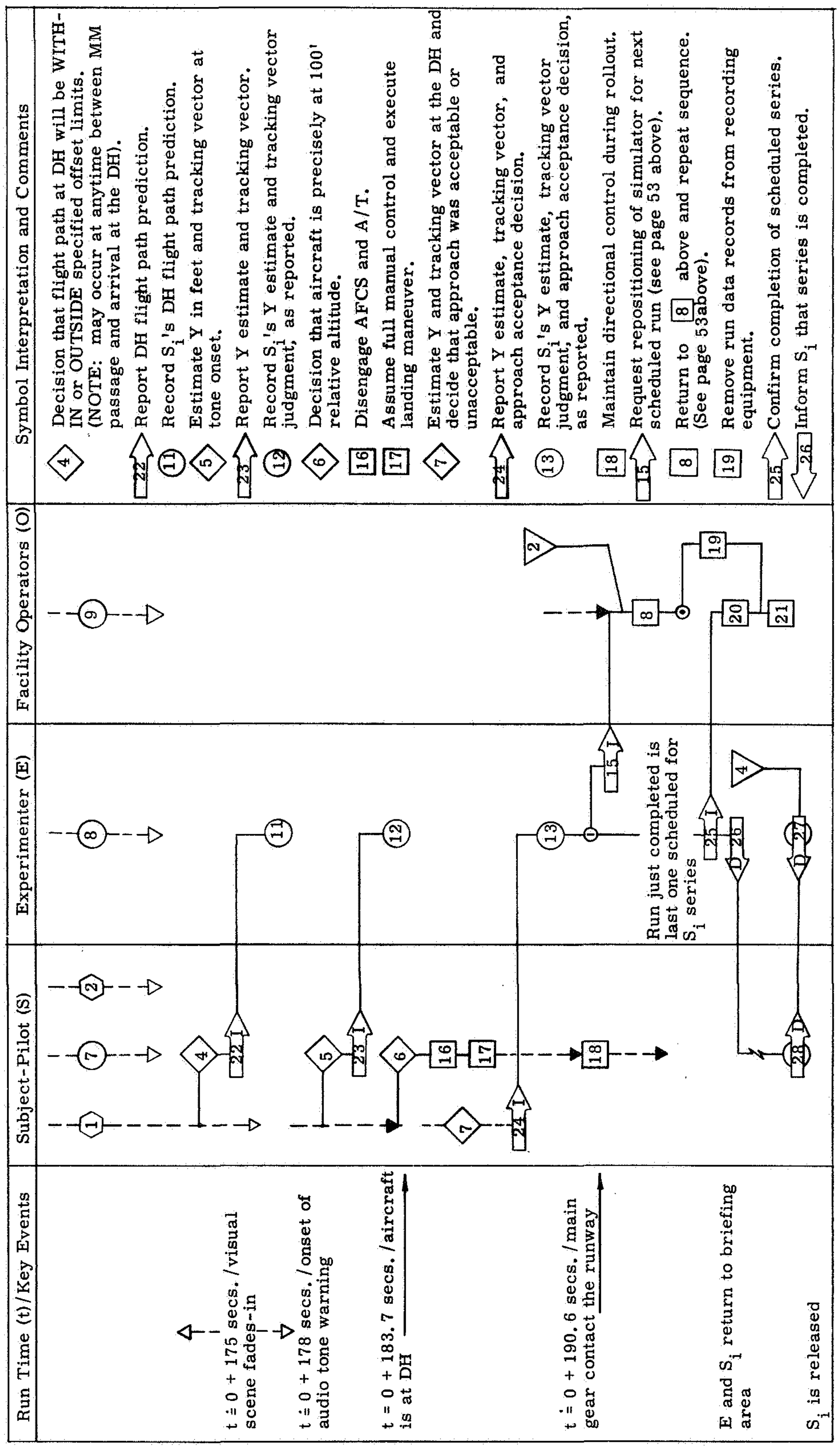


Figure 8. Simulation Sequence Description (continued)

Run Time (t)/Key Events	Subject-Pilot (S)	Experimenter (E)	Facility Operators (O)	Symbol Interpretation and Comments
				20 Secure simulator, recording equipment, and VFA. 21 Transfer run data records to E. 4 Subject debriefing forms (Appendix E). 27 Administer debriefing interview/questionnaire and release S_i. 28 Provide requested data.

Figure 8. Simulation Sequence Description (concluded)

Data Analysis and Interpretation

As outlined in the preceding Experimental Design section, the flight situation and subject response data recorded during the execution of each simulator run will provide the basis for deriving five key measures of flight management task performance and three measures of touchdown performance. These measures, in turn, will provide the basis for deriving summary statistics representing subject performance at specified data points, on designated run series, and/or under various combinations of the experimental variables. Procedures for deriving these measures and statistics and their subsequent use in assessing the effects of the experimental variables are discussed in this section. The application of these data to the issues raised in Appendix A is also discussed here.

To facilitate this discussion, the data to be recorded on each run are listed in Table 4 and the form in which they will be recorded is identified. Measures of interest can now be defined in terms of these data elements and the data processing required in the derivation of measures can be clarified. In what follows, data analysis and interpretation procedures associated with each of the major objectives of the study are delineated.

Table 4. Flight Situation and Subject Response Data Recorded on Each Simulation Run

Item	Symbol	Type of Record
1. X coordinate of aircraft position (Distance from glide slope/runway intersect point along the X axis which is aligned with the extended runway centerline.)	X	Continuous plot of scaled analog signal on strip chart recorder, from $t \doteq 0$ to $t \doteq 200$ secs. Values can be read in feet for any point in the sequence.
2. Y coordinate of aircraft position (lateral offset from the X axis)	Y	Same as Item 1.
3. Z coordinate of aircraft position (height above runway touchdown zone, also referred to as "Relative Altitude".)	Z	Same as Item 1.
4. Localizer Deviation	D_1	Same as Item 1., except that values can be read in micro-amps.
5. Glide slope deviation	D_g	Same as Item 1., except that values can can be read in micro-amps.
6. Subject judgment that D_1 exceeds 35 micro-amps.	$\overleftarrow{LO}$	Step change in LO event marker recording level on strip chart recorder; occurs when S depresses and holds LO button.
7. Subject judgment that D_1 has returned to a value less than 35 micro-amps.	$\overrightarrow{LO}$	LO event marker returns to baseline recording level; occurs when S releases LO button.

Table 4. Flight Situation and Subject Response Data Recorded on Each Simulation Run (continued)

Item	Symbol	Type of Record
8. Subject decision that aircraft is at precisely 500' relative altitude.	RA_5	Momentary step change in RA event marker recording level on strip chart recorder; occurs when S depresses the RA button.
9. Subject decision that aircraft is at precisely 200' relative altitude.	RA_2	Same as Item 8.
10. Subject depression of microphone button.	MB	Momentary step change in MB event marker recording level on strip chart recorder; occurs when S depresses the mike button.
11. Subject's prediction of flight path offset on arrival at the DH.	P	Recorded on E's data sheet as reported by S via the intercom; entry will be either "NONE" (i.e., no report given), "WITHIN", or "OUTSIDE".
12. Subject's estimate of lateral offset at tone onset.	$Y_{est.1}$	Recorded on E's data sheet as reported by S via intercom; entry will be "_____ feet left (or right)".
13. Subject's estimate of aircraft tracking vector at tone onset.	$\dot{Y}_{est.1}$	Same as Item 12., except that entry will be either "ON", "PARALLEL", "DIVERGING", or "CONVERGING".

Table 4. Flight Situation and Subject Response Data Recorded on Each Simulation Run (continued)

Item	Symbol	Type of Record
14. Subject's decision that aircraft is at precisely 100' relative altitude, i.e., at the DH.	AD	Same as Item 8., except that it occurs when S depresses the AD button.
15. Subject's estimate of lateral offset at the DH.	$Y_{est.2}$	Same as Item 12.
16. Subject's estimate of aircraft tracking vector at the DH.	$\dot{Y}_{est.2}$	Same as Item 13.
17. Subject's assessment of approach success.	AS	Recorded on E's data sheet as reported by S via intercom; entry will be either "ACCEPTED", "REJECTED", or "NONE" (no report given).
18. Aircraft cross-track velocity.	$\dot{Y}$	Same as Item 1., except that values can be read in feet per second.
19. Aircraft heading (magnetic).	ψ_m	Same as Item 1., except that values can be read in degrees.
20. Aircraft pitch attitude.	θ	Same as Item 1., except that values can be read in degrees.
21. Aircraft roll attitude (bank angle).	ϕ	Same as Item 1., except that values can be read in degrees.

Table 4. Flight Situation and Subject Response Data Recorded on Each Simulation Run (concluded)

Item	Symbol	Type of Record
22. Aircraft altitude above terrain (absolute altitude).	h_a	Same as Item 1.
23. Aircraft vertical velocity.	$\dot{h}$	Same as Item 1., except that values can be read in feet per second.

Evaluation of Subject's Ability to Judge Lateral Offset During the Approach

The measure selected for this assessment in the study is designated as e_1, the number of errors Ss make in detecting lateral offsets in excess of 35 micro-amps during the approach to 300'. This measure is defined in terms of D_1, $\overleftarrow{LO}$, and $\overrightarrow{LO}$ (items 4, 6, and 7 in Table 4). These data elements will all be recorded on the same strip chart so that the alignment of recorded LO events with values of D_1 can be examined. On runs where programmed flight path control is used (AFCS mode selection is AUTO or ROLL ONLY), D_1 values exceed 35 micro-amps on profiles P-2, P-3, P-4, P-6, P-7, and P-8 (see Figure 5), and lateral offsets of this magnitude may also occur on manually controlled runs. Allowing for some misalignment on the strip charts due to S's delay in perceiving these offset conditions and depressing the LO button (a 2 second lag will be used), an e_1 error is counted whenever $D_1 > 35$ micro-amps and $\overleftarrow{LO}$ does not occur or whenever $D_1 < 35$ micro-amps and $\overrightarrow{LO}$ does not occur.

The 35 micro-amp value was selected on the basis of performance requirements established by the FAA (ref. 6) for automatic pilot/coupler systems approved for Category II operations. The expression of lateral offset limits in terms of localizer deviation in micro-amps also assures a tightening of offset tolerances as the approach proceeds, since D_1 reflects angular deviation from the beam center rather than linear displacement in feet. A command pilot might of course accept greater lateral offsets; e.g., staying within one-dot (75 micro-amps) of the beam center, particularly early in the approach. However, the rationale here is that, although the 35 micro-amp limit might be a little tight for operational purposes, the pilot should be able to assess localizer tracking to these tolerances in order to determine that AFCS performance is satisfactory.

Data will be available from all 252 experimental runs for deriving this measure. Mean error scores ($\overline{e}_1$) taken on all twelve subjects, overall run conditions, and using the fully automatic control mode will be used as the most appropriate estimate of SST pilot performance on this task. The 108 runs conducted under these conditions represent the primary operating mode of the baseline SST system. However, $\bar{e}_1$'s can also be examined for all 252 runs and for other groupings of the data in order to look at differences, if any, which appear to be attributable to variations in run conditions, control mode, operating procedure, subject qualifications, etc. This measure will be used, in part, to resolve the issue raised on page A-7 of Appendix A. For evaluating the more critical operational job of assessing flight path alignment below 300' results obtained using the measures designated as a_1, a_2, e_8, and e_9 later in this discussion must be considered.

Evaluation of Subject's Ability to Estimate Relative Altitude

The measure selected for this assessment is the number of errors Ss make in estimating Z; i.e., their actual height above the runway touchdown zone. Measures will be taken at three points in the approach; one at 500' (designated as e_2), one at 200' (designated as e_3), and the last one at the 100 foot decision height (designated as e_4). Definition of these measures is in terms of Z, RA_5, RA_2, and AD (items 3, 8, 9, and 14 in Table 4). These data elements are also all recorded on the same strip chart and the value of Z when S depresses either the RA or AD button ($Z_{est.}$) can be readily determined. Since the operational significance of a precise determination of Z increases as the aircraft approaches the DH, different accuracy limits will be used to define e_2, e_3, and e_4. At 500' an e_2 error will be counted whenever $|Z - Z_{est.}| > 50'$, an e_3 error will be counted when $|Z - Z_{est.}| > 20'$, and at the DH an e_4 error will be counted whenever $|Z - Z_{est.}| > 12'$.

The issue to be resolved by obtaining these measures is discussed on page A-3 of Appendix A. The best estimate of SST pilot performance will again be provided by mean error scores taken on all twelve Ss during the 108 runs conducted using the fully automatic control mode. Programmed variations in terrain elevation approaching the runway will occur an equal number of times in these run series. Differences in estimating Z as a function of the terrain elevation selected can also be determined.

It should be noted that on the 9 runs executed by Ss in Group 3, using the "Head-up" procedure, the information available to the pilot will not be comparable to that available on other runs in the series. On these runs, Ss' full attention will be directed outside the cockpit and they will determine that they are at the DH by monitoring the offset of the audio alert tone and/or the First Officer's report that the aircraft has arrived at "minimums". Since the intent of the measure, i.e., to reflect the accuracy of Ss' estimates, is not served in this instance, no e_4 errors will be counted on these runs.

Evaluation of Subject's Ability to Predict Approach Success

This assessment is concerned with the pilot's ability to effectively "stay-ahead" of the airplane and is only indirectly related to the issues raised in Appendix A. Two measures were defined for this purpose, one to reflect the accuracy of approach outcome predictions and the other to indicate their timeliness. The accuracy measure, designated as e_5, is the number of errors Ss make in predicting that the aircraft will be within or outside of specified offset limits at the DH. The timeliness measure, designated as X_p, will be measured by determining the distance of the aircraft from the runway at the time this prediction is reported.

Definition of e_5 is in terms of Y, Z, and P (items 2, 3, and 11 in Table 4). The accuracy of the prediction (P) recorded on E's data sheet is determined by comparison with actual values of Y and Z at the DH recorded on the strip chart and e_5 errors are counted in accordance with the following "accuracy" index:

P	Y at DH:		Z at DH:		
	$>50'$	$<50'$	$<88'$	$88<Z<112'$	$>112'$
WITHIN	e_5 error	no error	e_5 error	no error	e_5 error
OUTSIDE	no error	e_5 error	no error	e_5 error	no error

X_p is defined in terms of X and MB (items 1 and 10 in Table 4) and is simply the value of X at the time MB occurs for Ss' report of P. The more timely predictions are thus represented by greater values of X. Mean values of e_5 and X_p taken on all 12 Ss on the 108 fully automatic runs will be used as the best estimate of pilot performance on this flight management task in the SST.

Evaluation of Subject's Ability to Estimate Lateral Offset and Tracking Vectors

This assessment represents a direct attempt to resolve the issues raised on pages A-11 and A-14 of Appendix A. Absolute errors in Ss' quantitative estimates of the aircraft's lateral displacement from the extended runway centerline, taken at two clearly defined points in the decision region, will be the measures used to evaluate lateral offset judgments. Errors in Ss' qualitative estimates of aircraft tracking tendencies at the same two points will be the measure used for the tracking judgment.

Lateral offset estimates are defined in terms of Y, $Y_{est. 1}$, and $Y_{est. 2}$ (items 2, 12, and 15 in Table 4). Y estimates recorded on E's data sheet will be compared with actual values of Y at tone onset and at the DH to determine their accuracy. The two accuracy measures, designated as a_1 and a_2, are defined as:

$$a_1 = |Y - Y_{est. 1}| \quad \text{and} \quad a_2 = |Y - Y_{est. 2}|$$

Error scores, designated as e_6 and e_7, will also be derived by imposing a 25' limit on a_1 and a_2. An e_6 error will be counted when $a_1 > 25'$ and an e_7 error will be counted when $a_2 > 25'$. These error scores will be used in the over-all evaluation of Ss' performance on all components of the approach assessment function (see discussion on page 69).

The measure selected for determining Ss' ability to judge the aircraft's tracking vectors is the number of errors they make in detecting cross-track velocities. This measure is defined in terms of items 13, 16, 18, and 19 in Table 4. $\dot{Y}$ estimates recorded on E's data sheet will be compared with actual values of $\dot{Y}$ at tone onset and at the DH, as recorded on the strip chart. Errors, designated as e_8 and e_9 will be counted in accordance with the following "accuracy" matrix:

$\dot{Y}_{est.}$ (1 or 2)	$\dot{Y}$ at tone: <4 fps	$\dot{Y}$ at tone: >4 fps	$\dot{Y}$ at DH: <4 fps	$\dot{Y}$ at DH: >4 fps
"ON" or "PARALLEL"	no error	e_8 error	no error	e_9 error
"DIVERGING"	e_8 error	no error*	e_9 error	no error*
"CONVERGING"	e_8 error	no error*	e_9 error	no error*

*If direction is correct; i. e., away from track when DIVERGING is reported, toward track when CONVERGING is reported.

Mean accuracy scores ($\overline{a}_1$ and $\overline{a}_2$) and mean tracking estimate error scores ($\overline{e}_8$ and $\overline{e}_9$) taken on the eight subjects in groups 1 and 2 on the 72 runs conducted under fully automatic control will be taken as the best estimate of SST pilot performance on this flight management task. The 36 runs flown by Ss in group 3 cannot be used here because they will be "head-up" below 200' and their lateral offset judgments will be based solely on external visual reference. Group 3 data will be used in determining the effects of the experimental variables (discussion of this on page 68). Again the same data on all 252 runs and for other groupings of the data can be examined in order to look at the effects of variations in run conditions and/or the flight control mode used.

Determination of Appropriate Lateral Offset Limits at the Decision Height

This assessment is concerned with Ss' willingness and ability to execute the "side-step" maneuver from various lateral offset positions and tracking vectors at the DH. On simulator runs calling for the use of automatic flight path control, six different offset/tracking situations will occur at the DH as listed below:

1. 40' left/10' low on glide slope/tracking parallel (Profile P-1)
2. 60' left/15' high on glide slope/tracking converging (Profile P-5)
3. 150' left/25' low on glide slope/tracking diverging (Profile P-9)
4. 10' right/18' high on glide slope/tracking diverging (Profile P-4)
5. 65' right/22' low on glide slope/tracking parallel (Profile P-8)
6. 135' right/5' high on glide slope/tracking converging (Profile P-3)
7. 25' left/20' low on glide slope/tracking converging (Profile P-7)
8. 70' left/10' high on glide slope/tracking diverging (Profile P-2)
9. 125' right/20' high on glide slope/tracking parallel (Profile P-6)

Additional offset/tracking situations will occur on manually controlled approaches. Ss' willingness to complete the landing maneuver from each of the DH situations distinguished will be indicated by AS (item 17 in Table 4). Since Ss will be instructed to attempt a landing out of each approach, their ability to effect a successful touchdown can be determined for each of the offset conditions of interest by obtaining data on touchdown position and rate-of-sink.

The measures selected for assessing touchdown performance are the number of lateral touchdown errors (designated as e_{10}), the number of longitudinal touchdown errors (e_{11}), and vertical velocity at touchdown ($\dot{h}_{td}$). FAA touchdown dispersion limits (ref. 6) and Table 4 items 1 and 2 are used to define e_{10} and e_{11}. An e_{10} error is counted whenever the actual value of Y recorded on the strip chart recorder at touchdown (i.e., when Z = 0) is greater than $\pm 27'$. An e_{11} error is counted whenever the recorded value of X at touchdown is not within + 1000' and -1500'. Vertical velocity at touchdown is given directly by item 23 in Table 4.

Mean touchdown error scores will be derived separately for all landings made from a specified DH offset/tracking situation. Data from all of the 252 runs, except those on which the landing attempt is aborted, will be used for this assessment. The proportion of runs made from each of the nine offset conditions, primarily by study design, is expected to be approximately equal. Touchdown error scores and $\dot{h}_{td}$ will also be used to determine the proportion of landing attempts which were completely successful; i.e., those on which neither e_{10} nor e_{11} errors occurred and $\dot{h}_{td} \leq 4$ fps. This measure will be designated as P_s.

Determination of the Effects of Variations in Operational Procedure and Control Task Loading on the Quality of the Approach Success Judgments

One objective of the study was to examine the joint and separate effects of alternative Operational Procedures (level of Factor A) and Control Task Loading (levels of Factor B) on the performance of suspect flight management tasks. This objective was explicitly considered in adopting the factorial design as a basis for grouping Ss and assigning them to experimental runs and will be accomplished by a straightforward analysis of variance technique. The structural model underlying this analysis is discussed by Winer (ref. 5, p. 298).

The analysis of experimental data will be reported in a conventional analysis of variance format, as follows:

Source of Variation	df	MS	F
Between Subjects	11		
A (Operational Procedure)	2	MS_A	F_A
SW (Subjects within group)	9	MS_{SW}	
Within Subjects	24		
B (Control Task Loading)	2	MS_B	F_B
AB	4	MS_{AB}	F_{AB}
B x SW	18	$MS_{B \times SW}$	

The primary criterion measure (CM) to be used for this analysis will be derived from the measures taken on the components of the approach success judgment and may thus be construed as a composite, weighted index of the overall quality of Ss' performance of these tasks under the experimental conditions which will be contrasted in the analysis. This measure is defined as:

$$CM = \sum_{i=1}^{9} e_i c$$

The component error scores, e_1 through e_9, are those just discussed in the foregoing subsections and "c" is a criticality coefficient used to weight each error in terms of its relative operational significance. Three values of "c" were applied to provide for this distinction among error types.

Errors in estimating relative altitude (e_4) and lateral offset (e_7) at the decision height are considered most critical and were assigned a "c" value of 3. Errors in judging tracking vectors at the decision height (e_9), in estimating relative altitude at 200 feet (e_3), and in estimating lateral offset at 150 feet (e_6) are considered somewhat less critical and were assigned a "c" value of 2. The remaining error types included lateral offset judgments (e_1) and relative altitude estimates (e_2) made earlier in the approach, the decision height prediction (e_5), and tracking vector judgments made at 150 feet (e_8). These errors are considered to be critical only in respect to their timeliness; i.e., they occur with sufficient time remaining for the Captain to assess their impact and take corrective action prior to arrival at the decision height, and are thus assigned a "c" value of 1.

The computation of mean squares (MS) and F ratios will be based on mean CM data as developed from weighted error counts. The structure of the computational procedure is shown in Table 5 (see also ref. 5, p. 306). Cell entries in Part A of this Table are summations of the products of error scores and associated "c" values for each subject based on data taken on all runs under the designated treatment combinations (e.g., a_1b_1). As indicated in the Table, "p" equals the number of levels of Factor A ($p = 3$), "q" equals the number of levels of Factor B ($q = 3$) and "n" equals the number of Ss in each experimental group ($n = 4$). The A x B summary data given in Part B of Table 5 is readily obtained from the data in Part A by summing the CM's for each subject group under each condition. Computational symbols (1) through (6) in Part C are simply the elements of a simplified derivation of the sum of squared deviations from the means for each source of variance. The computation of mean square deviations (MS) for these sources of variance is then shown in symbols (7) through (11). The denominator in each MS computation is the number of degrees of freedom (df) for the designated calculation.

Table 5

Computation of Elements of the Variance Analysis

A. Derivation of CM's from run data:

Levels of Factor A (p)	Subject (n per group)	Levels of Factor B (q) b_1	b_2	b_3	Totals
	1	CM_{11}*	CM_{12}	CM_{13}	T_1
a_1	2	CM_{21}	CM_{22}	CM_{23}	T_2
(Group 1)	3	CM_{31}	CM_{32}	CM_{33}	T_3
	4	CM_{41}	CM_{42}	CM_{43}	T_4
Totals		$\sum a_1b_1$	$\sum a_1b_2$	$\sum a_1b_3$	$T\ (G_1)$
	5	CM_{51}	CM_{52}	CM_{53}	T_5
a_2	6	CM_{61}	CM_{62}	CM_{63}	T_6
(Group 2)	7	CM_{71}	CM_{72}	CM_{73}	T_7
	8	CM_{81}	CM_{82}	CM_{83}	T_8
Totals		$\sum a_2b_1$	$\sum a_2b_2$	$\sum a_2b_3$	$T\ (G_2)$
	9	CM_{91}	CM_{92}	CM_{93}	T_9
a_3	10	CM_{101}	CM_{102}	CM_{103}	T_{10}
(Group 3	11	CM_{111}	CM_{112}	CM_{113}	T_{11}
	12	CM_{121}	CM_{122}	CM_{123}	T_{12}
Totals		$\sum a_3b_1$	$\sum a_3b_2$	$\sum a_3b_3$	$T\ (G_3)$
					G

*Subscripts simply denote subject number and level of Factor B.

B. A x B Summary Table:

	b_1	b_2	b_3	Totals
a_1	$\sum a_1b_1$	$\sum a_1b_2$	$\sum a_1b_3$	T_{a_1}
a_2	$\sum a_2b_1$	$\sum a_2b_2$	$\sum a_2b_3$	T_{a_2}
a_3	$\sum a_3b_1$	$\sum a_3b_2$	$\sum a_3b_3$	T_{a_3}
	T_{b_1}	T_{b_2}	T_{b_3}	G

Table 5. Computation of Elements of the Variance Analysis (concluded)

C. Computational Symbols:

$$(1) = G^2/npq = G^2/(4)(3)(3) = G^2/36$$

$$(2) = \sum(CM)^2 = (CM_{11})^2 + (CM_{12})^2 + \ldots (CM_{123})^2$$

$$(3) = \left[\sum A_i^2/nq\right] = T_{a_1}^{\ 2} + T_{a_2}^{\ 2} + T_{a_3}^{\ 2}/12$$

$$(4) = \left[\sum B_j^2/np\right] = T_{b_1}^{\ 2} + T_{b_2}^{\ 2} + T_{b_3}^{\ 2}/12$$

$$(5) = \left[\sum(AB_{ij})^2\right]/n = (\sum a_1b_1)^2 + (\sum a_1b_2)^2 + \ldots (\sum a_3b_3)^2/4$$

$$(6) = \sum T_k^{\ 2}/q = T_1^{\ 2} + T_2^{\ 2} + \ldots T_{12}^{\ 2}/3$$

$$(7) = MS_A = (3) - (1)/2$$

$$(8) = MS_{SW} = (6) - (3)/9$$

$$(9) = MS_B = (4) - (1)/2$$

$$(10) = MS_{AB} = (5) - (3) - (4) + (1)/4$$

$$(11) = MS_{B \times SW} = (2) - (5) - (6) + (3)/18$$

Data from this analysis will first be used to examine the joint effects of Factors A and B. The F ratio for this test is $MS_{AB}/MS_{B \times SW}$. If this statistic is significant, it will indicate that the effects of Control Task Loading differ when alternate Operational Procedures are employed; i.e., the effect of this factor on flight management task performance depends upon the Operational Procedure used. Depending upon the outcome of this test, appropriate tests of the separate effects of each of the two factors will be conducted. In general, these latter tests will be concerned with the extent to which differences in mean CM data taken under different levels of Factor A and B can be attributed to the effects of these variables rather than to variations in individual S performance across runs or differences between subject groups. If a significant effect is found, contrasts will be examined to identify statistically significant differences, if any, in the effects of a specified Operational Procedure or Control Task Loading condition.

Additional variance analyses could be run, using different criterion measures, to examine the effects of the experimental variables on specific components of the approach success judgment. For example, the analysis just outlined could be repeated using only e_4 (errors in estimating relative altitude at the decision height) or e_7 (errors in estimating lateral offset at the decision height) data. The effects on just these critical flight management task components, rather than the overall quality of the approach assessment function, could thus be determined. It may also be of interest to examine the effects of variations in Operational Procedures and Control Task Loading during the approach on touchdown performance. In this instance, a composite touchdown performance measure derived from e_{10}, e_{11}, and $\dot{h}_{td}$ would be used. The measure designated as P_s would be appropriate here. These additional analyses indicate the general character of exploratory investigations which the data available from the study will allow and which go beyond the primary aims of the study.

Subject Debriefing

As indicated in Figure 8, each S will be returned to the briefing area following the completion of his scheduled run series, and his impressions, opinions, and attitudes regarding the issues raised in the study and his participation as a subject will be solicited in a debriefing session. The general intent of this debriefing session is to obtain opinion data which can be used to augment the objective data recorded during simulation runs and to support the interpretation of study results. In addition, the debriefing session will allow the subjects to express any good or bad feelings they may have developed in their exposure to the simulation exercise and to offer critical comments, if they like, on the issues raised in the study or the manner in which the study was conducted. To the extent that run data can be quickly processed prior to the initiation of the debriefing session, subjects will also be given feedback on how they performed in the experimental task.

The debriefing session will be carried out by the Experimenter using an informal questionnaire/interview technique. The questionnaire attached to this report as Appendix E will be administered to the subject and the Experimenter will be present to solicit amplifying information and/or to explore any additional issues or questions raised by the subject. Subject responses to each item of the questionnaire will be summarized in reporting study results and will be cited, where appropriate, in the discussion and interpretation of subject performance measures derived from the objective data recorded during simulator runs.

REFERENCES

1. Gartner, W. B. and Shoemaker, R. E.: Study of Flight Management Requirements During SST Low Visibility Approach and Landing Operations, Final Summary Report, NASA CR 73243, June 1968.

2. Shoemaker, R.; Gartner, W.; Ereneta, W.; and Donohue, V: Study of Flight Management Requirements During Low Visibility Approach and Landing Operations, Vol. I, Definition of Baseline SST Landing System, NASA CR 73240, October 1967.

3. Gartner, W. B. and Shoemaker, R. E.: Study of Flight Management Requirements During SST Low Visibility Approach and Landing Operations, Vol. II, Delineation of Potential Problems in Supporting the Performance of Flight Management Tasks, NASA CR 73241, January 1968.

4. Gartner, W. B. and Shoemaker, R. E.: Study of Flight Management Requirements During SST Low Visibility Approach and Landing Operations, Vol. III, Recommendations for a Simulation Research Study of Selected Flight Management Support Problems, NASA CR 73242, June 1968.

5. Winer, B. J.: Statistical Principles in Experimental Design, McGraw-Hill Book Company, Inc., New York, 1962.

6. Federal Aviation Agency: Automatic Landing Systems, Advisory Circular 20-57, January 29, 1968.

APPENDIX A

POTENTIAL FLIGHT MANAGEMENT PROBLEMS IN JUDGING APPROACH SUCCESS

(Reproduced from Reference 3)

Potential Problems in Judging the Success of the Approach

An appreciation of the performance objectives of "landing" systems developed to satisfy Category II operating requirements suggests that these systems might be better understood and referred to as "approach" systems. Under such conditions, landing maneuvers are initiated only after the approach is judged to be successful and then only when external visual reference is considered acceptable to the pilot-in-command for subsequent control of the flare and touchdown. Approach systems can also be distinguished from landing systems for Category III conditions, since a positive assessment of the approach will also be necessary before automatic control of the landing sequence is initiated. The general concern in this section is with flight management problems in determining the success of the approach to pre-established minimum altitudes where the landing commitment decision is finally taken.

Consideration must first be given to the defining characteristics of a "successful" approach. As a point of departure, the following excerpt from FAA Advisory Circular 120-20, dated June 6, 1966, which outlines criteria for the approach of Category II landing systems, is given:

> Definition of a Successful Approach. For the purpose of the airborne system evaluation, a successful approach is one in which, at the 100' point:
>
> (1) The airplane is in trim so as to allow for continuation of normal approach and landing.
>
> (2) The indicated airspeed and heading are satisfactory for a normal flare and landing. If an auto throttle control system is used, speed must be ± 5 knots of programmed airspeed but may not be less than computed threshold speed.
>
> (3) The airplane is positioned so that the cockpit is within, and tracking so as to remain within, the lateral confines of the runway extended.

(4) Deviation from the glide slope does not exceed ± 75 microamps as displayed on the ILS indicator.

(5) No unusual roughness or excessive attitude changes occur after leaving the middle marker.

The 100-foot point in the foregoing definition is, of course, the established decision height for Category II operations. At this point a missed approach must be initiated if the approach is judged unsuccessful or when certain ground and/or airborne equipment operating requirements cannot be satisfied. For Category III operations, no formal minimum approach altitude has yet been established but it can be assumed that a decision height based on minimum altitude requirements for executing a go-around will be determined. The key requirements to be satisfied in achieving a successful approach are taken as those dealing with the aircraft's position and tracking velocities relative to the intended touchdown area on the runway as the descent to the established decision height proceeds. Discussions of these requirements are frequently expressed in terms of an "approach gate" or "window", defined by lateral and vertical flight path displacement limits, from which a "soft" landing (i.e., a touchdown rate-of-descent of about two feet per second) can be achieved within a tightly defined touchdown area without exceeding autopilot authority limits or imposing excessive demands on pilot skills in manually controlling the aircraft.

Assessing Relative Altitude as the Aircraft Approaches the Authorized Decision Height.

Relative altitude is the present elevation of the aircraft relative to the elevation of the intended touchdown area on the runway. The appraisal of approach success and, under Category II conditions, of the adequacy of external visual reference for controlling the subsequent landing maneuver must be completed before the wheels of the aircraft reach a specified relative altitude, i. e., the decision height. As the aircraft approaches the decision height, then, the Captain must monitor and assess relative altitude to ensure that the aircraft does not proceed below the decision height unless the approach is judged successful.

In the projected SST landing system, relative altitude is not directly represented. Dual low-range radio altimeter systems will be available and it is assumed that relative altitude judgments must be derived from several radio altitude displays. Scalar indications of radio altitude, resolvable to about five feet, will be continuously available below 300 feet. Based on information given in approach charts, an index on the radio altimeter can be set to correspond to the relative altitude at the decision height. Below 200 feet, radio altitude is displayed qualitatively on the Attitude Director Indicator (ADI) using a "rising runway" symbol. In addition, arrival at a pilot-selected radio altitude is indicated by both a legend light component of the approach progress display and an auditory signal. Conventional readouts of barometric altitude will also be available and could be used to cross-check or supplement radio altitude information.

During the approach to the decision height, it is assumed that the Captain will simply monitor the scalar radio altitude indicator and/or have the First Officer call out altitude at 200 feet. When arrival at the decision height is imminent, i. e., at approximately 200 feet or over the middle marker, the Captain will direct primary attention to external visual reference and passively monitor the pre-set aural signal. The First Officer will continue to monitor radio altitude displays and may also report arrival at the decision height using established crew communication conventions.

The principal difficulty in this assessment is that the absolute altitude indications available from the radio altimeter systems can differ significantly from relative altitude due to irregularities in terrain features along the approach path. As Litchford reported several years ago (ref. 4):

> The pilot wants to know his height above his touchdown, which is some 3300 feet in front of him if he is indeed at 100 feet. But the terrain leading to the approaches of many of our major airports is usually very irregular, and this is becoming more common as runways are extended out over tidal waters and ravines to provide suffcient length for landing jets.

This point was illustrated by the terrain profiles schematized in Figure 2 for twelve major United States airports. It should be clear that considerable uncertainty regarding actual height above the intended touchdown surface can occur when radar altimeters are used over approaches such as those shown for the Pittsburgh and Dallas airports. The use of a pre-set relative altitude on the radio altimeter will provide a discrete indication of arrival at the decision height, but the problem of anticipating arrival at the decision height when approaching over uneven terrain remains. False discrete indications of arrival at the decision height are possible when the approach terrain is higher than the runway elevation. The use of currently operational barometric altimeters to supplement or cross-check radio altitude displays does not seem promising. Their use under Category II conditions is considered "basically unsafe" by the ALPA All-Weather Flying Committee (ref. 2) and in FAA tests of various methods for determining the 100 foot point on the glide slope, barometric altimeters were found to be the least accurate technique. Reported difficulties include inaccurate pressure settings, effects of rapid pressure changes due to wind conditions, inadequate provisions for detecting instrument errors, and instrument readability problems.

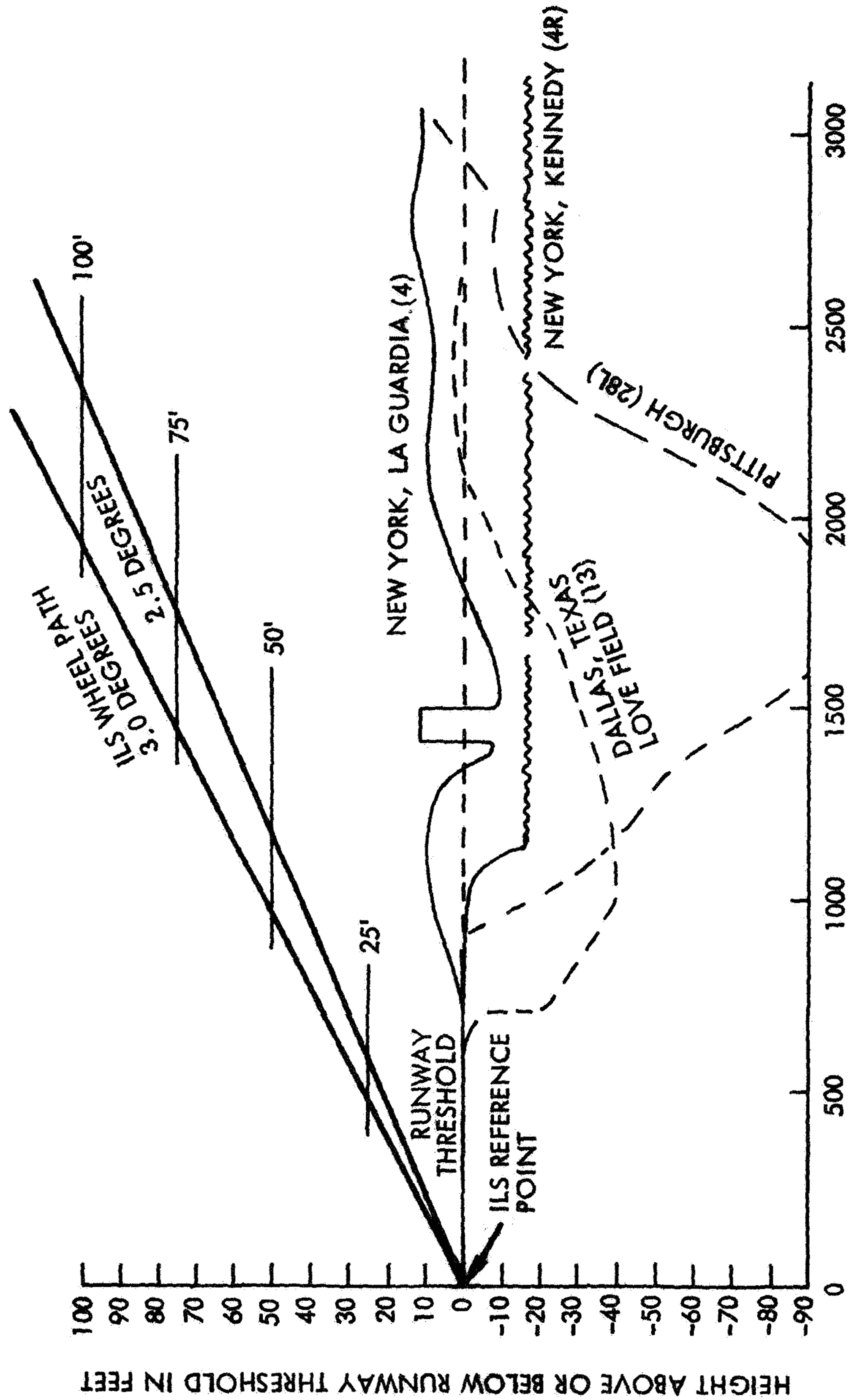


Figure 2. Terrain Profiles (Various Airports)
(from Ref. 1)

Assessing Flight Path Alignment with the Runway

As indicated earlier, one of the key requirements to be satisfied in a successful approach is that the aircraft's position and velocity vectors at the decision height are such that a "soft" landing within a well-defined touchdown area on the runway can be accomplished without exceeding autopilot authority and/or pilot-defined maneuvering limits. Most analyses of tolerable lateral offset limits suggest that lateral flight path alignment at the 100-foot decision height should be within 50 feet of the runway centerline extended and that velocity vectors (flight path projections) should be parallel or converging with respect to this reference line. Approaching the decision height, the Captain must judge flight path alignment to be within these limits or to be correcting so as to arrive within these limits by the time the decision height is reached.

In the projected landing system, flight path alignment with the runway centerline is not directly represented. The principal basis for judging flight path alignment is assumed to be the expanded localizer deviation indicator. Boeing design goals for localizer tracking during the final approach are to maintain the aircraft within ± 20 microamps of the localizer beam, an indicated deviation of about one-quarter dot (ref. 5). As the aircraft closes to the decision height, visual cues will "fade in" and may also be used by the Captain to judge flight path alignment and tracking tendencies. The First Officer will continue to monitor the localizer deviation indicator and report excessive cross-track error and/or divergent tracking tendencies when the aircraft arrives at the decision height.

Some mention should also be made of the "approach gate monitor" cited in the B-2707 Model Specification (ref. 6). It is called out as a requirement to ". . . warn the crew if the airplane exceeds the boundaries of a pre-established 'gate' or 'window' through which a safe landing can normally be accomplished". Since no subsequent identification or description of this indicator is provided in the B-2707 proposal documents, this display was not included in the landing system design concepts adopted in this study.

There are three unresolved issues associated with supporting this flight management requirement. Each one is cited below in the form of a question and briefly discussed.

1. <u>What is an appropriate lateral offset limit for the B-2707 at the 100-foot decision height?</u>

Firm criteria for judging excessive cross-track error at the decision height have not been established for the SST. From the previously cited FAA Advisory Circular, absolute limits on the horizontal dimensions of the approach gate, at 100 feet, may be set at ± 75 feet from the runway centerline (i.e., tracking within the lateral confines of the runway extended, with a standard runway width of 150 feet assumed). However, somewhat stricter limits must be placed on lateral displacement limits when the pilot's ability to correct for a lateral offset condition is considered. This is illustrated in Figure 3 which shows a shaded region of localizer deviations from which pilots made acceptable manual alignments for proper landings. These data are based on British studies of the ability of airline pilots to execute the "sidestep" maneuver, as reported in reference 1.

Note that lateral offsets in excess of a 20% localizer scale deflection (approximately 75 feet and consistent with the FAA limit) were clearly outside the range of acceptable conditions for manual landing success. Limits on this range of acceptable offsets, begin, however, with localizer scale deflections of about 14% or approximately 50 feet from the runway centerline. The reported range of limits for

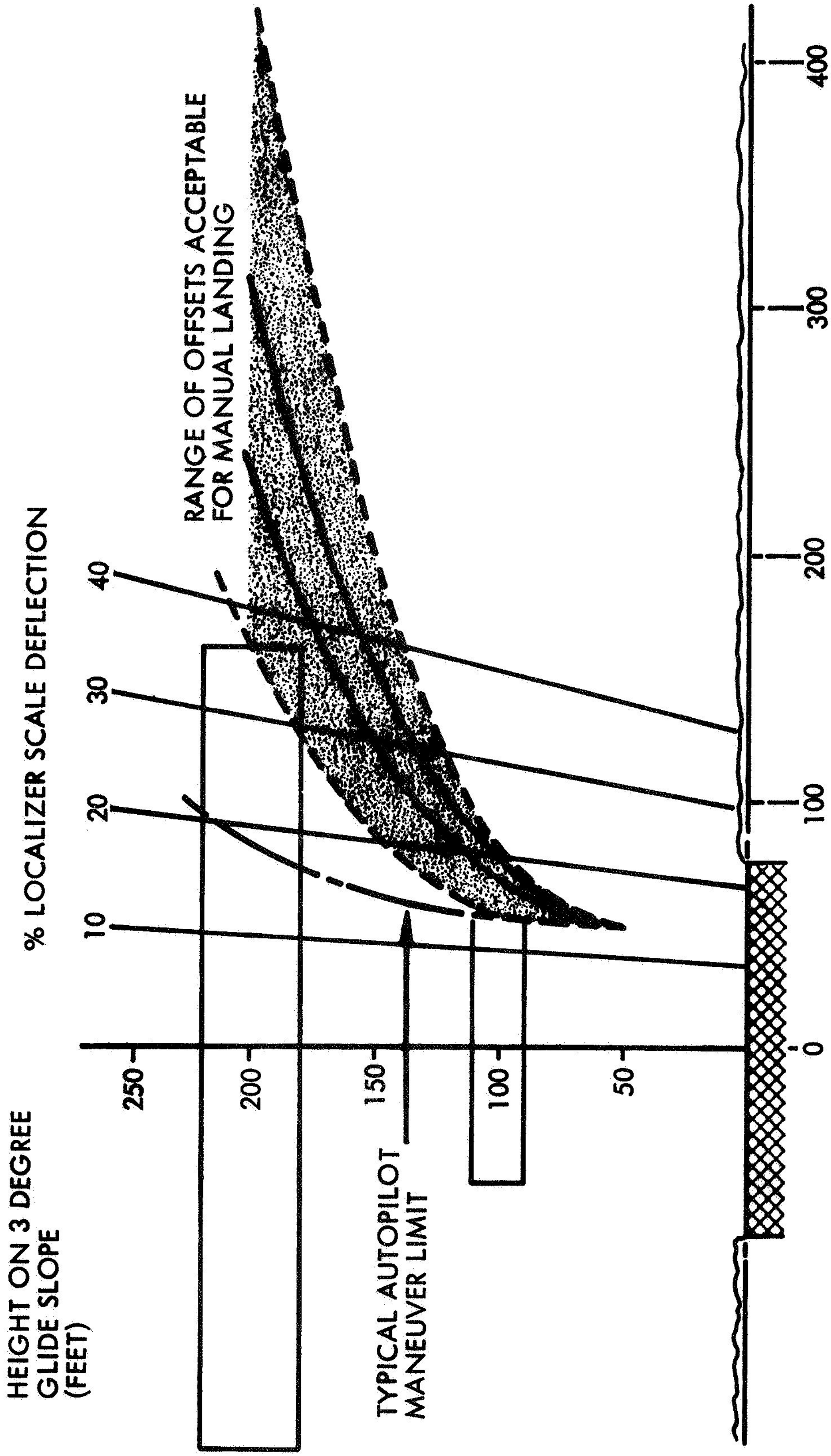


Figure 3. Lateral Displacement from Runway Centerline (Feet), Visual Acceptance Windows (Adapted from Ref. 1, Vol. I)

successful recoveries is due in part to the fact that pilots employed different degrees of roll angle in effecting the re-alignment. Note that a strict offset limit of approximately 50 feet is imposed if corrections are to be made by the autopilot with bank angle commands limited, as is usually the case at this point in the approach, to five degrees.

The pertinent implications of the foregoing are that an offset limit of ±50 feet may be a more appropriate criterial value for judging excessive cross-track error than the FAA standard of ±75 feet, and, perhaps more important, that criterial values should be based on a determination of offset distances from which pilots can comfortably perform lateral correction maneuvers in the SST. The data in Figure 3 were obtained using aircraft representative of conventional subsonic jet transports and should be derived again for the SST.

As Beck has indicated (ref. 2), it may be that pilots would not be willing to accept any degree of lateral displacement which would necessitate a correction at the 100-foot point:

> The first step that must be required to deliver this aircraft to the "success" gate at 100 feet will be the manner in which the crew operates the equipment. This then involves consideration of all the ramifications and techniques that will have to be employed in a mixed automatic/human environment where the airplane is flown to much tighter tolerances, because at the 100-foot point, the airplane must be "in the slot"; that is, aligned with the runway, on glide slope, on speed, at the proper sink rate, and stabilized. <u>There can be practically no side-step adjustment after becoming visual.</u>

Other analyses (ref. 1) have indicated that an uncorrected landing maneuver, committed on the basis of an indicated 20% localizer deviation, could miss the runway completely and that one committed with only a 10% deviation can result in a touchdown dangerously close to the edge of the runway. The problem here, then, is that there is currently considerable uncertainty with respect to the degree of lateral offset which should be judged "excessive" by the SST Captain. It is suggested that criterial values for this assessment be established on the basis of demonstrated pilot ability and willingness to manually execute a lateral correction from the decision height.

2. Can pilots accurately estimate lateral offset and tracking vectors by instrument reference?

This question is applicable to approach success assessments under both Category II and III conditions. It suggests that the expanded ILS localizer deviation information used as the primary basis for this assessment, together with basic flight situation instruments such as the heading indicator which may also be used, will not enable pilots to judge cross-track error and tracking tendencies to the required accuracies. An early indication of this potential problem emerged in Phase II of the joint FAA-USAF Pilot Factors Study of control-display concepts applicable to flying the SST under low visibility conditions (ref. 7). Phase II was conducted, in part, to examine advanced display concepts which would enable the pilot to manually fly the aircraft to the runway threshold on instruments. The following excerpt from the discussion of results provides a clear statement of the basic problem (underlining added):

> Control of the Cross-Track Component The lateral requirements for routine operation inside the middle marker demand more than keeping the aircraft within the center half of the runway. The lateral velocity vector of the aircraft becomes increasingly important to the success of the approach under 200 ft. For a constant approach speed the lateral velocity vector of the aircraft determines the direction and speed that it moves with respect to the runway centerline. As a consequence the cross-track component of the aircraft's lateral velocity vector must be maintained within tolerances about zero so that the aircraft will be moving parallel to the runway centerline upon breakout or, in the case of a touchdown on instruments, straight down the runway for roll-out. Certainly, there are trade-offs involved between displacement and the cross-track rate component. But in any event, there is no question but that both parameters must be controlled for successful operation inside the middle marker.

Localizer deviation showed that the standard flight director displays presented control information which was adequate with respect to lateral displacement inside the middle marker. However, the standard flight director configuration apparently did not provide the proper type of information to the pilot for maintaining the cross-track component of the aircraft's lateral velocity vector within tolerances. Indicative of this inadequacy was the finding that 12% of the coupled touchdowns, 16% of the semi-automatic touchdowns, and 32% of the manual touchdowns had a cross-track component of a magnitude that precluded a safe roll-out. A number of times, the hooded subject pilots expressed surprise upon a quick take-over at touchdown that such a cross-track component existed. Everything "looked good" on the panel.

This is understandable when one considers the information that the flight director presented and the way that it was displayed. The bank steering bar, when centered, was limited to telling the pilot that the aircraft was either on localizer or returning at the proper re-intercept rate. The pilot must necessarily devote a great deal of attention to the steering bars under 200 ft. because they are the primary control elements. On the horizontal situation indicator, displacement from localizer was presented by means of the Course Deviation Indicator (CDI). The rate of movement of the CDI reflected that rate at which the displacement was being incurred or reduced; this was an approximation of the lateral velocity vector. But either the location or the quality or a combination of both might have been the cause for the pilot's apparently not making use of the lateral rate information when he needed it. Heading information was presented by means of a card which rotated and a fixed index. Quite probably the display was too insensitive for presenting the quality of information required.

The problem related to maintaining the cross-track component of the lateral velocity vector within tolerances using just the standard flight director displays did not appear in the T-39 flying until the vertical path information requirements had been resolved. Even then the problem did not become evident until touchdown, because of the quick response of the T-39. The problem undoubtedly would appear further back along the approach with a heavier aircraft. Thus, attention should be devoted to satisfying this information requirement of the pilot in the lateral plane.

In the projected SST landing system, the integration of an expanded scale localizer deviation indicator into the ADI may improve the pilot's ability to estimate offset distance and cross-track velocities, but this possibility should be confirmed. Even with such display improvements, however, difficulties in assessing actual lateral offset and tracking tendencies remain due to localizer beam characteristics and the information processing required to translate indicated localizer deflections to offset distances in feet.

One set of problems stems from the well-documented sources of noise in the localizer signal. These include beam distortions produced by reflectance from large buildings and other objects in the airport surrounds, reflection interference from overflying aircraft, spurious transmissions due to atmosphere effects and interference from remote transmitters, transmitter drift, etc. Considerable effort is being devoted to monitoring such noise sources and to controlling their effects in the improved Category II ILS, but some problems remain. Other problems stem from the fact that information regarding displacement from the beam center is provided via localizer receivers as a signal proportional to <u>angular</u> displacement rather than linear displacement. Thus, a given offset distance from the centerline will produce a variable signal depending on the aircraft's distance from the transmitter. Since transmitters are typically installed at the far end of the instrument runway, the offset distance corresponding to a given beam displacement at any given distance from the runway threshold will vary as a function of runway length.

In order to determine actual offset distance, then, the Captain would require relative transmitter distance information, which will not be available, and would have to recall a complex conversion table for translating qualitative beam deviation indications into microamp displacements and then into offset distance in feet. It is, of course, unreasonable to assume that such data processing will occur. It is likely that deviation indications on the order of one-quarter dot or less will be accepted as providing adequate runway alignment until, under Category II conditions, track alignment and tracking can be confirmed by external visual reference. Potential problems in using visual cues are discussed next; the problem of accurately judging lateral offset and cross-track velocities under Category III conditions remains.

3. Can pilots accurately estimate lateral offset and tracking vectors using external visual cues?

This question is applicable only to an approach under Category II conditions wherein the Captain attempts to assess flight path alignment and tracking relative to the runway by reference to visual cues emerging in the extremely limited time period just prior to arrival at the decision height. It should be noted that the approach success judgment can be made solely on the basis of instrument reference and visual confirmation, strictly speaking, is not required. However, it will be recalled that the Captain is assumed to be "head up" at this point in the approach in order to assess the adequacy of exernal visual reference for the landing and it is further assumed that the compelling character of even fragmentary visual cues is such that they will influence his final judgment regarding flight path alignment. The potential problem here is that information available from these visual cues may prove to be a highly unreliable basis for judging flight path alignment, and, further, that the severe time constraints on resolving the judgment, together with psychological factors which can be expected to bias the judgment in favor of a positive assessment, will increase the already high error probability in this component of the approach success decision.

The general character of this problem from the pilot's viewpoint has been briefly outlined by Beck (ref. 2) as follows:

> No pilot under the stress of a Category II approach, should ever be required to mentally process and evaluate what he has seen in order to be able to recognize where he is. The above considerations now lead directly into the basic concept of tracking.
>
> You are doing one of three things: tracking on or parallel to, tracking away from, or tracking toward a desired path over the ground. When you're moving fast at a low altitude and the visibility is restricted, you can only determine where you are by first observing a known object such as a light, for example, then observing another light or series of them and comparing them, basically, with what you first saw.
>
> Experience has shown that, in order to do this, a pilot must see a horizontal segment of lights equivalent to about three seconds of reaction time, and in an aircraft approaching at 140 knots, he will require a length of at least 700 feet. To mentally digest this information, evaluate it, and decide whether you are or are not tracking as you wish to, may take a fraction of a second or it may take several seconds, depending on the clarity, readability and simplicity of your cues. You can even complicate and delay this decision by having your plane in the not uncommon position where it is yawed to the right due to a crosswind and the autopilot has placed the plane to the left of the centerline but is now correcting back to "on course" - you think! The cockpit slant range visibility is 810 feet and, as you approach the 100-foot decision point, your visual cues are appearing outside the window to the left.
>
> Now, are you tracking properly or not? From the 100-foot decision height to the threshold the pilot will have approximately six seconds, then another six seconds to touchdown. During the extremely short interval necessary to make the correct decision in this example, there is grave doubt whether a pilot can positively recognize a tracking tendency.

From British studies of low visibility conditions (ref. 8), it can be concluded that there is a high probability of achieving visual contact and a 500-foot visual segment prior to reaching the 100-foot decision height, with contact occurring in most instances (70%) at altitudes between 200 and 300 feet. These data suggest that the total elapsed time from the first "fade-in" of visual cues to arrival at the Category II decision height will be on the order of 10 to 15 seconds, assuming a nominal rate of descent of about 12 feet per second. During this time interval, which must be reduced to allow the pilot to transition from near-field to far-field viewing conditions and to acquire and recognize usable visual cues, the Captain must also assess his vertical situation and the adequacy of visual conditions for completing the landing maneuver under manual control. Potential problems in performing these assessment tasks are discussed in subsequent sections, but they are cited here to note that some time-sharing among flight management tasks will be necessary during this brief time interval, further reducing the time available for assessing flight path alignment with the runway.

It is anticipated, then, that pilots may experience considerable difficulty in extracting timely and accurate indicators of flight path alignment from visual cues expected to be available in Category II conditions. This problem is related to the problem of the adequacy of visual cues for assessing the vertical situation and the more general issue of what constitutes "adequate" visual reference for resolving the landing commitment decision. Discussions of these issues are given later in this report and are also applicable here.

Assessing Vertical Flight Path Alignment

The second major component of the approach success judgment is the determination that the aircraft's relative altitude (see above), vertical flight path angle, airspeed, and rate of descent are within appropriate limits for effecting a landing within the "touchdown zone". The touchdown zone is defined by the FAA (ref. 9) as the first 3000 feet of runway, beginning at the threshold, and in specifying Category II operating requirements this agency requires that a missed approach be initiated when a touchdown cannot be accomplished within this area. Somewhat more stringent constraints on the desired touchdown point have been suggested by other interested agencies. The Air Transport Association, in a proposed Advisory Circular to the FAA on Automatic Landing System Standards, dated 14 December 1966, calls for longitudinal touchdown dispersion limits of -300 feet to +1000 feet from a line on the runway which is the intersection of the linear extension of the glide slope with the runway. As an indication of preferred touchdown areas in current operations, the mean touchdown point of 1510 feet obtained in an FAA study of hundreds of jet landings by experienced pilots under visual conditions may be cited (ref. 10).

In any event, the Captain must be confident, prior to reaching the established decision height, that the landing can be completed within an acceptable distance from the threshold. On the basis of British studies of the adequacy of external visual reference for vertical flight path control, it is reasonable to assume that this assessment must be made solely by instrument reference. This point has been reiterated by Morrall in a recent paper (ref. 8):

> In making the decision whether to continue with the landing or not after becoming visual the pilot must assess not only his position relative to the ideal flight path but also his velocities, both cross-track and vertical, to determine where the aircraft is going. Whilst it is reasonable to expect a proficient pilot to be able to assess the aircraft's position and velocity in the horizontal plane by looking at a segment of approach lighting which includes only one cross bar, it is more difficult in the absence of the horizon, if not impossible, to make a similar assessment in the pitch plane from the same picture. Even gross errors may be difficult to detect in the time available after visual contact in operations to the lower decision heights of Category II. It is believed that visual control of the aeroplane in pitch begins

to become reliable when the pilot can see the threshold and does not become really good until he can see the point on the ground at which his approach path is heading. This means that to achieve high standards of safety in these low visibility conditions instrument guidance in pitch is required to heights of at least 100 feet.

In the projected SST landing system, the principal basis for making this judgment will be the glide slope deviation indicator and the direct readouts of airspeed, radio altitude, and vertical speed. Problems associated with the use of radio altitude displays for determining relative altitude have already been discussed. No direct representation of vertical flight path angle is available and no problems are anticipated in monitoring airspeed and vertical speed.

The potential problem associated with the use of these instruments to assess the vertical situation approaching the decision height is that the information provided will not allow the Captain to determine that his touchdown will occur within acceptable limits. Following an analysis of touchdown dispersion outlined by Osder (ref. 1), it can be shown that SST touchdowns can occur well beyond the 3000-foot touchdown zone even when the instruments accurately reflect the fact that the aircraft is precisely on the glide slope, maintaining appropriate airspeed and vertical velocity, and at the appropriate relative altitude as the aircraft arrives at the decision height. The basic elements of this analysis are indicated in Figure 4, which shows the path that would be followed by an aircraft initiating a flare from a 2.5 degree glide slope at approximately 50 feet. Assuming a glide slope intersection with the runway at about 1200 feet, notice that an ideal flare maneuver, executed to reduce sinkrate to about one foot/second, would result in a touchdown over 4000 feet down the runway.

This basic problem is well documented in the literature on proposed Category II landing systems employing existing ILS installations and it is generally conceded that lower minima touchdowns will occur at a

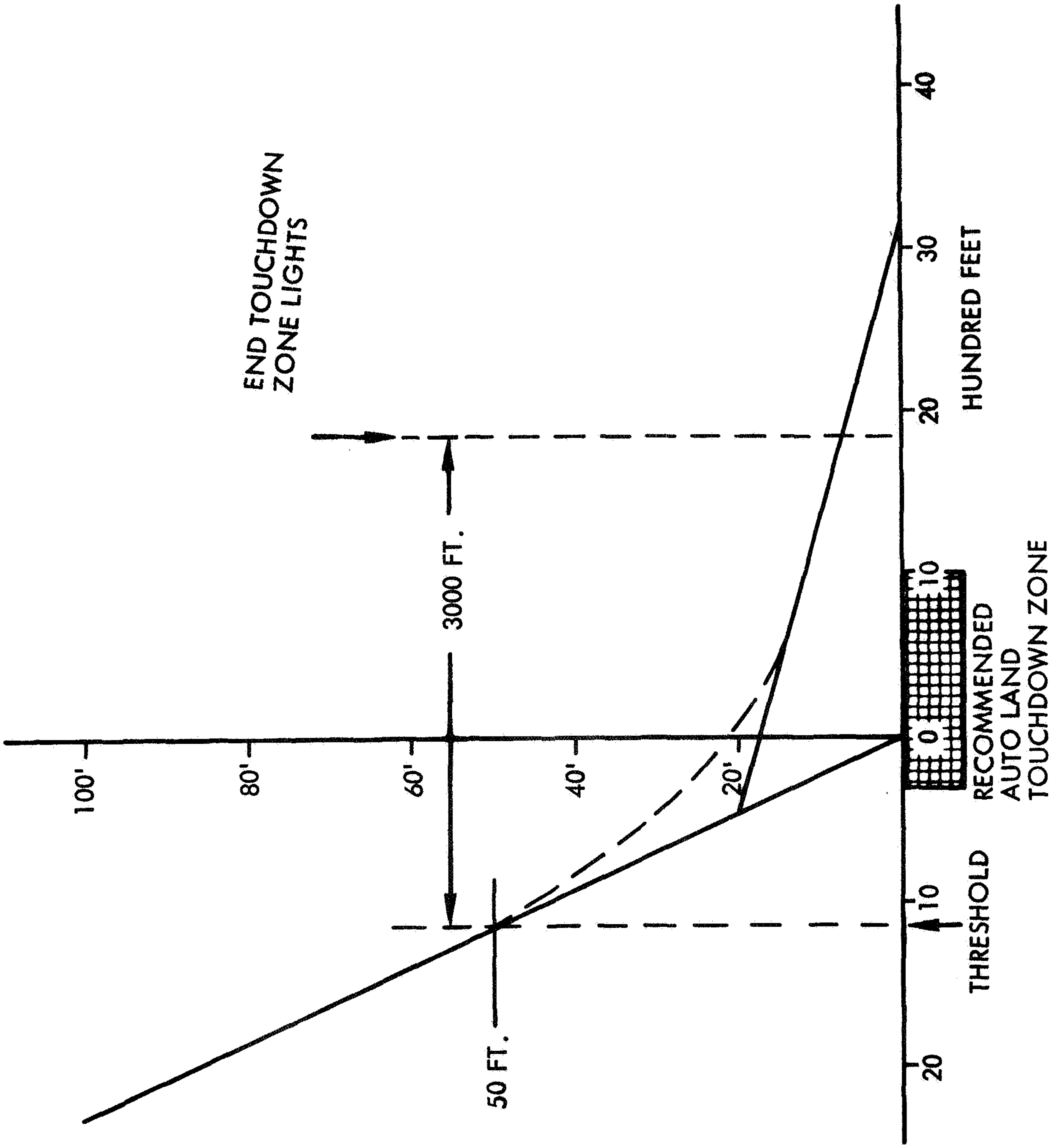


Figure 4. Touchdown Geometry for Soft Landing (from Ref. 1)

considerable distance down range of the glide slope intersection point. Lower minima flareout trajectories start tangent to the glide slope and thereafter always remain above it. Data reported by Litchford (ref. 4) indicates that glide slope intersection points range from about 700 feet to more than 1500 feet past the runway threshold, so the 1200 foot intersection used in Figure 4 is not unrealistic. When it is recalled that flare initiation will occur at 75 feet in the SST, rather than the 50 feet used in Osder's analysis, the present concern for the Captain's ability to assure a touchdown within the touchdown zone can be appreciated.

Pilots, of course, are concerned about stopping distances and prefer to touchdown much closer to the runway threshold, especially under low visibility conditions. In Category I conditions, this has been accomplished by performing a "duck under" maneuver as soon as adequate visual reference is achieved and prior to initiating the flare. As many writers have pointed out (refs. 4, 2, and 1), this maneuver cannot be tolerated under Category II conditions due to the rapid increase in sink rate that would occur close to the ground.

The problem posed here is one of enabling the Captain to determine that he can touchdown within acceptable longitudinal distance limits before he is committed to land. It should be clear, however, that this is one of the major unresolved issues in achieving acceptable low visibility landing objectives and will also affect flight management tasks in assessing the initiation and execution of the landing maneuver. This maneuver and the wind conditions under which it is performed will, of course, finally determine where the aircraft will touchdown. Potential problems associated with its management are outlined in a later section.

APPENDIX B

RUN SCHEDULE

AND

SPECIFICATION OF RUN CONDITIONS

Subject #1 Schedule Date/Time: ____________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
1	FA	P-1	TP-1	Calm	1200	145	95
2	FA	P-6	TP-3	051/15	1200	135	85
3	FA	P-8	TP-2	321/15	1600	190	140
4	SA	P-4	TP-1	186/10	1600	145	95
5	SA	P-5	TP-2	Calm	1600	190	140
6	FM		TP-3	321/15	1200	135	85
7	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
8	FA	P-6	TP-3	051/15	1200	135	85
9	FA	P-2	TP-2	051/15	1600	190	140
10	FA	P-4	TP-1	186/10	1600	145	95
11	FA	P-7	TP-1	186/10	1200	145	95
12	FA	P-3	TP-3	321/15	1200	135	85
13	FA	P-1	TP-1	Calm	1200	145	95
14	FA	P-8	TP-2	321/15	1600	190	140
15	FA	P-5	TP-2	Calm	1600	190	140
16	FA	P-9	TP-3	Calm	1200	135	85
17*	SA	P-2	TP-2	051/15	1600	190	140
18	SA	P-4	TP-1	186/10	1600	145	95
19	SA	P-5	TP-2	Calm	1600	190	140
20	SA	P-3	TP-3	321/15	1200	135	85
21	SA	P-9	TP-3	Calm	1200	135	85
22	SA	P-6	TP-3	051/15	1200	135	85
23	SA	P-8	TP-2	321/15	1600	190	140
24	SA	P-7	TP-1	186/10	1200	145	95
25	SA	P-1	TP-1	Calm	1200	145	95
26	FM		TP-1	186/10	1600	145	95
27	FM		TP-2	Calm	1600	190	140
28	FM		TP-3	321/15	1200	135	85
29	FM		TP-1	186/10	1200	145	95
30	FM		TP-3	051/15	1200	135	85
31	FM		TP-1	Calm	1200	145	95
32	FM		TP-2	051/15	1600	190	140
33	FM		TP-3	Calm	1200	135	85
34	FM		TP-2	321/15	1600	190	140

*Two refresher runs will be completed prior to the execution of run #17. Run conditions for these runs will be as specified for runs 17 and 26.

Subject # 2 Schedule Date / Time: ____________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
35	FA	P-1	TP-1	Calm	1200	145	95
36	FA	P-6	TP-3	051/15	1200	135	85
37	FA	P-8	TP-2	321/15	1600	190	140
38	SA	P-4	TP-1	186/10	1600	145	95
39	SA	P-5	TP-2	Calm	1600	190	140
40	FM		TP-3	321/15	1200	135	85
41	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
42	FM		TP-2	051/15	1600	190	140
43	FM		TP-2	Calm	1600	190	140
44	FM		TP-1	Calm	1200	145	95
45	FM		TP-3	051/15	1200	135	85
46	FM		TP-3	321/15	1200	135	85
47	FM		TP-1	186/10	1600	145	95
48	FM		TP-1	186/10	1200	145	95
49	FM		TP-3	Calm	1200	135	85
50*	FM		TP-2	321/15	1600	190	140
51	SA	P-6	TP-3	051/15	1200	135	85
52	SA	P-5	TP-2	Calm	1600	190	140
53	SA	P-1	TP-1	Calm	1200	145	95
54	SA	P-7	TP-1	186/10	1200	145	95
55	SA	P-9	TP-3	Calm	1200	135	85
56	SA	P-2	TP-2	051/15	1600	190	140
57	SA	P-8	TP-2	321/15	1600	190	140
58	SA	P-3	TP-3	321/15	1200	135	85
59	SA	P-4	TP-1	186/10	1600	145	95
60	FA	P-5	TP-2	Calm	1600	190	140
61	FA	P-6	TP-3	051/15	1200	135	85
62	FA	P-7	TP-1	186/10	1200	145	95
63	FA	P-4	TP-1	186/10	1600	145	95
64	FA	P-8	TP-2	321/15	1600	190	140
65	FA	P-9	TP-3	Calm	1200	135	85
66	FA	P-2	TP-2	051/15	1600	190	140
67	FA	P-3	TP-3	321/15	1200	135	85
68	FA	P-1	TP-1	Calm	1200	145	95

*Two refresher runs will be completed prior to the execution of run #51. Run conditions for these runs will be as specified for runs 51 and 60.

Subject # 3 Schedule Date / Time: ____________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
69	FA	P-1	TP-1	Calm	1200	145	95
70	FA	P-6	TP-3	051/15	1200	135	85
71	FA	P-8	TP-2	321/15	1600	190	140
72	SA	P-4	TP-1	186/10	1600	145	95
73	SA	P-5	TP-2	Calm	1600	190	140
74	FM		TP-3	321/15	1200	135	85
75	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
76	FA	P-8	TY-2	321/15	1600	190	140
77	FA	P-4	TP-1	186/10	1600	145	95
78	FA	P-2	TP-2	051/15	1600	190	140
79	FA	P-5	TP-2	Calm	1600	190	140
80	FA	P-7	TP-1	186/10	1200	145	95
81	FA	P-1	TP-1	Calm	1200	145	95
82	FA	P-3	TP-3	321/15	1200	135	85
83	FA	P-9	TP-3	Calm	1200	135	85
84	FA	P-6	TP-3	051/15	1200	135	85
85*	FM		TP-3	051/15	1200	135	85
86	FM		TP-2	051/15	1600	190	140
87	FM		TP-2	Calm	1600	190	140
88	FM		TP-3	Calm	1200	135	85
89	FM		TP-1	186/10	1200	145	95
90	FM		TP-1	Calm	1200	145	95
91	FM		TP-3	321/15	1200	135	85
92	FM		TP-1	186/10	1600	145	95
93	FM		TP-2	321/15	1600	190	140
94	SA	P-5	TP-2	Calm	1600	190	140
95	SA	P-7	TP-1	186/10	1200	145	95
96	SA	P-2	TP-2	051/15	1600	190	140
97	SA	P-9	TP-3	Calm	1200	135	85
98	SA	P-6	TP-3	051/15	1200	135	85
99	SA	P-8	TP-2	321/15	1600	190	140
100	SA	P-4	TP-1	186/10	1600	145	95
101	SA	P-3	TP-3	321/15	1200	135	85
102	SA	P-1	TP-1	Calm	1200	145	95

*Two refresher runs will be completed prior to the execution of run #85. Run conditions for these runs will be as specified for runs 85 and 94.

Subject #4 Schedule Date/Time: ____________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
103	FA	P-1	TP-1	Calm	1200	145	95
104	FA	P-6	TP-3	051/15	1200	135	85
105	FA	P-8	TP-2	321/15	1600	190	140
106	SA	P-4	TP-1	186/10	1600	145	95
107	SA	P-5	TP-2	Calm	1600	190	140
108	FM		TP-3	321/15	1200	135	85
109	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
110	SA	P-5	TP-2	Calm	1600	190	140
111	SA	P-3	TP-3	321/15	1200	135	85
112	SA	P-4	TP-1	186/10	1600	145	95
113	SA	P-6	TP-3	051/15	1200	135	85
114	SA	P-2	TP-2	051/15	1600	190	140
115	SA	P-7	TP-1	186/10	1200	145	95
116	SA	P-8	TP-2	321/15	1600	190	140
117	SA	P-9	TP-3	Calm	1200	135	85
118	SA	P-1	TP-1	Calm	1200	145	95
119*	FA	P-4	TP-1	186/10	1600	145	95
120	FA	P-9	TP-3	Calm	1200	135	85
121	FA	P-6	TP-3	051/15	1200	135	85
122	FA	P-8	TP-2	321/15	1600	190	140
123	FA	P-1	TP-1	Calm	1200	145	95
124	FA	P-5	TP-2	Calm	1600	190	140
125	FA	P-7	TP-1	186/10	1200	145	95
126	FA	P-2	TP-2	051/15	1600	190	140
127	FA	P-3	TP-3	321/15	1200	135	85
128	FM		TP-2	321/15	1600	190	140
129	FM		TP-3	321/15	1200	135	85
130	FM		TP-2	051/15	1600	190	140
131	FM		TP-1	186/10	1600	145	95
132	FM		TP-3	Calm	1200	135	85
133	FM		TP-3	051/15	1200	135	85
134	FM		TP-1	186/10	1200	145	95
135	FM		TP-1	Calm	1200	145	95
136	FM		TP-2	Calm	1600	190	140

*Two refresher runs will be completed prior to the execution of run #119. Run conditions for these runs will be as specified for runs 119 and 128.

Subject #5 Schedule Date/Time:______________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
137	FA	P-1	TP-1	Calm	1200	145	95
138	FA	P-6	TP-3	051/15	1200	135	85
139	FA	P-8	TP-2	321/15	1600	190	140
140	SA	P-4	TP-1	186/10	1600	145	95
141	SA	P-5	TP-2	Calm	1600	190	140
142	FM		TP-3	321/15	1200	135	85
143	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
144	FA	P-6	TP-3	051/15	1200	135	85
145	FA	P-2	TP-2	051/15	1600	190	140
146	FA	P-4	TP-1	186/10	1600	145	95
147	FA	P-7	TP-1	186/10	1200	145	95
148	FA	P-3	TP-3	321/15	1200	135	85
149	FA	P-1	TP-1	Calm	1200	145	95
150	FA	P-8	TP-2	321/15	1600	190	140
151	FA	P-5	TP-2	Calm	1600	190	140
152	FA	P-9	TP-3	Calm	1200	135	85
153*	SA	P-2	TP-2	051/15	1600	190	140
154	SA	P-4	TP-1	186/10	1600	145	95
155	SA	P-5	TP-2	Calm	1600	190	140
156	SA	P-3	TP-3	321/15	1200	135	85
157	SA	P-9	TP-3	Calm	1200	135	85
158	SA	P-6	TP-3	051/15	1200	135	85
159	SA	P-8	TP-2	321/15	1600	190	140
160	SA	P-7	TP-1	186/10	1200	145	95
161	SA	P-1	TP-1	Calm	1200	145	95
162	FM		TP-1	186/10	1600	145	95
163	FM		TP-2	Calm	1600	190	140
164	FM		TP-3	321/15	1200	135	85
165	FM		TP-1	186/10	1200	145	95
166	FM		TP-3	051/15	1200	135	85
167	FM		TP-1	Calm	1200	145	95
168	FM		TP-2	051/15	1600	190	140
169	FM		TP-3	Calm	1200	135	85
170	FM		TP-2	321/15	1600	190	140

*Two refresher runs will be completed prior to the execution of run #153. Run conditions for these runs will be as specified for runs 153 and 162.

Subject #6 Schedule Date/Time: ______________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
171	FA	P-1	TP-1	Calm	1200	145	95
172	FA	P-6	TP-3	051/15	1200	135	85
173	FA	P-8	TP-2	321/15	1600	190	140
174	SA	P-4	TP-1	186/10	1600	145	95
175	SA	P-5	TP-2	Calm	1600	190	140
176	FM		TP-3	321/15	1200	135	85
177	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
178	FM		TP-2	051/15	1600	190	140
179	FM		TP-2	Calm	1600	190	140
180	FM		TP-1	Calm	1200	145	95
181	FM		TP-3	051/15	1200	135	85
182	FM		TP-3	321/15	1200	135	85
183	FM		TP-1	186/10	1600	145	95
184	FM		TP-1	186/10	1200	145	95
185	FM		TP-3	Calm	1200	135	85
186	FM		TP-2	321/15	1600	190	140
187*	SA	P-6	TP-3	051/15	1200	135	85
188	SA	P-5	TP-2	Calm	1600	190	140
189	SA	P-1	TP-1	Calm	1200	145	95
190	SA	P-7	TP-1	186/10	1200	145	95
191	SA	P-9	TP-3	Calm	1200	135	85
192	SA	P-2	TP-2	051/15	1600	190	140
193	SA	P-8	TP-2	321/15	1600	190	140
194	SA	P-3	TP-3	321/15	1200	135	85
195	SA	P-4	TP-1	186/10	1600	145	95
196	FA	P-5	TP-2	Calm	1600	190	140
197	FA	P-6	TP-3	051/15	1200	135	85
198	FA	P-7	TP-1	186/10	1200	145	95
199	FA	P-4	TP-1	186/10	1600	145	95
200	FA	P-8	TP-2	321/15	1600	190	140
201	FA	P-9	TP-3	Calm	1200	135	85
202	FA	P-2	TP-2	051/15	1600	190	140
203	FA	P-3	TP-3	321/15	1200	135	85
204	FA	P-1	TP-1	Calm	1200	145	95

*Two refresher runs will be completed prior to the execution of run #187. Run conditions for these runs will be as specified for runs 187 and 196.

Subject # 7 Schedule Date / Time: ____________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
205	FA	P-1	TP-1	Calm	1200	145	95
206	FA	P-6	TP-3	051/15	1200	135	85
207	FA	P-8	TP-2	321/15	1600	190	140
208	SA	P-4	TP-1	186/10	1600	145	95
209	SA	P-5	TP-2	Calm	1600	190	140
210	FM		TP-3	321/15	1200	135	85
211	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
212	FA	P-8	TY-2	321/15	1600	190	140
213	FA	P-4	TP-1	186/10	1600	145	95
214	FA	P-2	TP-2	051/15	1600	190	140
215	FA	P-5	TP-2	Calm	1600	190	140
216	FA	P-7	TP-1	186/10	1200	145	95
217	FA	P-1	TP-1	Calm	1200	145	95
218	FA	P-3	TP-3	321/15	1200	135	85
219	FA	P-9	TP-3	Calm	1200	135	85
220	FA	P-6	TP-3	051/15	1200	135	85
221*	FM		TP-3	051/15	1200	135	85
222	FM		TP-2	051/15	1600	190	140
223	FM		TP-2	Calm	1600	190	140
224	FM		TP-3	Calm	1200	135	85
225	FM		TP-1	186/10	1200	145	95
226	FM		TP-1	Calm	1200	145	95
227	FM		TP-3	321/15	1200	135	85
228	FM		TP-1	186/10	1600	145	95
229	FM		TP-2	321/15	1600	190	140
230	SA	P-5	TP-2	Calm	1600	190	140
231	SA	P-7	TP-1	186/10	1200	145	95
232	SA	P-2	TP-2	051/15	1600	190	140
233	SA	P-9	TP-3	Calm	1200	135	85
234	SA	P-6	TP-3	051/15	1200	135	85
235	SA	P-8	TP-2	321/15	1600	190	140
236	SA	P-4	TP-1	186/10	1600	145	95
237	SA	P-3	TP-3	321/15	1200	135	85
238	SA	P-1	TP-1	Calm	1200	145	95

*Two refresher runs will be completed prior to the execution of run #221. Run conditions for these runs will be as specified for runs 221 and 230.

Subject # 8 Schedule Date / Time: ____________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
239	FA	P-1	TP-1	Calm	1200	145	95
240	FA	P-6	TP-3	051/15	1200	135	85
241	FA	P-8	TP-2	321/15	1600	190	140
242	SA	P-4	TP-1	186/10	1600	145	95
243	SA	P-5	TP-2	Calm	1600	190	140
244	FM		TP-3	321/15	1200	135	85
245	FM		TP-3	Calm	1200	135	85
			(Experimental Series)				
246	SA	P-5	TP-2	Calm	1600	190	140
247	SA	P-3	TP-3	321/15	1200	135	85
248	SA	P-4	TP-1	186/10	1600	145	95
249	SA	P-6	TP-3	051/15	1200	135	85
250	SA	P-2	TP-2	051/15	1600	190	140
251	SA	P-7	TP-1	186/10	1200	145	95
252	SA	P-8	TP-2	321/15	1600	190	140
253	SA	P-9	TP-3	Calm	1200	135	85
254	SA	P-1	TP-1	Calm	1200	145	95
255*	FA	P-4	TP-1	186/10	1600	145	95
256	FA	P-9	TP-3	Calm	1200	135	85
257	FA	P-6	TP-3	051/15	1200	135	85
258	FA	P-8	TP-2	321/15	1600	190	140
259	FA	P-1	TP-1	Calm	1200	145	95
260	FA	P-5	TP-2	Calm	1600	190	140
261	FA	P-7	TP-1	186/10	1200	145	95
262	FA	P-2	TP-2	051/15	1600	190	140
263	FA	P-3	TP-3	321/15	1200	135	85
264	FM		TP-2	321/15	1600	190	140
265	FM		TP-3	321/15	1200	135	85
266	FM		TP-2	051/15	1600	190	140
267	FM		TP-1	186/10	1600	145	95
268	FM		TP-3	Calm	1200	135	85
269	FM		TP-3	051/15	1200	135	85
270	FM		TP-1	186/10	1200	145	95
271	FM		TP-1	Calm	1200	145	95
272	FM		TP-2	Calm	1600	190	140

*Two refresher runs will be completed prior to the execution of run #255. Run conditions for these runs will be as specified for runs 255 and 264.

Subject #9 Schedule Date / Time: ____________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
273	FA	P-1	TP-1	Calm	1200	145	95
274	FA	P-6	TP-3	051/15	1200	135	85
275	FA	P-8	TP-2	321/15	1600	190	140
276	FA	P-4	TP-1	186/10	1600	145	95
277	FA	P-5	TP-2	Calm	1600	190	140
278	FA	P-3	TP-3	321/15	1200	135	85
279	FA	P-9	TP-3	Calm	1200	135	85
			(Experimental Series)				
280	FA	P-6	TP-3	051/15	1200	135	85
281	FA	P-2	TP-2	051/15	1600	190	140
282	FA	P-4	TP-1	186/10	1600	145	95
283	FA	P-7	TP-1	186/10	1200	145	95
284	FA	P-3	TP-3	321/15	1200	135	85
285	FA	P-1	TP-1	Calm	1200	145	95
286	FA	P-8	TP-2	321/15	1600	190	140
287	FA	P-5	TP-2	Calm	1600	190	140
288	FA	P-9	TP-3	Calm	1200	135	85

Subject #10 Schedule Date/Time:________________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
289	FA	P-1	TP-1	Calm	1200	145	95
290	FA	P-6	TP-3	051/15	1200	135	85
291	FA	P-8	TP-2	321/15	1600	190	140
292	FA	P-4	TP-1	186/10	1600	145	95
293	FA	P-5	TP-2	Calm	1600	190	140
294	FA	P-3	TP-3	321/15	1200	135	85
295	FA	P-9	TP-3	Calm	1200	135	85
			(Experimental Series)				
296	FA	P-2	TP-2	051/15	1600	190	140
297	FA	P-5	TP-2	Calm	1600	190	140
298	FA	P-1	TP-1	Calm	1200	145	95
299	FA	P-6	TP-3	051/15	1200	135	85
300	FA	P-3	TP-3	321/15	1200	135	85
301	FA	P-4	TP-1	186/10	1600	145	95
302	FA	P-7	TP-1	186/10	1200	145	95
303	FA	P-9	TP-3	Calm	1200	135	85
304	FA	P-8	TP-2	321/15	1600	190	140

Subject # 11 Schedule Date / Time: ____________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
305	FA	P-1	TP-1	Calm	1200	145	95
306	FA	P-6	TP-3	051/15	1200	135	85
307	FA	P-8	TP-2	321/15	1600	190	140
308	FA	P-4	TP-1	186/10	1600	145	95
309	FA	P-5	TP-2	Calm	1600	190	140
310	FA	P-3	TP-3	321/15	1200	135	85
311	FA	P-9	TP-3	Calm	1200	135	85
			(Experimental Series)				
312	FA	P-8	TP-2	321/15	1600	190	140
313	FA	P-4	TP-1	186/10	1600	145	95
314	FA	P-2	TP-2	051/15	1600	190	140
315	FA	P-5	TP-2	Calm	1600	190	140
316	FA	P-7	TP-1	186/10	1200	145	95
317	FA	P-1	TP-1	Calm	1200	145	95
318	FA	P-3	TP-3	321/15	1200	135	85
319	FA	P-9	TP-3	Calm	1200	135	85
320	FA	P-6	TP-3	051/15	1200	135	85

Subject #12 Schedule Date /Time:______________

Run #	Control Mode	Approach Profile	Terrain Profile	Wind Vector	RVR	Audio Alert	MDA
			(Practice Series)				
321	FA	P-1	TP-1	Calm	1200	145	95
322	FA	P-6	TP-3	051/15	1200	135	85
323	FA	P-8	TP-2	321/15	1600	190	140
324	FA	P-4	TP-1	186/10	1600	145	95
325	FA	P-5	TP-2	Calm	1600	190	140
326	FA	P-3	TP-3	321/15	1200	135	85
327	FA	P-9	TP-3	Calm	1200	135	85
			(Experimental Series)				
328	FA	P-5	TP-2	Calm	1600	190	140
329	FA	P-3	TP-3	321/15	1200	135	85
330	FA	P-4	TP-1	186/10	1600	145	95
331	FA	P-6	TP-3	051/15	1200	135	85
332	FA	P-2	TP-2	051/15	1600	190	140
333	FA	P-7	TP-1	186/10	1200	145	95
334	FA	P-8	TP-2	321/15	1600	190	140
335	FA	P-9	TP-3	Calm	1200	135	85
336**	FA	P-1	TP-1	Calm	1200	145	95

**The sixteen refresher runs completed in Ss 1 through 8 brings the total number of runs to 352.

APPENDIX C

SUBJECT ORIENTATION BOOKLET AND BACKGROUND DATA COLLECTION SHEET

ORIENTATION

The Man-Machine Integration Branch here at the NASA Ames Research Center is engaged in a broad program of research concerned with flight crew factors in the operation of commercial jet transport aircraft. The study you have been asked to participate in today is being carried out by Serendipity, Inc., under contract to Ames and is one of a series of simulation research projects designed to examine the duties and responsibilities of the pilot-in-command during Category II approach and landing operations. You are one of the twelve pilots who were specially selected to help us obtain valid and operationally relevant data from the simulation and to promote acceptance of study results by the aviation community.

Our principal objective in conducting this study is to determine how well command pilots in heavy turbojet aircraft will be supported in their role as monitors and decision makers by the "information environment" projected for a baseline SST instrumented for Category II approach and landing. This information environment is comprised, primarily, of flight deck instruments and auditory displays (e.g., aural warning signals and radio voice communications). It also includes flight planning information and in-flight reference materials such as Approach Charts and flight data sheets. We have attempted to represent this information environment in one of Ames' piloted, fixed base flight simulators and we are going to ask you to serve as the pilot-in-command on a series of simulated approach and landing sequences.

It should be clearly understood that the study is not intended, in any sense, to evaluate the quality of your judgmental or decision making abilities as an individual pilot. Your job will be to carry out certain approach management and flight control tasks under the conditions represented in the simulator. You will be asked to make certain assessments of the aircraft's flight path during the approach, to judge the success of the approach in terms of your relative position and tracking vector at the decision height, and to execute the landing maneuver through the touchdown and roll out on the runway. Data taken on each simulation run will be used to determine the accuracy and timeliness of the assessments and decisions you are asked to make. As noted above, the analyses are designed to evaluate the information and displays made available to you as the basis for your judgments and not to assess your individual skills and abilities. Control techniques were deliberately included in the study design so that the contribution of individual differences among pilots to the study results could be systematically accounted for in the data analysis.

The material presented in this booklet is intended to provide you with an overview of what to expect during the rest of the session, to briefly identify the simulated equipment and operating conditions, and to outline the tasks you will perform as a subject in this experiment. If you would like to know more about the aims of the study, we will be happy to discuss your interests with you after the completion of the experiment. The availability of your experience, skills, and knowledge is an important element in the success of our investigation and we appreciate your contribution of time and effort. We would like to thank you for participating in this project.

Background Data

Before proceeding to the more specific orientation material, please complete the brief Background Data Sheet attached to this booklet. The information requested is of interest only to the project staff and will be used in subsequent interpretations of study results. You will not be identified by name in the publication of study results and data records for designated individuals will not be released to outside agencies or individuals. This also applies to any comments you may make during the course of the day or to opinions you will be asked to express during the debriefing session following the completion of the simulator run series.

General Time Commitment and Schedule of Activities

You are scheduled to fly a total of 36 runs in the simulator today. As soon as this orientation session is over we will proceed to the simulator crew compartment and carry out a series of seven practice runs. After a brief coffee break we will then complete the first nine runs of the experimental series for the record. Following lunch, we'll let you fly two refresher runs before completing the last two experimental series of nine runs each. A debriefing session will then be conducted back here in this area and that will complete the day's activities.

It will take a full day to complete this schedule. Barring unforeseen incidents or delays, the schedule should work out as outlined on the next page.

0830 - 0915:	Orientation to study
0915 - 0930:	Coffee break - proceed to simulator
0930 - 1030:	Simulator familiarization & practice run series
1030 - 1130:	Complete first experimental run series
1130 - 1230:	Lunch
1230 - 1245:	Complete two refresher runs
1245 - 1345:	Complete second experimental run series
1345 - 1400:	Break
1400 - 1500:	Complete third experimental run series
1500 - 1515:	Break - return to briefing area
1515 - 1600:	Debriefing

Flight Sequence and Equipment Represented in the Simulation

The operational context represented in the simulator runs is an ILS approach and landing under Category II conditions on runway 1R at Dulles International Airport. Each run in the simulator will represent the execution of a flight sequence beginning with the aircraft at approximately eight nautical miles from the runway, stabilized on the localizer course, and maintaining the assigned initial approach altitude. This sequence ends with the aircraft on the runway decelerating to a nominal turn-off speed. A copy of the current Jeppesen Approach Chart for Dulles will be provided by the Experimenter.

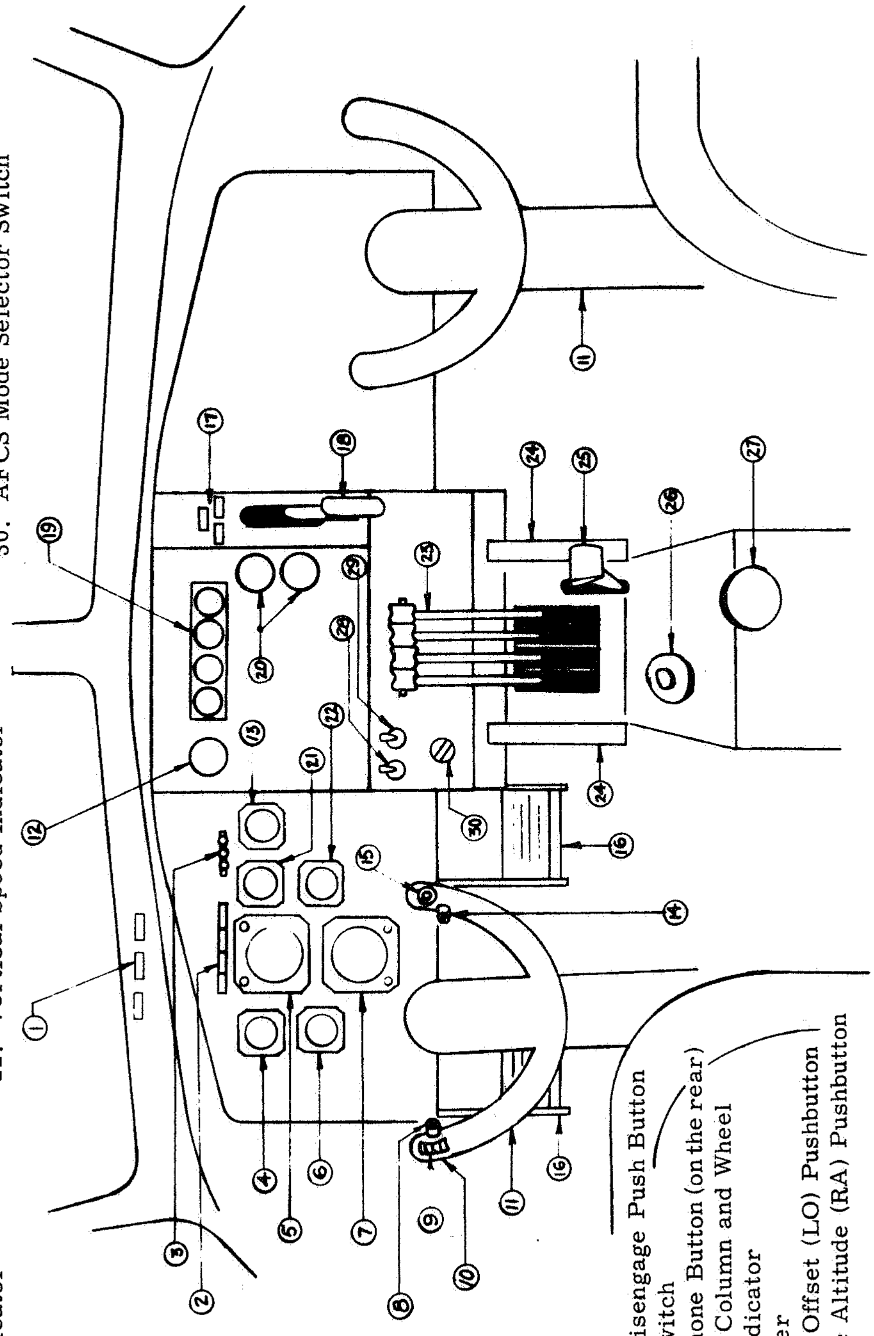
Aircraft response characteristics and flight control system dynamics represented in the simulation are those of the DC-8 airplane. The crew compartment is a conventional transport-type cab mounted on a stationary raised platform (no motion cues are provided). You will occupy the Captain's seat and function as the pilot-in-command on all runs. In contrast to the training simulators you have flown, our research simulator will probably appear to be somewhat austere. No attempt has been made to reproduce the flight deck configuration for any particular aircraft type and a full complement of instrumentation and controls is not provided. The instrumentation and controls which will be available to you are identified in Figure C-1. Flight instrumentation and controls on the Captain's side were selected to support the approach management and flight control tasks you will be asked to perform. Some additional instruments and controls are available on the center panel and aisle control stand, but the First Officer's station is not fully represented and the instruments and controls typically available on overhead panels, side panels, and the control panels mounted on the aisle control stand are not available in the simulator.

Detailed familiarization with these instruments and controls will be given at the simulator; however the equipment characteristics outlined below should be noted and if you have any general questions we will attempt to resolve them at this time.

1. Primary flight situation and command information is provided by the Collins FD-109 Integrated Flight System. (The principal features of this system are illustrated in the booklet provided by the Experimenter.)

2. The limit marks on each side of the expanded localizer scale represent 1/4 dot displacement (about 20 micro-amps) on the conventional localizer deviation indicator on the Course Indicator.

3. Three different flight control modes will be used in the run series. With the AFCS MODE SELECT control set to AUTO (AFCS refers to the Automatic Flight Control System), a fully coupled control mode is represented (i.e., both localizer and glide slope tracking will be accomplished by the autopilot). When ROLL ONLY is selected, a split-axis autopilot mode is represented



1. Touchdown Indicators
2. Approch Progress Indicators
3. Marker Beacon Indicators
4. Airspeed Indicator
5. Flight Director Indicator
6. Clock
7. Course Indicator
8. AFCS Disengage Push Button
9. Trim Switch
10. Microphone Button (on the rear)
11. Control Column and Wheel
12. Trim Indicator
13. Altimeter
14. Lateral Offset (LO) Pushbutton
15. Relative Altitude (RA) Pushbutton
16. Rudder Pedal
17. Landing Gear Position Indicators
18. Landing Gear Control Handle
19. Thrust Indicators
20. Flap Position Indicators
21. Radio Altitude Indicator
22. Vertical Speed Indicator
23. Thrust Levers
24. Elevator Trim Wheel
25. Flap Position Control
26. Rudder Trim Wheel
27. Aileron Trim Wheel
28. Auto Throttle Engage/Disengage Switch
29. Command Airspeed Selection Switch
30. AFCS Mode Selector Switch

Figure C-1 Flight Instruments and Controls Provided at the Subject-Pilot's Station wherein localizer tracking continues to be automatic, while manual control via the control column is assumed in the pitch axis. (In some aircraft this mode is selected by placing an autopilot control in an "elevator disconnect" or "pitch disengage" position.) The OFF position is used when full manual control in both pitch and roll axes is called for (i.e., the autopilot is either not engaged or is used for stability augmentation only).

4. An autothrottle function is also simulated. When the A/T control is in the ON position, the selected command airspeed (CMD AS SELECT) will be maintained to within ±5 kts automatically. It should be noted, however, that in the simulator this will not be accomplished by automatic positioning of the throttle levers.

The simulator is also equipped with a Visual Flight Attachment which will provide you with a color TV projection of the runway and its surrounds. Since Category II conditions will be represented, (1200' RVR on some runs, 1600' RVR on others) an "in-cloud" condition will be simulated until the aircraft is sufficently close to the approach lights and/or runway for visual cues to fade-in. Configuration "A" approach lights will be simulated with sequenced flashing lights, hi-intensity runway lights, touchdown zone lights, and runway center-line lights also available.

Operating Procedure

Your role in the simulation sequence, as already indicated, will be to act as pilot-in-command and to carry out designated flight management and control tasks. We are primarily interested in your ongoing assessment of the success of the approach to the decision height (DH). At specified points in the sequence you will indicate the outcome of judgments you make regarding the aircraft's lateral offset from the assigned approach course, its relative altitude (i.e., height above the runway touchdown zone), and its tracking vector (i.e., alignment of the aircraft's flight path with the approach course). On every run, regardless of the aircraft's offset position at the DH, when you determine that you are precisely at the 100-foot DH you will disengage the AFCS, if it is engaged, and execute the landing maneuver under manual control.

The general procedures you will follow on each run are outlined below. Variations in flight control mode and environmental conditions will occur from run to run and the effects of these variations on the procedures to be followed are noted where applicable. You will be exercised in carrying out these procedures in the simulator prior to performing the experimental series. An experimenter (E) will be present in the cab to monitor and coordinate the simulation sequence on each run. E will brief you on run conditions and will simulate the radio voice communications normally handled by the First Officer (FO). At the start of each run the simulator will be appropriately positioned and at the initial approach altitude. The simulation will go dynamic immediately after E gives you your approach clearance (item 4 below).

1. Receive briefing on run conditions. E will identify the control mode (fully automatic, split-axis, or fully manual) and the approach terrain profile for the designated run. One of three alternate terrain profiles will be specified: (1) "Level-95'" - this is the actual terrain profile at Dulles, 95' is the Radio Altitude specified on the approach chart for the glide slope height at the 100' DH (Inner Marker); (2) "Low-140'" - this is the first variation and represents a drop in terrain elevation to -40' relative altitude, the Radio Altitude cited on the Approach Chart for this profile

would thus be 140'; (3) "High-85'" - this variation represents rising terrain to a relative altitude of +15', published Radio Altitude would therefore be 85'.

2. Set up flight deck for initial approach:
   a) Gear up.
   b) Flaps set to 30°.
   c) Set airspeed bug #1 to programmed speed for initial approach (150 kts will be used on all runs).
   d) Set airspeed bug #2 to programmed speed for final approach (135 kts on all runs).
   e) Select AFCS mode in accordance with E's briefing (item 1 above).
   f) If run is not fully manual, engage autothrottle function (A/T control to ON) and select initial command airspeed.
   g) If A/T function is used, position throttles for disconnect (this is a simulator-peculiar item, throttles should be set to a designated position marker).
   h) Set Radio Altimeter reference bug to appropriate DH value (item 1 above).
   i) Trim aircraft for initial approach.

3. Report to E when ready to initiate run.

4. Monitor flight instruments and voice communications. The simulator will go dynamic shortly after you receive your ILS approach clearance.

5. If selected AFCS mode is not automatic, hand-fly aircraft as required.

6. Assess localizer tracking throughout the approach to 300' (relative altitude). Whenever you are confident that the aircraft's lateral displacement from the center of the

localizer beam is greater than 35 micro-amps in either direction, depress and hold the lateral offset (LO) button on the inboard horn of the control wheel. When lateral displacement returns to within 35 micro-amps, release this button.

7. Monitor decrease in glide slope deviation as aircraft approaches the Outer Marker (OM).

8. Monitor and acknowledge FO call-out of Approach Check List items. (Drop gear at one-dot below glide slope and call-out lights, extend flaps to 50° crossing OM.)

9. Monitor FO report to Tower at OM, receipt of final landing clearance, and report on airport weather.

10. Monitor glide slope capture and FO check of glide slope altitude at OM.

11. Continue to assess localizer and glide slope tracking. When you are confident that the aircraft is at precisely 500' above the touchdown zone, depress and release the Relative Altitude (RA) button on the inboard horn of the control wheel.

12. When you are confident that the aircraft is at precisely 200' above the touchdown zone, depress and release the RA button.

13. At any time after Middle Marker passage and prior to arrival at the DH, at your discretion, report your prediction regarding the outcome of the approach. If you are confident, based on your assessment of the aircraft's flight path and projected position, that you will arrive at the DH with <u>both</u>:

a) a lateral offset no greater than 50' on either side of the extended runway centerline, and

b) a vertical displacement from the glide slope no greater than 12' (high or low),

depress the mike button and report: "DH POSITION WILL BE WITHIN LIMITS". If you are confident that one or both of these offset limits will be exceeded, report: "DH POSITION WILL BE OUTSIDE LIMITS". If you do not feel confident that you can predict the outcome of the approach, make no report.

14. If you are instructed to use the "Head-up" prodecure, direct your attention exclusively to the external visual display immediately after passing the Middle Marker. The following steps will then be performed solely by visual reference and without cross-checking flight instruments. If a "cross-check" procedure is used, you may divide your attention between the instrument panel and external visual reference at your own discretion. When the "Head-down" procedure is specified, you must direct your attention exclusively to the instrument panel and not look up until you are confident that you are at the DH (see item 16 below).

15. Fifty feet above the bug setting on the Radio Altimeter an auditory alert tone will sound in your headset. At the onset of this tone, estimate the aircraft's cross-track position (lateral displacement from the extended runway center line) and its tracking vector and report this to E using the intercom system. Give your best estimate of cross-track position in feet at the initiation of the tone and then report the aircraft's tracking vector as "...ON" or "...PARALLEL" when the flight path of the aircraft at that time is judged to be aligned with the extended runway centerline, report

"... TRACK DIVERGING" when the aircraft is judged to be moving away from this track, or report "... TRACK CONVERGING" when the aircraft is judged to be moving in toward the runway from an offset position. The general format for this report will thus be as follows:

"ESTIMATE OFFSET AT THE TONE TO BE
_____ FEET LEFT, TRACKING PARALLEL."

On some runs, when the "Head-up" procedure is being used, you may not consider external visual reference to be adequate for making this estimate. In these instances report, "UNABLE TO JUDGE OFFSET AT THE TONE".

16. When you are confident that the aircraft is at precisely 100' above the runway, (i.e., at the DH) depress and release the AFCS DISENGAGE button on the left horn of the control wheel. This control action is necessary on all runs, whether the AFCS is "engaged" or not, to indicate your judgment of approach progress. On runs using the fully automatic or split-axis mode, both the AFCS and A/T will be disengaged when this button is depressed and you will immediately assume full manual control. On runs made from the outset under full manual control, no change in control mode will occur and you will continue to hand-fly the aircraft through the landing maneuver.

17. Execution of the landing maneuver should be accomplished by external visual reference with cross-checking of flight instruments at your discretion. Your goal, of course, is to correct your alignment with the runway, if necessary, and achieve an acceptably soft touchdown on the runway within the 3000-foot touchdown zone. To stay within established touchdown limits, you should attempt to land within ±27 feet of the runway centerline and at a point

along the runway where you can see at least the last four bars of the touchdown zone lights. We would like you to attempt the landing on every approach, even when you feel that your offset situation at the DH is excessive. However, do not use control techniques that you would not use under actual Category II approach conditions, i.e., do not use excessive roll rates or bank angles and do not accept an excessively hard landing in order to touchdown within the limits just cited. Remember, this exercise is not a test of your ability to salvage a bad approach. Touchdown performance will be interpreted as an indication of aircraft response characteristic under the conditions represented in the simulation, not as an assessment of your piloting skills. If at any time after initiating the landing attempt you feel that a safe touchdown on the runway cannot be accomplished without excessive maneuvering, initiate a go-around and the simulation sequence will be terminated.

18. At the DH, again estimate the aircraft's cross-track position in feet and its tracking vector and, after you have assumed manual control, report this estimate to E using the reporting format established in item 15 above. When this report is given, add your own judgment regarding the acceptability of the approach. Based solely upon the aircraft's position and tracking tendencies at DH, report "APPROACH ACCEPTABLE" if you would routinely attempt a landing given the same conditions in actual flight, or "MISSED APPROACH" if you would routinely reject the approach and go-around. This decision should not include a consideration of the adequacy of external visual reference.

At some point during the roll out the simulator will be repositioned for the next run in the scheduled series and the general procedure just outlined will be repeated. If you have any questions regarding the procedures just outlined, please ask the experimenter for further clarification.

BACKGROUND DATA SHEET

Subject No. ________
Date ______________

1. Name: ____
(This entry is optional)
2. Airline: ____
3. Current aircraft type ratings: _________________________
(Please underline type currently flown, if more than one type is cited)
4. Most frequently flown routes: __________________________
(Specify major terminals; e.g., LAX, DCA, etc.)
5. Crew position: Captain __________ First Officer ______________
6. Additional flight and/or ground duties: ____________________
(e.g., Check pilot, training, safety chairman, etc.)
7. Approximate total airline flying hours: Jet __________ Prop ______
8. Age: __________
9. Years pilot experience: Command: __________ First Officer: ______
10. Approximate total military flying hours: ________________
11. Principal military aircraft type (check one):

    Transport __________ Bomber __________

    Fighter __________ Other __________

12. Please indicate the extent to which your are familiar with Category II operating requirements and equipment developments: (Circle as many as are applicable.)

    a. Have completed formal Category II classroom and simulator/flight training program with my airline.

    b. Have flown Category II qualification check ride with FAA designated Company Check Pilot.

    c. Have personally participated as research pilot or consultant in development projects concerned with all-weather landing systems.

d. Have participated in actual approach and landing under Category II conditions (i.e., reported ceiling lower than 200' and/or RVR lower than 2600')

13. What are the lowest minimums to which you are currently certified?

    RVR__________ Ceiling (if applicable)__________

14. What type of flight director/attitude indicator is the aircraft you usually fly equipped with? (e.g., Collins FD-109 system, Sperry HZ-4, etc.)__________

15. Is the aircraft you typically fly equipped with Radio Altimeters?______ Does the system include an audio warning tone?______

16. Have you ever flown aircraft equipped with automatic throttle control? ______

17. With the equipment you usually fly, what are the lowest minimums you feel confident and comfortable with?

    RVR__________ Ceiling__________

18. Have you ever been a subject in a flight simulation research study before?________ If so, please give approximate date and briefly indicate type of study.

APPENDIX D

EXPERIMENTER'S COMMUNICATIONS REFERENCE SHEET

EXPERIMENTER'S COMMUNICATIONS REFERENCE SHEET

Intercom messages transmitted by the experimenter for the purpose of simulating the First Officer's communications with Air Traffic Control and in calling out check list items should follow the content and format outlined below. Communication activities cited in Figure 8 (see Procedures section, page 50) are referenced to indicate where the message occurs in the simulation sequence.

Approach Clearance

This message is used to initiate the simulation sequence and inform the subject regarding RVR conditions (18 in Figure 8):

AMES FIVE FOUR, DULLES APPROACH CONTROL, CLEARED ILS APPROACH TO RUNWAY ZERO ONE RIGHT. REPORTED RUNWAY VISUAL RANGE ONE THOUSAND TWO (or SIX) HUNDRED. CONTACT DULLES TOWER ON ONE, TWO, ZERO DECIMAL ONE, OVER.

Acknowledgement:

DULLES APPROACH CONTROL, AMES FIVE FOUR, ROGER.

Final Landing Check List

The call-out of the Check List items outlined below is initiated as the aircraft approaches the Outer Marker (at approximately one-dot below the glide slope, 19 in Figure 8). Each item will be acknowledged by the subject. Special timing considerations in calling out certain items are noted parenthetically.

Prior to arrival at OM, call out:

1. ALTIMETER SET TO 29.92
2. MACH TRIM - OFF
3. VOR/ADF SELECTORS - SET, IDENTIFICATION CHECKED
4. RUDDER BOOST - ON, PRESSURE CHECKED
5. WING FLAPS - 30°
6. INSTRUMENT WARNING - ARMED
7. NO SMOKING - ON
8. ANTI-SKID - ON
9. AUTOTHROTTLE - ON, 150 kts (or OFF)
10. THROTTLES - SET (if autothrottle is ON)
11. GLIDE SLOPE CAPTURE - ARMED
12. GEAR HANDLE - DOWN (call out after gear is dropped)

Call-out over OM:

13. LANDING GEAR - THREE GREEN LIGHTS, PRESSURE CHECKED
14. COMMAND AIRSPEED - 135 kts (if autothrottle ON)
15. WING FLAPS - 50°
16. ALTITUDE AT OUTER MARKER - CHECK

Contact Local Control

This message is transmitted as aircraft arrives over the Outer Marker. If necessary, interrupt the call-out of checklist items for this communication (21 in Figure 8):

DULLES TOWER, AMES FIVE FOUR, OUTER MARKER INBOUND.

Reply:

AMES FIVE FOUR, DULLES TOWER, CLEARED TO LAND. WIND _______(give direction specified for run; i. e., CALM, ZERO FIVE ZERO, THREE TWO ZERO, or ONE NINER ZERO) AT_______(give velocity unless calm; i. e., ONE FIVE or ONE ZERO). RUNWAY ZERO ONE RIGHT VISUAL RANGE ONE THOUSAND TWO (or SIX) HUNDRED, OVER.

Acknowledgement:

DULLES TOWER, AMES FIVE FOUR, ROGER.

Instrument Check

This message is given as the aircraft passes through 500 feet. To avoid conflict with the subject's report of relative altitude, provide the instrument check after the subject's report:

INSTRUMENTS O. K.

APPENDIX E

SUBJECT-PILOT DEBRIEFING QUESTIONNAIRE

SUBJECT-PILOT DEBRIEFING QUESTIONNAIRE

Based on your experience in carrying out the flight management activities during the simulation exercise, we would like you to comment on certain aspects of the procedures employed, the simulation equipment, and your reactions to the task we asked you to perform. In addition, we would like to solicit your opinion regarding operational procedures, flight instrumentation, control techniques, etc., which might be developed to make your job safer and easier in carrying out actual approach and landing operations under Category II conditions.

1. Did you consider the study orientation and simulator familiarization you received to be adequate preparation for the tasks you were asked to perform? If not, what additional information or familiarization exercise do you think would have been helpful?

2. Did any of the simulated flight instruments, controls, or procedures differ significantly from your experience with Category II certified aircraft (or from your expectations of what Category II equipment would be like)?

3. Which flight instruments or other sources of information did you use to assess lateral offset from the localizer course early in the approach (i.e., prior to reaching 300 feet)? List them in the general order of their importance or usefulness to you.

4. Was the use of the LO button to indicate your lateral offset judgment awkward or limiting in any way?

5. Which instruments or other sources of information did you use to estimate relative altitude at 500 feet? At 200 feet? Arrival at the 100 foot decision height (DH)?

6. Was the use of the RA button for indicating this judgment awkward or limiting?

7. Which instruments (or information) did you use to estimate cross-track position at the onset of the radio altimeter alert tone? At the decision height?

8a. How confident do you feel about your quantitative estimates of cross-track position at tone onset?

a. They were highly accurate (within 25 feet) ________

b. They were close enough (within 50 feet) ________

c. I was somewhat uncertain about them ________

d. I was highly uncertain - wouldn't rely on them ________

8b. At the decision height?

a. They were highly accurate (within 25 feet) ________

b. They were close enough (within 50 feet) ________

c. I was somewhat uncertain about them ________

d. I was highly uncertain - wouldn't rely on them ________

9. Where do you think the lateral offset limits at the decision height should be set, i.e., what is the maximum lateral displacement in feet that you would accept as an initial condition for a routine landing maneuver?

9a. How about vertical offset limits, in terms of feet above or below the glide slope on arrival at the Inner Marker?

10. Did you notice anything peculiar about the behavior of the flight instruments or their agreement with each other during fully-coupled runs?

11. Were there any peculiarities of the flight simulator or the procedures you were asked to follow which you feel made your behavior in the simulator differ from what you would do in an actual Category II situation?

12. Which particular judgments or estimates did you find most difficult?

13. What additional instrumentation or changes in how available instruments are designed do you feel would improve your ability to monitor a Category II approach or increase your confidence in judging the ongoing flight situation?

14. Are there any particular aspects of Category II equipment availability, design, or operating procedures that you have become aware of in your Category II training and familiarization that you feel are being neglected or require more emphasis?

15. With just the equipment represented in the simulation for this study, would you attempt an approach:

Under 1600 feet RVR conditions? ___________

1200 feet RVR? ___________

Lower? ___________

16. Did you feel that your performance of the flight management task was degraded on runs where you had to hand fly the airplane in the pitch axis or in both axes during the approach? Was there any noticeable difference between the split-axis ("ROLL ONLY") and fully manual (AFCS "OFF") mode?

17. Briefly state your general attitude towards flight simulators (in terms of the validity or applicability of simulation data to the actual operational situation).

18. Do you think that your time was well spent in participating in this study? (Please feel free to offer any critical comment you would care to make in regard to your experience as a subject or to the issues raised in the study.)