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A SIMULATOR STUDY OF FLIGHT MANAGEMENT TASK PERFORMANCE DURING LOW VISIBILITY APPROACH AND LANDING USING BASELINE CATEGORY II FLIGHT INSTRUMENTATION

By Walter B. Gartner

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Sherman Oaks, California

Serendipity inc.

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Prepared Under Contract NAS2-4406 By

SERENDIPITY, INC.

Sherman Oaks, California

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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PREFACE

The simulation study documented in this report was carried out as a collaborated effort by Serendipity, Inc. and the Man Machine Integration Branch (MMIB) of the Biotechnology Division at the Ames Research Center. Mr. Charles C. Kubokawa of MMIB provided guidance and direction in the design of the study and participated in the execution of the simulation exercises. His ideas and services in the implementation of the study were important contributions to the completion of the project and are hereby acknowledged.

Mr. Kenneth M. Baldwin and Mr. William J. Ereneta were the principal contributors on the Serendipity project staff. Mr. Baldwin coordinated the development and operation of the simulation facility and designed and programmed the data acquisition procedures for the SEL 840 computer system. Mr. Ereneta conducted many of the simulation sequences acting as the experimenter and carried out analyses of the data obtained on subject-pilot task performance.

The contributions of many other individuals, both Ames personnel and Serendipity staff, were also essential to the design and conduct of the study. The presentation which follows is intended to reflect the efforts and contributions of all the people who participated in this project.

Author

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A SIMULATOR STUDY OF FLIGHT MANAGEMENT TASK PERFORMANCE DURING LOW VISIBILITY APPROACH AND LANDING USING BASELINE CATEGORY II FLIGHT INSTRUMENTATION

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SUMMARY

In earlier research efforts, the importance of effective flight management task performance during low visibility approach and landing operations in civil jet transport aircraft was established. Subsequent analysis of pilot information processing associated with the performance of flight management 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 (LVLS) is in serious doubt.

The simulation research project documented in this report was conducted as an empirical extension of the earlier analytic study (ref. 1). It is the first of a series of projects which are being designed to assess the potential flight management problems defined in the analysis and, subsequently, to develop and test such solution concepts as changes in flight

instrumentation, crew preparation, and system operating procedures. In this initial study, the investigation was focused on the command pilot's ability to judge his approach to the authorized Category II minimum decision altitude (100 feet above the runway) and on the effects of various flight path offset conditions at this decision height on his ability to carry out the landing maneuver. The study was carried out as a joint effort by Serendipity and the Man-Machine Integration Branch at the Ames Research Center.

Twelve currently active senior airline pilots, individually certified for Category II operations, flew a total of 252 approach and landing sequences under simulated Category II visibility conditions (1200- and 1600-feet RVR) and data was taken on the accuracy of selected estimates and judgments of the flight situation. The approach sequences were flown under various combinations of three alternative pilot operating procedures and three different flight control modes to determine the effects of these variables on the accuracy of flight progress judgments. The data obtained in this study support the contention that baseline flight instrumentation will be inadequate for accurate monitoring and assessment of the approach to Category II operating minimums.

INTRODUCTION

One of the principal conclusions of a recent analysis of system concepts and operational problems in the development of an all weather landing capability for advanced commercial jet transport aircraft (ref. 2) was that the main impediments to the introduction of all weather landing involved operational procedures rather than individual technical problems. The role of the pilot in managing the aircraft was cited as a major source of controversy and it was concluded that methods of using the crew to monitor performance of the automatic equipment and a definition of crew procedures for various failure situations are critical problems which remain to be worked out for low visibility approach and landing operations. A clear statement of the importance of resolving the many outstanding issues with respect to the pilot's role in all weather landing operations is given by Beck in the conclusion to a comprehensive overview of crew factor problems in achieving Category II operational goals (ref. 3).

> Beginning with the initiation of a Category II approach, the success of each segment of the flight, as it progresses toward the touchdown and rollout, depends on a compatible pilot/aircraft relationship that can react properly to and take cognizance of each of the multitudinous factors that will be involved in making this approach consistent, reliable, of high quality, and above all operationally safe. In October, 1965 the All-Weather Study Group of the International Federation of Air Line Pilots made the following statement: "It is the Study Group's view that, in the very low minima envisaged, it is no longer possible to compromise and make exceptions to accommodate unique circumstances. The operation is too critical for that. Standardization now becomes essential. If ALL requirements cannot be met, the operation should not take place".

In view of the many problems which remain to be resolved, why should such operations take place? Former FAA Administrator Najeeb Halaby, now a senior executive with Pan American World Airways, has cited the three principal reasons in an article on current developments in all-weather operations (ref. 4. The first reason is safety ("If we can operate with instrumented precision during bad weather, we can systematize operations during good weather so as to reduce incidents and accidents ..."), the second is reliability ("The traveler wants to deplane at his real destination at the time promised..."), and the third is efficiency ("Not having all-weather capability costs the airlines, it has been estimated, about $70 million a year beyond regular on-time operations"). In the same article, Halaby also made it clear that Pan Am, at least, fully intends to conduct flight operations under the lower visibility conditions:

> To confirm that we mean business, I cite the expenditure of $13-million on our present fleet to qualify its equipment to progress from Category I to Category II operations. This is for equipment only and does not include the costs of the most advanced training for pilots and copilots and for simulators, etc.

If these operations are to take place, and if safety, reliability and cost-effectiveness goals are to be achieved, the critical problem of effective flight management must be considered. In earlier research efforts (ref. 1), a comprehensive analysis of requirements for flight management task performance during low visibility approach and landing operations was conducted. From these efforts, it was concluded that certain of these tasks will impose excessive information processing demands on the Captain.

This analysis was based on a projection of flight instrumentation and crew roles envisioned for a baseline low visibility landing system. The general concern of the analysis was to determine how well the command pilot would be supported by this system in carrying out his flight management responsibilities. Insofar as support for flight management activities is concerned, each of the suspect tasks identified in the analysis points to a potential inadequacy in projected landing system design features and/or operational procedures.

As a point of departure for the analysis, flight management was distinguished from other in-flight on... control functions, such as flight control and navigation, as being concerned with assessing the on-going flight situation, judging the significance of aircraft and subsystem operating states, and with formulating and resolving action decision problems arising out of these assessments. It was also necessary to adopt a firm position with respect to the pilot's role in implementing the flight management function, as indicated in the following excerpt (ref. 5):

> In any systematic consideration of the means required to implement system functions in man-machine systems, issues arise regarding the assignment or allocation of functions to either man, machine, or man-machine components. Such issues are seldom straightforward or easily resolved on the basis of explicit and widely accepted criteria, and these difficulties are compounded in flight management activities by considerations of "responsibility" and "authority." With considerable oversimplification, it can be said that responsibility has to do with the consequences or effects of system performance and involves the notion of accountability for these outcomes; authority has to do with the means provided for direct and effective control over the system being managed.
>
> The general position underlying the present study is that issues expressed in terms of "allocation of functions to man or machine" or "degree of automation" are misleading in dealing with "command" or "management" functions in manned systems. Such functions are distinguished more by the assignment (or assumption) of responsibility for achieving system performance objectives and satisfying established safety and economic constraints than by the means employed. It is here asserted that this responsibility can only be assumed by people, in this instance, the pilot-in-command. When severe demands are imposed on their ability to make the necessary judgments and decisions, provisions must be made for more adequately supporting management/command personnel. Corresponding provisions must be incorporated into the system design to give the pilot-to-command the necessary authority to implement management decision, e.g., provisions for entering command data and/or effecting corrective actions.
>
> This assertion should not be construed as imposing arbitrary constraints on the extent to which particular component functions of the flight management function can be mechanized or automated. It simply means that even in the hypothetical case of a fully automated system, the pilot-in-command must be equipped to assess the overall flight situation and the particular conditions encountered to determine the manner

in which the system will be employed (e.g., the on-line configuration of equipment units and their operating mode) as well as any corrective actions necessary to achieve operational objectives. No restrictions, as such, are thus placed on the degree of automation of such system design features as self-monitoring and automatic mode switching or disconnect. System design provisions of this sort are seen as one means of supporting the pilot-in-command.

This study is the first of a series of projects which are being designed to provide an assessment of the problems defined in the analysis and, subsequently, to develop and test such solution concepts as changes in flight instrumentation, crew preparation, and system operating procedures. The investigation was focused on the pilot's ability to judge his approach to the authorized Category II minimum decision height (100 feet above the runway) and on the effects of various flight path offset conditions at the decision height on his ability to successfully carry out the landing maneuver.

Airline pilots currently qualified for Category II approach and landing operations served as subjects in the study. The simulator runs were designed to assess pilot performance of selected approach assessment tasks under nominal Category II operating conditions, using simulated information inputs representing the ongoing flight situation as they would be presented to command pilots in the projected operational environment. The specific objectives of the simulation exercise were:

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.

For the reader's convenience, the analysis of potential problems in judging the success of a Category II approach, from which the foregoing study objective were derived, is reproduced as Appendix A to this report. Analyses of the data recorded during the simulation exercise and documented in this report provides an estimate of the number and type of errors in pilot judgment which may be expected to occur in actual flight operations under the conditions represented. The interpretation of these results is related to the issues discussed in Appendix A. The study was also intended to support subsequent simulation research projects by distinguishing the particular components of the flight management task 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.

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METHOD

Overview of How the Study Was Conducted

The basic plan of the study can be understood as a test of the extent to which the information environment projected for the baseline low visibility landing system (LVLS) can be expected to support the command pilot in his assessment of approach success. The information environment is comprised, primarily, of flight deck instruments and auditory display channels (e.g., aural warning signals and radio voice communications), and study results may be expected to apply to the selection or development of these landing system components. It also includes flight planning data and in-flight reference materials (e.g., clearances, approach charts, flight data sheets, etc.), the air and ground environment, and the stored (in memory) products of learned procedures and perceptual expectancies.

It should be clear that the study was not intended, in any sense, to evaluate the quality of the individual pilot's judgmental or decision making abilities. The experimental plan gave explicit consideration to controlling the effects of individual differences in pilot skills in this area. Moreover, during a debriefing session, pilots were asked to provide critical evaluations of the information and display characteristics available to them in the simulation. The pilot's primary role was to carry out assigned approach management and landing control tasks in accordance with the orientation given. Insofar as it is feasible to do so, pilot selection and orientation to the experimental task was directed toward achieving behavior in the simulator that could be construed as representative of the behavior of command pilots in an actual operational situation.

An overview of the structure of the simulation study is presented in Figure 1. Each run in the simulator represented the execution of an approach and landing sequence. The sequence was initiated with the aircraft at approximately ten nautical miles from the runway, stabilized on the assigned localizer course, and maintaining an assigned initial approach altitude. The run ended with the aircraft on the runway decelerating to a nominal turn-off speed, or with the pilot's decision to reject the approach and initiate a go-around. During this simulated flight sequence, pilots performed specified flight management tasks, responding to simulated information inputs to the command pilot. These inputs were intended to represent the ongoing flight situation as it is presented in the LVLS and impose the same information processing demands on pilots in the simulation as those associated with the operational situation. To accomplish this objective, both the flight information provided and the display characteristics (i.e., presentation mode, type of display, and display-referent relationships) were carefully matched to their assumed counterparts in the baseline system.

On each run, data on pilot performance were recorded as indicated by the pilot outputs shown in Figure 1. At the same time, data were 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, served as the immediate basis for pilot judgments. Objective data on the simulated flight situation (e.g., actual aircraft track) and on pilot judgments (e.g., estimated cross-track position) were used to derive accuracy scores for determining how well the specified flight management tasks were performed. In addition, subjective data obtained in debriefing sessions (e.g., pilot's reports of how judgments were made and appraisals of flight instruments) were available to support the interpretation of objective performance data.

Notice that simulated information inputs, pilot task assignments, and the data taken were held constant on all baseline simulator runs. Controlled

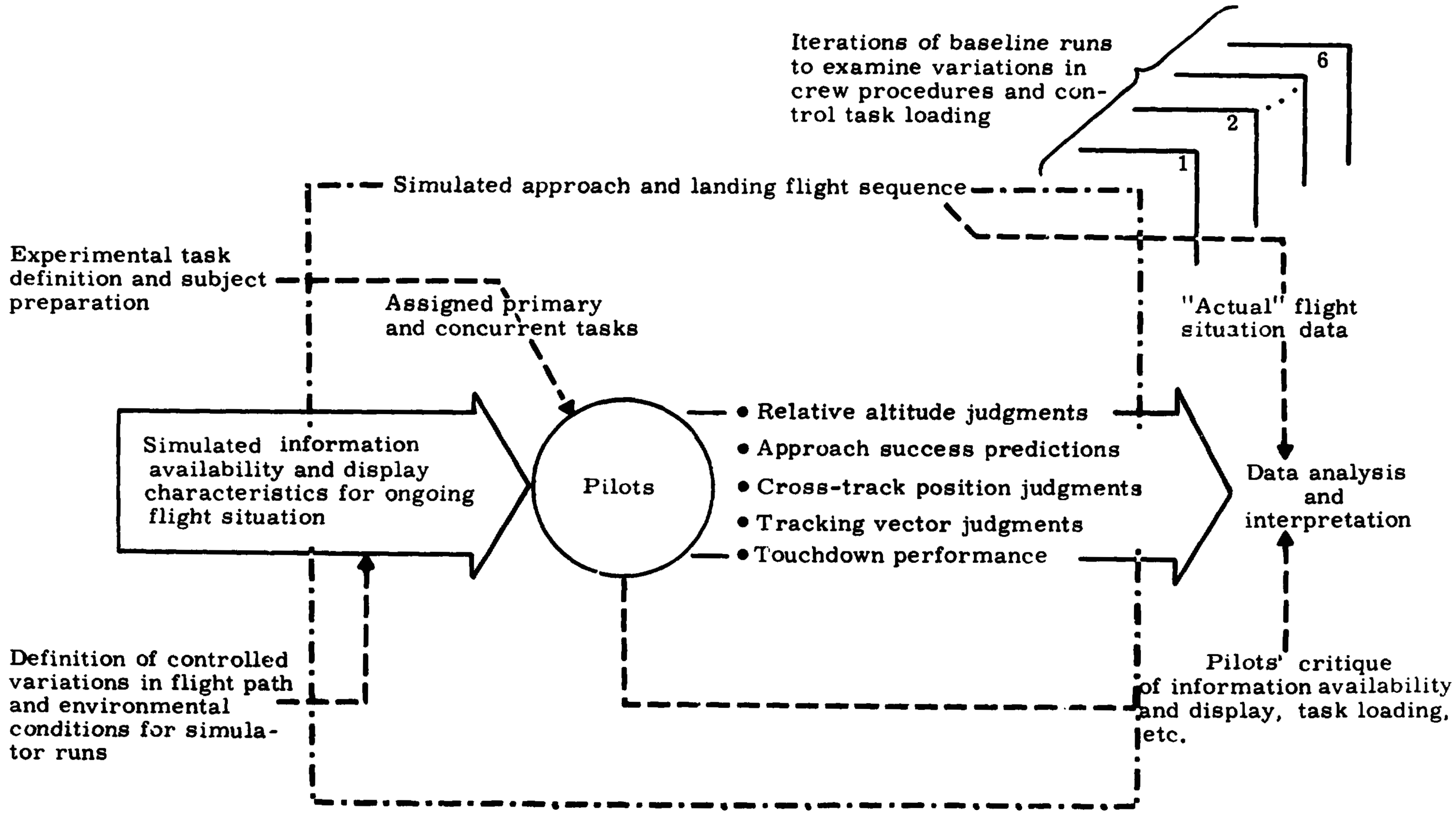

Figure 1. Schematic Representation of the Overall Structure of the Simulation Study.

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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 dicision height, runway visibility, etc.) were 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 was worked out to ensure an appropriate sampling of conditions of interest.

The study was 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 differentially 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) were 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 were conducted with a fully-coupled automatic flight control mode simulated and employing 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 continuously assesses his altitude above the runway and flight path alignment with the runway by instrument reference. On arrival at the 100-foot decision altitude he goes "head-up" to assess the adequacy of external visual reference, resolve the landing commitment decision and, at that point, either abort the approach or assume manual control to complete the landing maneuver. As indicated in Figure 1, six iterations of the baseline scheme were carried out to examine the effects of alternative flight control modes and crew procedures. The structure of the study, as schematized, was essentially unchanged in these iterations, but in each of the iterations a different combination of control mode and crew procedure was represented to govern the pilot's task orientation and the simulation of the flight sequence.

The Simulated Approach and Landing Flight Sequence

The operational context adopted as a framework for the experimental manipulations in the study was a Category II approach and landing sequence. For convenience, the recently published Category II approach to runway 1R at Dulles International Airport (DIA) was selected to define the assigned flight profile and was used on all simulation runs as the reference profile. The current Approach Chart for this profile is reproduced in Figure 2. Specific features of the simulation profile, which may differ from those shown in Figure 2, and descriptions of controlled variations in simulated flights paths will be made with reference to this approach.

Controlled Variations in Flight Profiles

Since the principal concern of the simulation sequence was to exercise pilots in specified approach assessment tasks, it was considered desirable to include a number of different flight situations for them to judge. The key parameters on which the approach was assessed were:

1. Vertical offset (altitude relative to the runway),
2. Lateral offset (cross-track position), and
3. Tracking vector (alignment of the aircraft's horizontal flight

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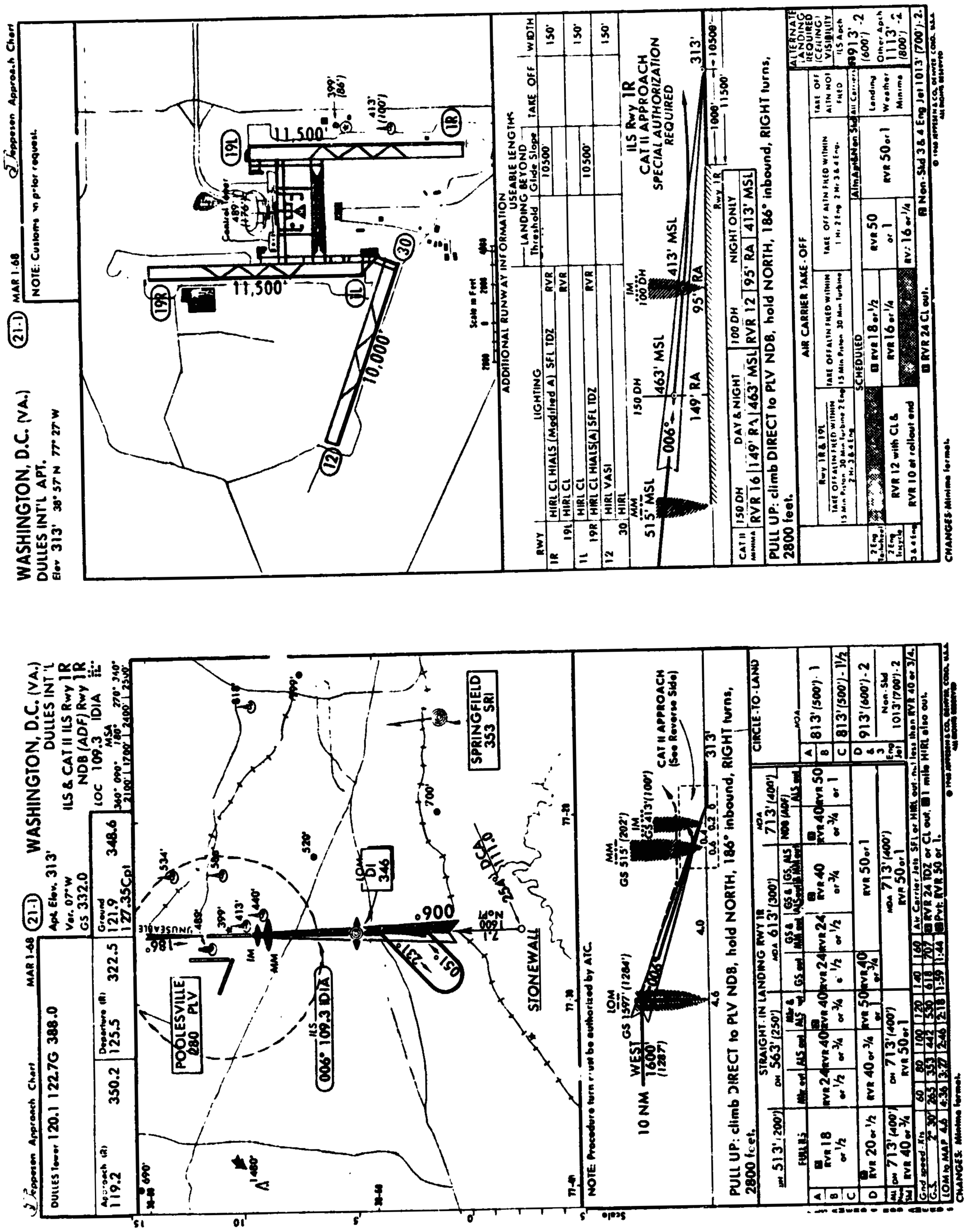

Figure 2. Category II Approach Profile for Dulles International Airport

path with the localizer course, i.e., parallel, converging, or diverging), as the aircraft approaches the decision height.

By systematically varying the values assigned to these parameters on any given run and providing for reasonable variations in flight path control earlier in the approach, nine different profiles were defined to cover all of the different flight situations which were of interest in the study. These profiles were defined as indicated in Table 1, by combining three vertical offset conditions ("on", "high", and "low") with three lateral offset conditions ("on", "marginal", and "excessive") and three tracking vector conditions ("parallel", "converging", and "diverging"). Each of these combinations defines a different flight situation at the decision height and may thus be construed as the "terminal condition" for a given approach. One of three possible variations in approach history was associated with each of these terminal conditions: a "cross-over" flight path defined by sinusoidal variations around the assigned profile, a consistent tendency to be either "high" or "low" on the glide slope, or a consistent tendency to be to the "right" or "left" of the localizer course.

A tenth profile has been identified in Table 1 as a reminder that the controlled variations in simulated flight paths called for in profiles P-1 through P-9 were generated only on simulation runs for which the automatic flight control mode was specified. On some runs, manual control was exercised on one or more axes and the corresponding flight path parameters (i.e., vertical offset when pitch axis control is manual, lateral offset and tracking vectors when control of the roll axis is also manual) then, of course, assumed whatever values resulted from the pilot's performance of the control task.

The intended application of the profiles defined in Table 1 in the study was, as already indicated, to exercise the pilots in judging a wider range of flight situations than would be the case if only "typical"

Table 1. Definition of Alternative Flight Profiles for Controlled Simulation Sequences.

	Terminal Condition			Approach History	
Profile Designator	Vertical Offset	Lateral Offset	Tracking Vector	Glideslope Tracking	Localizer Tracking
P-1	on	on	parallel	cross-over	cross-over
P-2	on	marginal	diverging	high	left
P-3	on	excessive	converging	low	right
P-4	high	on	diverging	cross-over	right
P-5	high	marginal	converging	high	cross-over
P-6	high	excessive	parallel	low	left
P-7	low	on	converging	cross-over	left
P-8	low	marginal	parallel	high	right
P-9	low	excessive	diverging	low	cross-over
P-10	(As attained by manual flight path control)				

or "in-tolerance" runs were simulated. For this reason, excessive deviations from optimum control system performance were deliberately included without regard to the probability of their actual occurrence in the operational situation. The intent was to include some marginal and excessive offset conditions to provide a more complete sample of situations to be judged. A systematic procedure was defined for specifying the profile to be followed on each run to ensure that pilots were exposed to similar run patterns and that similar run patterns were used for alternate experimental conditions.

Controlled Variations in Environmental Conditions

Simulated flight sequences are further defined by variations in the environmental conditions represented during the run series. These include irregularities in terrain elevation approaching the runway, weather and runway visibility conditions, the location and characteristics of final approach marker beacons, the approach and runway lighting system, the location and operating characteristics of ILS antennas, and runway characteristics. A brief statement of the more important features and controlled variations in these conditions which were included in the simulation sequence is given below:

a. Terrain elevation - controlled variations in terrain elevation approaching the runway were included in order to provide a more complete test of the pilot's ability to assess relative altitude. Two variations in the comparatively level terrain situation represented by the actual approach to DIA (the profile designated TP-1 in Figure 3) were defined. One of these is characterized by a sharp drop in terrain elevation on the approach end of the runway (TP-2 in Figure 3). With this terrain profile, absolute altitude at the decision height would be 140 feet and "arrival at the decision height", if it were judged by reference to a radio altimeter without considering the difference between absolute and relative altitude, would occur quite late in the approach. The second variation (TP-3 in Figure 3) is characterized by rising terrain off the approach end of the runway. With this terrain profile, "arrival at the decision height" again judged without explicit consideration of terrain elevation, would occur early.

b. Weather ceiling and runway visibility - on all runs, the fade-in of visual cues, representing the penetration of cloud cover in the vicinity of the runway, occurred within the decision region, i.e., between the middle marker and the decision height. To preclude the use of emerging visual cues for judging relative altitude and to vary the conditions affecting the landing commitment decision, two variations in runway visibility were represented by simulating a runway visual

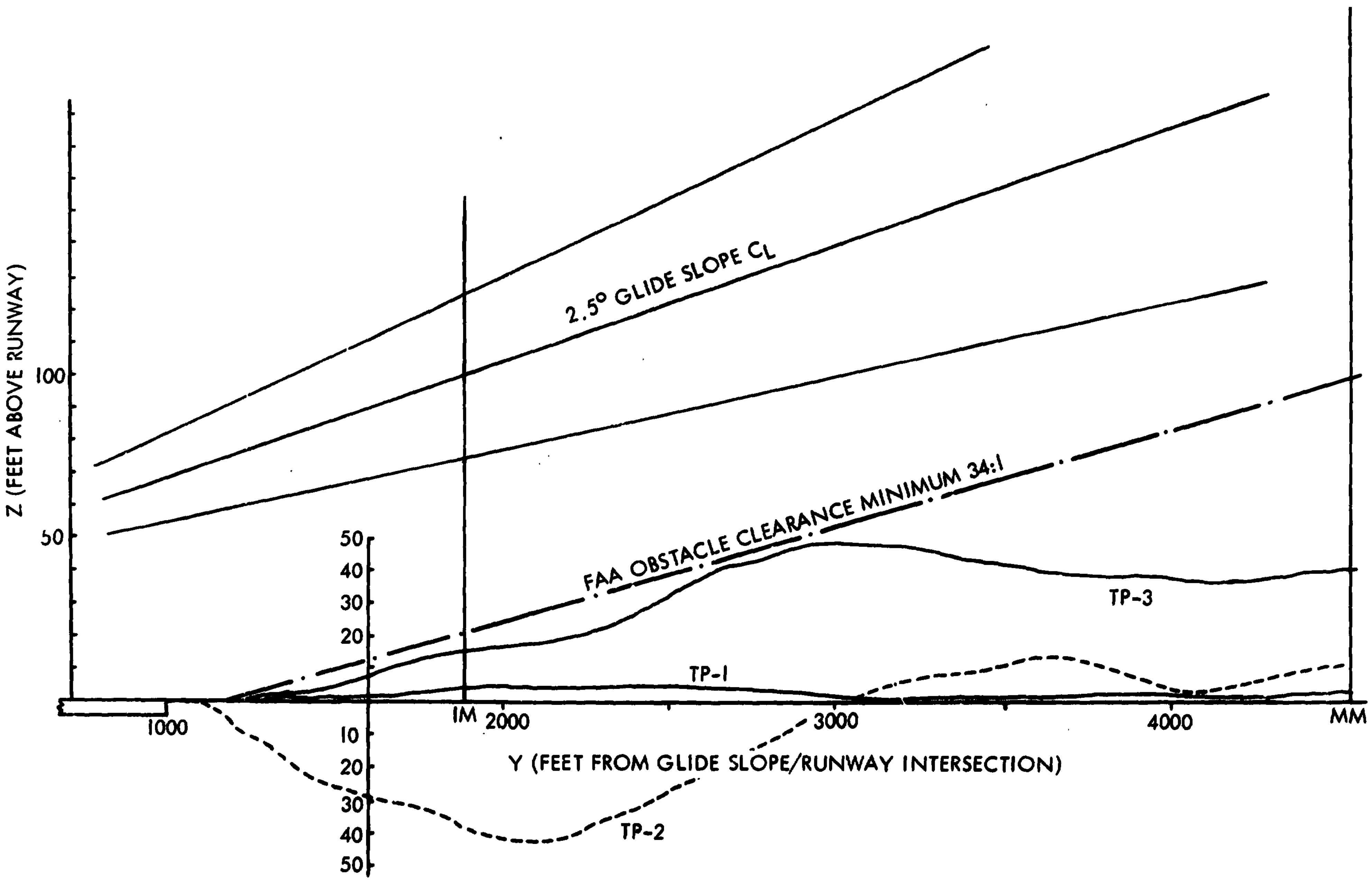

Figure 3. Programmed Variations in Terrain Elevation Approaching Runway.

range (RVR) of 1200 feet on some runs and 1600 feet on others.

c. Location and characteristics of final approach marker beacons - an outer marker beacon located 4.6 nautical miles from the runway, a middle marker at 0.6 nautical miles, and an inner marker at 0.2 nautical miles, as shown in Figure 2, were represented in the simulation.

d. Approach and runway lighting system - a visual guidance system, consisting of configuration "A" approach lights with sequenced flashing lights, high intensity runway edge lighting, touchdown zone lights, and centerline lighting was represented on the visual flight attachment.

e. Location and operating characteristics of ILS antennas - a standard ILS installation was represented with the localizer antenna array located a nominal 1000 feet beyond the far end of the runway and with the glide slope antenna located 1000 feet from the runway threshold. In the simulation sequence the localizer beam was precisely aligned with the designated localizer course at DIA (006^{o}) and the glide slope was accurately aligned with a 2.5^{o} vertical approach path. Allowable deviations in beam alignment, in accordance with ICAO standards, were considered in the analysis and interpretation of data, but not included in the simulation.

f. Runway characteristics - runway elevation, length, and width were as specified for runway 1R at DIA, i.e., 313 feet Mean Sea Level (MSL), 11,500 feet, and 150 feet, respectively. All weather runway markings were not represented.

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Apparatus

The simulation facility used for this study was an Ames Research Center fixed-base transport simulator equipped with a closed-circuit color television visual display attachment. The principal components of the facility and a generalized representation of signal flow are schematized in Figure 4. The principal components of the facility are: (1) the crew compartment, (2) visual display system, (3) the analog computation of aircraft equations of motion and display functions, and (4) data recording equipment. A brief characterization of the design features and functional capabilities of each of these components is delineated below. Emphasis has been placed upon 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 was a conventional transport-type cab mounted on a stationary raised platform. Two forward facing seats were installed with a control pedestal in the usual location between the seats. Functional control columns and rudder pedals were available at both crew stations, but complete instrumentation was provided only at the Captain's station on the left side. The left seat served as the pilot's station.

Flight instruments and controls available to the pilot were located as shown on the station configuration drawing (Figure 5). No attempt was made to reproduce the flight deck configuration for a particular aircraft type. The requirements of the study were met by providing the same information as that available in the projected baseline landing system for the approach and landing tasks and by employing functionally equivalent displays, i.e., instrumentation that imposes the same kind of information processing requirements on the pilot. In general, only

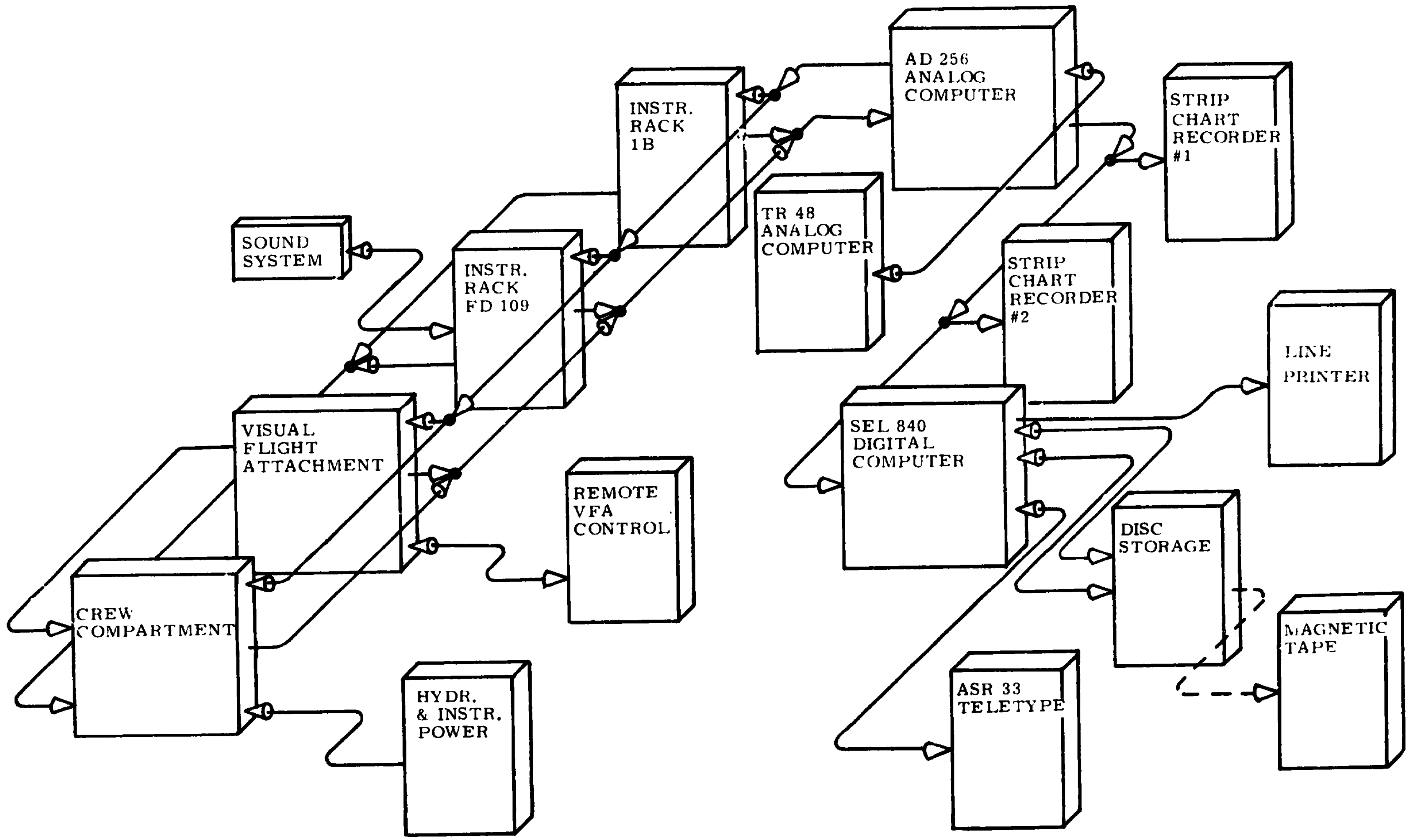

Figure 4. Block Diagram of the Simulation Facility

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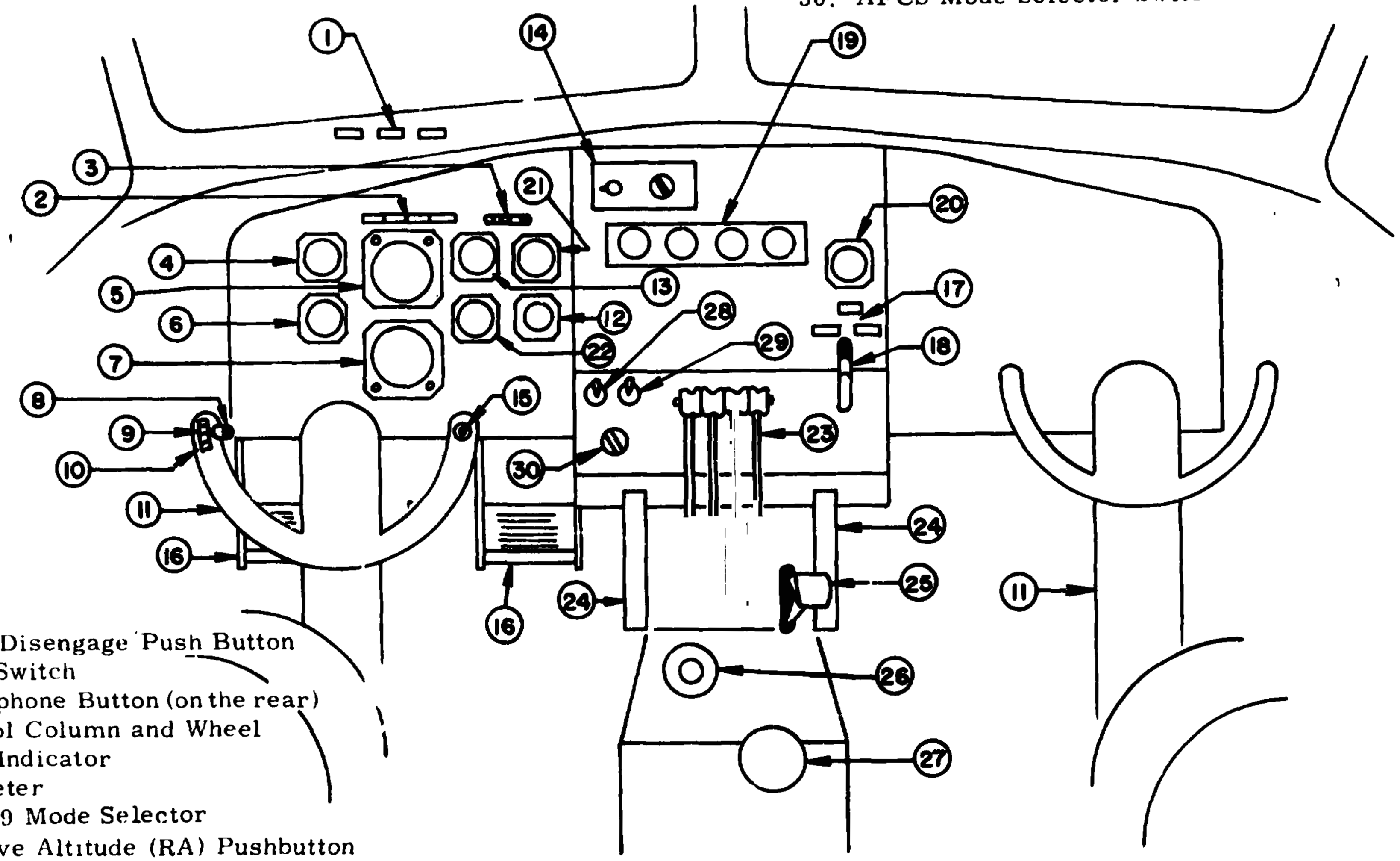
1. Touchdown Indicators
2. Approch Progress Indicators
3. Marker Beacon Indicators
4. Airspeed Indicator
5. Flight Director Indicator
6. Clock
7. Course Indicator
16. Rudder Pedal
17. Landing Gear Position Indicators
18. Landing Gear Control Handle
19. Thrust Indicators
20. Flap Position Indicators
21. 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



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. FD-109 Mode Selector
15. Relative Altitude (RA) Pushbutton

Figure 5. Flight Instruments and Controls Provided in the Pilot's Station.

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the controls and instrumentation which directly support the selected experimental tasks were provided. For this reason, complete engine instrumentation and system status/warning displays were not installed.

Primary flight situation/director information was 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 indicator elements. The rising runway (absolute altitude) indicator was not used in the present study. Display elements of the Flight Director Indicator (FDI) and Course Indicator (CI), the principal display units of the FD-109 system, are more clearly represented in Figure 6. The details of other pilot station flight instruments and controls are also shown in this figure. The characteristics of the pilot station flight instrumentation are outlined in Table 2.

An experimenter was seated at the station to the right of the pilot's seat. This position allowed the experimenter to observe the pilot's behavior during simulator runs and to monitor the flight instruments and external visual display available to the pilot. No controls or instrumentation were at this location. However, the experimenter was equipped with a separate TV monitor of the external visual field, and with a headset and microphone which he used to communicate with both the pilot and the simulation facility operators via an intercom system.

Visual Flight Attachment

The Visual Flight Attachment (VFA) used in the study was designed and manufactured by General Precision Systems, Ltd., and is comprised of a moving-belt type terrain model, a closed-circuit TV camera and optical attachment, a TV projection system, two monitors equipped with virtual image lenses, 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 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.

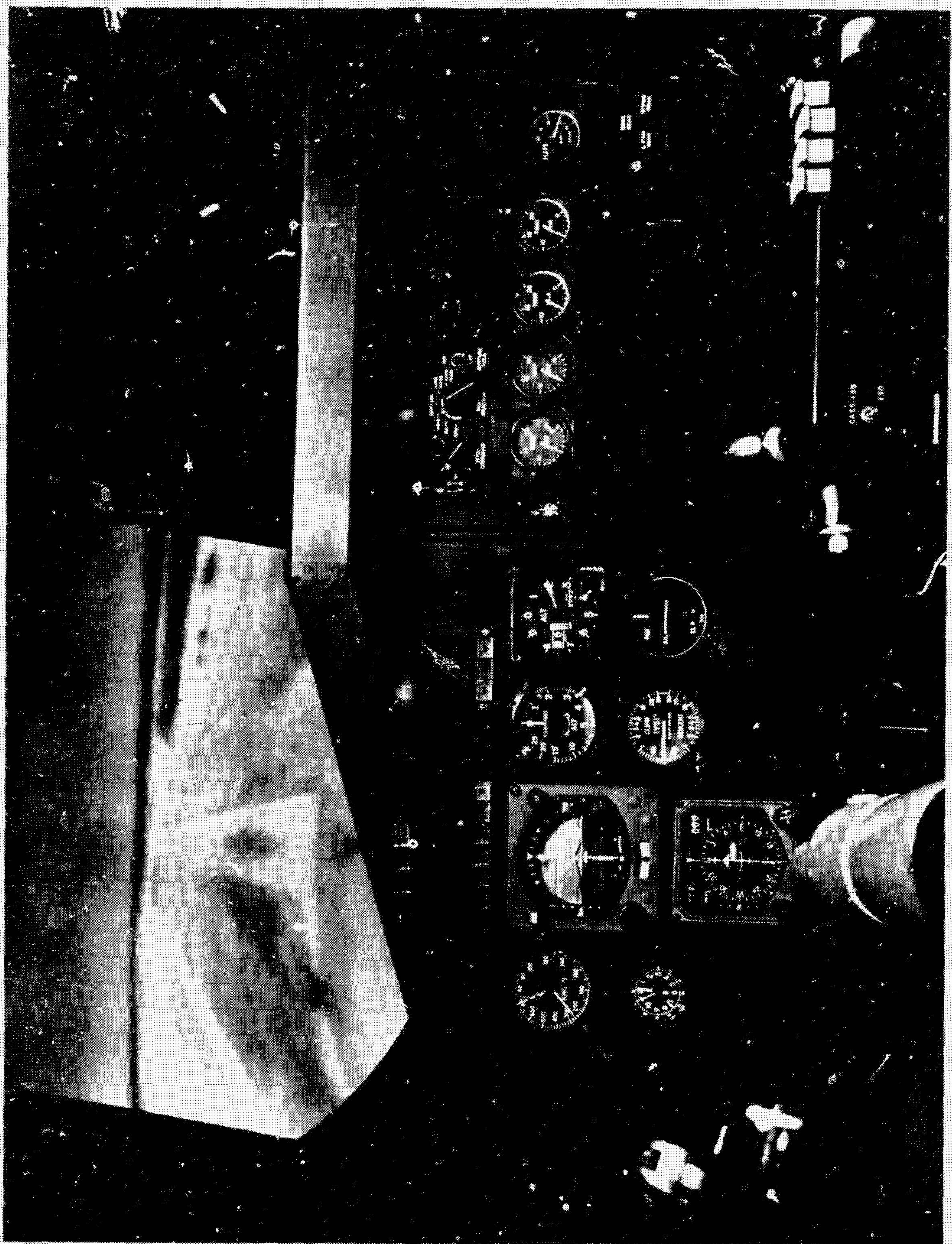

Figure 6. Flight Instrumentation Details.

Table 2. Characteristics of Pilot-station Flight Instrumentation.

Name of Instrument	Type of Indication	Range	Lowest Scale Division
Airspeed	Scale-pointer	0-800 knots	20 knots
Altimeter...............	Scale-pointer Drum	0-1000 feet 0-99950 feet	50 feet 100 feet
Radio Altitude............	Scale-pointer	0-2500 feet	10 feet
Vertical Speed...........	Scale-pointer	0±30000 fpm	100 fpm
Thrust..................	Scale-pointer	0-20000 lbs	1,000 lbs
Flap Position	Scale-pointer	0(up) to 50°(down)	10°
Trim....................	Relative Position		
Flight Director			
a)Pitch Attitude........	Relative Position	± 90°	5°
b)Roll Attitude.........	Relative Position	360°	
	Scale-pointer	± 60°	10°
c)Expanded Localizer...	Relative Position	0±75 μa	75 μa
d)Glide slope Deviation .	Relative Position	0±150 μa	75 μa
e)Minimum Decision Alt.	Light		
Course Indicator			
a) Heading	Scale-pointer	360°	5°
b) Course..............	Drum	360°	1°
c)Course Deviation.....	Relative Position	0±150 μa	75 μa
d)Glide slope Deviation .	Relative Position	0±150 μa	75 μa
Touchdown.............	Lights		
Approach Progress	Lights		
Marker Beacon.........	Lights		
Landing Gear Position...	Lights		

servo systems controlled by corresponding drive signals from the simulation computer.

On all runs in this study, the descent to the decision region (between 200 feet and the 100-foot decision height) was conducted with the external visual scene obscured to represent an "in-cloud" condition. The fade-in of visual cues began 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 1200 or 1600 feet was selected at the Remote VFA Control Console prior to each run. Subject-pilots executed the landing maneuver by reference to the visual display on every run.

Analog Computation

The AD256 and TR48 analog computers were used to furnish the drive signals for flight instruments and the visual flight attachment. A DC-8 aircraft was represented in the aerodynamic simulation and all aerodynamic control and aircraft configuration effects occurring in routine approach and landing operations were included. Ground effect was computed. The computation of earth-referenced flight situation quantities (e.g., flight path coordinates, ILS deviation, absolute altitude, etc.) was based on the representation of an approach to the runway lR at Dulles International Airport and on the selected variations in environmental conditions cited earlier.

Basic flight path control computations were driven, as they typically are in piloted flight simulators, by manual control inputs from the pilot. In order to generate the controlled variations in the flight profiles, 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) were programmed on diode function generators as functions of X (distance from the glide slope intersection with the runway) for the nine different approach profiles (see Table 1) which were, in turn, used to control aircraft position. In effect, the computer then acted as a controller. Y and Z inputs available from the diode function generators for a designated profile were combined with actual aircraft position coordinates to generate error signals which were then used to generate the necessary control inputs for following the selected profile. The pilot was thus relieved of the manual flight control task, just as he would be when using the autopilot-ILS coupler in the actual aircraft.

In the split-axis mode, the pilot retained manual control of the pitch axis while roll axis control was derived from programmed values of the Y function. When this mode was selected, the vertical component of the flight path and associated display functions were governed by manual control column displacements rather than programmed values of Z. The automatic and split-axis modes were selected by placing the AFCS MODE SELECT control in the crew compartment (see Figure 5) in the AUTO (automatic) or ROLL ONLY (split-axis) positions. Depression of the AFCS DISENGAGE switch located on the left side of the pilot's control wheel returned the computer to the full manual mode, wherein the computations were again driven by manual control inputs from the pilot.

Automatic control of pilot-selected command airspeeds was also included in the simulation. When the A/T selector (Figure 5) was in the ON position, the basic computation of indicated airspeed (V) on the basis of throttle position and aerodynamic forces was interrupted. A simplified autothrottle function was then simulated by maintaining V within ± 5 knots of the pilot-selected command airspeed (V_c). Only two command airspeeds were 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 was approximately 36,000 feet, i.e., when the aircraft was one dot below the glide slope. The airspeed change was commanded by the pilot using the CMD A/S SELECT control (Figure 5).

Depression of the AFCS DISENGAGE switch also served to terminate the simulation of the autothrottle function and V was again computed on the basis of throttle position and aerodynamic factors. To minimize transition problems when the autothrottle function was terminated, the throttles were positioned, prior to initiation of automatic runs, so that computed V for conditions at the decision height did not differ excessively from the 135 knot command airspeed.

Flight Instruments

The simulation of the primary flight deck display functions was a straightforward product of the solution of aerodynamic equations and the application of computer outputs, via suitable buffering and scaling amplifiers and synchro converters, 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 were computed by the 562P-1E pitch computer and the 562R-1E roll computer components of the FD-109 system. Steering commands were presented via an integrated pitch and roll command bar. Both the steering commands and the expanded-scale display of localizer deviation available on the Flight Director Indicator (FDI) were scaled as a function of glide slope and localizer deviation inputs. A full-scale deflection (one dot) on the expanded localizer deviation indicator corresponded to a 20 microamp deviation signal from the localizer receiver. The steering computer was also designed to automatically change the glide slope input gain when activated by a preset radio altitude trip point. The trip point was set at 200 feet. At this altitude, the gain for pitch steering commands was reduced to half the nominal value over a 7.5 second period.

Radio altitude was derived in the simulation computer by summing Z and the programmed values of terrain elevation. The three alternate approach terrain profiles (see Figure 3) were programmed on diode function generators as functions of X to represent the variations in this environmental condition. A minimum decision altitude (MDA) trip signal was provided by a comparator matching the radio altitude signal with a preset voltage representing the MDA, i.e., the value which corresponds to a Z of 100 feet at the Inner Marker. This preset MDA reference value was different for each of the terrain profiles used in the problem.

The MDA trip signal was used to illuminate the MDA light on the Flight Director Indicator. Another MDA trip signal was generated by comparing the radio altitude signal to a preset signal representing an altitude which was 50 feet higher than the MDA. This second trip signal was used to initiate an audio tone warning applied to the pilot's head-set. Onset of the tone thus occurred at 50 feet above the preset altitude, increased in volume as the aircraft descended, and terminated abruptly when the MDA trip signal was generated.

Data Recording Equipment

Objective recording of flight situation data and pilot response events for the subsequent assessment and interpretation of flight management task performance was accomplished by utilizing the SEL 840 Digital Computer System and two strip chart recorders. In order to record subject response events, the following controls and/or control design features were added to the pilot's station (see Figure 5):

1. A momentary contact type pushbutton, labelled RA for Relative Altitude, was located on the front of the inboard horn of the control wheel (15). A discrete voltage level change occurred each time this button was depressed.

2. A discrete voltage level change occurred as the AFCS was disengaged. The AFCS DISENGAGE (AD) button was located on the inside of the outboard horn of the control wheel (8).

The parameters and events recorded on the strip chart recorders are identified in Tables 3 and 4. Eight channels of data were monitored by the SEL 840 Digital Computer System. During the execution of an experimental run the outputs of the analog-to-digital converters were sampled to detect flight situation and pilot response events. As these events occurred the values of selected channels were stored into computer memory for subsequent error calculation and recording onto disc storage system. The data monitored by the 840 system are identified in Table 5.

Table 3. Flight Situation Data and Events Recorded on Strip Chart Recorder No. 1.

TRACE	PARAMETER	DYNAMIC RANGE	RESOLUTION	DESCRIPTION/REMARKS
	TIMING	----	----	----
1	X	a)48000 to 10500' b)10500 to -2000'	a) 750' b) 250'	Horizontal Distance Requires scale change @ 10500' (X)
2	Y	0 ± 250'	10'	Lateral Offset
3	Z	a)1600 to 400' b) 400 to 0'	a) 24' b) 8'	Height above Runway Requires scale change @ 400' (Z)
4	D_1	0 ± 150 ua (± 2 dots)	6 ua	Localizer Deviation
5	D_g	0 ± 150 ua (± 2 dots)	6 ua	Glide slope Deviation
6	RA	EVENT MARKER	----	Relative Altitude Button (Pilot Response)
7	---	----	----	Not Used
8	AD	EVENT MARKER	----	AFSC Disengage Button (Pilot Response)

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Table 4. Flight Situation Data and Events Recorded on Strip Chart Recorder No. 2

TRACE	PARAMETER	DYNAMIC RANGE	RESOLUTION	DESCRIPTION/REMARKS
1	$\dot{Y}$	$\pm$ 25 fps	1 fps	Cross-track Velocity
2	ψ_m	$\pm$ 25 degrees	1 degree	Heading
3	θ	$\pm$ 25 degrees	1 degree	Pitch Attitude
4	ϕ	$\pm$ 50 degrees	2 degrees	Roll Attitude
5	h_a	0 to 250'	5'	Absolute Altitude (Record not needed above 250')
6	$\dot{h}$	$\pm$ 25 fps	1 fps	Vertical Velocity
7	OP	EVENT MARKER	----	AD 256 Computer Operate Button (Pilot Start Response)
8	RA	EVENT MARKER	----	Relative Altitude Button (Pilot Response) (Used for time correlation with No. 1)
	TIMING	----	----	----

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Table 5. Flight Situation Data and Events Monitored by the SEL 840 Computer System

CHANNEL	FUNCTION	SCALE FACTOR	DESCRIPTION
DATA (17)	RA	EVENT MARKER	Relative Altitude Button (Pilot Response)
DATA (19)	X	304 ft. /volt	Horizontal Distance
DATA (20)	Z	20 ft. /volt	Height above Runway
DATA (21)	$\dot{Y}$	10 ft. /sec. /volt	Cross-track Velocity
DATA (22)	Y	60. 8 ft. /volt	Lateral Offset
DATA (23)	AD	EVENT MARKER	AFCS Disengage Button (Pilot Response)
DATA (24)	$\dot{h}$	10 ft. /sec. /volt	Vertical Velocity
DATA (25)	OP	EVENT MARKER	AD-256 Computer Operate Button (Pilot Start Response)

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At the conclusion of a run sequence, the pilot's estimates were entered manually into the computer memory via the ASR-33 teletype terminal. Error scores based on the pilot's estimates and recorded data values were then calculated and a run summary printout provided through the teletype terminal. To prevent loss of information, data stored on the disc storage system were periodically transferred to magnetic tape. This magnetic tape was then used at the end of the study as the source of data for analysis.

Procedure

The study was carried out by having twelve Category II-qualified airline pilots fly a total of 252 approach and landing sequences in the simulator for the record. A complete run schedule for each pilot included three simulator-familiarization runs, conducted under clear visibility conditions and with no experimental tasks assigned, to give them the "feel" of the device and the simulated instrumentation. Six practice runs were then completed under the conditions appropriate to the pilot's role in the experiment to allow him to learn the assigned experimental tasks and to practice landing maneuvers under the 1200- and 1600-foot RVR conditions. Eight pilots then flew twenty-seven runs for record and four flew nine runs as described in the experimental design section.

A standardized orientation was given to each pilot. Each pilot read a booklet (see Appendix B) describing his role in the simulation exercise, the principal characteristics of the simulation sequence, and the equipment, and the specific experimental tasks they would be asked to perform. An Experimenter provided amplifying comments and briefed the pilots on the procedures to be followed in the simulator. Background data was taken on the pilots at this time.

After completing the orientation session, pilots were taken to the simulator crew compartment and briefed on the location and operation of all controls and displays they would use during the scheduled run series. The Experimenter then flew two "talk-through" demonstration runs to familiarize the pilots with the general sequence of events and the correct performance of the experimental tasks. The pilot was then seated and allowed to complete three familiarization runs.

Prior to initiating the practice run series, the simulator was positioned at the Inner Marker and then placed successively in six different lateral and vertical offset positions. Visibility was reduced to simulate 1200- and 1600-foot RVR at the other three. Pilots were thereby given a static demonstration of how the variations in flight path offset they would encounter later in the dynamic sequence would appear under the Category II visibility conditions represented in the simulation. The simulator was then repositioned and set-up for initial run conditions and the practice run series was completed.

Experimental runs were completed in blocks of nine-run series, as called for by the experimental design. The longest run schedules required approximately 3 hours to complete. A lunch break was scheduled after the first hour and pilots were allowed to fly two refresher runs prior to completing the afternoon schedule. In a debriefing session following the simulator run series, an open-ended interview was conducted, using a questionnaire form (see Appendix C). This procedure allowed the pilots to comment on their experience and to express their opinions regarding the operational procedures, flight instrumentation and control techniques represented in the simulation.

Pilots

Fifteen currently active, senior airline pilots participated as subjects in the study. Most of the pilots (9) were flying with Pan American, 4 were with Trans World Airlines, and 2 were with United Airlines. Two of these pilots flew the simulator during simulator checkout and procedure verification exercises and 12 flew for the record. The last pilot was

Captain R. H. Beck, IFALPA committee chairman for All Weather Operations and author of many papers on the pilot's role in reduced minima operations. He was invited to experience the simulation exercise and to critique the study. The contributions of these pilots is hereby gratefully acknowledged.

All of the 12 pilots who flew for the record were Captains and had completed their company's training program and certification requirements for Category II operations. Four of the pilots were company check pilots and training Captains and two were chairmen of the local ALPA Councils for their airlines. The average pilot was 47 years old and had 16,425 hours of total airline flying; 6,875 of these hours were in jet transports. With the exception of three pilots who had served for many years as Navigators and subsequently qualified as pilots, the average number years of command pilot experience represented was fourteen years.

Experimental Design

The design of the study is best understood as a composite structure comprised of three separate and distinguishable component experiments which were all carried out within the context of the same set of simulated approach and landing sequences. Its basic structure, as schematized earlier in Figure 1, was simply a testing sequence wherein the twelve pilots were exposed to controlled variations in aircraft behavior and data was taken on their performance of specified flight management tasks. All of the runs in this test series were 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 were interpreted with reference to external criteria of accuracy, timeliness, appropriateness, etc. For example, the accuracy of lateral offset judgments was assessed by comparing pilot 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 pilots over all controlled variations in flight path and environmental conditions, was 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 second component in the composite design was the iterations of the test series which were carried out in order to examine the effects of differences in crew procedures and control task loading on flight management task performance. This examination called for a statistical assessment of differences in flight management performance under alternative conditions. Including baseline conditions, three alternate operational procedures and three alternate control task loadings were distinguished, as outlined below, to define the levels of these experimental variables.

Operational Procedure:

1. Cross-check - Under this condition, experimental tasks were initially performed solely by instrument reference. As the aircraft approached the anticipated breakout altitude, and at his discretion, the pilot was permitted to look out to see if the runway or approach lights were visible. As visual cues become available, the pilot could replace or supplement information obtained by instrument reference with information from the external visual field. The frequency and duration of shifts in visual reference were at the pilot's discretion. Full control authority was retained by the pilot throughout the approach and landing sequence.

2. Head-down - Under this procedure, the pilot was instructed to perform assigned experimental tasks solely by instrument reference all the way to the decision height and to rely on the Experimenter, acting as First Officer, to

monitor external visual conditions. As a matter of discipline in operating procedure, the pilot was constrained not to look up for visual cues until he determined that the aircraft was at the 100-foot DH. At that time, the pilot was instructed to assume manual control and execute the landing maneuver by visual reference.

3. Head-up - Under this procedure, control authority was assumed to be assigned to the First Officer and the subject-pilot concerned himself exclusively with managing the approach. In the operational situation, the First Officer would remain head down to closely monitor autopilot performance or exercise manual control. At 200 feet above the runway, the pilot was therefore free to go head-up and to direct his full attention to the search for visual cues. Under this condition, then, all flight path alignment judgments made in the vicinity of the DH were made strictly by visual reference. Arrival at the DH was indicated by tone offset and the illumination of the MDA light. When this event occurred, the pilot disengaged the automatic control system and completed the landing by external visual reference.

Control Task Loading:

1. Fully Automatic - For this control mode the Automatic Flight Control System (AFCS) was placed in the AUTO mode to represent automatic tracking of both the glide slope and localizer beams. In this mode, the programmed flight profiles governed the aircraft's flight path (see Table 1 for definition of these profiles).

2. Split Axis - In this mode, the AFCS was engaged in the roll axis only and localizer tracking was automatic. Vertical flight path control (pitch axis) was concurrently exercised manually by the pilot.

3. Fully Manual - In this mode, the AFCS was disengaged and both horizontal and vertical flight path control was manual.

A two-by-three factorial design with repeated measures on one factor (ref.6, p. 298) was adopted for carrying out this second component of the experiment and also served to establish the detailed basis for scheduling pilot exposure to run variations and experimental conditions for all components of the study. This design is schematized in Figure 7.

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)	(see text for explanation of Group 3)	

Using this design, comparisons between different levels of Factor A are confounded with differences between groups of pilots. However, the effects of Factor B and of interactions between A and B are free of this confounding and the tests of these effects are more sensitive than those on the effects of A. The eight pilots required to carry out this design were randomly assigned to two experimental groups comprised of four pilots each. The four pilots in Group 1, using the "Cross-check" procedure, completed 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 completed the same run series using the "Head-down" procedure. Four additional pilots were assigned to a third Group and completed only nine runs under a condition defined by pairing the "Head-up" procedure with the "Fully Automatic" control mode. In the baseline 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 full manual control would, therefore, be meaningless.

The third experiment in the composite design was 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 (Appendix A, pp. A-8 and A-16). 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, an examination of touchdown performance associated with a wide range of terminal conditions (i.e., vertical offset, lateral offset, and tracking vector at the decision height) was possible. Pilots were instructed to attempt the landing maneuver on all runs, even those on which terminal offset conditions were considered excessive. For purposes of the experiment, pilots were 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 pilot's ability and willingness to execute the side-step maneuver from various lateral offset positions at the decision height.

Schedule of Pilot's Exposure to Run Variations and Experimental Conditions

The twelve pilots available for the simulation study were randomly assigned to three experimental groups. Membership in a group determined the operational procedure to be used by a given pilot on all runs. Group 1 used the "Cross-check" procedure, Group 2 was "Head-down", and Group 3 was "Head-up". The order in which pilots in Groups 1 and 2 were exposed to different levels of Control Task Loading was counterbalanced so that differences in performance would 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 was as indicated below for pilots in both Group 1 and Group 2 :

First Series	Second Series	Third Series
b_1	b_2	b_3
b_3	b_2	b_1
b_1	b_3	b_2
b_2	b_1	b_3

Ea. . es consisted of nine approach and landing sequences (runs). Au...atically controlle flight paths were used under conditions b_1 and b_2 (see Figure 7) and the same pattern of variations in flight profile and environmental conditions was applied on all run series. Variations in flight path and environmental conditions were combined to define nine basic run condition alternatives. One of these alternatives was specified for each run. Definitions for these alternatives, designated A1, A2, A3,... A9, are given in Table 6 by specifying the approach profile, terrain profile, and RVR used on a designated run.

Table 6. Definition of Alternative Run Conditions

Alternative Designator	Approach Profile*	Terrain Profile**	RVR (ft.)
A ·	P-1	TP-1	1200
A 2	P-2	TP-2	1600
A 3	P-3	TP-3	1200
A 4	P-4	TP-1	1600
A 5	P-5	TP-2	1600
A 6	P-6	TP-3	1200
A 7	P-7	TP-1	1200
A 8	P-8	TP-2	1600
A 9	P-9	TP-3	1200

NOTES: * Approach profiles are defined in Table 1.
** Terrain profiles are defined in Figure 4.

To further counterbalance carry-over effects and to preclude pilot detection of commonalities in the flight situations he is exposed to from run to run, the order of pilot exposure to run alternatives was randomized. A table of random numbers was used to generate the twelve run patterns given in Table 7. Cell entries identify the run condition alternative, as defined in Table 6, selected for each run in a series of nine runs. The run pattern adopted for a particular series thus establish the order in which these alternatives were presented.

Table 7. 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
L	4	5	3	7	6	1	2	9	8

The foregoing considerations were used to fully structure the study in terms of the total number of simulator runs required, pilot assignments to particular run series, and the flight situation to be represented on each run. Each of the eight pilots in Groups 1 and 2 flew 36 runs;

nine familiarization practice runs and 27 for record. Pilots in Group 3 flew 18 runs; nine preliminary and nine for record. The total number of runs was thus 360, of which 252 provided the data used in the analysis and interpretation of results.

Data Recording and Analysis for Assessing Flight Management Task Performance

The basic structure of the simulation exercise, as indicated earlier, was a straightforward testing sequence designed to determine how well the pilots could perform the component tasks of the approach success judgment under the conditions represented in the simulation. One subset of these conditions is intended to be taken as the most likely conditions for actual Category II approach and landing operations and is defined by pairing the "Fully Automatic" flight control mode with the "Head-down" operational procedure. Data taken on simulator runs carried out under these conditions is therefore used as the basis for deriving the best estimates of command pilot performance during actual flight operations.

Thirty six approach and landing sequences were flown under the nominal Category II conditions; the four pilots assigned to this condition each flew a series of nine runs for the record. Flight situation and pilot response data were recorded on each run to provide the basis for deriving criterion measures of flight management task performance for each component of the approach success judgment. The measures adopted and their derivation from recorded run data are briefly defined below.

Evaluation of Pilot's Ability to Estimate Relative Altitude

The measure selected for this assessment was the number of errors pilots made in estimating their actual height above the runway touchdown zone. Response indicators of pilot estimates of this parameter (Z) were obtained at three points in the approach: one at 300 feet (designated as e_2), one at 200 feet (designated as e_3), and the last one at the 100 foot decision height (designated as e_4). When the pilot was confident that the aircraft was at precisely 300 feet (and later at 200 feet), he depressed and released the RA (relative altitude) button. When he was confident that the aircraft was precisely 100 feet above the runway (i.e., at the DH), he depressed and released the AFCS DISENGAGE (AD) button. Activation of these pushbuttons was sensed by the 840 computer and the actual value of Z at the time of these events was determined for subsequent print-out and derivation of error scores. Activation of the RA and AD buttons was also recorded on the strip chart recorders and could be compared with corresponding recorded values of Z.

The value of Z at the time the pilot depressed the designated pushbuttons ($Z_{est.}$) was recorded and then used to derive error counts. Since the operational significance of a precise determination of Z increases as the aircraft approaches the DH, different accuracy limits were used to define e_2, e_3, and e_4. At 300 feet an e_2 error was counted whenever $|Z - Z_{est.}| > 50$ feet, an e_3 error was counted when $|Z - Z_{est.}| > 20$ feet, and at the DH an e_4 error was counted whenever $|Z - Z_{est.}| > 12$ feet. Pilot performance on this component of the approach success judgment is reflected in summary statistics on $Z_{est.}$ data and by error ratios formed by dividing e_2, e_3 and e_4 error counts by the number of runs in a series or subset of interest.

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

Absolute errors in the pilot's quantitative estimates of the aircraft's lateral displacement from the extended runway centerline, taken at the time he depressed the AD button, were the criterion measures used to evaluate lateral offset judgments. Errors in the pilot's qualitative estimates of aircraft tracking tendencies at the same point in the approach were used to assess the tracking judgment. Pilots were instructed to report quantitative estimates of the aircraft's lateral offset from the extended runway centerline (Y) verbally, via the intercom system, and these estimates were recorded, as reported, by the experimenter. After subsequent entry into the 840 computer Y estimates were compared with actual values of Y at the time the depressed the AD button in order to derive the error measures. On "Fully Manual" runs, the same data was obtained from values of Y recorded when the computer sensed the pilot's depression of the RA button in the vicinity of the 100 foot DH.

At the time pilots reported Y estimates at the DH, they included in their transmission a qualitative estimate of the alignment of the aircraft's direction of flight over the ground with the extended runway centerline. Pilots were instructed to report "..... tracking ON (or PARALLEL)", when no significant misalignment was perceived; ".....track DIVERGING", when the aircraft was judged to be moving away from the desired track; or "..... track CONVERGING", when the aircraft was judged to be moving toward the desired track.

Error measures, designated as e_7 errors, for pilot estimates of lateral offset are based on the absolute value of the difference between the actual value of Y and the pilot's Y estimates; an e_7 error was counted whenever $|Y - Y_{est.}| > 25$ feet. Subject performance on this component of the approach success judgment is thus reflected in summary statistics on $|Y - Y_{est.}|$ data and by error ratios formed by dividing e_7 error counts by the total number of runs in a designated series or subset.

Pilot errors in judging the aircraft's tracking tendencies were determined by comparing his verbal qualitative estimates, which were recorded on the experimenter's data sheet, with cross-track velocities ($\dot{Y}$) recorded at the time these estimates were made, i.e., when the AL button was depressed. Errors, designated as e_9, were counted in accordance with the following "accuracy" matrix:

When the subject's report was:	And the recorded value of $\dot{Y}$ was: < 4 fps	> 4 fps
"ON" or "PARALLEL"	no error	e_9 error
"DIVERGING"	e_9 error	no error*
"CONVERGING"	e_9 error	no error*

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

Err[illegible] for e_9 errors were used to represent pilot performance o[illegible] of the approach success judgment.

Evaluation of Pilot's Ability to Predict Approach Success

This assessment was concerned with the pilot's ability to extrapolate his ongoing determination of the aircraft's flight path to the terminal conditions of the approach. It was included as a general test of the extent to which baseline flight instrumentation enabled the pilot to accurately judge whether or not he would arrive at the DH within specified flight path offset limits.

The measure selected for this test was the number of errors pilots made in predicting that the aircraft would be within or outside prescribed offset limits on arrival at the DH. Pilots were instructed to attempt this prediction just after making their first estimate of height above touchdown at 300 feet. The prediction was given verbally, using the intercom system, and reflected the pilot's go/no-go judgment that the aircraft would be within 50 feet of the extended runway centerline and not more than 12 feet above or below the 100-foot DH on arrival at the Inner Marker. This report was recorded by the Experimenter and relayed to the data monitor who subsequently entered the data into the 840 Data Acquisition System. Errors, designated e_5 errors, were counted whenever a "Within" prediction was reported and actual offsets exceeded either of the limits or when an "Outside" report was given and actual offsets were within both limits.

Data Treatment for Assessing the Effects of Operational Procedure and Control Task Loading

Summary statistics on the measures of flight management task performance under alternative operational procedures and control task loading were also derived for contrast with those obtained under the more representative operational conditions. In addition, the joint and separate effects of the variations in Operational Procedure (Factor A) and Control Task Loading (Factor B) were examined by analysis of variance techniques. The structural model underlying the basic factorial design and the corresponding computational procedures used for the analysis are discussed in Winer (ref. 6 , p. 298). When the variance analysis indicated significant overall effects for one or both of these variables, the Newman-Keuls method (ref. 6, p. 80) was used to test the differences between particular levels of the two factors.

Contrasts between performance under the "Head-up" condition and the conditions included in the basic factorial arrangement were carried out by using appropriate t tests (ref. 6, p. 24). The performance of the 4 pilots assigned to Group 3 could be contrasted with that of 4 different pilots in Group 1 or 2 under the treatment combinations of interest.

In addition to certain of the measures already identified for components of the approach success judgment, a composite measure of the overall quality of pilot performance was defined for the examination of the effects of alternative procedures and control task loading. This measure was a weighted sum of the e_2, e_3, e_4, e_5, e_7, and e_9 errors defined in the preceding section. The differential weighting of these error scores reflects the operational importance attributed to the corresponding judgments.

Errors in estimating relative altitude (e_4) and lateral offset (e_7) at the decision height were considered most critical and were assigned a weighting value of 3. Errors in judging tracking vectors at the decision height (e_9) and in estimating relative altitude at 200 feet (e_3) were considered somewhat less critical and were assigned a value of 2. The remaining error types included the relative altitude estimate made earlier in the approach (e_2) and the decision height prediction (e_5). These errors are considered to be comparatively less critical and were assigned a weighting value of 1.

Data Treatment for Evaluating the Effects of Flight Path Offset at the Decision Height (DH) on Landing Performance

This assessment was concerned with the pilot's willingness and ability to execute the landing maneuver from various flight path offset positions and tracking vectors at the DH. By combining 3 lateral offset situations with 2 tracking conditions and 3 vertical offsets, 18 different terminal situations were defined and touchdown performance was considered for each of these DH situations. The pilot's willingness to complete the landing maneuver from each of the DH situations was indicated by his verbal report, recorded by the Experimenter, of his acceptance of the offset and tracking situation actually encountered at the DH on each run. Since the pilots were instructed to attempt a landing out of each approach, their ability to effect a successful touchdown was determined for each of the terminal conditions of interest by obtaining data on touchdown position and velocities.

The measures selected for assessing touchdown performance were lateral touchdown position (Y), longitudinal touchdown position (X), vertical velocity ($\dot{h}$), and cross-track velocity ($\dot{Y}$) at touchdown. FAA touchdown dispersion limits (ref.) were used to assess recorded touchdown positions. Lateral displacement was considered excessive whenever the recorded value of Y was greater than ± 27 feet. Touchdown along the runway was acceptable only when the recorded value of X at touchdown was within +1000 and -1500 feet. Since X=0 occurs at the glideslope intersection with the runway (GSX), the actual runway threshold is defined by X = 1,000 feet. A touchdown at greater positive values of X 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 restruction in the pilot's forward visibility of approximately 25 feet in front of the aircraft when it is in the landing attitude, a main gear touchdown at or before the point X = -1,500 feet was 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" (ref. 7). These dispersion limits are illustrated in Figure 8.

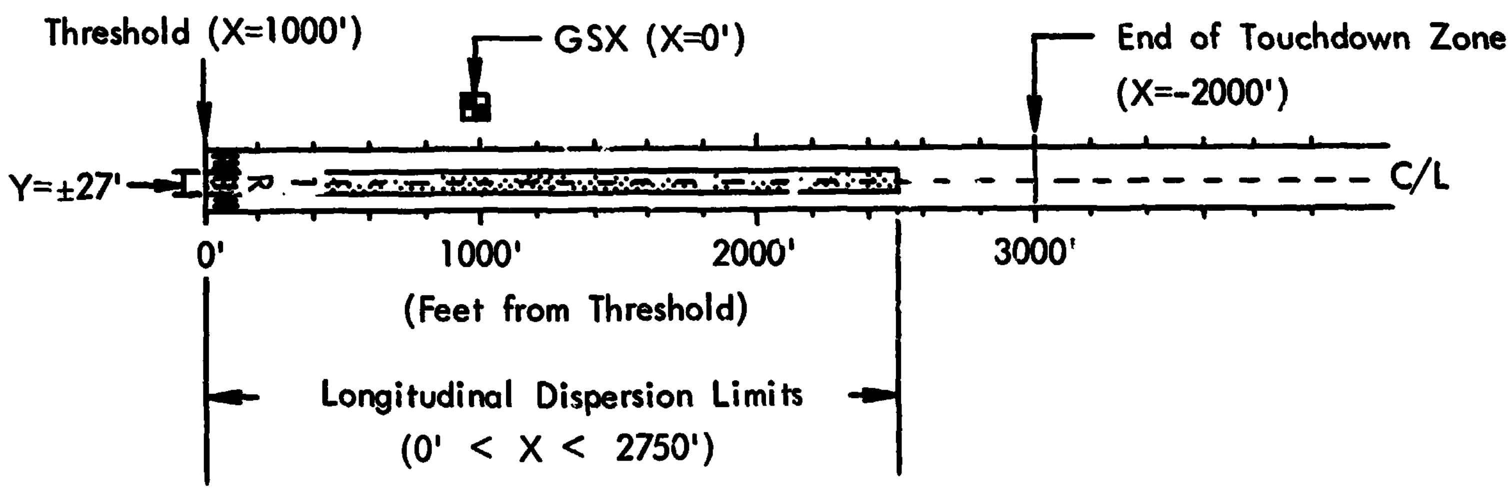

Figure 8. Touchdown Dispersion Limits Used to Assess Landing Performance.

Criterion values used for assessing touchdown velocities were six feet per second for $\dot{h}$ and eight feet per second for $\dot{Y}$. Landings were considered to be completely successful only when recorded touchdown velocities were below these values.

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RESULTS AND DISCUSSION

Data reflecting pilot performance on the assigned experimental tasks are presented in this section. Analyses of the effects of control task loading and operational procedure on flight management task performance and data reflecting the pilot willingness and ability to execute the landing maneuver from various flight path offset situations at the decision height are also reported here. The presentation of these data is structured by the specific issues and questions raised in the analysis underlying the simulation study.

Each of these issues will be briefly restated and a summary statement of the study results pertinent to that issue is given. Supporting data is then cited and discussed in terms of its relevance to the issues of interest and of its statistical and practical significance. A complete record of error scores, pilot estimates of specified flight situation parameters, and the recorded values of these parameters at key points in the approach and landing sequence is presented in Appendix D.

Flight Management Task Performance

The general intent of the simulation study was to exercise appropriately qualified 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 low visibility landing system (LVLS). Data recorded during the simulator runs provides an estimate of the number and type of errors in pilot judgment which may be expected to occur in actual flight operations under the conditions represented.

Operationally significant errors occurred on more than a third of these runs in the present study. With respect to the support provided to the command pilot for flight management activities, this general finding indicates inadequacies in the LVLS design features and/or operational procedures assumed in the underlying analysis. A breakdown of pilot task performance data for specific elements of the approach success judgment follows.

Pilot Estimates of Height Above Touchdown

The analysis underlying the study questioned the pilot's ability to accurately estimate relative altitude, i.e., the aircraft's height relative to the intended touchdown point on the runway, as the aircraft approaches the authorized minimum decision altitude (Appendix ', p. A-4). Irregularities in terrain elevation approaching the runway were cited as a major factor in the difficulties anticipated for the pilot in judging his arrival at the 100 foot decision height (DH).

Data taken under the most representative operational conditions included in the simulation indicate that significant errors in judging arrival at the DH will occur on 36% of the approaches. Variations in terrain profile were found to have a significant adverse effect on these judgments. When irregularities in terrain elevations approaching the runway were represented in the simulator, errors in judging arrival at the DH occurred on more than half of the runs.

Summary data on pilot estimates of height above touchdown (HAT) for the major variations in operational conditions represented in the simulator are presented in Table 8. As indicated earlier, the "Fully Automatic" control mode paired with the "Head Down" procedure is considered to be most representative of operational conditions. Data taken on the 36 runs under these conditions (column 2) may thus be interpreted as the best estimators of pilot performance in the operational situation.

Table 8. Accuracy of Pilot Estimates of Height Above Touchdown at Three Points in the Approach.

Control Mode →		Fully Automatic			Split-axis		Fully Manual	
Operational Procedure →	measure*	X-check	Head-down	Head-up	X-check	Head-down	X-check	Head-down
Data taken: at 300 feet	M	299	301	298	308	304	298	307
	(n)	(34)	(36)	(36)	(36)	(36)	(36)	(35)
	sd	31	11	15	29	11	31	12
	E/R	.12	0	0	.08	0	.08	0
Data taken: at 200 feet	M	206	203	202	217	210	207	209
	(n)	(34)	(36)	(36)	(36)	(36)	(35)	(36)
	sd	34	16	18	25	14	30	18
	E/R	.47	.19	.31	.56	.22	.45	.33
Data taken: at 100 feet (DH)	M	104	105	NA	107	111	108	105
	(n)	(36)	(36)	NA	(36)	(36)	(30)	(36)
	sd	24	13	NA	27	24	16	21
	E/R	.47	.36	NA	.42	.42	.33	.56

This condition considered most representative of operational conditions. (Fully Automatic, Head-down)

* M = Mean of Pilot (P) estimates - feet

(n) = Number of observations

sd = Standard deviation

E/R = Error ratio: Number of runs on which errors occurred/total number of runs

It is of interest to note that pilot performance under these conditions was consistently better than under any alternative condition.

Mean pilot estimates of HAT, in most instances, were quite close to the actual values at all three altitudes. The variability of these estimates, however, is very high, as indicated by the corresponding standard deviations. Error ratios (E/R) are reported in Table 8 to provide an indication of the operational significance of this variability in pilot performance. These ratios were formed by dividing the error count for a specified run series by the total number of runs (a run is one approach and landing sequence in the simulator).

At 300 feet an error was counted when the pilot's estimate was not within 50 feet of this value. In almost all instances, the variability in 300-foot estimates was within these limits. As the aircraft approaches the decision height, more accurate judgments are required; at 200 feet a one-dot deflection on the glideslope deviation indicator represents 28 feet above or below the glideslope and at the 100-foot decision height the one-dot displacement is only 14 feet. Accordingly, errors in the 200-foot estimate were counted when estimates were more than 20 feet off and errors in estimating the 100-foot point were counted when estimates were more than 12 feet off. Further justification for adopting the 12-foot accuracy limits for the DH judgment is provided by the FAA requirement that glideslope tracking be accomplished "... to within ±35 microamperes or ±12 feet, whichever is larger" (ref. 7)

The effect of varying approach terrain elevation profiles on HAT estimates at the DH is shown in Table 9 (see the Method section for a definition of the terrain profiles). Data from 210 simulator runs were reorganized to separate runs on the basis of the terrain profile represented. The slight departure from the experimental plan, which called for 72 runs under each terrain profile, is due to missing data. On six of the fully manual runs, pilots forgot to indicate arrival at the 100-foot point. Variability in pilots and other run conditions was the same for the three sets of data summarized in Table 9.

Table 9. Effect of Approach Terrain Elevations on Pilot Judgments of Arrival at the 100-Foot Decision Height.

Measure	Low	Level	High
Mean P estimate - feet (Number of observations)	108 (69)	98 (70)	114 (71)
Standard deviation	27	11	20
Total errors	41	12	37
Error ratio	.59	.17	.52

It is clear from the summary data that, in contrast with the "Level" profile, both the variability of pilot estimates and the number of significant errors increased when either the "High" or the "Low" profile was represented. An analysis of variance, based on a rearrangement of the data in accordance with a single factor design with repeated measures (ref. 6, p. 105), shows the effect of differences in terrain profile on the error ratios to be significant when α is set at .01. A summary of this analysis is presented in Table 10.

Table 10. Analysis of Variance for Terrain Profile Effects.

Source of Variation	df	MS	F
Between pilots	7		
Within pilots	16		
Terrain profile	2	.425	10.89**
Residual	14	.039	
Total	23		

** $F_{.99}(2, 14) = 6.51$

A test of the differences between error ratios for the three terrain profiles, using the Newman-Keuls method (ref. 6, p. 80), indicates that error ratios for both the "Low" and "High" profiles differ significantly from those for the "Level" profile ($\alpha = .01$). Differences between error ratios for the "Low" and "High" profiles are not significant.

Summary data presented in Table 8 for alternative run conditions reflects higher error ratios and thus provides further support for the assertion that difficulties may be expected in judging relative altitude. Variations in operational procedure do not affect the estimates made prior to the emergence of visual cues at 300 and 200 feet. The increased task loading in going from "Fully Automatic" runs to the manual control modes was expected to increase error scores or variability in HAT estimates, but the data do not support this contention. An analysis of variance on error ratio data, arranged in a 2 x 3 factorial design with repeated measures (ref. 6, p. 302) revealed no significant effects of either control mode, operational procedures, or the interaction of these two variables on the critical estimate of arrival at the DH.

Based on the data obtained in the simulator, pilot estimates of relative altitude can be expected to be highly variable (and therefore unreliable) and to be adversely affected to a marked degree by variations in approach terrain elevations. In the debriefing session following the simulation exercise, pilots identified the information sources for their HAT estimates. Six of the twelve pilots used both the Barometric and Radio altimeter for the 300-foot estimate, five pilots reported exclusive use of the Radio Altimeter, and one pilot relied solely on the Barometric instrument. At 200 feet, less use of the Barometric Altimeter was reported. At the DH all twelve pilots used the Radio Altimeter. Six used this instrument exclusively, five used it together with the auditory tone, and one used it in conjunction with the Barometric Altimeter. It is interesting to note that none of the pilots reported using the Minimum Decision Altitude (MDA) light located on the Flight Director Indicator.

Inspection of the error scores for individual pilots revealed no systematic differences which might be attributal to the information source used. Consistent use of either the auditory tone or MDA light should have minimized the effects of variations in terrain profile, but there was no indication of this in the data. Consideration was given to the possible effects of delayed pilot reaction times on HAT estimates. However, this factor would tend to produce pilot estimates which were lower than the altitudes being judged and the mean pilot estimates reported in Table 8, with only three exceptions, are consistantly higher than the target values. Reaction time is therefore dismissed as a biasing factor.

Responses to the debriefing questionnaire show that only two of the tweleve pilots found the use of the pushbutton to be awkward or or limiting for indicating HAT estimates. Four pilots reported some awkwardness on the first few runs but no problems thereafter and the rest reported no difficulties with this procedure.

Pilot Estimates of Flight Path Alignment and Tracking

As the aircraft approaches the DH, the command pilot must be able to determine that its flight path is within specified lateral offset limits from the extended runway centerline and that it is tracking so as to remain within these limits. The component judgments of estimating lateral oofset and tracking vectors, by reference to either flight instruments or external visual reference, were considered suspect in the background analysis of flight management task performance (Appendix A, p. A-11). Current trends in Category II training and equipment procurement suggest that qualitative indications of localizer deviation will be relied upon for assessing flight path alignment until visual cues fade-in and can be used for a final determination of cross-track position and tracking tendencies.

Seventy-eight percent of the pilot estimates of lateral offset, based strictly on instrument reference, were within 25 feet of the aircraft's actual cross-track position. It is interesting to note that when these estimates were made by external visual reference, only 56% were within this same accuracy limit. This finding suggests that external visual reference under Category II visibility conditions is not an adequate information source for "confirming" flight path alignment judgments made earlier in the approach by instrument reference.

The assessment of aircraft tracking tendencies was more accurate by visual reference. On instruments, errors in judging tracking vectors occurred on 47% of the simulator runs; when the tracking judgment was made by visual reference this error rate dropped to 31%. Apparently, the visual cues provide a better basis for detecting rate and direction of movement, even under degraded visibility conditions, than the flight situation instruments.

Summary data on the accuracy of flight path alignment and tracking judgments is presented in Table 11. Error measures are derived from the differences between pilot estimates of flight path alignment at the DH and the recorded values of cross-track position (Y) and drift ($\dot{Y}$) at that point in the approach. Arrival at the DH was indicated by the pilots by depressing either the AD or RA pushbutton on the control wheel (see Method section) and both the pilot estimates and recorded values of Y and $\dot{Y}$ were referenced to this event.

On the average, pilot estimates of lateral offset were within about 20 feet of the actual cross-track position. Again, the variability of pilot estimates was high; at one standard deviation the magnitude of estimate errors is about twice as high as the mean. The actual cross-track positions judged by the pilots ranged from 0 to more than 150 feet, though on most runs they were less than 50 feet. Errors in judging the more divergent flight paths were clearly larger, as indicated in Figure 9. These errors in judging the less critical offset positions tend to slightly inflate the error measures reported in Table 11, but their effect is the same across all experimental conditions.

Table 11

Accuracy of Pilot Estimates of Flight Path

Alignment and Tracking Tendencies at the 100 Foot Decision Height

Control Mode →	Fully Automatic			Split Axis		Fully Automatic	
Operational Procedure →	X-check	Head-down	Head-up	X-check	Head-down	X-check	Head-down
Measure:							
- Mean error in P's estimates of lateral offset in feet	22	19	29	13	19	19	26
(n)	(36)	(36)	(36)	(36)	(36)	(30)	(36)
- Standard deviation	21	26	24	13	19	17	28
- Error ratio for errors in judging lateral offset	.33	.22	.44	.17	.25	.33	.39
- Error ratio for errors in judging tracking	.22	.47	.31	.42	.58	.47	.31

This condition considered most representative of operational conditions (Fully Automatic, Head-down)

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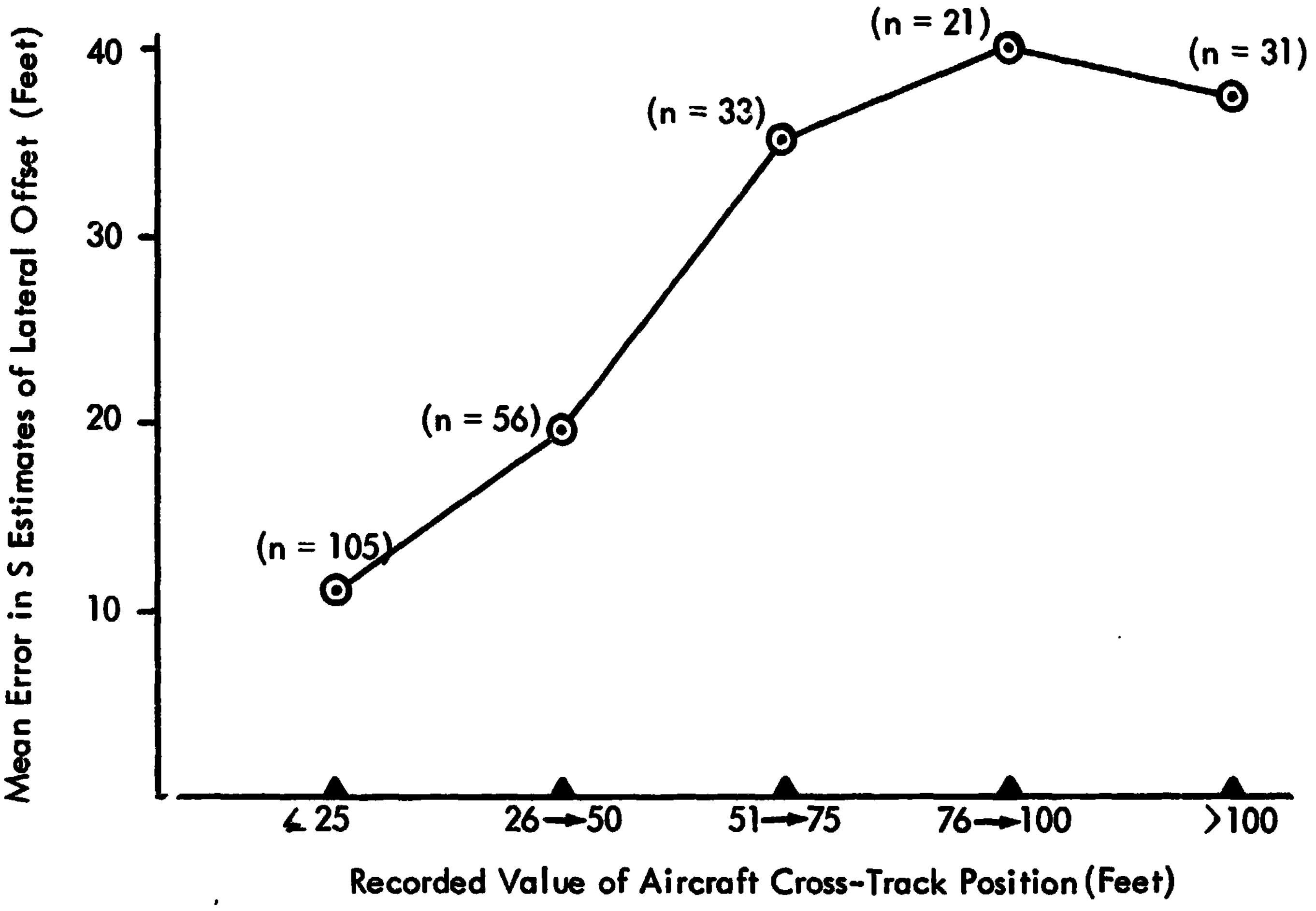

Figure 9. Errors in Judging Lateral Offset for Various Aircraft Cross-Track Positions at the Decision Height

Mean estimate errors for the "Head-up" condition (judgments made solely by external visual reference) appear to be considerably higher than those obtained under the nominal "Head-down" condition (judgments made by instrument reference), but the difference is not statistically significant [based on the two data sets, $t^2 = 3.37$ and $F_{.95}(1, 6) = 5.99$]. However, when the two conditions are contrasted, using the error ratio for lateral offset judgments as the criterion measure, the increase in errors under the "Head-up" condition is significant with α set at .05 [$t^2 = 12.25$, $F_{.95}(1, 6) = 5.99$]. This contrast between "Head-up" versus "Head-down" procedures was based on data taken under the same "Fully Automatic" control mode and with similar patterns of variation in run conditions operating during the two run series. An analysis of variance on error ratio data for the lateral offset estimate, as indicated in Table 11 disclosed no significant effects of either control mode, operational procedure, or their interaction.

Errors in judging the aircraft's tracking tendencies occurred on about 40% of the simulator approaches. The error ratios presented in Table 11 for this judgment were based on discrepancies between pilot reports of aircraft movement relative to the runway centerline (i.e., parallel, converging, or diverging) and the recorded values of Y and $\dot{Y}$ (see Method section). An analysis of variance on these data, arranged in a 2 x 3 factorial design, disclosed a significant interaction in the effects of Control Mode and Operational Procedure on tracking judgments. Summary data on pilot performance under each combination of these two variables is presented in Table 12. The cell entries in this table are summations of error counts for the 36 runs (30 for one combination due to missing data) carried out under each treatment combination.

Table 12. Number of Pilot Errors in Judging Tracking Tendencies for Six Combinations of Control Mode and Operational Procedure.

Operational Procedure:	Control Mode		
	Automatic	Split-axis	Manual
Cross-check	8	15	14 (n = 30)
Head-down	17	21	11

When the error counts shown in Table 12 are converted to ratios, a consistent tendency for errors to increase as the Control Mode varies from "Automatic" to "Manual" is apparent, except for the pairing of the "Head-down" procedure with the "Manual" mode. This trend and the indicated reversal accounts for the significant interaction effects found in the analysis of variance. A subsequent test of the simple effects of the two variables (e.g., the effect of alternative Control Modes when only one Operational Procedure is considered at a time) indicated that differences in the effects of Control Mode are significant with α set at .01. The effect of differences in

Operational Procedure was significant at the .05 level for the "Automatic" control mode, but not significant for either "Split-axis" of "Manual" modes. The overall analysis is summarized in Table 13.

Table 13. Analysis of Variance for the Effects of Control Mode and Operational Procedure on Pilot Tracking Judgments.

Source of Variation	df	MS	F
Between Pilots	7		
A (Operational Procedure)	1	.031	-
Subjects within groups	6	.0432	
Within Pilots	16		
B (Control Mode)	2	.0605	4.42
AB (Interaction)	2	.096	7.01**
B x Pilots within groups	12	.0137	
Simple Effects:			
A for b_1 (Automatic Mode)	1	.122	5.19*
A for b_2 (Split-axis Mode)	1	.04	1.70 (NS)
A for b_3 (Manual Mode)	1	.06	2.55 (NS)
Within Cell	18	.0235	
B for a_1 (Cross-check Procedure)	2	.97	70.8*
B for a_2 (Head-down Procedure)	2	.58	42.3*
B x Pilots within groups	12	.0137	

NOTES: * $F_{.95}(1, 18) = 4.41$

** $F_{.99}(2, 12) = 6.93$

In summary, then, the foregoing analysis shows that subject performance in judging aircraft tracking tendencies was degraded when manual flight control war required, particularly in the split-axis mode, and, further, that when flight control was automatic the number of errors in judging tracking strictly by instrument reference (Head-down) was significantly higher than those made when cross-checking of visual cues was permitted. An apparent reversal of this finding occurred for the "Head-down" condition when full manual control was exercised. Under this treatment combination, tracking judgments were correct more often than when lateral flight path control was automatic. The fact that the pilots were actually controlling aircraft tracking tendencies apparently had a positive effect on their judgments of this situation.

A cursory look at the effects of runway visual range (RVR) on the lateral offset and tracking judgment indicates that there is no significant difference in performance under the two visibility conditions. Data taken on the 36 runs under "Head-up" conditions are summarized in Table 14.

Table 14

Accuracy of Lateral Offset and Tracking Estimates for 1200 Feet and 1600 Feet RVR Conditions

Measure:	RVR 1200 feet	RVR 1600 feet
- Mean error is P's estimates of lateral offset in feet	30	29
(n)	(20)	(16)
- Standard deviation	28	23
- Total lateral offset estimate errors	9	7
- Error ratio	.45	.44
- Total tracking judgment errors	5	6
- Error ratio	.25	.37

In the debriefing sessions, half of the pilots stated that the cross-track position estimate was the most difficult judgment they were asked to make. Two others identified the tracking judgment to be the most difficult. Only two pilots felt that their cross-track position estimates were "highly accurate (within 25 feet)". Four felt they were "somewhat uncertain" about their estimates and one pilot was "highly uncertain -- wouldn't rely on them". The rest (five) felt they were "... close enough (within 50 feet)". It is interesting to note that one of the most confident pilots actually was "highly accurate" - his average estimate was within 12 feet of the value being judged and the variance of his estimates was the lowest achieved (the standard deviation was 11.2 feet).

Both the objective task performance data and the subjective reports thus support the contention that difficulties can be expected in judging flight path alignment and tracking. All pilots except those specifically instructed to make this judgment by external visual reference reported that the expanded localizer indicator on the Flight Director Indicator (FDI) was used as the information source. It should be noted that identifiable localizer errors -- such as alignment with the runway centerline, airborne centering errors, and course bends -- were not represented in the simulation. An analysis of just those localizer errors which are within current (1967) International Civil Aircraft Organization (ICAO) standards for Category II ILS has shown that root sum of square (RSS) localizer errors at the DH can accumulate to about 55 feet on a three-sigma basis (ref. 8). Errors of this kind must be added on an RSS basis, to errors in pilot estimates when these judgments are made by reference to ILS-derived instruments such as the expanded localizer indicator.

Pilot's Ability to Predict Approach Success

This component of the approach success judgment was concerned with the pilot's ability to effectively "stay-ahead" of the aircraft and is only indirectly related to the issues raised in Appendix A. It was considered to be of some interest to determine how accurately pilots could anticipate their flight situation at the DH by monitoring the ongoing flight path offsets and tracking tendencies. At 300 feet above the runway, just after making the relative altitude judgment, pilots were instructed to report their predictions regarding the outcome of the approach in terms of lateral offset limits.

The accuracy of these predictions is shown in Table 15. Since the predictions were made prior to the fade-in of visual cues, differences in Operational Procedure are not relevant here; all of the predictions were made "Head-down", i.e., by instrument reference. Pilots were instructed to report "Within" if they were confident that the aircraft would arrive at the DH within ±50 feet of the extended runway centerline or "Outside" if they felt that these limits would be exceeded. The error counts presented in Table 15 were based on discrepancies between pilot reports and the actual cross-track position of the aircraft at the 100 foot DH.

Table 15

Accuracy of Pilot Predictions of Approach Success by Control Mode

Measure:	Control Mode: Fully Automatic	Split Axis	Fully Manual	All
- Total errors	50	38	42	130
(n)	(108)	(72)	(66)	(246)
- Error ratio	.46	.54	.64	.53

It is clear from the error ratios in Table 15 that the accuracy of pilot predictions of approach success is no better than chance and possibly not as good. It might be argued that the programmed flight profiles used on Automatic runs in the simulator were unrealistically unpredictable, but the data summarized in Table 15 contradict this notion. Error ratios for the "Fully Manual" runs are clearly higher than those obtained on either the "Fully Automatic" or "Split-axis" runs. An analysis of variance, using only the data on the eight pilots who flew all three conditions, indicated that Control Mode was not a significant factor for approach success predictions ($F < 1$).

Much of the error in predicting approach success can be attributed to a "positive" or "accepting" bias which was noted in the pilot's predictions. A marked preference for reporting that the flight path would be within specified offset limits at the DH was apparent, even when the aircraft's actual lateral offset was excessive and/or tracking tendencies were diverging. Pilots predicted "Within" on 209 of the 252 experimental runs (83%). Only 65% of these runs were actually within the 50 feet offset limits at the DH.

Effect of Control Task Loading and Operational Procedure on Flight Management Task Performance

Nominal Category II conditions represented in the simulation called for the flight control function to be fully automatic, leaving the pilot free to devote all of his time and attention to the flight management task. In addition, pilots were instructed to adopt a procedure wherein all component estimates of the approach success judgment were made strictly by instrument reference, i.e., the "Head-down" procedure. In order to assess the effects of alternative control task loadings and operating procedures, additional data on flight management task performance were obtained under seven combinations of Control Mode and Operational Procedure (see Method section).

The effects of these two factors on specified components of the approach success judgment have already been represented in preceding sections. To further explore their effect, a composite index of the overall quality of the approach success judgment was adopted as a criterion measure. This measure is a weighted summation of error counts derived from performance on each component of the approach success judgment (see Method section) and can range from 0, when no errors are counted for a given run, to a high of 12 per run when all possible errors occur.

Mean error counts per run, using this composite measure, are presented in Table 16 for each of the seven combinations of the two factors. The expected impairment in performance as control task loading increases in the more manual modes is evident for the "Head-down" procedure, but this trend is reversed when the "Cross-check" procedure is considered. The overall quality of flight management task performance appears to be best when the "Head-up" procedure is paired with the "Fully Automatic" control mode. However, errors in judging arrival at the DH are not reflected in the composite measure for this condition. It will be recalled that pilots in the "Head-up" group were not required to make the relative altitude judgment at the DH by external visual reference.

Table 16

Effect of Control Mode and Operational Procedure on a Composite Measure of the Pilot Accuracy of Approach Success Judgments

	Control Mode:			
Operational Procedure:	Fully Automatic	Split-axis	Fully Manual	Across Control Modes
Cross-check	4.42 (n = 36)	4.31 (n = 36)	3.81 (n = 36)	4.17 (n = 108)
Head-down	3.53 (n = 36)	4.12 (n = 36)	4.89 (n = 36)	4.18 (n = 108)
Head-up	2.94 (n = 36)	NA	NA	2.94 (n = 36)
Across Procedures	3.64 (n = 108)	4.22 (n = 72)	4.34 (n = 72)	4.01 (n = 252

* Cell entries are mean composite error scores - see text.

With the data on six combinations ("Head-up" data excluded) arranged in a 2 x 3 factorial design with repeated measures (ref. 6, p. 302), no significant differences in error counts were indicated by analysis of variance in either the main effects of the two factors or their interaction. A comparison of all mean error counts with the nominal condition ("Head-down" - "Fully Automatic") taken as a control (ref. 6, p. 89), also disclosed no significant differences (the largest t statistic computed was 2.51; Dunnett's $t_{.975}(12) = 3.10$). The data thus indicate that the overall quality of the approach success judgment is the same under all of the combinations of Control Mode and Operational Procedure which were examined in the study.

The earlier analyses of component flight management tasks suggest that only the flight path alignment estimates made at the DH were differentially affected by variations in Control Mode and Operational Procedure. No consistent trend in the effects of these variables is evident in the data, however, and the specific influence of increasing control task loading and/or varying in formation sources remains unclear.

Effects of Flight Path Offset at the DH on the Success of the Landing Maneuver

In order to assess pilot performance on flight management tasks, a wide range of flight path offset and tracking situations at the DH were programmed for the simulated approach sequences. Displacements from the glide slope and localizer also occurred when manual flight path control was exercised. Landing performance from a variety of known offset and tracking conditions could thus be examined in an attempt to clarify the problem of establishing appropriate criteria for defining a successful approach (Appendix A, p. A-8)

The initial criterion measure adopted for assessing the effect of flight path offset on landing performance was the probability or proportion of completely successful touchdowns (P_s). A completely successful touchdown was one that satisfied the following criteria:

1. Lateral displacement from the runway centerline was within ±27 feet,

2. Touchdown along the runway occurred between the threshold and a point located 2500 feet down the runway,

3. Touchdown rate-of-descent was 6 ft./sec. or less, and

4. Cross-track velocity at touchdown was 8 ft./sec. or less.

For the landings attempted under the simulated Category II conditions in the present study, these criteria proved to be exceedingly difficult to satisfy. Even when flight path offsets at the initiation of the landing maneuver were at minimum values (less than 25 feet laterally and within 12 feet of the prescribed 100-foot decision altitude) and the aircraft's track was parallel or converging, only 6% of the touchdowns were completely successful. Excessive rate-of-descent at touchdown disqualified most of the landings; the mean value for this parameter over all landing attempts (n = 238) was 11.2 ft./sec. However, lateral displacement from the runway centerline was also excessive in many instances and the dispersion of touchdown points was high.

A more complete picture of the touchdown performance data for various lateral offset conditions at the DH is provided in Figure 10. In order to provide a clearer indication of the effects of lateral offset, the data summarized in Figure 10 are based only on runs for which the aircraft's tracking vector at the DH was aligned with the runway or converging. Diverging tracks at this point in the approach were expected to degrade touchdown performance and were omitted from this first inspection of the data.

Mean touchdown positions along the runway are well within the 2500-foot limit for each of the five lateral offset situations and are all near the expected value of 1000 feet. Seven of the 158 landings represented in Figure 10 were short of the runway; the distribution of these short touchdowns over the five offset conditions is 4, 1, 0, 1, 1. Only

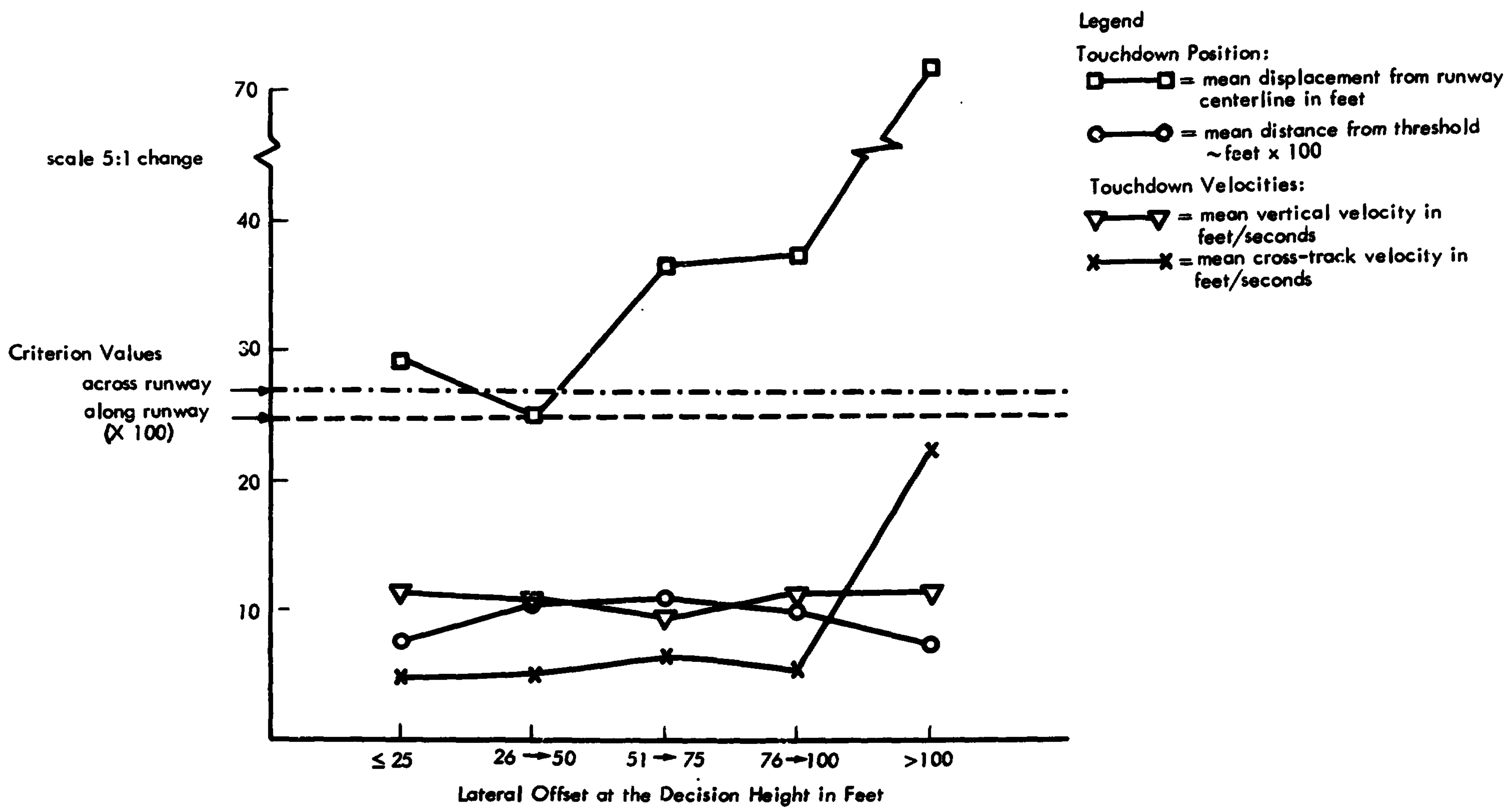

Figure 10. Effect of Lateral Offset at the Decision Height on Touchdown Position, Vertical Velocity, and Cross-Track Velocity.

four touchdowns exceeded the 2500 foot limit and were evenly distributed over the last four offset conditions. For the most part, then, the second criterion for successful landings was easily satisfied. However, the excessive touchdown vertical velocities may have been the price paid for landing within the touchdown zone.

With respect to lateral displacement from the runway centerline, mean touchdown positions were near or within the criterion values only when lateral offsets at the DH were 50 feet or less. When the aircraft was more than 100 feet from the approach course, 8 of the 19 landings were clearly off the edge of the runway. In an analysis of usable runway width, allowing for landing gear width restrictions and moderate crab angles at touchdown, the amount of runway actually available for landing a large jet transport was shown to be about ±45 feet from the centerline of a 150-foot runway (ref. 8). Eleven of the 19 landings from the widest DH offset position exceeded this offset limit.

Although the trends in the lateral touchdown position data plotted in Figure 10 clearly indicate that limits on allowable lateral offset at the DH should be set no wider than ±50 feet, the excessive variability around the data points precludes any straightforward generalizations. On a one standard deviation basis, touchdowns as far as 73 feet from the centerline could occur from minimum offset positions at the DH. Twelve of the 66 landings attempted from DH offset positions of 25 feet or less (18%) resulted in touchdowns that exceeded limits on useful runway width (±45 feet).

It is also clear from Figure 10 that touchdown rate-of-descent and cross-track velocity was excessive on an unacceptably high proportion of the landing attempts under all of the flight path offset conditions considered. Average touchdown rates-of-descent recorded in earlier studies, using the same simulator and pilots of comparable experience, were about 4 ft./sec. (ref. 9). In these earlier studies, however, flight control was fully manual throughout the approach and landing and degraded visibility conditions were not represented in the simulation.

There is an interesting possibility that the very poor touchdown performance exhibited in this study, from all offset situations at the DH, supports the contention that the visual cues available under Category II visibility conditions are inadequate for flight control, particularly for controlling the aircraft in the vertical axis (see discussion, Appendix A, p. A-17). British investigators have repeatedly stressed this problem, as indicated in the following quote:

> The main safety problem in bad weather landing using present-day techniques is considered to be the shortcomings of the visual control in pitch during the final phase of the approach and landing especially in low visibilities ....
>
> 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, 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. (ref. 10).

Summary data on touchdown performance under all conditions of flight path offset, tracking vector, and relative altitude at the initiation of the landing maneuver are presented in Table 17. Data from 238 landing attempts are represented in the Table; on 14 of the experimental runs the pilot elected to abort the landing manuever. It is interesting to note that 72% of the DH flight situations were judged to be "Acceptable" by the pilots, i.e., they indicated that they would have attempted the landing. The data in Table 17 shows that only 104 of the 238 approaches (44%) were within ± 50 feet of the runway centerline and tracking properly (aligned or converging). Again (see p. 72, above), pilots exhibited a positive bias in their judgment of the flight situation.

There is some tendency for lateral displacements ($\overline{Y}$) and cross-track velocities ($\dot{Y}$) to be higher for the wider DH offset positions, and for the variability in touchdown position and velocities to increase. As indicated earlier, however, touchdown performance is operationally marginal or unacceptable for all DH situations. The proportion of successful touchdowns appears to be highest when lateral offsets at the DH were between 50 and 75 feet, with a parallel or converging flight

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CONCLUSIONS

Command pilot performance of selected flight management tasks during simulated Category II approach and landing operations was evaluated in this study. The intent was to determine the extent to which flight instrumentation expected to be available in a baseline low visibility landing system would support the pilot in carrying out his flight management responsibilities. Estimates of pilot performance were obtained under nominal operating conditions and under two alternate combinations of operational procedure and flight control mode. In addition, the effects of various flight path offset situations at the 100-foot Category II decision height on the success of the landing maneuver were examined.

The data obtained in this study support the following conclusions:

1. Baseline flight instrumentation will be inadequate for accurate monitoring and assessment of the approach to Category II minimums. Operationally significant errors occurred on more than a third of the approaches conducted under the condition considered most representative of the actual operational situation, i.e., with flight control fully automatic and pilot judgment made strictly by instrument reference.

2. Pilot judgments of height above touchdown will be unreliable. Under nominal conditions, significant errors in judging arrival at the 100-foot decision height occurred on 36% of the approaches. Mean pilot estimates of height above touchdown at 300 feet and 200 feet were highly accurate, but the variability of these estimates was high.

3. Variations in terrain elevations approaching the runway can be expected to have a significant adverse effect on relative altitude judgments. When irregularities in terrain profiles were represented in the simulation, errors in judging arrival at the decision height occurred on more than 50% of the runs. When comparatively level

terrain profiles were represented, errors occurred on only 17% of the approaches.

4. Both the objective task performance data and the pilot's subjective reports support the contention that difficulties can be expected in judging flight path alignment and tracking. Mean estimates of lateral offset at the decision height were within 20 feet of the aircraft's actual cross-track position, but again the variability was high; at one standard deviation the magnitude of estimate errors was 45 feet. Errors in judging tracking tendencies occurred on 47% of the approaches under nominal conditions. In debriefing sessions, half of the pilots stated that the cross-track position estimate was the most difficult judgment they were asked to make, two others identified the tracking judgment as the most difficult, and all but two expressed low confidence in their estimates.

5. External visual reference under Category II visibility conditions is not an adequate information source for confirming flight path alignment estimates made earlier in the approach by instrument reference. Seventy eight percent of the lateral offset estimates made by instrument reference were within 25 feet of the actual cross-track position; when the same estimates were made by visual reference only 56% were within the 25-foot accuracy limit.

6. Pilots will not be able to make accurate predictions concerning the outcome of the approach. The accuracy of approach success predictions was found to be no better than that expected by chance.

7. Pilots will exhibit a positive bias in judging approach success. A marked preference for reporting that the flight path would be within specified offset limits at the decision height was apparent, even when the aircraft's actual offset was excessive and/or tracking vectors were diverging at the time the predictions were made.

8. The deviations from nominal conditions in operational procedure and flight control task loading examined in this study will neither

improve nor degrade the overall quality of approach success judgments. No significant differences in error counts were indicated by analysis of variance in either the main effects of the two factors or their interaction. Analysis of components of the approach success judgment suggested that flight path alignment and tracking estimates at the decision height were differentially affected by variations in flight control mode and procedure, but no consistent trend in the effects of these variables was evident in the data.

9. Touchdown performance under Category II conditions may be expected to exceed established criteria for successful landings. Even when flight path offsets at the initiation of the landing maneuver were at minimum values (less than 25 feet laterally and within 12 feet of the perscribed 100-foot decision altitude) and the aircraft's track was parallel or converging, less than 6% of the touchdowns were completely successful.

10. There is an interesting possibility that the poor touchdown performance exhibited in this study, from all offset situations at the decision height, supports the often cited contention that visual cues available under Category II visibility conditions are inadequate for flight control during the landing maneuver, particularly for controlling the aircraft in the vertical axis.

The foregoing conclusion statements indicate the potential impact on Category II approach and landing operations if instrumentation similar in function and general design to the baseline system represented in this simulator study is used. Summary data cited in support of each conslusion reflects the performance of highly qualified airline pilots under a carefully developed simulation of flight management task demands. However, any generalization to particular operational situations must be tempered by unavoidable limitations in the physical and psychological fidelity of the simulation and by the experimental procedures adopted to render the flight management task "visible" for measurement and analysis.

With respect to psychological fidelity, for example, it cannot be demonstrated that the simulation included all of the information sources for pilot judgments which are available in the actual situation or that critical visual cues were faithfully reproduced. Thus, although visual segments appropriate to 1600 and 1200-foot RVR conditions were accurately represented, such factors as fog structure and the brightness and resolution of visual features in the runway surrounds probably were not phenomenally equivalent to their real world counterparts. The influence of such factors on the pilot's head-up judgments and landing performance in the simulator is therefore undetermined.

The general point of the foregoing remarks is that further verification of the data presented here is desirable, as it is with any simulator study, prior to its use in characterizing actual flight operations. However, the study raises important questions regarding the adequacy of the flight instrumentation which many airlines are planning to use in Category II operations. The data presented are consistent with the findings of earlier analyses of pilot factors and flight instrumentation in low visibility approach and landing operations (refs. 1, 2, 3, 8, 10, 15, 16 and 18). The study documented in this report provides an additional empirical basis for consideration of these issues by the many agencies and individuals who are working to assure the effectiveness and safety of low visibility approach and landing in jet transport aircraft.

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APPENDIX A

POTENTIAL FLIGHT MANAGEMENT PROBLEMS IN JUDGING APPROACH SUCCESS

(Reproduced from Reference 11)

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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. 12):

> 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. 3) 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.

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. 13). 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. 14). 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 A-1, 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 2.

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

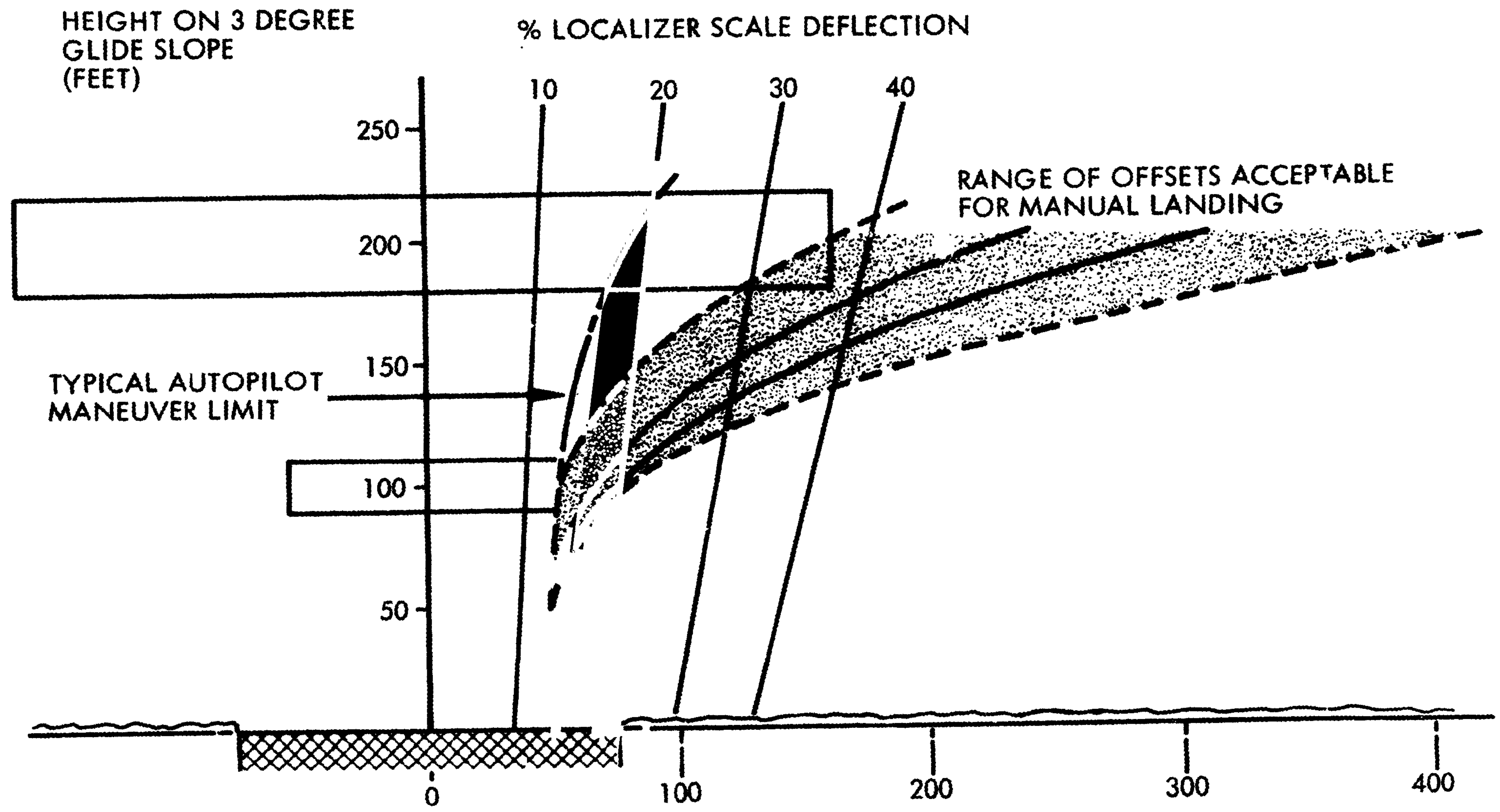

Figure A-1. Lateral Displacement from Runway Centerline (Feet), Visual Acceptance Windows (Adapted from Ref. 1, Vol. I).

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 A-1 were obtained using aircraft representative of conventional subsonic jet transports and should be derived again for the SST.

As Beck has indicated (ref. 3), 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 environ ment 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. 2) 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. 15). 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 angular 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. <u>Can pilots accurately estimate lateral offset and tracking vectors using external visual cues?</u>

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. 3) 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. 16), 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. 17) 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 · 1510 feet obtained in an FAA study of hundreds of jet landings by experienced pilots under visual conditions may be cited (ref. 12).

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. 16):

> 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. 2), 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 A-2 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

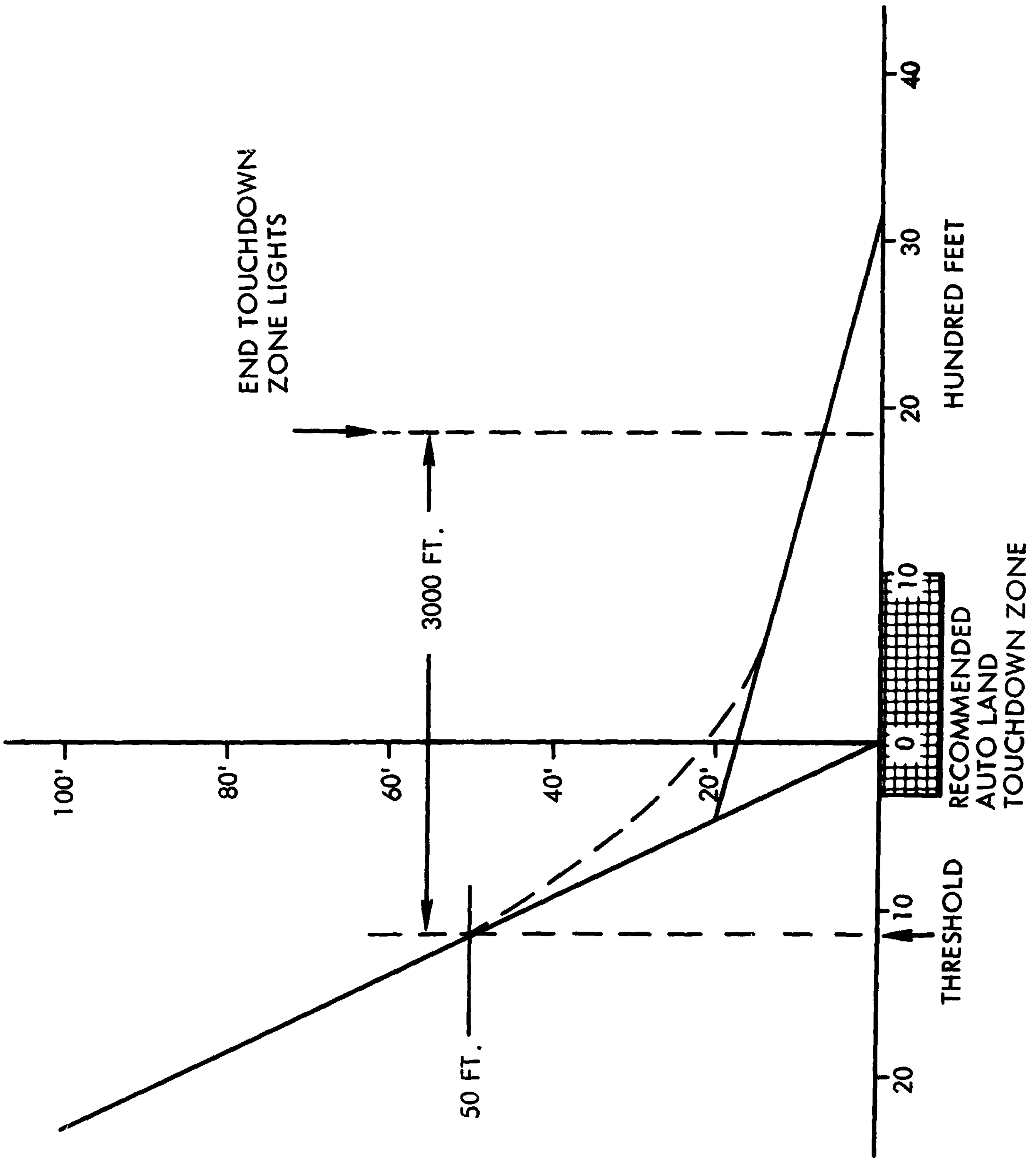

Figure A-2. Touchdown Geometry for Soft Landing (from Ref. 2).

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. 12) 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 Fig. A-2 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. 12, 2, and 3), 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

PILOT ORIENTATION BOOKLET AND BACKGROUND DATA COLLECTION SHEET

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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. Co[illegible] 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 __ 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 familiarization runs After a brief coffee break you 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.

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*NOTE: This schedule was appropriately modified for pilots assigned to Group 3.

0815 - 0900	Orientation to study
0900 - 0915	Coffee break - proceed to simulator
0915 - 1100	Simulator familiarization & practice run series
1100 - 1200	Complete first experimental run series
1200 - 1300	Lunch
1300 - 1315	Complete two refresher runs
1315 - 1430	Complete second experimental run series
1430 - 1445	Break
1445 - 1545	Complete third experimental run series
1545 - 1600	Break - return to briefing area
1600 - 1630	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 descending to the assigned initial approach attitude 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 B-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.

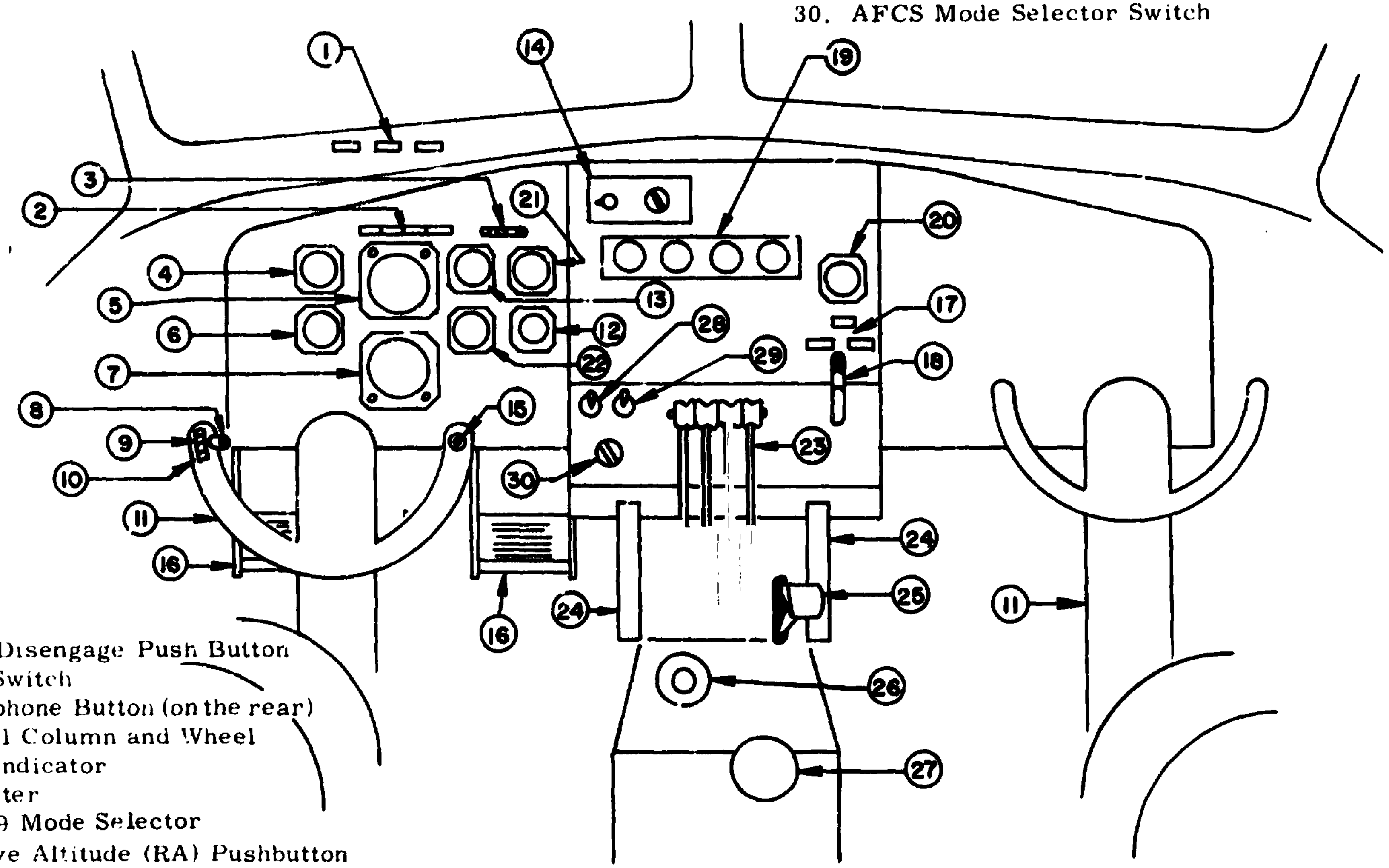
Detailed familiarization with these instruments and controls will be given at the simulator; however the equipment characteristics outlined below should be noted and if you have any general questions we will attempt to resolve them at this time.

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. A full on-dot deflection on the expanded localizer scale represents the same 75 micro-amp deviation signal as that available on a smaller scale on the Course Indicator. At the decision point, a full scale deflection would indicate a lateral offset of about 190 feet.

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
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



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. FD-109 Mode Selector
15. Relative Altitude (RA) Pushbutton

Figure B-1. Flight Instruments and Controls Provided at the 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 sufficiently 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 centerline 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 take care of certain run setup controls. E will also handle the gear and flaps on your command. At the start of each run, the simulator will be appropriately positioned above the initial approach altitude. You will initiate each run 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 to programmed speed for initial approach (150 kts will be used on all runs).

   d) Select AFCS mode in accordance with E's briefing (item 1 above).

   e) If run is not fully manual, engage autothrottle function (A/T control to ON) and select initial command airspeed.

   f) If A/T function is used, position throttles for disconnect (this is a simulator-peculiar item, throttles should be set to a thrust index of 5,000 lbs).

   g) Set Radio Altimeter reference bug to appropriate DH value (item 1 above).

   h) Trim aircraft for initial approach (or for AFCS disconnect).

3. E will indicate readiness to start the run. Acknowledge by placing simulator in OPERATE mode, using control on left side of cockpit.

4. Simulation will now go dynamic. Monitor flight instruments and voice communications.

5. If selected AFCS mode is not automatic, hand-fly aircraft as required. Initial maneuver is to descend to initial approach altitude.

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

7. Call for gear extension at one-dot below glide slope and flap extension to 50° crossing OM.

8. Monitor glide slope capture.

9. Call for adjustment of command airspeed to 135 K.

10. Continue to assess localizer and glide slope tracking. When you are confident that the aircraft is at precisely 300' above the touchdown zone, depress, and release the Height Above Touchdown (HAT) button on the inboard horn of the control wheel.

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

12. 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 both:

    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),

    make a verbal report as follows: "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.

13. Request instruction from E regarding procedure to be followed in transitioning to visual reference. It is important that you carefully follow the suggested procedure on all scheduled runs.

14. 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, carefully estimate the aircraft's cross-track position (lateral displacement from the extended runway center

line) and its tracking vector (drift as the aircraft approaches the DH and prepare to report this estimate to E, using the intercom system. Give your best estimate of cross-track position in feet on arrival at the 100' DH 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 center line, 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 DH TO BE
> _____ FEET LEFT, TRACKING PARALLEL."

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.

15. 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. <u>This control is necessary on all runs, whether the AFCS is "engaged" or not, to indicate your judgment of arrival at the 100' DH</u>. 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.

16. 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 3,000-foot touchdown zone. To stay within established touchdown limits, you should attempt to land within ± 27 feet of the runway center line 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/or terminate the simulation sequence by depressing the IC control.

At some point during the roll-out, reposition the simulator for the next run in the scheduled series by depressing the IC button. The general position just outlined will then be repeated for the next scheduled run. If you have any questions regarding the procedures just outlined, please ask the experimenter for further clarification.

APPENDIX C

PILOT DEBRIEFING QUESTIONNAIRE

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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 500 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 300 feet? At 200 feet? Arrival at the 100 foot decision height (DH)?

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

7. Which instruments (or information) did you use to estimate cross-track position at the decision height?

8. How confident do you feel about your quantitative estimates of cross-track position at the decision point?

   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.)

APPENDIX D

COMPUTER PRINT-OUT OF SIMULATOR RUN DATA

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APPENDIX D
COMPUTER PRINT-OUT OF SIMULATOR RUN DATA

The following computer print-outs present the error counts and the recorded values of designated flight situation parameters at key points in the approach for each run in the experimental schedule. Familiarization and practice runs are not included. The data are presented by run numbers for each subject.

The data entries in each column of the print-out can be understood by reference to the following translation of column headings (the reader should consult the Method section for a more complete definition of the measures):

RUN = The designated run number taken from the experimental run schedule.

CM = Error count for the composite measure, i.e., the overall index of the quality of approach success judgments.

E_2 = Error count for errors in estimating HAT at 300 feet.

E_3 = Error count for errors in estimating HAT at 200 feet.

E_4 = Error count for errors in estimating HAT at the 100-foot decision height.

E_5 = Error count for errors in predicting approach success.

E_7 = Error count for errors in estimating lateral offset at the decision height.

E_9 = Error count for errors in judging tracking tendencies at the decision height.

E_{10} = A "1" entry indicates an excessive lateral touchdown position, i. e., touchdown was more than 27 feet from the runway centerline.

E_{11} = A "1" entry indicates a touchdown position outside longitudinal dispersion limits, i. e., short of the runway threshold or more than 2500 feet down the runway.

PPS = Partial proportion of successful touchdowns -- a "1" entry indicates that all four of the criteria for a completely successful landing were satisfied.

ZRA3 = The recorded value of the aircraft's height above the runway (Z), in feet, when the subject pressed the RA button near 300 feet.

ZRA2 = The recorded value of Z when the RA button was pressed near 200 feet.

ZAD = The recorded value of Z when the AFCS was disengaged (or when the RA button was pressed) near 100 feet.

YAD = The recorded value of aircraft cross-track position (Y), in feet, when the subject disengaged the AFCS (or pressed the RA button near 100 feet).

YDAD = The recorded rate of change in Y, in feet per second, at the same point in the approach (YD is read "Y dot").

YTD = The recorded value of Y at touchdown.

YDTD = The recorded value of cross-track velocity ($\dot{Y}$), in feet per second, at touchdown.

XTD = The recorded value of distance from the point of glide slope intersection with the runway (GSX), in feet, at touchdown; since X = 0 at GSX, negative values are beyond this point (GSX is located 1000 feet from the runway threshold).

HDTD = The recorded value of vertical velocity (rate-of-descent) at touchdown, in feet per second.

The designators on the side for 9-run subsets indicate the flight control mode used on the associated run series. "FA" represents the Fully Automatic mode, "SA" stands for Split-axis, and "FM" identifies the Fully Manual runs.

Run conditions are not specified on the computer print-out. This information may be obtained for each run by using Table B-1. The cell entries in this table refer to the alternative run conditions defined in Table 6 of the body of this report (see p.41). Note that run numbers cannot be used directly in Table B-1. To determine the conditions represented for a designated run in the print-out, use the following procedure:

1. First determine the control mode (FA, SA, or FM) used on the run series,

2. Then locate the designated run in the associated run series, e.g., the 6th FA run for subject 1.

3. Now determine, from Table B-1, the alternative run condition designator for the run under consideration (e.g., for the 6th FA run for subject 1, this designator would be "1").

4. Refer to Table 6 in the body of the report for a definition of the corresponding run conditions (e.g., for designator 1, Approach Profile 1, Terrain Profile 1, and an RVR of 1200 feet were represented).

Table D-1. Alternative Run Conditions for Experimental Run Series by Subject

		Alternative Run Condition Designator*																										
		Fully Automatic Runs									Split-Axis Runs									Fully Manual Runs								
	Subject	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Group 1 (Cross-check)	1	6	2	4	7	3	1	8	5	9	2	4	5	3	9	6	8	7	1	4	5	3	7	6	1	2	9	8
	2	5	6	7	4	8	9	2	3	1	6	5	1	7	9	2	8	3	4	2	5	1	6	3	4	7	9	8
	3	8	4	2	5	7	1	3	9	6	5	7	2	9	6	8	4	3	1	6	2	5	9	7	1	3	4	8
	4	4	9	6	8	1	5	7	2	3	5	3	4	6	2	7	8	9	1	8	3	2	4	9	6	7	1	5
Group 2 (Head-down)	5	6	2	4	7	3	1	8	5	9	2	4	5	3	9	6	8	7	1	4	5	3	7	6	1	2	9	8
	6	5	6	7	4	8	9	2	3	1	6	5	1	7	9	2	8	3	4	2	5	1	6	3	4	7	9	8
	7	8	4	2	5	7	1	3	9	6	5	7	2	9	6	8	4	3	1	6	2	5	9	7	1	3	4	8
	8	4	9	6	8	1	5	7	2	3	5	3	4	6	2	7	8	9	1	8	3	2	4	9	6	7	1	5
Group 3 (Head-up)	9	6	2	4	7	3	1	8	5	9	NA									NA								
	10	2	5	1	6	3	4	7	9	8																		
	11	8	4	2	5	7	1	3	9	6																		
	12	5	3	4	6	2	7	8	9	1																		

*See Table 6 in Method section for definition of run conditions.

Serendipity inc.

SUBJECT NUMBER: 1

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
FA	8	6	0	0	1	1	0	1	0	0	1	*.	.	141.	35.	-14.	7.	3.	-512.	1.
FA	9	6	0	0	1	1	0	1	0	0	0	.	.	176.	-20.	-4.	-2.	-2.	224.	8.
FA	10	7	1	1	1	1	0	0	0	0	1	239.	165.	125.	10.	3.	-8.	-3.	-307.	6.
FA	11	6	0	0	1	0	1	0	0	0	0	267.	194.	115.	-22.	8.	23.	6.	-174.	8.
FA	12	11	1	1	1	0	1	1	1	0	0	231.	149.	119.	97.	4.	-33.	-6.	-181.	8.
FA	13	7	1	1	1	1	0	0	0	0	0	229.	100.	78.	2.	.	24.	4.	-322.	10.
FA	14	8	0	1	1	1	0	1	0	0	1	272.	153.	75.	41.	3.	17.	3.	456.	6.
FA	15	6	0	0	1	1	0	1	0	0	0	266.	185.	135.	-33.	1.	10.	2.	-227.	8.
FA	16	4	0	1	0	0	0	1	0	0	0	252.	159.	103.	-38.	.	8.	-3.	160.	7.
SA	17	6	0	0	1	1	0	1	1	0	0	298.	208.	53.	-59.	-4.	-43.	-5.	-664.	2.
SA	18	0	0	0	0	0	0	0	1	0	0	267.	201.	108.	7.	2.	-29.	-1.	24.	6.
SA	19	8	0	1	1	1	0	1	1	0	0	288.	224.	176.	-24.	1.	29.	1.	-128.	8.
SA	20	9	0	0	1	1	1	1	1	0	0	264.	187.	132.	82.	4.	-68.	3.	-485.	9.
SA	21	0	0	0	0	0	0	0	0	0	1	285.	186.	102.	-10.	4.	4.	-5.	-269.	4.
SA	22	6	0	0	1	1	0	1	0	0	1	271.	208.	119.	-39.	.	-1.	-2.	-318.	5.
SA	23	9	0	1	1	1	1	0	0	0	1	261.	169.	140.	66.	-5.	-22.	-4.	-333.	4.
SA	24	4	0	1	0	0	0	1	0	0	0	271.	157.	101.	4.	-6.	-14.	2.	-197.	11.
SA	25	2	0	1	0	0	0	0	0	0	1	254.	165.	106.	-22.	-1.	20.	1.	-781.	5.
FM	26	0	0	0	0	0	0	0	0	0	1	263.	202.	.	.	.	-1.	-3.	-986.	4.
FM	27	2	0	1	0	0	0	0	1	0	0	257.	169.	.	.	.	-35.	-7.	-447.	18.
FM	28	2	0	1	0	0	0	0	0	0	0	285.	161.	.	.	.	-4.	.	-394.	12.
FM	29	5	0	0	0	0	1	1	0	0	0	281.	180.	11.	-41.	4.	-11.	9.	-903.	6.
FM	30	4	0	0	1	1	0	0	0	0	0	260.	198.	134.	-1.	1.	-5.	5.	183.	8.
FM	31	2	0	1	0	0	0	0	0	0	1	258.	168.	107.	16.	2.	-16.	-2.	-124.	5.
FM	32	6	1	0	0	0	1	1	0	0	1	227.	185.	108.	44.	1.	-24.	2.	-1244.	6.
FM	33	4	0	1	0	0	0	1	0	1	0	253.	160.	104.	20.	12.	-12.	.	-1518.	9.
FM	34	2	0	1	0	0	0	0	0	0	1	256.	165.	.	.	.	-1.	-3.	-637.	3.

*Blank entries indicate missing data.

SUBJECT NUMBER: 2

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	42	6	0	0	0	1	1	1	1	0	0	300.	193.	109.	-20.	.	30.	5.	-637.	6.
	43	7	1	1	1	1	0	0	0	0	0	360.	288.	148.	8.	-2.	13.	2.	604.	9.
	44	6	0	1	1	1	0	0	1	0	0	299.	221.	119.	102.	17.	222.	3.	183.	10.
	45	6	0	1	1	1	0	0	1	1	0	320.	246.	134.	-17.	-20.	500*	500*	-5000.*	10.
FM	46	8	0	1	1	1	0	1	0	0	0	323.	223.	135.	75.	-2.	-4.	-5.	-478.	15.
	47	4	0	1	0	0	0	1	1	0	0	284.	177.	96.	-26.	-2.	-36.	.	-204.	10.
	48	0	0	0	0	0	0	0	1	0	0	278.	209.	93.	-7.	12.	87.	.	175.	13.
	49	6	0	0	0	1	1	1	0	0	0	297.	195.	97.	79.	6.	10.	-11.	-629.	10.
	50	9	0	0	1	1	1	1	1	0	0	253.	210.	124.	-182.	-1.	-100.	18.	722.	6.
	51	9	1	1	1	1	0	1	1	0	0	359.	255.	173.	-24.	23.	333.	24.	107.	4.
	52	6	0	1	1	1	0	0	1	0	0	344.	254.	65.	20.	5.	61.	-13.	-671.	8.
	53	2	0	1	0	0	0	0	1	0	0	325.	234.	101.	17.	2.	55.	3.	445.	20.
	54	4	0	1	0	0	0	1	0	0	0	337.	228.	98.	32.	4.	22.	-8.	16.	8.
SA	55	7	1	1	1	1	0	0	1	0	0	359.	265.	120.	-35.	-11.	-102.	-3.	711.	11.
	56	8	0	1	1	1	0	1	1	0	0	312.	240.	53.	-75.	-5.	-95.	7.	-512.	6.
	57	6	0	1	1	1	0	0	1	1	0	338.	236.	66.	62.	-1.	45.	-8.	-2824.	7.
	58	7	1	1	0	1	1	0	0	1	0	351.	253.	95.	121.	-11.	-1.	-4.	-1806.	13.
	59	4	0	1	0	0	0	1	1	0	0	337.	233.	92.	13.	-7.	-34.	1.	312.	7.
	60	3	0	0	1	0	0	0	1	0	0	306.	184.	49.	38.	6.	79.	7.	77.	9.
	61	3	1	1	0	0	0	0	1	1	0	354.	258.	88.	168.	12.	500.	500.	-5000.	9.
	62	2	0	1	0	0	0	0	1	0	0	335.	245.	92.	15.	6.	47.	4.	81.	13.
	63	0	0	0	0	0	0	0	1	0	0	284.	207.	89.	-22.	-9.	-40.	10.	-1093.	11.
FA	64	2	0	1	0	0	0	0	1	0	0	315.	233.	88.	94.	4.	51.	-4.	103.	11.
	65	6	0	1	1	1	0	0	1	1	0	317.	251.	124.	-1.	-10.	-73.	1.	1645.	18.
	66	6	0	1	1	1	0	0	1	0	0	336.	255.	65.	-72.	-5.	-79.	6.	297.	15.
	67	8	0	1	1	1	0	1	0	0	0	350.	264.	120.	133.	-4.	-9.	-23.	684.	3.
	68	1	0	0	0	1	0	0	1	0	0	338.	220.	91.	23.	.	56.	4.	642.	19.

* These entries indicate that touchdown did not occur, i.e., the subject elected to abort the landing attempt.

SUBJECT NUMBER: 3

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	76	3	0	0	1	0	0	0	0	0	0	295.	198.	75.	56.	-5.	2.	-15.	532.	10.
	77	2	0	0	0	0	0	1	1	0	0	287.	190.	104.	-16.	-6.	-48.	5.	-14.	13.
	78	7	0	0	1	1	1	0	0	0	0	306.	210.	119.	-54.	-6.	4.	4.	-18.	8.
	79	1	0	0	0	1	0	0	0	0	0	305.	205.	102.	-36.	4.	14.	6.	456.	14.
FA	80	1	0	0	0	1	0	0	0	1	0	290.	204.	93.	-13.	5.	1.	.	1273.	15.
	81	4	0	0	0	1	1	0	0	0	0	286.	189.	98.	-13.	1.	-4.	-2.	513.	15.
	82	6	0	1	0	1	1	0	0	0	0	318.	234.	104.	93.	-10.	-8.	-6.	532.	14.
	83	9	0	1	1	1	1	0	0	0	0	312.	236.	122.	-21.	-11.	5.	-9.	608.	3.
	84	5	0	1	1	0	0	0	1	1	0	320.	224.	147.	59.	18.	500.	500.	-5000.	3.
	85	6	0	0	1	1	0	1	0	0	0	317.	.	84.	-10.	1.	7.	-10.	-474.	9.
	86	4	0	1	0	0	0	1	1	0	0	327.	237.	102.	-16.	3.	-31.	-7.	-223.	5.
	87	6	0	1	1	1	0	0	1	0	0	342.	251.	122.	-10.	-1.	-30.	-3.	509.	3.
	88	0	0	0	0	0	0	0	0	0	0	310.	220.	98.	44.	-6.	-13.	-3.	-496.	17.
FM	89	2	0	1	0	0	0	0	0	0	0	305.	172.	99.	-11.	-8.	-16.	8.	536.	12.
	90	0	0	0	0	0	0	0	0	0	0	292.	209.	97.	-4.	7.	24.	-6.	783.	16.
	91	9	1	1	1	1	0	1	0	0	1	355.	254.	135.	-19.	-3.	21.	-2.	-7.	6.
	92	0	0	0	0	0	0	0	0	0	0	309.	211.	94.	-21.	-2.	-2.	4.	616.	17.
	93	2	0	1	0	0	0	0	0	0	0	345.	261.	.	.	.	8.	-10.	711.	11.
	94	7	0	1	1	0	0	1	0	0	0	337.	228.	131.	-12.	-4.	-4.	-6.	289.	9.
	95	3	0	1	0	1	0	0	1	1	0	327.	235.	97.	-11.	4.	500.	500.	-5000.	9.
	96	6	0	1	1	1	0	0	1	1	0	340.	244.	134.	-45.	-5.	500.	500.	-5000.	9.
	97	7	0	0	1	1	1	0	0	0	1	297.	209.	127.	-66.	-9.	22.	5.	69.	3.
SA	98	0	0	0	0	0	0	0	0	0	0	316.	211.	104.	79.	17.	-17.	-22.	149.	13.
	99	8	0	1	1	1	0	1	1	0	0	334.	241.	145.	76.	-5.	-34.	10.	141.	15.
	100	0	0	0	0	0	0	0	1	0	0	286.	213.	98.	-1.	-8.	-36.	.	418.	10.
	101	3	0	0	0	1	0	1	1	0	0	301.	206.	100.	100.	-6.	-35.	6.	119.	4.
	102	0	0	0	0	0	0	0	0	0	0	288.	203.	92.	-11.	-1.	-4.	-8.	115.	7.

SUBJECT NUMBER: 4

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
SA	110	4	0	0	1	1	0	0	1	0	0	306.	216.	123.	12.	-5.	30.	6.	722.	7.
	111	6	0	1	0	1	1	0	1	0	0	321.	223.	100.	51.	-4.	31.	2.	582.	12.
	112	2	0	0	0	0	0	1	0	0	0	265.	211.	97.	1.	-2.	24.	11.	715.	21.
	113	0	0	1	0	1	1	0	1	0	0	316.	226.	90.	-7.	8.	45.	7.	654.	10.
	114	2	0	0	0	0	0	1	0	0	0	305.	211.	108.	-13.	-3.	14.	16.	540.	10.
	115	0	0	0	0	0	0	0	0	0	0	304.	201.	88.	-25.	.	-1.	7.	456.	7.
	116	2	0	0	0	0	0	1	1	0	0	309.	198.	104.	63.	-1.	72.	-3.	-143.	9.
	117	2	0	1	0	0	0	0	0	0	0	318.	226.	102.	-24.	-5.	19.	20.	688.	13.
	118	0	0	0	0	0	0	0	0	0	0	305.	205.	95.	-7.	-2.	10.	5.	388.	10.
FA	119	0	0	0	0	0	0	0	0	0	0	294.	200.	96.	2.	-4.	11.	9.	-30.	18.
	120	2	0	1	0	0	0	0	1	0	0	309.	222.	111.	-3.	-5.	71.	-1.	115.	6.
	121	6	0	1	0	1	1	0	0	0	0	323.	231.	88.	3.	7.	17.	-1.	399.	10.
	122	7	0	0	1	1	1	0	1	0	0	305.	200.	127.	71.	-4.	45.	-13.	-341.	9.
	123	1	0	0	0	1	0	0	0	0	0	291.	199.	96.	.	-2.	11.	5.	661.	17.
	124	4	0	0	0	1	1	0	1	0	0	300.	206.	103.	30.	-3.	31.	4.	608.	14.
	125	3	0	0	0	0	1	0	0	1	0	297.	204.	88.	-45.	2.	1.	21.	1295.	13.
	126	3	0	0	0	0	1	0	0	0	0	305.	213.	112.	-36.	-4.	-19.	-2.	39.	11.
	127	3	0	0	0	0	1	0	0	0	0	318.	218.	103.	50.	-4.	22.	7.	821.	14.
FM	128	6	0	0	0	1	1	1	1	0	0	310.	209.	101.	57.	8.	59.	3.	-364.	5.
	129	5	0	1	0	0	1	0	1	0	0	324.	227.	91.	48.	3.	35.	4.	-436.	7.
	130	9	0	0	1	1	1	1	1	0	0	308.	214.	117.	29.	8.	125.	4.	.	12.
	131	3	0	0	0	0	1	0	1	0	0	301.	205.	95.	31.	-2.	52.	-3.	5.	2.
	132	0	0	0	0	0	0	0	1	0	0	315.	217.	93.	29.	-1.	63.	-5.	-109.	1.
	133	0	0	0	0	0	0	0	1	0	0	329.	211.	91.	50.	12.	40.	-20.	118.	3.
	134	0	0	0	0	0	0	0	1	0	0	283.	180.	97.	13.	9.	54.	-4.	483.	16.
	135	0	0	0	0	0	0	0	1	0	0	298.	206.	.	.	.	30.	4.	-516.	16.
	136	6	0	0	0	1	1	1	1	0	0	309.	212.	101.	57.	6.	58.	-5.	52.	11.

SUBJECT NUMBER: 5

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	144	3	0	0	0	0	1	0	1	0	0	313.	216.	92.	151.	11.	125.	-25.	399.	14.
	145	4	0	0	1	1	0	0	1	0	0	304.	195.	116.	-35.	-5.	38.	2.	426.	9.
	146	2	0	0	0	0	0	1	1	0	0	300.	192.	102.	-7.	-6.	-30.	9.	39.	18.
	147	2	0	0	0	0	0	1	0	1	0	296.	204.	100.	7.	5.	27.	-1.	1405.	14.
FA	148	6	0	0	0	1	1	1	1	1	0	320.	202.	108.	142.	-4.	57.	-36.	1128.	15.
	149	0	0	0	0	0	0	0	1	0	0	296.	200.	104.	4.	-2.	30.	5.	927.	18.
	150	8	0	0	1	0	1	1	1	0	0	302.	201.	76.	75.	-5.	38.	-10.	631.	15.
	151	0	0	0	0	0	0	0	1	0	0	308.	198.	104.	5.	3.	39.	6.	673.	18.
	152	6	0	1	1	1	0	0	0	1	0	328.	225.	120.	-14.	-12.	19.	25.	1880.	20.
	153	5	0	0	0	0	1	1	1	1	0	311.	204.	104.	-50.	-5.	-56.	9.	1033.	17.
	154	2	0	0	0	0	0	1	1	0	0	296.	200.	100.	40.	-5.	31.	.	411.	11.
	155	5	0	0	1	0	0	1	1	0	0	296.	208.	130.	-1.	-5.	41.	10.	92.	12.
	156	6	0	0	1	1	0	1	0	0	0	301.	220.	180.	110.	8.	14.	4.	939.	12.
SA	157	6	0	1	1	1	0	0	1	1	0	314.	232.	124.	-24.	-9.	59.	9.	1022.	10.
	158	3	0	0	0	0	1	0	1	0	0	321.	217.	92.	111.	18.	82.	-28.	851.	8.
	159	3	0	0	1	0	0	0	1	1	0	305.	214.	121.	81.	-4.	29.	-13.	1125.	13.
	160	3	0	0	0	1	0	1	0	1	0	300.	211.	96.	16.	3.	22.	-1.	1254.	10.
	161	1	0	0	0	1	0	0	1	0	0	300.	208.	96.	-2.	-2.	65.	4.	54.	10.
	162	4	0	0	0	1	1	0	1	0	0	300.	200.	100.	-42.	17.	71.	2.	-124.	11.
	163	4	0	0	1	1	0	0	1	0	0	320.	200.	152.	27.	-20.	68.	-7.	-75.	15.
	164	9	0	1	1	1	1	0	1	0	0	325.	237.	119.	-71.	3.	76.	5.	718.	7.
	165	2	0	0	0	0	0	1	0	0	0	300.	217.	99.	31.	-8.	-20.	2.	851.	13.
FM	166	3	0	1	0	[illegible]	0	0	0	0	0	324.	227.	106.	2.	-8.	18.	18.	760.	2.
	167	7	0	0	1	1	1	0	0	1	0	302.	216.	145.	31.	16.	25.	-15.	1375.	21.
	168	6	0	0	1	1	0	1	0	0	1	308.	212.	120.	-8.	-9.	4.	-2.	-113.	6.
	169	6	0	1	1	1	0	0	1	0	0	328.	232.	124.	-9.	-4.	34.	15.	935.	4.
	170	4	0	0	1	1	0	0	0	0	0	320.	208.	116.	-16.	3.	-2.	-3.	-352.	11.

SUBJECT NUMBER: 6

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	178	4	0	0	1	1	0	0	1	1	0	304.	217.	124.	-53.	-16.	-42.	25.	1428.	12.
	179	9	0	0	1	1	1	1	1	0	0	312.	207.	120.	89.	20.	-30.	-11.	202.	8.
	180	4	0	0	0	1	1	0	1	0	0	292.	196.	88.	-81.	15.	97.	9.	141.	14.
	181	7	0	1	0	0	1	1	0	0	1	313.	225.	92.	27.	13.	10.	7.	-60.	6.
FM	182	4	0	1	0	0	0	1	0	0	0	320.	224.	105.	-13.	-11.	11.	12.	396.	10.
	183	6	0	0	0	1	1	1	1	0	0	300.	200.	102.	135.	2.	42.	-26.	510.	21.
	184	1	0	0	0	1	0	0	1	0	0	296.	208.	90.	62.	16.	68.	-16.	904.	8.
	185	3	0	1	0	1	0	0	1	0	0	320.	232.	111.	-103.	14.	47.	-37.	-667.	5.
	186	7	0	0	1	1	1	0	1	0	0	296.	216.	122.	65.	-7.	-59.	21.	-341.	8.
	187	3	0	1	0	1	0	0	1	0	0	328.	228.	108.	115.	17.	88.	-21.	783.	9.
	188	2	0	0	0	0	0	1	0	0	0	298.	200.	90.	42.	4.	27.	-10.	-417.	8.
	189	4	0	0	1	1	0	0	0	0	0	288.	204.	80.	27.	3.	18.	-11.	-269.	4.
	190	7	0	1	0	0	1	1	0	0	0	296.	156.	104.	22.	5.	-24.	-13.	175.	7.
SA	191	1	0	0	0	1	0	0	1	0	0	320.	216.	92.	-94.	-7.	-91.	14.	267.	17.
	192	1	0	0	0	1	0	0	1	0	0	312.	216.	104.	-50.	-8.	-32.	16.	5.	5.
	193	3	0	0	0	1	0	1	1	0	0	280.	212.	112.	99.	-6.	33.	-10.	164.	8.
	194	8	0	1	0	1	1	1	1	0	0	324.	228.	104.	148.	-10.	-108.	-23.	175.	14.
	195	0	0	0	0	0	0	0	0	0	0	294.	206.	88.	22.	-9.	-7.	6.	350.	11.
	196	2	0	0	0	0	0	1	1	0	0	312.	208.	102.	-1.	3.	47.	.	160.	12.
	197	4	0	1	0	0	0	1	1	0	0	324.	228.	108.	146.	3.	339.	80.	912.	19.
	198	4	0	0	1	1	0	0	0	0	0	292.	192.	82.	26.	4.	18.	-9.	950.	14.
	199	0	0	0	0	0	0	0	1	0	0	300.	192.	100.	-6.	-9.	-59.	-4.	-41.	27.
FA	200	5	0	0	0	0	1	1	0	0	1	302.	208.	96.	103.	-4.	-23.	-3.	229.	6.
	201	4	0	0	1	1	0	0	1	0	0	308.	218.	124.	-14.	-13.	-68.	12.	434.	13.
	202	7	0	0	1	1	1	0	0	0	0	310.	208.	116.	-42.	-7.	-1.	17.	403.	10.
	203	4	0	1	0	0	0	1	1	0	0	312.	232.	104.	152.	-14.	-69.	-11.	210.	7.
	204	0	0	0	0	0	0	0	1	0	0	292.	192.	94.	12.	4.	44.	-6.	-79.	14.

SUBJECT NUMBER: 7

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	212	6	0	1	0	1	1	0	1	0	0	286.	160.	91.	89.	-6.	50.	-4.	-136.	5.
	213	2	0	0	0	0	0	1	0	0	0	292.	200.	98.	45.	-2.	4.	-4.	84.	19.
	214	8	0	1	1	1	0	1	0	0	0	303.	226.	116.	-35.	-4.	10.	8.	-140.	11.
	215	4	0	1	0	0	0	1	0	1	0	300.	174.	95.	.	-2.	19.	7.	1109.	15.
FA	216	2	0	0	0	0	0	1	0	0	0	283.	201.	104.	.	.	15.	-2.	893.	7.
	217	2	0	0	0	0	0	1	1	0	0	297.	196.	97.	27.	3.	76.	8.	-98.	25.
	218	7	0	0	1	1	1	0	1	1	0	279.	215.	141.	120.	2.	39.	-18.	1219.	24.
	219	6	0	1	1	1	0	0	1	1	0	317.	222.	124.	5.	-12.	-69.	.	1591.	13.
	220	4	0	0	1	1	0	0	1	1	0	282.	181.	122.	50.	20.	157.	2.	1170.	8.
	221	9	0	1	1	1	1	0	1	0	0	327.	232.	126.	64.	27.	167.	-14.	491.	13.
	222	6	0	0	1	1	0	1	1	0	0	290.	189.	75.	-45.	-6.	51.	4.	46.	17.
	223	4	0	0	1	1	0	0	0	0	0	313.	186.	76.	-13.	-17.	5.	4.	24.	10.
	224	8	0	1	1	1	0	1	1	0	0	320.	228.	124.	-21.	-6.	72.	.	-288.	9.
FM	225	4	0	0	1	1	0	0	1	0	0	300.	204.	64.	10.	-12.	-106.	-2.	-75.	14.
	226	8	0	1	1	1	0	1	1	1	0	284.	144.	120.	131.	10.	83.	-39.	-1575.	17.
	227	6	0	1	0	1	1	0	1	0	0	312.	228.	107.	-155.	5.	265.	42.	244.	4.
	228	0	0	0	0	0	0	0	0	0	0	308.	200.	100.	-33.	-4.	-9.	11.	950.	13.
	229	4	0	0	0	1	1	0	1	0	0	296.	216.	97.	-338.	4.	87.	39.	62.	12.
	230	2	0	0	0	0	0	1	1	0	0	302.	209.	112.	-5.	-1.	39.	2.	974.	9.
	231	2	0	0	0	0	0	1	0	0	0	296.	200.	92.	15.	3.	19.	-4.	980.	11.
	232	7	0	0	1	1	1	0	1	0	0	304.	203.	80.	-70.	-3.	-94.	-2.	-128.	10.
	233	11	0	1	1	1	1	1	1	0	0	317.	221.	128.	-53.	-9.	-99.	6.	510.	5.
SA	234	6	0	1	1	1	0	0	1	0	0	320.	232.	160.	5.	19.	78.	-11.	-557.	6.
	235	6	0	0	1	1	0	1	1	0	0	300.	207.	76.	54.	-1.	50.	-3.	58.	23.
	236	2	0	0	0	0	0	1	1	0	0	297.	203.	101.	13.	-5.	-45.	-6.	361.	14.
	237	9	0	1	1	1	1	0	1	0	0	314.	228.	129.	120.	-5.	-76.	-23.	327.	9.
	238	2	0	0	0	0	0	1	0	0	0	300.	212.	104.	-10.	1.	23.	2.	500.	15.

SUBJECT NUMBER: 8

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
SA	246	4	0	0	1	1	0	0	0	0	0	301.	209.	168.	12.	-6.	-24.	8.	-724.	17.
	247	6	0	0	1	1	0	1	0	0	0	313.	220.	119.	128.	4.	-8.	-8.	-162.	16.
	248	2	0	0	0	0	0	1	1	0	0	292.	191.	94.	-4.	-6.	-30.	1.	213.	12.
	249	8	0	1	1	1	0	1	0	1	0	317.	222.	130.	131.	11.	.	-16.	-1503.	17.
	250	2	0	0	0	0	0	1	0	0	0	298.	208.	112.	-46.	-5.	-4.	-1.	145.	19.
	251	3	0	0	0	0	1	0	1	0	0	291.	192.	101.	-2.	5.	29.	-4.	12.	14.
	252	9	0	0	1	1	1	1	0	0	0	297.	202.	139.	70.	-5.	8.	5.	-52.	11.
	253	6	0	0	1	1	0	1	0	1	0	314.	216.	131.	-38.	1.	-24.	-9.	-1586.	19.
	254	0	0	0	0	0	0	0	0	0	0	291.	191.	92.	-1.	1.	8.	-4.	-1009.	17.
FA	255	0	0	0	0	0	0	0	1	0	0	290.	189.	98.	-20.	-6.	-51.	5.	-235.	20.
	256	0	0	0	0	0	0	0	0	0	0	309.	217.	108.	-28.	-10.	7.	11.	16.	16.
	257	3	0	0	0	1	0	1	1	1	0	310.	219.	104.	125.	11.	500.	500.	-5000.	16.
	258	6	0	0	0	1	1	1	0	0	0	292.	188.	108.	73.	-5.	13.	-10.	582.	10.
	259	0	0	0	0	0	0	0	0	0	0	288.	188.	97.	1.	3.	-11.	-5.	-466.	12.
	260	6	0	0	1	1	0	1	0	0	0	300.	201.	121.	-13.	-1.	4.	-2.	-709.	17.
	261	4	0	0	1	1	0	0	0	0	0	288.	197.	80.	14.	-1.	5.	-5.	221.	12.
	262	0	0	0	0	0	0	0	0	0	0	298.	199.	100.	-28.	2.	24.	8.	-622.	17.
	263	6	0	0	1	1	0	1	0	0	0	312.	215.	115.	116.	-5.	-15.	6.	-117.	14.
FM	264	3	0	0	0	0	1	0	1	0	0	304.	193.	97.	-10.	2.	67.	5.	-899.	21.
	265	8	0	1	1	0	1	0	0	1	0	.	222.	57.	-91.	12.	24.	-3.	-1548.	17.
	266	0	0	0	0	0	0	0	0	0	0	300.	190.	88.	-27.	4.	-1.	7.	-223.	8.
	267	1	0	0	0	1	0	0	1	1	0	292.	182.	103.	-68.	-12.	-30.	6.	-1556.	20.
	268	6	0	1	1	1	0	0	0	0	0	315.	221.	126.	-30.	-3.	23.	2.	-755.	10.
	269	4	0	0	1	1	0	0	0	0	0	317.	213.	117.	16.	7.	10.	10.	-618.	13.
	270	9	0	0	1	1	1	1	0	0	0	293.	203.	81.	85.	-4.	-24.	-1.	-945.	12.
	271	4	0	0	1	1	0	0	0	0	0	291.	202.	84.	-30.	-1.	-2.	3.	-60.	21.
	272	2	0	0	0	0	0	1	0	0	0	301.	205.	97.	11.	-13.	-13.	7.	-641.	10.

SUBJECT NUMBER: 9

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	280	6	0	1	0	1	1	0	0	0	1	302.	223.	89.	-66.	-8.	4.	6.	-424.	5.
	281	6	0	0	0	1	1	1	0	0	0	290.	198.	100.	66.	2.	-4.	-5.	84.	10.
	282	2	0	0	0	0	0	1	0	0	0	295.	192.	92.	20.	6.	1.	-9.	-865.	4.
	283	1	0	0	0	1	0	0	0	0	0	299.	194.	92.	24.	-5.	-7.	7.	-238.	13.
FA	284	6	0	0	0	1	1	1	0	0	0	304.	216.	102.	-96.	7.	-14.	-6.	-295.	12.
	285	0	0	0	0	0	0	0	0	0	0	288.	194.	94.	35.	-2.	-14.	.	-743.	14.
	286	8	0	1	0	1	1	1	0	0	1	336.	248.	136.	-65.	5.	-27.	.	-174.	3.
	287	2	0	1	0	0	0	0	1	0	0	327.	241.	95.	33.	-2.	-31.	3.	-698.	3.
	288	0	0	0	0	0	0	0	0	0	0	305.	209.	95.	42.	8.	-13.	-3.	-143.	14.

SUBJECT NUMBER: 10

RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
296	0	0	0	0	0	0	0	1	1	0	299.	203.	120.	-16.	-7.	-47.	6.	1060.	12.
297	0	0	0	0	0	0	0	1	0	0	304.	207.	111.	-32.	2.	35.	1.	323.	9.
298	0	0	0	0	0	0	0	0	0	0	293.	192.	97.	3.	1.	25.	-2.	688.	20.
299	6	0	1	0	1	1	0	1	1	0	315.	228.	87.	168.	10.	500.	500.	-5000.	20.
300	5	0	0	0	0	1	1	0	0	0	315.	215.	136.	133.	4.	2.	-16.	669.	8.
FA 301	0	0	0	0	0	0	0	1	0	0	292.	196.	96.	-14.	-7.	-57.	-6.	-37.	20.
302	0	0	0	0	0	0	0	1	0	0	290.	194.	94.	13.	6.	51.	2.	-37.	6.
303	0	0	0	0	0	0	0	1	0	0	312.	217.	109.	-17.	-9.	-35.	8.	-208.	15.
304	5	0	0	0	0	1	1	1	0	0	304.	206.	140.	100.	-6.	-30.	-2.	183.	8.

SUBJECT NUMBER: 11

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	312	4	0	0	0	1	1	0	1	0	0	309.	203.	135.	99.	-7.	31.	5.	-219.	9.
	313	0	0	0	0	0	0	0	0	0	0	295.	200.	95.	-26.	-8.	16.	8.	-459.	15.
	314	4	0	0	0	1	1	0	1	0	0	303.	206.	114.	-62.	-8.	38.	9.	-83.	12.
	315	0	0	0	0	0	0	0	1	0	0	301.	206.	102.	5.	5.	41.	3.	456.	18.
FA	316	0	0	0	0	0	0	0	0	0	0	294.	200.	88.	5.	2.	24.	10.	-227.	14.
	317	0	0	0	0	0	0	0	1	0	0	290.	197.	93.	1.	5.	35.	-1.	137.	22.
	318	6	0	1	0	1	1	0	1	0	0	314.	222.	85.	92.	-16.	34.	4.	468.	16.
	319	2	0	1	0	0	0	0	0	1	0	319.	222.	111.	-32.	-13.	5.	13.	1246.	7.
	320	5	0	1	0	0	1	0	1	1	0	311.	222.	84.	183.	7.	500.	500.	-5000.	7.

SUBJECT NUMBER: 12

	RUN	CM	E2	E3	E4	E5	E7	E9	E10	E11	PPS	ZRA3	ZRA2	ZAD	YAD	YDAD	YTD	YDTD	XTD	HDTD
	328	5	0	0	0	0	1	1	1	0	0	287.	183.	131.	65.	-5.	30.	-6.	380.	11.
	329	6	0	0	0	1	1	1	1	0	0	279.	180.	98.	103.	-9.	-79.	5.	-648.	13.
	330	0	0	0	0	0	0	0	1	0	0	276.	180.	94.	-42.	-6.	-96.	-7.	-189.	12.
	331	5	0	1	0	0	1	0	1	0	0	286.	179.	114.	108.	14.	-34.	-4.	-1047.	17.
FA	332	1	0	0	0	1	0	0	1	0	0	276.	183.	129.	-72.	-6.	-73.	12.	122.	13.
	333	3	0	1	0	1	0	0	1	0	0	274.	178.	96.	-29.	5.	-65.	-3.	-75.	14.
	334	6	0	0	0	1	1	1	1	0	0	277.	181.	142.	93.	-7.	-42.	-5.	517.	19.
	335	8	0	1	0	1	1	1	1	0	0	284.	174.	116.	106.	3.	-99.	-12.	342.	13.
	336	4	0	1	0	0	0	1	0	0	0	280.	176.	95.	-22.	.	13.	-4.	289.	15.