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Test and Evaluation of a Multifunction Keyboard and a Dedicated Keyboard for Control of a Flight Management Computer

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1.0 SUMMARY

The flight management computer (FMC) control display unit (CDU) test was conducted to compare two types of input devices: a fixed legend (dedicated) key board and a programmable legend (multifunction) keyboard. The task used for comparison was operation of the flight management computer for the Boeing 737-300. The same tasks were performed by 12 pilots on the FMC control display unit configured with a programmable legend keyboard and with the currently used B737-300 dedicated keyboard. Flight simulator work activity levels and input task complexity were varied during each pilot session. Half of the pilots tested were previously familiar with the B737-300 dedicated keyboard CDU and half had no prior experience with it. The data collected included simulator flight parameters, keystroke times and sequences, and pilot questionnaire responses. A timeline analysis was also used for evaluation of the two keyboard concepts.

For operation of the FMC, the number of keystrokes needed to complete each task on the multifunction keyboard (MFK) was generally more than that needed on the dedicated keyboard (DK). The majority of the additional keystrokes are attributable to the double keystroke needed to enter alpha information. All pilots, familiar and unfamiliar, performed the tasks faster on the DK. The average time per keystroke, however, was found to be lower on the MFK than the DK for unfamiliar pilots. This shows a tendency for pilots equally familiar with both units (i.e., the unfamiliar pilots in this study) to perform keystrokes faster on the MFK.

Several factors of interest in this study were not affected by the CDU type. Although flight activity had a greater effect on the average time per keystroke, there was no relative difference in the performance on the two CDU types. No difference between CDUs was found in the pilot performance of the flying tasks. Also, the number of errors per keystroke was not significantly different on the MFK and the DK.

The input time was found to increase from numeric to alpha to system command and line select for both CDU types. The type of CDU did not have a differential effect on input times, although it is possible that this interaction may have been masked.

Pilot opinion was not favorable for some logic and task structure aspects of the MFK. The problem areas appear to be in the total number of steps required, and in the input of alpha information. Pilots perceived the workload to be higher on the MFK than on the DK. TLA results, however, show that for implementation of an advanced flight deck concept, the MFK performs as well as or better than the DK in terms of workload.

Functions chosen for implementation on an MFK should be selected on the basis of task structure as compared to a conventional DK. In particular, the number of keystrokes on the MFK should not greatly exceed the keystrokes on the DK. Several methods of enhancing MFK operation in other applications include tailoring the keyboard to the flight phase, using the line select keys to call up input keyboards, providing a mix of dedicated and multifunction keys, and the use of artificial intelligence in conjunction with the MFK.

2.0 INTRODUCTION

2.1 BACKGROUND

A dedicated keyboard (DK) has keys, or switches, which always perform the same function. Activation of a given key will always give the same results. A multifunction keyboard (MFK) has keys that are capable of changing their function. The current function of a particular key is displayed on its programmable legend keyface. The MFK requires fewer keys than the dedicated keyboard to accomplish the same functions, and can incorporate several dedicated controls into one unit.

If space requirements can be reduced by using a single multifunction input device in place of several dedicated devices, displays and controls can be located more optimally with respect to the pilot's vision and reach envelopes. Multifunction controls also have the potential for reducing crew workload and managing the information flow by restricting the information presented to that which is relevant to the current task. Information not relevant can be made available on request so that it can be accessed if needed.

Before implementation of an MFK on the flight deck, the effect it will have on the pilot must be evaluated. "Research must be conducted to determine the optimal method of implementing the multifunction control and identify the data display and switching requirements. Once a candidate multifunction control is designed, it is necessary to evaluate it in comparison with the operator's conventional controls. Design and evaluation must continue until the use of multifunction controls increases the control capability and information available to the operator and makes the completion of the required tasks more effective" (ref. 1). One criterion of effectiveness is the time it takes an operator to perform a task. "The time cost required for setting each function using the multipurpose device must be less than or equal to the time cost required for setting the function using a dedicated control" (ref. 2).

Other criteria are of importance when replacing conventional controls with a multifunction unit. The overall workload imposed by the unit must be assessed and compared to the existing workload condition. Pilot acceptance must also be considered. It is unlikely that a control will be placed on the flight deck over the strong objections of pilots, regardless of improvements theoretically possible.

2.2 PURPOSE

Previous research has established some guidelines for MFK design (refs. 3 and 4), and has made recommendations regarding the MFK control logic (refs. 3, 5, and 6). The purpose of this study was to investigate some basic questions a flight deck designer must ask when deciding whether or not to implement a multifunction control. This study was designed to examine the differences in pilot performance and acceptance between the MFK and the DK when used for input to a flight management system. Several factors were of interest. The input type (alpha versus numeric versus system command versus line select) was thought to be a source of variance between the MFK and the DK. A second factor was pilot familiarity with dedicated keyboards (i.e., how does the fact that a pilot is already acquainted with the dedicated keyboard control affect the performance on and acceptance of the same unit configured with a multifunction keyboard?) In relation to the task environment, it was desired to study the differences due to the pilot activity demanded by the flight task. The effect of the complexity of the task was also of interest. Finally, a comparison of the workload required to operate an MFK control and a DK control and an analysis of error rates was desired.

The flight management computer CDU test compared two types of input devices: a dedicated keyboard and a multifunction keyboard. The task that was used for evaluation purposes was the operation of the flight management computer (FMC) for the Boeing 737-300. The FMC control display unit (CDU) is the interface between the crew and the FMC. Pilots were asked to perform the same tasks on the FMC CDU configured with a multifunction keyboard and with the currently used B737-300 dedicated keyboard. The display contents were the same for both units; only the keyboard type changed.

Twelve pilots participated in the experiment. All performed a number of tasks on the dedicated keyboard (DK) CDU and on the multifunction keyboard (MFK) CDU. Pilots who were unfamiliar with both units and pilots who had extensive experience using the B737-300 FMC participated in the experiment. Some tasks were conducted while flying the simulator; flight simulator work activity was varied between tasks. The complexity of the CDU task was also varied.

Performance measures were taken on the flight parameters and on keystroke times and sequences. Subjective evaluations of the pilots were recorded via questionnaires. An analytical study was also performed to compare the work load differences in the operation of the two CDU types.

3.0 METHOD

3.1 SUBJECTS

Twelve pilots participated in this experiment. Six of the pilots were familiar with the flight management computer operation. Five of these six were Boeing Flight Crew Training pilots. The sixth was a military pilot and had participated in FMC development as a Boeing engineer.

All of the familiar pilots had extensive experience with FMC operation. The five Flight Crew Training pilots train commercial airline pilots on the FMC. Because they use the FMC so often in training situations, they have achieved a greater level of familiarity with FMC operation than most airline pilots achieve under normal circumstances. The sixth familiar pilot, because of his involvement with FMC development, was also quite familiar with its operation. These pilots were selected for participation in this study because it was thought that their level of familiarity with the FMC would cause them to be sensitive to differences between the dedicated and multifunction keyboards.

Six pilots unfamiliar with FMC operation also participated in the test. Five were currently pilots flying for commercial airlines. The sixth was an air line pilot who had recently retired with over 25,000 hours of flight time. None had experience operating the FMC or had more than a cursory knowledge of the keyboard layout.

3.2 EXPERIMENTAL DESIGN

Four factors were investigated in this study: pilot familiarity, CDU type, flight simulator activity, and input task complexity. Pilot familiarity had two levels (familiar versus unfamiliar), and was the only factor not to have repeated measures. CDU type (two levels) included the dedicated keyboard CDU currently used to operate the FMC on the 737-300 and a multifunction keyboard CDU.

Flight simulator activity occurred at three levels, or flight phases. These were defined as on the ground (none or low activity), climbing with control wheel steering (medium activity), and hand flying prior to top of descent during moderate turbulence (high activity).

The fourth factor was task complexity (two levels). A high complexity task required more steps to complete and generally contained more system command entry or changing to different "pages" in the FMC data base, as compared to a low complexity task.

The flight activity and task complexity factors together defined the operations used during the test. For each of the three flight activity levels, two operations were performed (one low complexity and one high complexity); resulting in a total of six test scenarios. See Table 1 for a description of the scenarios.

The experimental design was a factorial experiment with repeated measures on all but one factor. The experimental design is displayed graphically in Figure 1. Table 2 presents a summary of the calculations for mean square and F ratio used in the analysis of variance of the objective performance data. The degrees of freedom for the F ratios are the denominators of the mean square terms. The significance level was defined at $p < .05$.

Table 1. Scenario Description

Scenario Number	Operation	Flight Activity	Task Complexity		Number of Keystrokes Alpha	Numeric	System/LS	Total
1	Flight Plan Entry	Low	High	MFK:	33	2	18	53
				DK:	17	2	17	36
2	Performance Initialization	Low	Low	MFK:	0	21	12	33
				DK:	0	19	11	30
3	Route Modification	Medium	High	MFK:	28	0	14	42
				DK:	14	0	12	26
4	Altitiude Restriction Entry	Medium	Low	MFK:	2	9	8	19
				DK:	1	8	4	13
5	Approach Setup	High	Low	MFK:	0	0	8	8
				DK:	0	0	9	9
6	Time/Distance to Crossing Radial	High	High	MFK:	6	5	12	23
				DK:	3	4	9	16
	Total (Scenarios 1 Through 6)			MFK:	69	37	72	178
				DK:	35	33	62	130

Whenever task performance is measured under several different treatment conditions over an extended period of time, learning and/or fatigue may affect performance on later trials. An appropriate counterbalancing scheme was designed to prevent carryover effects from differentially affecting the performance measures for the different treatment conditions. Each pilot performed all the trials on a given CDU before moving on to the next. This is done to facilitate

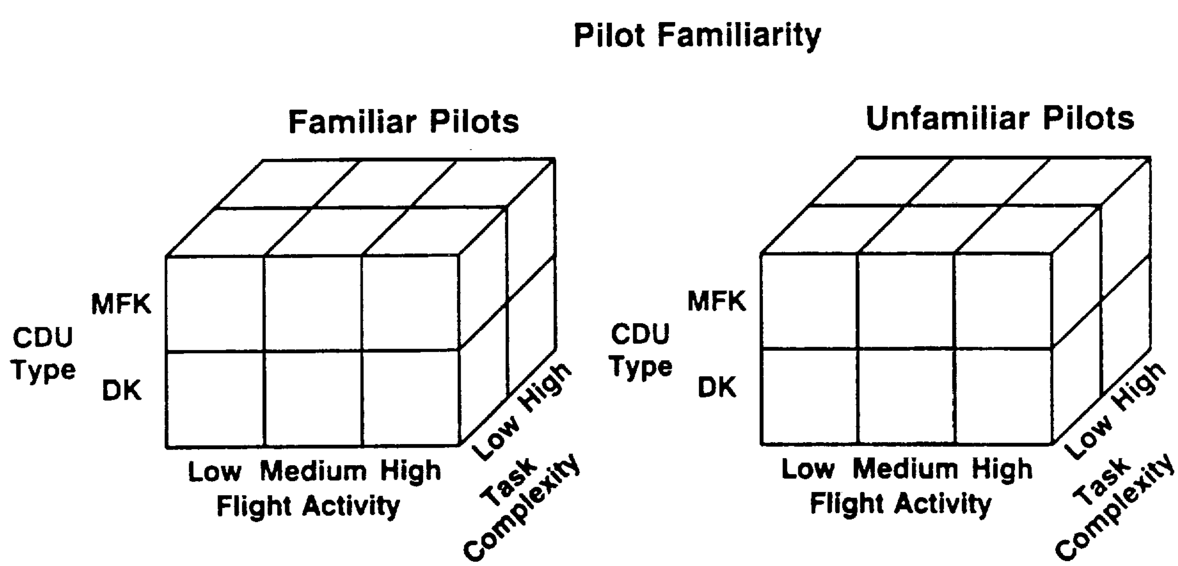

Figure 1. Experimental Design

Table 2. Summary Calculations for Analysis of Variance, Ax (BxCxDxS)

SOURCE	MEAN SQUARE	F
A	$SS_A/(a-1)$	$MS_A/MS_{S/A}$
Between Subject Error (S/A)	$SS_{S/A}/(s-a)$	
B	$SS_B/(b-1)$	$MS_B/MS_{BS/A}$
AB	$SS_{AB}/(a-1)(b-1)$	$MS_{AB}/MS_{BS/A}$
Within Subject Error (BS/A)	$SS_{BS/A}/(b-1)(s-a)$	
C	$SS_C/(c-1)$	$MS_C/MS_{CS/A}$
AC	$SS_{AC}/(a-1)(c-1)$	$MS_{AC}/MS_{CS/A}$
Within Subject Error (CS/A)	$SS_{CS/A}/(c-1)(s-a)$	
D	$SS_D/(d-1)$	$MS_D/MS_{DS/A}$
AD	$SS_{AD}/(a-1)(d-1)$	$MS_{AD}/MS_{DS/A}$
Within Subject Error (DS/A)	$SS_{DS/A}/(d-1)(s-a)$	
BC	$SS_{BC}/(b-1)(c-1)$	$MS_{BC}/MSB_{BCS/A}$
ABC	$SS_{ABC}/(a-1)(b-1)(c-1)$	$MS_{ABC}/MS_{BCS/A}$
Within Subject Error (BCS/A)	$SS_{BCS/A}/(b-1)(c-1)(s-a)$	
BD	$SS_{BD}/(b-1)(d-1)$	$MS_{BD}/MS_{BDS/A}$
ABD	$SS_{ABD}/(a-1)(b-1)(d-1)$	$MS_{ABD}/MS_{BDS/A}$
Within Subject Error (BDS/A)	$SS_{BDS/A}/(b-1)(d-1)(s-a)$	
CD	$SS_{CD}/(c-1)(d-1)$	$MS_{CD}/MS_{CDS/A}$
ACD	$SS_{ACD}/(a-1)(c-1)(d-1)$	$MS_{ACD}/MS_{CDS/A}$
Within Subject Error (CDS/A)	$SS_{CDS/A}/(c-1)(d-1)(s-a)$	
BCD	$SS_{BCD}/(b-1)(c-1)(d-1)$	$MS_{BCD}/MS_{BCDS/A}$
ABCD	$SS_{ABCD}/(a-1)(b-1)(c-1)(d-1)$	$MS_{ABCD}/MS_{BCDS/A}$
Within Subject Error (BCDS/A)	$SS_{BCDS/A}/(b-1)(c-1)(d-1)(s-a)$	

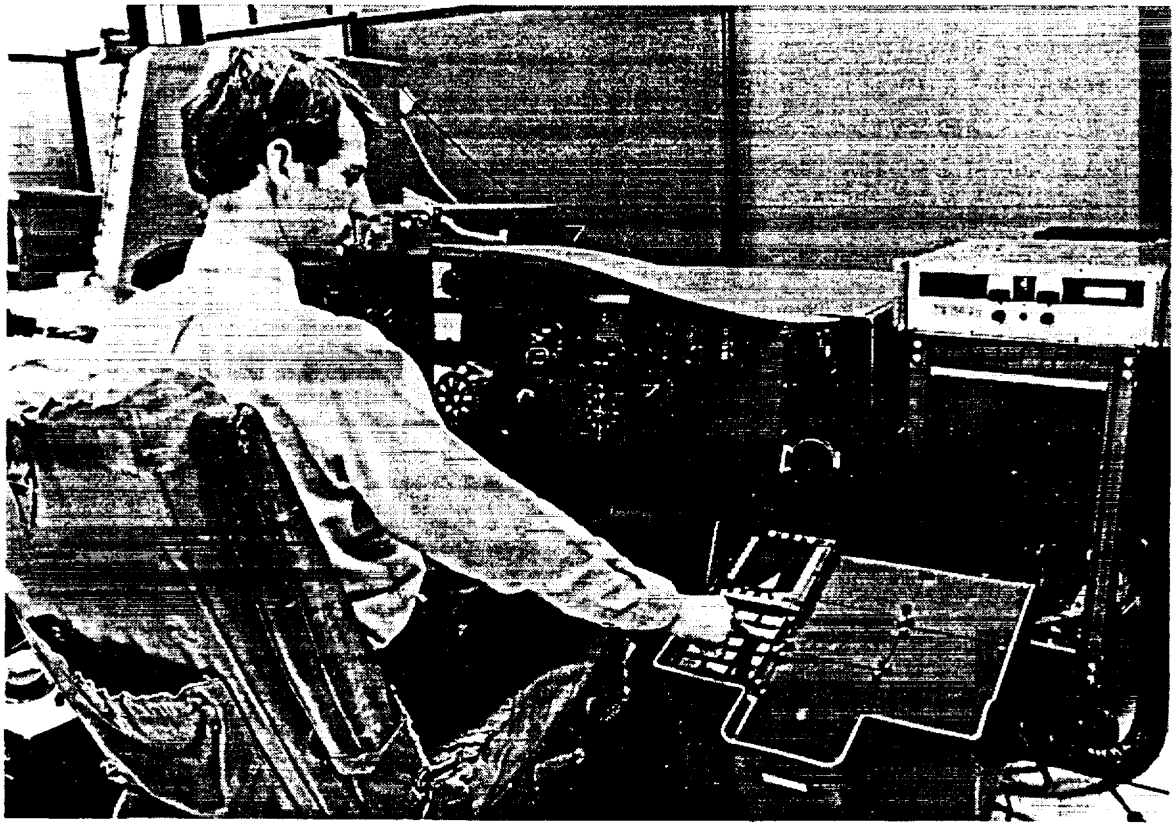

Figure 2. Test Setup

training and reduce the potential for confusion between CDU operations. The order of receiving the different CDU types and the order of task assignment within CDU type were randomly assigned to prevent order bias from confounding the results.

3.3 EQUIPMENT

3.3.1 Hardware

The test setup is shown in in Figure 2. A test-bench flight simulator is shown in the figure. The MFK CDU was physically larger than the DK CDU. The test-bench center console could accommodate only the DK CDU, and modifications to the console were not considered acceptable. A new console was constructed, therefore, which accommodated both CDU types. It was located to the right of the test bench, and the pilots flew from the right-hand seat. Thus, the relationship of the CDU to the pilot's control and displays was configured as if the pilot were flying from the left-hand seat, except that the throttles were located on the pilot's right. This was not expected to have an effect on the test results, as little throttle input was required during the flying tasks.

CDUs were swapped halfway through the test, so that both CDU types would be operated from the same location. The console was positioned so that pilots, when adjusted to the eye reference position, could easily see and reach the CDU. A chair was placed to the right of the CDU console for the instructor/observer pilot.

The console to the left of the test bench controlled the simulator. The initial conditions for each task were set at this location, and the flight parameter data collection was controlled here also. The principle investigator operated the test console and was able to observe the subject pilot from this location.

The two types of CDUs used in the test are shown in Figures 3 and 4. The dedicated keyboard CDU is currently used as the pilot interface to the FMC on the B737-300 and is very similar to the B757 and B767 FMC CDUs. The multifunction keyboard CDU was made up of a Litton display and a Microswitch keyboard. The available display area on the MFK was longer than that on the DK, but the area of the display used (programmed) for the test was virtually identical.

The primary character size was 0.165-in high for data on the DK display, and 0.172-in high on the MFK display.

The content of the displays on the MFK CDU and the DK CDU were identical. This was done to eliminate any differences in pilot performance due to the displays so that a direct comparison could be made between keyboard types.

The MFK contained 15 programmable switches. Entry of an alpha character into the scratch pad required the pilot to make two switch hits. The keyboard for alpha entry was configured as shown in Figure 5, with three letters per key. To enter the letter H, the pilot selected the key GHI. The keyboard would reconfigure to offer the choice of G, H, or I, as shown in Figure 6. The three letters in the reduced alpha configuration always appeared in the same key row as the root key. For example the three keys S,T, and U appeared in the third row of keys after the STU key was selected from the full alpha keyboard configuration. The double hit requirement is largely responsible for the difference between the MFK and the DK in the total number of switch hits required to complete a scenario, although some differences do occur in the number of numeric and system command switch hits required. Table 1 lists the number of keystrokes required to complete each scenario, and breaks down the total number into three categories: alpha, numeric, and the combination of system command plus line select.

3.3.2 Software

The control logic has been called "one of the most critical design considerations" for a multifunction control (ref. 3). Two types of control logic for use on a multifunction control have received the most attention from investigators: tailored logic and branching logic. Branching logic follows a logic tree and does not change during a flight. Tailored logic provides access to functions frequently used; the functions on the switches are dependent on the flight mode. Tailored logic serves to reduce the number of key hits required to reach the desired keyboard configuration. Studies have shown that pilot performance on a multifunction control is enhanced when tailored logic is used instead of or in conjunction with branching logic (refs. 3, 5, and 6).

In this test, the concept of tailored logic was applicable to a limited extent. Keyboard configurations that would allow input of alpha or numeric information were only one or two levels down from the top level configuration. However, tailored logic was used when possible. An example is selection of the DEP/ARR (departure/arrival) switch on the top level keyboard. On the ground, the pilot would then have to indicate whether departure or arrival pages were to

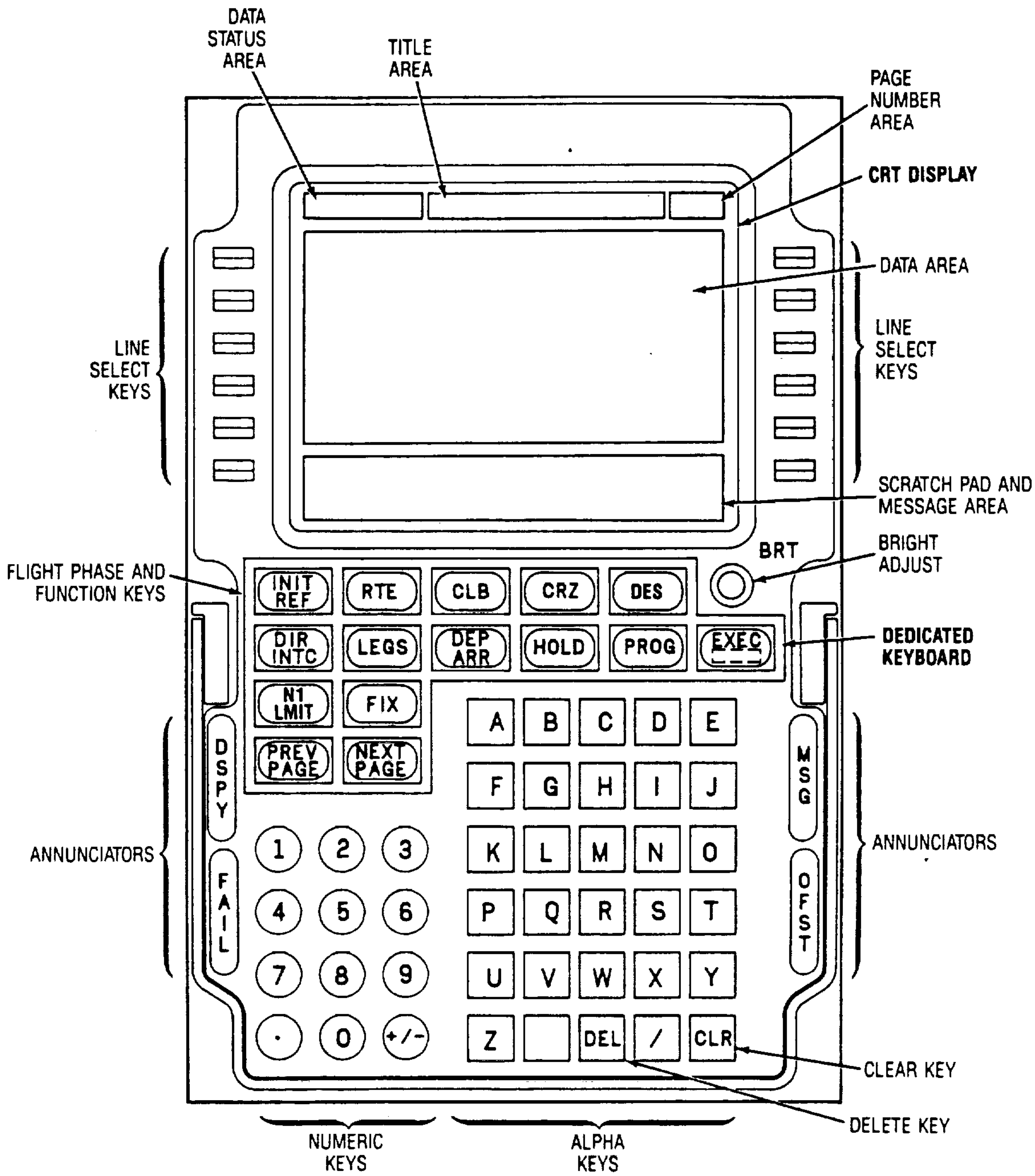

Figure 3. Dedicated Keyboard CDU

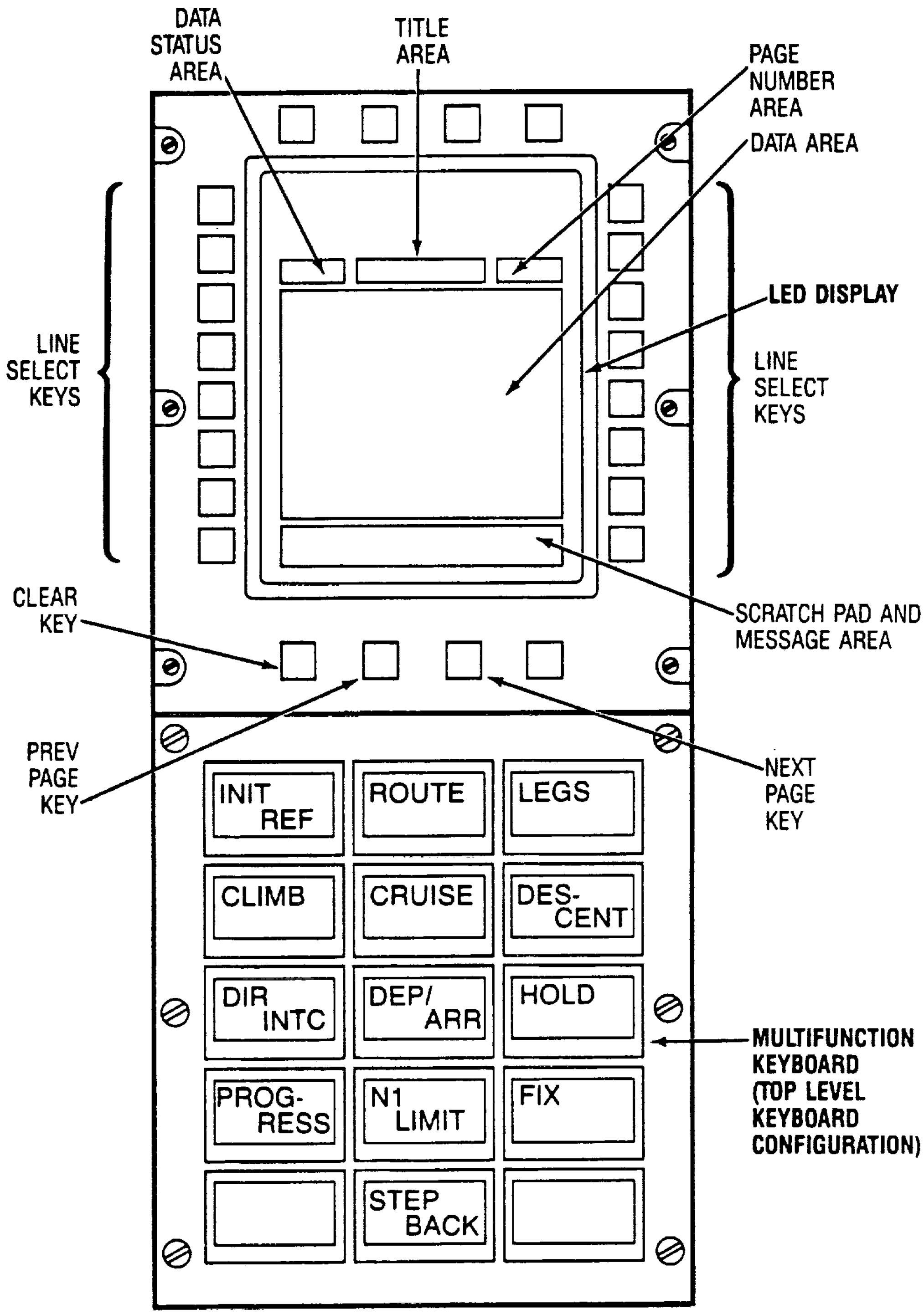

Figure 4. Multifunction Keyboard CDU (Top Level Keyboard Configuration)

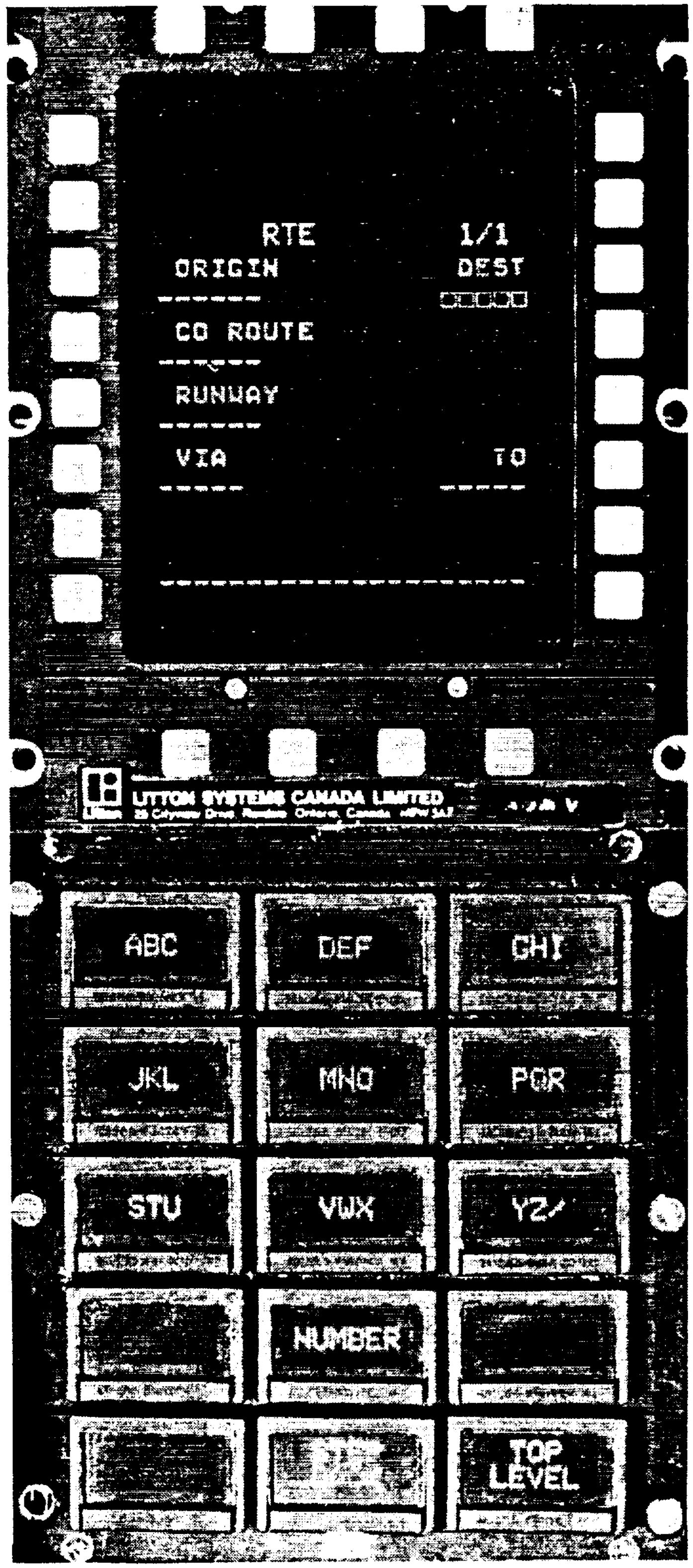

Figure 5. Full Alpha Configuration

ORIGINAL PAGE IS
OF POOR QUALITY

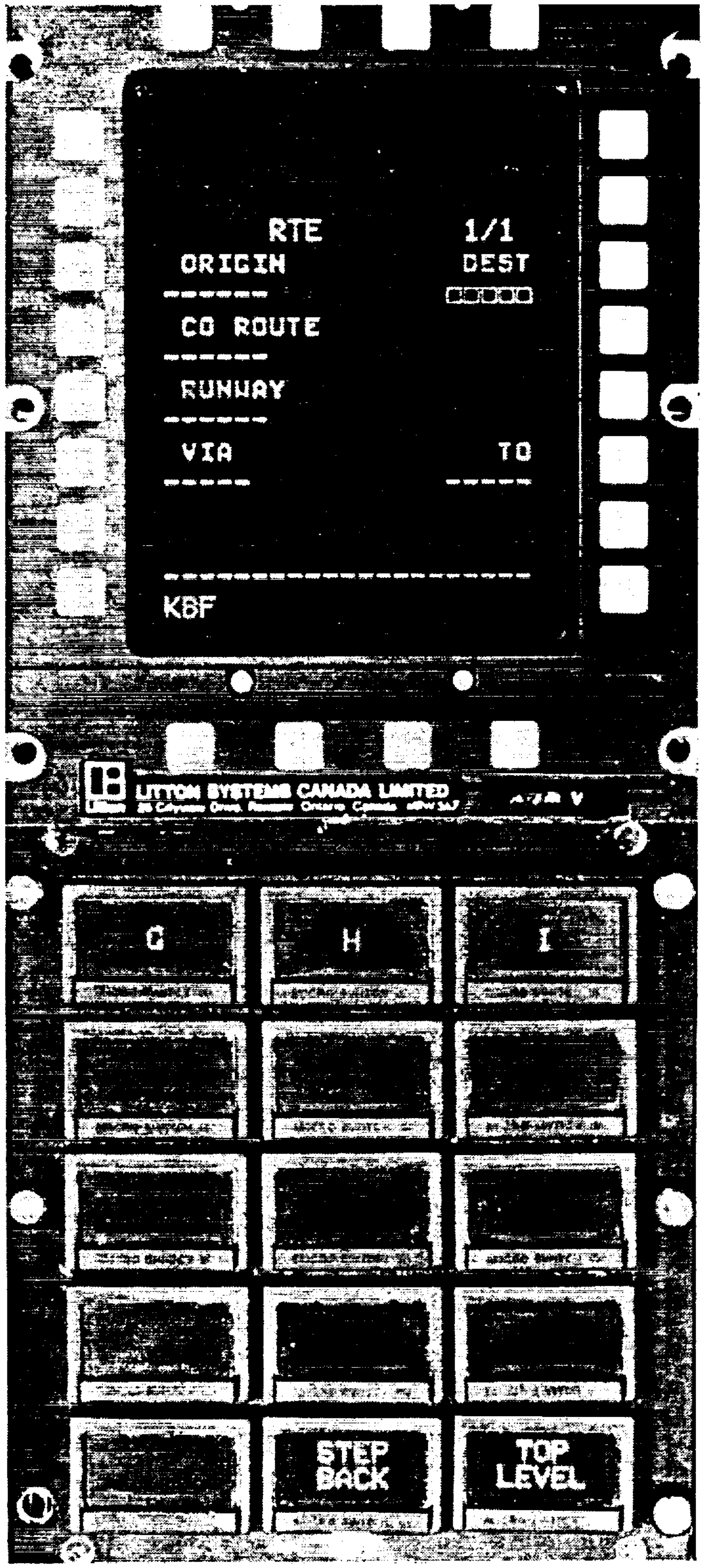

Figure 6. Reduced Alpha Configuration

be displayed. In the air, the departure pages are not needed, and selection of the DEP/ARR switch automatically brings up the arrival pages. This was incorporated into Scenario 5. Other efforts were made to "tailor" keyboard configurations, independent of flight phase. For example, if the majority of information to be entered onto a display page was alpha rather than numeric, the keyboard one step down from the top level keyboard would automatically provide the alpha configuration. The numeric keyboard could be accessed if needed by selecting the "number" switch on the alpha keyboard.

3.4 PERFORMANCE MEASURES

There were two types of objective performance measures taken during the test: flight parameter data and keystroke data. Flight parameters were recorded by the mainframe computer which ran the simulated airplane. The parameters recorded were altitude, airspeed, flightpath angle, and magnetic heading. Keystroke sequences and times were monitored and printed out.

In addition to the objective measures, subjective data was collected using questionnaires. Three questionnaires were administered to each pilot. A postflight questionnaire was given to the pilots after operation of the DK and again after operation of the MFK to gather pilots' immediate impressions. These postflight questionnaires asked pilots to rate the CDU just used on specific characteristics and operational aspects. A third questionnaire, the program questionnaire was given to the pilots upon completion of the test. This questionnaire included comparisons between the two CDU types. Appendix A contains the questionnaires with a summary of all pilots' responses.

3.5 PROCEDURE

One pilot was run per session for a total of 12 sessions. Each pilot was sent a copy of a training manual approximately one week prior to his scheduled session. A copy of the training manual is contained in Appendix B. It describes the test purpose, serves as an introduction to both the DK and MFK CDUs, and describes the test conditions and procedures.

On arrival at the test location, the pilot was given a brief verbal introduction to the test purpose, setup, and procedure. A period of familiarization with the first CDU (either the DK or the MFK—the order of the test conditions were randomized over all subjects) was conducted using training scenarios. The six training scenarios were functionally identical to the scenarios used during the test, but contained different alphanumeric data so that pilots could not memorize the keystroke sequences. The six training and six test scenarios are listed in Appendix C. The instructor pilot presented the navigation maps and explained what would occur in each scenario. The next scenario was introduced only after the pilot was able to complete the current training scenario with no errors.

After all six training scenarios were completed, the pilot was adjusted to the eye reference position and allowed to fly the simulator to familiarize himself with the feel of the simulated airplane in both the control wheel steering (CWS) and turbulence conditions. Also, a training scenario was performed on the CDU while flying. After the pilot indicated he was ready to begin the test, the six test scenarios were performed on the first CDU.

The test scenarios were randomly presented. The pilot was told verbally which scenario and corresponding flight phase would be done next. Flying tasks for Scenarios 3 through 6 were presented verbally to the pilot before the simulator was active, and are listed below each scenario in Appendix C. At the signal from the instructor pilot, the principle investigator started the simulation and data recording apparatus. The pilot was instructed to begin the CDU operation only after he felt comfortable with the flight task (for the four out of six scenarios in the air). At the end of the CDU operation, the simulation and data recording was terminated, and the equipment was reset for the next scenario condition.

The postflight questionnaire on the first CDU was given to the pilot after completion of all six scenarios. At this time, the CDUs were changed out. A familiarization period was then conducted with the second CDU, and the same six scenarios were performed on the second CDU. The postflight questionnaire for the second unit was given to the pilot. When this was completed, the program questionnaire was given to the pilot to complete. Sessions lasted from 2 to 4 hours; pilots familiar with FMC operation generally took less time as they required less training time.

4.0 RESULTS

4.1 PERFORMANCE DATA ANALYSIS

4.1.1 Total Time to Complete Tasks

The total time to complete the tasks are analyzed in Table 3. All of the main effects tested significant at the $p<.05$ level. Pilots familiar with FMC operation performed the tasks faster than unfamiliar pilots. Flight activity was also significant. Total time to complete the tasks decreased with increasing simulator activity. This result is not meaningful, however, due to the different numbers of keystrokes required at the different activity levels. The two tasks that comprise the low activity level total 152 keystrokes, the medium activity level required 100 keystrokes, and the high activity level required 56 keystrokes.

Pilots performed tasks faster on the DK than on the MFK. As with the flight activity effect, there was a difference in the total number of keystrokes required on the MFK as compared to the DK. The MFK required 178 keystrokes to complete all six tasks, while the DK required 130. This difference is mostly caused by the fact that the MFK requires two switch hits for an alpha entry, while the DK requires one switch hit.

Figure 7 shows the interaction between pilot familiarity and task complexity. The unfamiliar pilots took a proportionally greater time on the high task complexity versus the low task complexity conditions as compared to the familiar pilots.

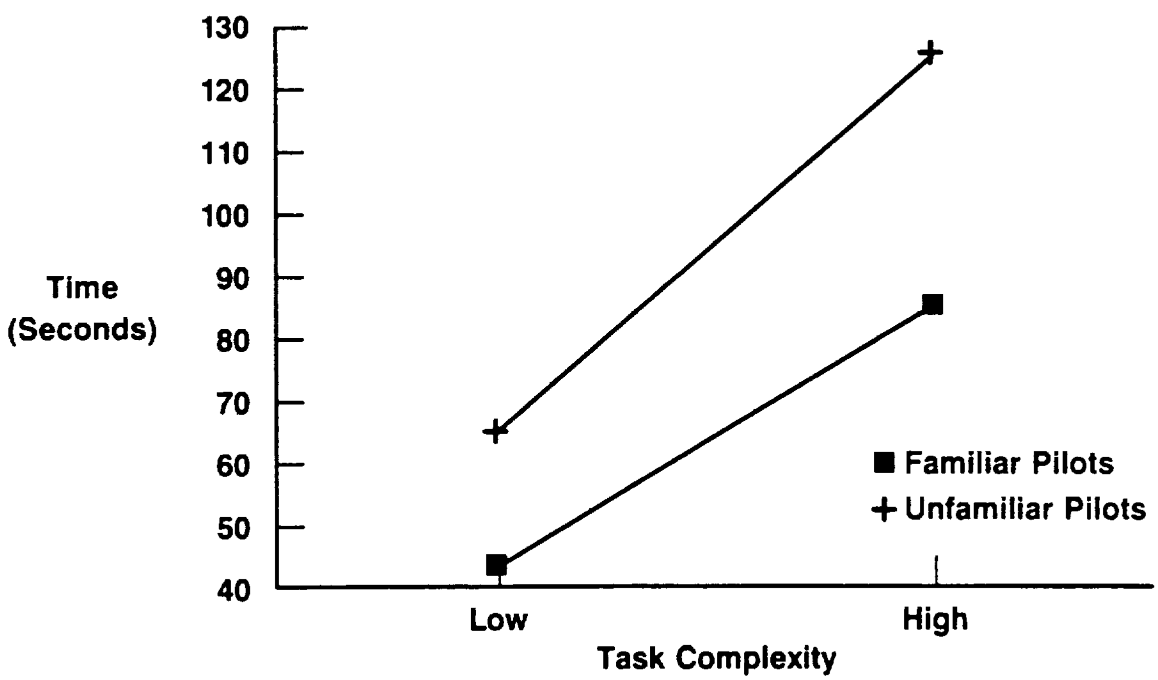

Figure 7. Pilot Familiarity x Task Complexity (Total Time)

Table 3. Summary of Analysis of Variance From Total Time to Complete Tasks in Seconds (by Pilot Familiarity, Flight Activity, Task Complexity, and CDU Type)

SOURCE OF VARIANCE	DF	F
Main Effects:		
Pilot familiarity	1	22.8*
Flight activity	2	25.6*
Task complexity	1	335.5*
CDU type	1	15.9*
Interactions:		
Complexity X CDU type	1	46.4*
Pilot familiarty X flight activity	2	1.6
Pilot familiarity X Task complexity	1	14.2*
Pilot familiarity X CDU type	1	3.4
Flight activity X Task complexity	2	3.0
Flight activity X CDU type	2	2.8
Flight activity X Task complexity X CDU type	2	4.8*
Pilot familiarity X Task complexity X Flight activity	2	2.0
Pilot familiarity X Flight activity X CDU type	2	.2
Pilot familiarity X Task complexity X CDU type	1	.9
Pilot familiarity X Flight activity X Task complexity X CDU type	2	3.3

* probability < .05

Cell means and effects (in seconds):

Pilot familiarity

Familiar	Unfamiliar
62.9	95.6

Pilots familiar with FMC operation performed the tasks faster.

Flight activity

Low	Medium	High
94.2	78.9	64.6

Table 3. Summary of Analysis of Variance From Total Time to Complete Tasks in Seconds (by Pilot Familiarity, Flight Activity, Task Complexity, and CDU Type) (Concluded)

Total time to complete task decreased with increasing flight activity.

Task complexity

Low	High
54.4	104.1

Tasks with high complexity took more time to complete.

CDU type

MFK	DK
87.6	70.8

Pilots performed tasks faster on the dedicated keyboard CDU than on the multifunction keyboard CDU.

Pilot familiarity X Task complexity

	Familiar	Unfamiliar
Low	43.1	65.6
High	82.6	125.6

Unfamiliar pilots took a relatively longer time on the high task complexity conditions as compared to the familiar pilots (see Figure 7).

Task complexity X CDU type

	Low	High
MFK	56.6	118.7
DK	52.2	89.4

The high task complexity conditions on the MFK show a disproportionately long time for task completion. This relationship is shown in Figure 8.

Flight activity X Task complexity X CDU type

	Low		Medium		High	
	Low	High	Low	High	Low	High
MFK	69.1	141.6	59.9	121.3	40.7	93.3
DK	67.5	98.4	40.1	94.3	49.0	75.6

The low task complexity/low flight activity condition shows the MFK total time just slightly higher than the DK. The low task complexity high flight activity condition shows the MFK total time as less than the DK's. See Figure 9 for a graphic representation of this relationship.

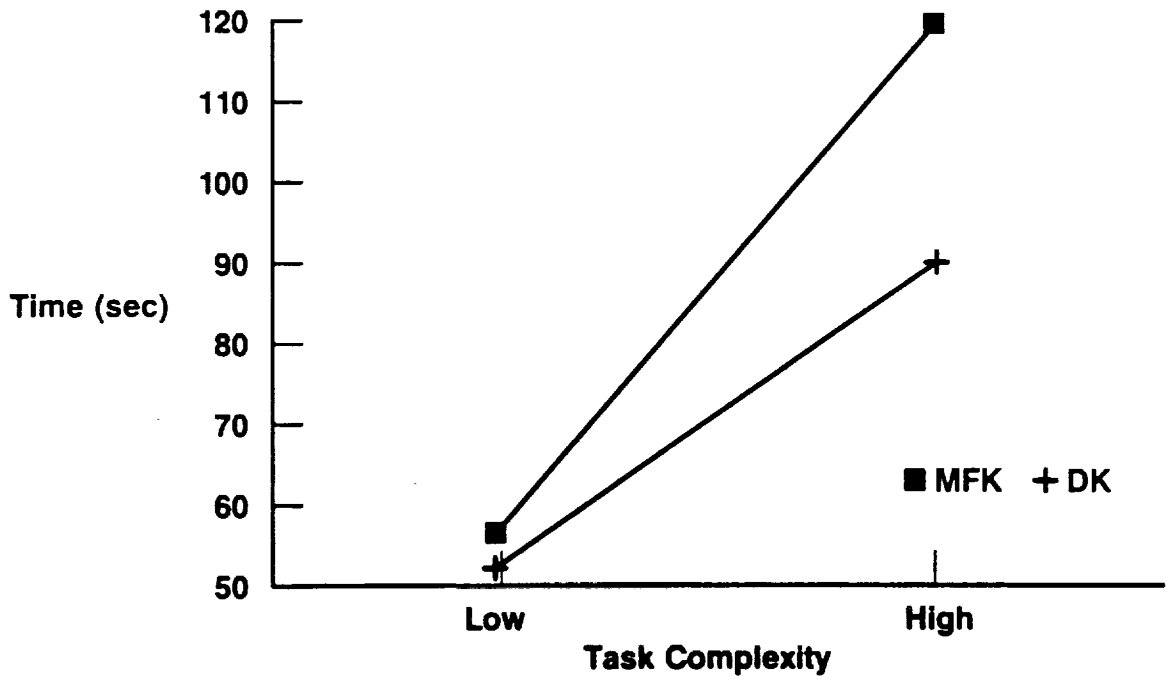

Figure 8. Task Complexity x CDU Type (Total Time)

The significant interaction between task complexity and CDU type is depicted in Figure 8. The high task complexity condition on the MFK took disproportionately longer than the others. Again, this result is not meaningful because there is a difference in the number of keystrokes required for the tasks. Because the low complexity conditions were mostly system command entry, there was little difference in the keystrokes required on the two CDU types (60 for the MFK and 52 for the DK). But because the high complexity conditions contained more alpha entries, the difference between the MFK and DK becomes greater (118 and 98, respectively).

The interaction between flight activity and task complexity and CDU type, pictured in Figure 9 shows the low task complexity/low flight activity condition (i.e., task 2) almost equal on the MFK and the DK. The number of keystrokes required for Task 2 is 33 on the MFK and 30 on the DK. Figure 9 also shows that the low task complexity/high flight activity condition (task 5) took less time on the MFK than on the DK. This was the only scenario that required fewer keystrokes on the MFK than on the DK (8 versus 9, respectively).

4.1.2 Average Time per Keystroke

The average time per keystroke for a given task was calculated by dividing the total time for a given task by the total number of switch hits (including errors). This was done to eliminate the differences between the two CDU types due to the number of keystrokes, as the multifunction keyboard generally required more keystrokes for a given task than the dedicated keyboard. The significant results are presented below; see Table 4 for a summary of the analysis of variance.

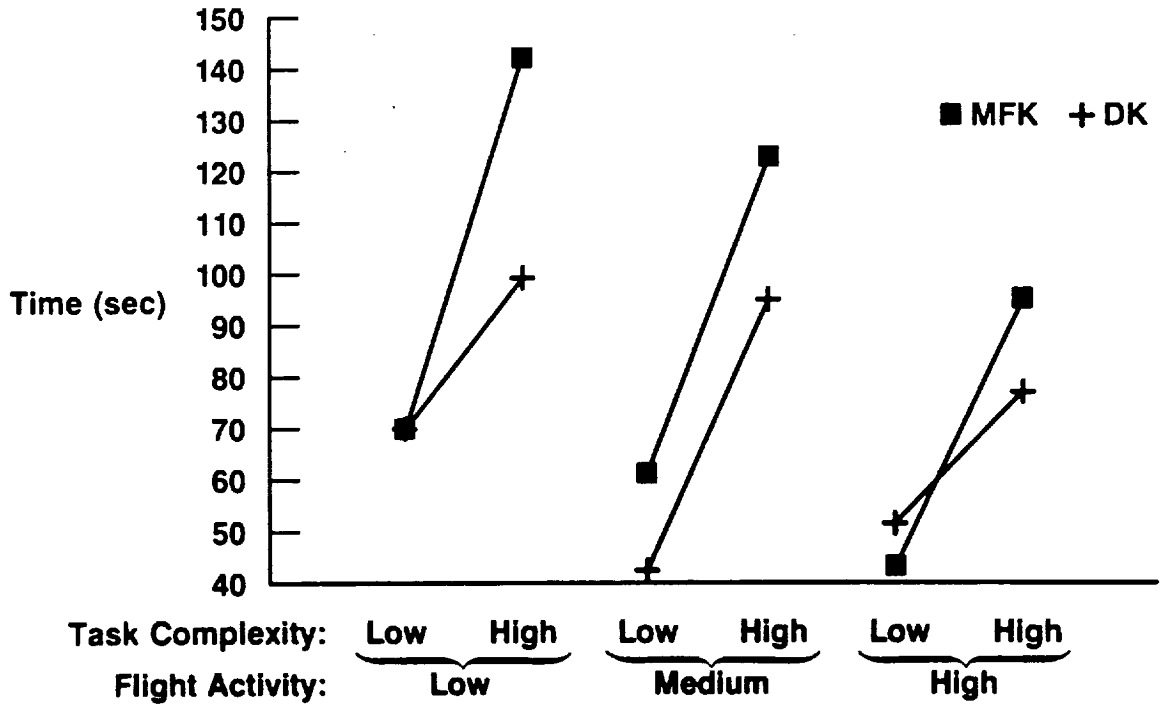

Figure 9. Flight Activity x Task Complexity x CDU Type (Total Time)

Pilots familiar with FMC operation had a overall lower average keying time than pilots unfamiliar with FMC operation. Pilots familiar with FMC operation had a lower average keying time on the dedicated keyboard versus the multifunction keyboard, while for pilots unfamiliar with FMC operation, the converse was true. This interaction is shown in Figure 10.

The type of CDU (multifunction keyboard versus dedicated keyboard) did not significantly affect the average time per keystroke for a given task. Although the total time to complete a task may be greater on the MFK than on the DK due to the greater number of keystrokes required on the MFK (as discussed above), there is no significant difference in terms of average keying times.

The amount of flight simulator activity occurring during a task significantly affected average time per keystroke. The higher the activity, the more time taken per average keystroke.

Unfamiliar pilots had relatively higher average keying times during the high flight activity condition (see fig. 11). The significant interaction between task complexity and flight activity shows a significantly higher average keystroke time for the high activity, low task complexity combination (see fig. 12). This task (task 5) was comprised entirely of system command entry. As will be seen in Section 4.1.3, pilots made system command inputs slower than alpha or numeric inputs.

The significant four-way interaction is shown in Figure 13. It can be seen that the unfamiliar pilots performed better on the DK than on the MFK only for one task. This is due to the fact that the MFK required twice as many system command/line select switch hits for that task than did the DK. The discussion below shows that this would result in a longer average time per keystroke.

Table 4. Summary of Analysis of Variance for Average Sec/Keystroke (by Pilot Familiarity, Flight Activity, Task Complexity, and CDU Type)

SOURCE OF VARIANCE	DF	F
Main Effects:		
Pilot familiarity	1	16.6*
Flight activity	2	49.1*
Task complexity	1	.1
CDU type	1	.1
Interactions:		
Pilot familiarity X CDU type	1	5.6*
Pilot familiarity X Flight activity	2	4.2*
Flight activity X Task complexity	2	23.8*
Pilot familiarity X Task complexity	1	1.8
Flight activity X CDU type	2	.1
Task complexity X CDU type	1	.4
Pilot familiarity X Flight activity X Task complexity	2	0
Pilot familiarity X Flight activity X CDU type	2	1.0
Pilot familiarity X Task complexity X CDU type	1	1.0
Task complexity X Flight activity X CDU type	2	2.1
Pilot familiarity X Flight activity X Task complexity X CDU type	2	3.9*

* probability < .05

Cell means and effects (in seconds):

Pilot familiarity

Familiar	Unfamiliar
2.57	3.80

Pilots familiar with FMC operation had a lower average keying time.

Table 4. Summary of Analysis of Variance for Average Sec/Keystroke (by Pilot Familiarity, Flight Activity, Task Complexity, and CDU Type) (Concluded)

Flight activity

Low	Medium	High
2.34	2.89	4.34

Average keying times increased as flight simulator activity increased

Pilot Familiarity X CDU type

	MFK	DK
Familiar	2.71	2.43
Unfamiliar	3.56	4.04

Familiar pilots performed faster on the DK versus the MFK. For unfamiliar pilots, the converse was true. Figure 10 shows this relationship.

Pilots familiarity X Flight activity

	Low	Medium	High
Familiar	1.85	2.49	3.38
Unfamiliar	2.82	3.29	5.29

Average keying times for unfamiliar pilots at the high activity level were relatively greater than for familiar pilots. See Figure 11 for a graphic representation of this relationship.

Task complexity X Flight activity

	Low	Medium	High
Low	2.12	2.10	4.88
High	2.56	3.08	3.80

The low task complexity/high activity combination had high average keying times. See Figure 12 for a graphic representation.

Pilot familiarity X Flight activity X Task complexity X CDU type

	Familiar						Unfamiliar					
	Low		Medium		High		Low		Medium		High	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
MFK	1.83	2.15	2.43	2.68	4.25	2.93	2.25	2.95	3.33	2.98	5.15	4.73
DK	1.62	1.80	2.18	2.65	3.58	2.77	2.78	3.33	2.83	4.00	6.55	4.75

Unfamiliar pilots performed better (faster average keying times) on the DK than on the MFK for the low task complexity, medium flight activity condition (task 4). This is the reverse of the results for all other tasks. Figure 13 shows the interaction. Also, familiar pilots performed as well on the MFK as on the DK during the high task complexity, medium flight activity condition (task 3).

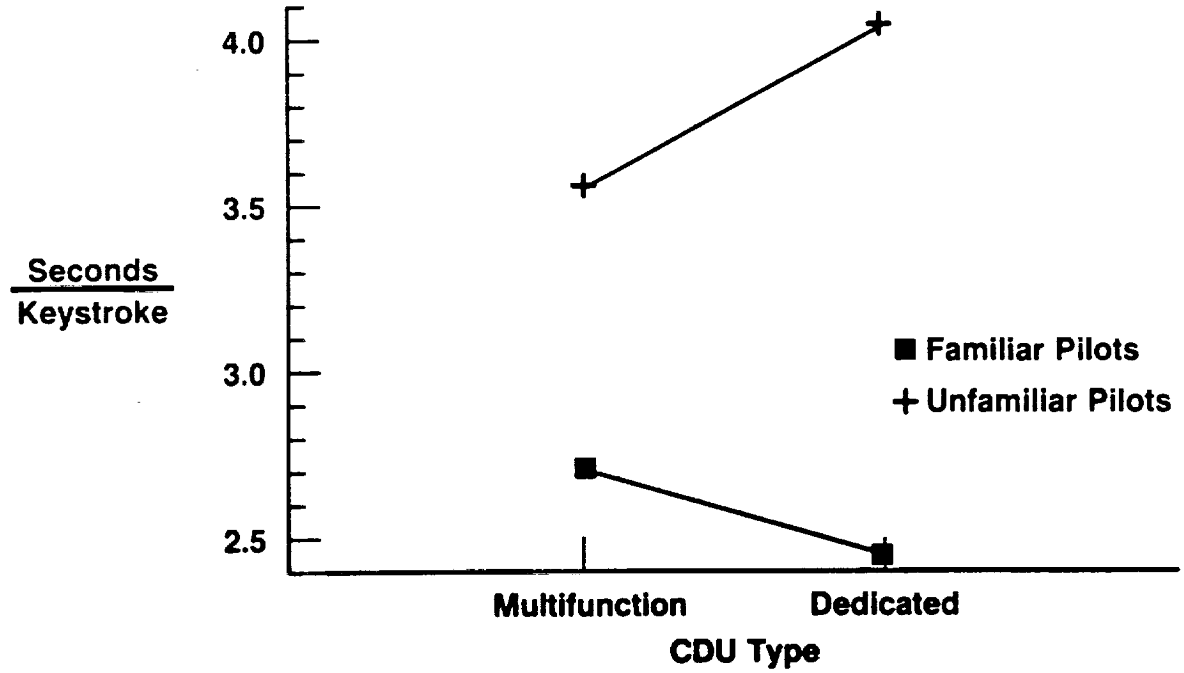

Figure 10. Pilot Familiarity x CDU Type (Average Keying Times)

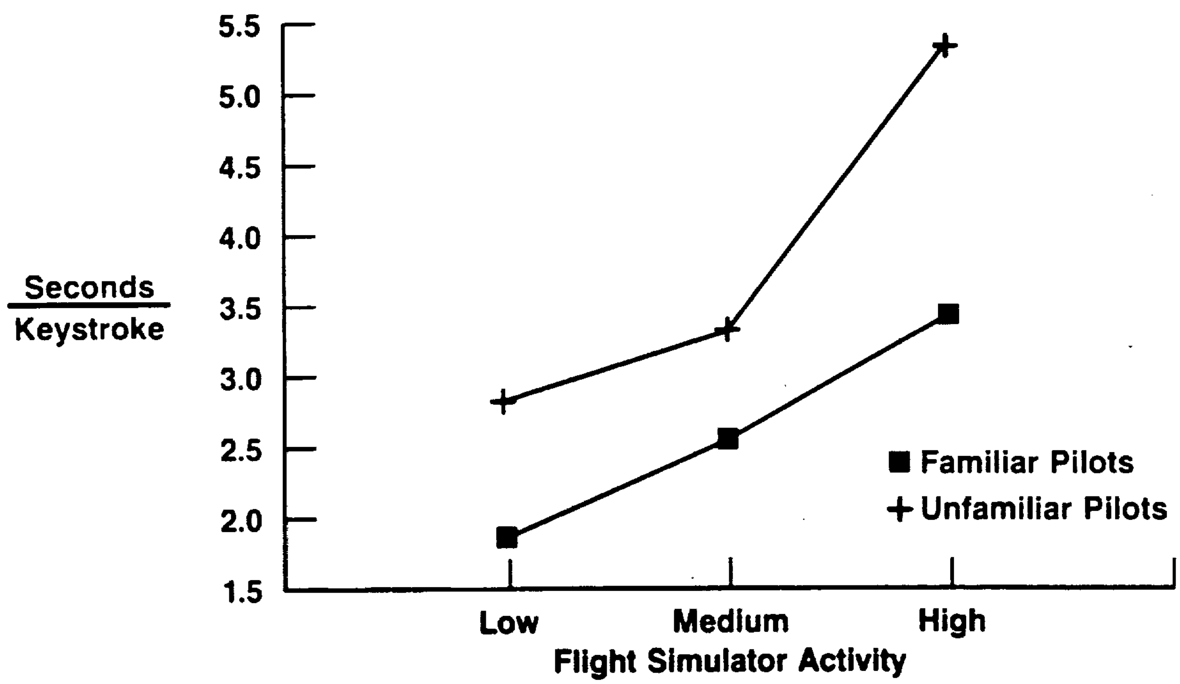

Figure 11. Pilot Familiarity x Flight Activity (Average Keying Times)

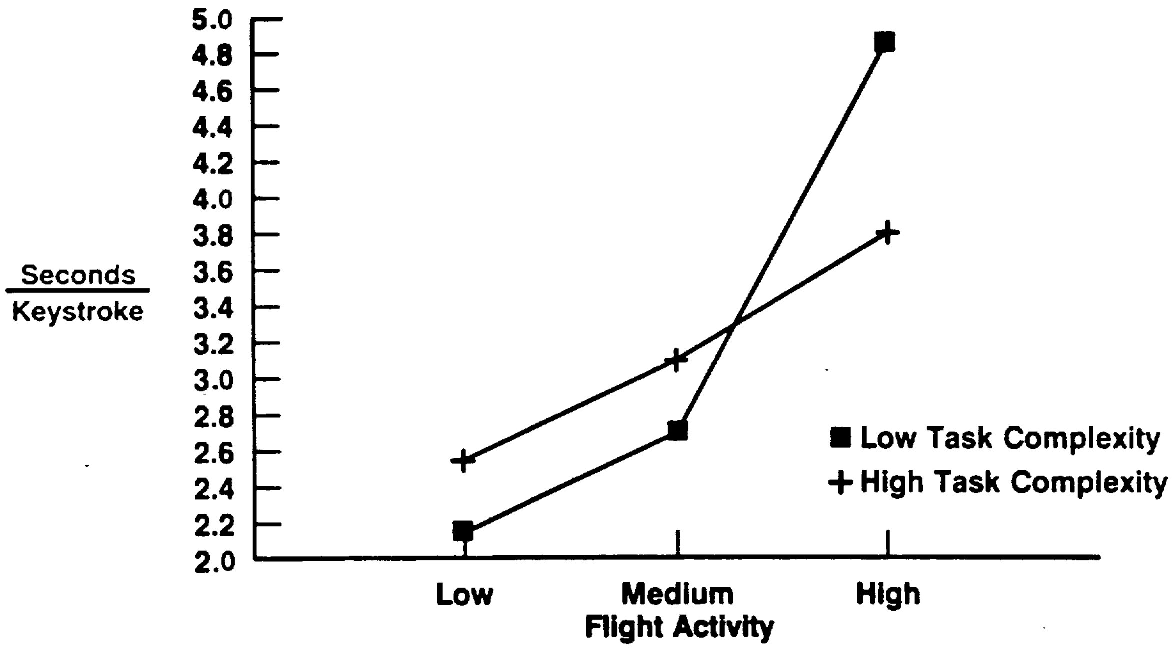

Figure 12. Flight Activity x Task Complexity (Average Keying Times)

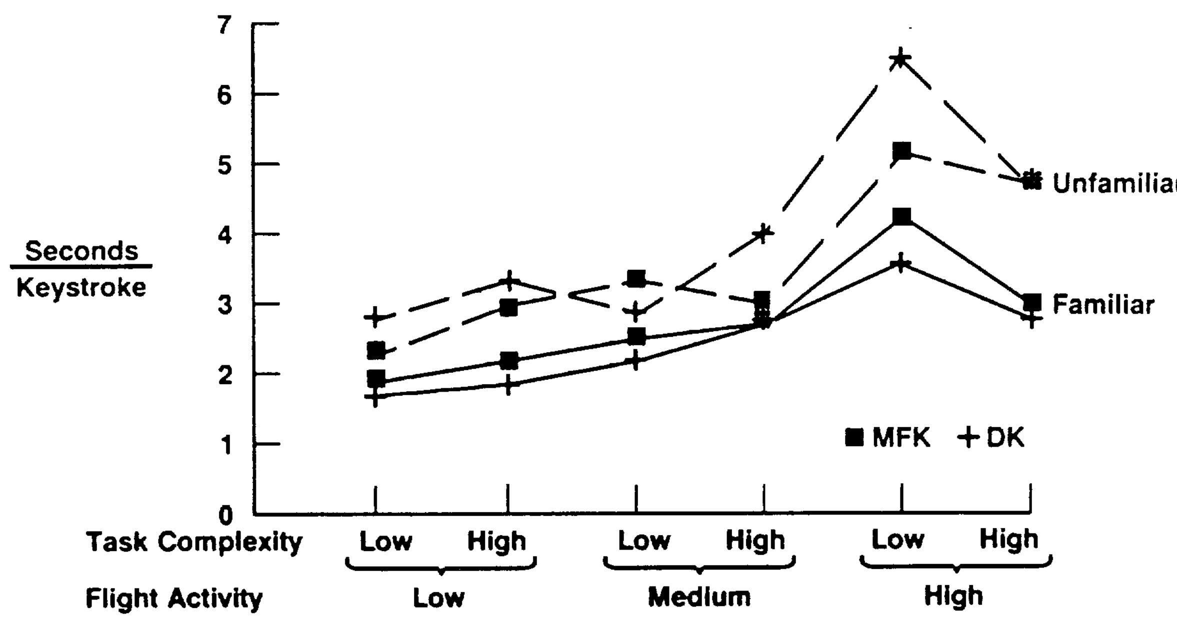

Figure 13. Pilot Familiarity x Flight Activity x Task Complexity x CDU Type (Average Keying Times)

4.1.3 Input Type

A single task was analyzed to examine the differing types of key inputs. The types of inputs were categorized as alpha, numeric, system command, and line select. Task 6 was chosen because it has a good mix of input types; no one input type predominated. Task 6 was the high flight activity, high complexity condition and required a total of 23 keystrokes on the MFK and 16 on the DK. The analysis was obtained by computing each pilots' average time per input for each key type. Alpha input times for the multifunction keyboard were defined as the total time for the two keystrokes required for an alpha input. Table 5 summarizes the analysis of variance.

Pilots familiar with FMC operation were faster than pilots unfamiliar with FMC operation. This result was also obtained in the analysis of total task time and of average keystroke time discussed above.

Average times were significantly different between input types. Average times increased in the following order: numeric, alpha, system command, line select. Additional analysis revealed that the system command and line select times were not significantly different from each other. As in the analysis of average keying times above, this analysis revealed no significant difference in the type of CDU (multifunction keyboard versus dedicated keyboard) being used to perform Task 6.

Further analysis was performed on the two alpha keystrokes comprising one alpha input for the multifunction keyboard. Because two keystrokes are required to enter an alpha character, it was desired to break the total alpha times into the first and second alpha keystrokes for Task 6. See Table 6 for the analysis of variance.

The second keystroke for entering an alpha was performed significantly faster than the first. The data show that the second keystroke cell mean was less than half of the first keystroke cell mean. This is to be expected, as the second keystroke was a choice of 3 letters as opposed to 26.

4.1.4 Keystroke Error Analysis

A true error analysis could not be done for this test. Because the multifunction CDU ran a canned program, immediate feedback was provided when an error occurred. An incorrect keystroke on the multifunction keyboard resulted in a question mark in the scratch pad, which the correct keystroke would erase. In contrast, operation of the dedicated keyboard did not provide this type of feedback and required the proper steps to erase or negate the erroneous key stroke(s). Therefore, for analysis purposes, "error sequences" were counted rather than single incorrect keystrokes. One error sequence is defined as all incorrect keystrokes (and correction keystrokes for the dedicated keyboard) in a single sequence.

Table 7 summarizes the analysis of variance. It shows that significantly more error sequences occurred on the multifunction keyboard than on the dedicated keyboard.

The MFK required more keystrokes to accomplish the same tasks than did the DK, thus allowing greater opportunity for errors. A second analysis of variance was done on the number

Table 5. Summary of Analysis of Variance for Average Sec/Input, Task 6 Only (by Pilot Familiarity, CDU Type, and Keytype)

SOURCE OF VARIANCE	DF	F
Main effects:		
Pilot familiarity	1	13.6*
CDU type	1	1.2
Keytype	3	21.5*
Interactions:		
Pilot familiarity X CDU type	1	.6
Pilot familiarity X Keytype	3	1.1
CDU type X Keytype	3	2.7
Pilot familiarity X CDU type X Keytype	3	.4

* probability < .05

Cell means and effects (in seconds):

Pilot familiarity

Familiar	Unfamiliar
3.4	5.31

Pilots familiar with FMC operation were faster than unfamiliar pilots.

Keytype

Numeric	Alpha	System command	Line select
1.87	3.59	5.41	5.82

Average input time increase from numeric to alpha to system command and line select (system command and line select cell means not significantly different from each other).

Table 6. Summary of Analysis of Variance Average Sec/Keystroke, Task 6 MFK Alpha Only (by Pilot Familiarity and Alpha Keytype)

SOURCE OF VARIANCE	DF	F
Main effects:		
Pilot familiarity	1	4.2
Alpha keytype	1	27.0*
Interactions:		
Pilot familiarity X Keytype	1	1.9

* probability < .05

Cell means and effects:

Alpha keytype

Alpha1	Alpha2
2.64	1.20

The second keystroke for entering alpha information was performed faster than the first.

of errors per keystroke (the number of errors for a given task divided by the number of keystrokes to complete the task with no mistakes). This analysis showed no significant difference between the two CDU types.

Flight Performance Data

Tasks 1 and 2 occurred while on the ground and therefore had no flight parameters associated with them. Because pilots were instructed to maintain constant airspeed in Tasks 3 and 4, this flight parameter was chosen for analysis. Similarly, altitude was the parameter of interest for Tasks 5 and 6, as pilots were instructed to maintain constant altitude for those tasks.

An attempt was made to subtract out the RMS errors of the time period before CDU operation commenced. This would have resulted in an RMS delta, and would have allowed an analysis on only the effect of using the two CDU types. However, in some cases pilot performance as defined by RMS error improved after CDU operation began. The log of the RMS error was used for the analysis of variance, as this generally results in a more normal distribution.

Table 7. Summary of Analysis of Variance for Error Sequences (by Pilot Familiarity and CDU Type)

SOURCE OF VARIANCE	DF	F
Main effects:		
Pilot familiarity	1	4.1
CDU type	1	15.4*
Interactions:		
Pilot familiarity X CDU type	1	0

* probability < .05

Cell means and effects:

CDU type

MFK	DK
4.8	2.7

More error sequences occurred on the MFK than on the DK.

Neither log RMS error for airspeed (tasks 3 and 4) or log RMS error for altitude (tasks 5 and 6) was significantly effected by pilot familiarity, task complexity, or CDU type.

4.2 SUBJECTIVE EVALUATION

The results of the pilots subjective evaluation is a compilation of the ratings and comments from three questionnaires: the Multifunction Keyboard CDU Postflight Questionnaire, the Dedicated Keyboard CDU Postflight Questionnaire, and the Program Questionnaire, which contained comparison questions regarding the two CDU types. Appendix A contains the questionnaire results. The Kolmogorov-Smirnov test was the nonparametric statistic used in testing the significance of the questionnaire responses. The null hypothesis for the Kolmogorov-Smirnov test is that the responses of the pilots to a particular question are distributed equally among the the response categories. A significant Kolmogorov-Smirnov result means that the unequal distribution of responses among the various response categories cannot be attributed solely to chance. The level of significance was chosen at $p < .05$.

The combined responses of the familiar and unfamiliar pilots were analyzed. The questionnaire results in Appendix A list the responses separately for the familiar and unfamiliar pilots. When a distinct division of opinion occurred between familiar and unfamiliar pilots, this is noted in the results section below. In general, the distributions of opinion for the familiar and unfamiliar pilots are similar.

4.2.1 Hardware Characteristics

In general, the hardware characteristics for both the MFK and the DK were rated favorably by the pilots on the two postflight questionnaires. Most of the characteristics rated in both the DK and the MFK questionnaire tested significant. Eighty-eight percent of the DK responses and 85% of the MFK responses were good and very good.

On the comparison questionnaire, no significant preference was noted regarding key arrangement. Half of the pilots considered the key arrangement better on the DK, and half considered the key arrangement on the MFK was equal to or better than the DK. All pilots felt that the DK was equal to or better than the MFK for key operating forces. This preference tested significant.

In areas of key separation, key legend readability, key legend abbreviations, display readability, display brightness, and appearance of character on the display when a key is pressed, pilots did not indicate a significant preference for either the MFK or the DK.

4.2.2 Logic and Task Structure

All of the logic and task structure aspects on the DK postflight questionnaire were rated favorably by a significant number of pilots, with 89% of the ratings recorded as good or very good. On the MFK postflight questionnaire, the pilot opinion varied from very poor to very good; 54% of the responses overall were good or very good. Only the MFK aspects of "entering system commands" and "entering numeric information" showed a significant number of favorable pilot responses.

Pilot opinion on the comparison questionnaire was split on ease of locating the desired key, with no significant preference shown. Half of the pilots preferred the DK, one pilot responded that the MFK and DK were equal, and five pilots preferred the MFK. There was no significant preference shown for either the DK or the MFK in the areas of entering system commands, numeric information, and "knowing where you are in the logic."

For entering alpha information, a combination of alpha and numeric information, and in comparing the number of steps required, the pilots showed a significant preference for the DK over the MFK. Comments by several unfamiliar and one familiar pilot were made to the effect that alpha entry was not satisfactory on the MFK.

4.2.3 Workload

When asked to rate the difficulty level of operating the CDU while maintaining piloting functions during each task on the postflight questionnaire, a significant number of pilots rated the DK favorably on Tasks 1 through 4. Only Tasks 1 and 2 were rated significantly favorable for the MFK. When the pilots were asked to compare the ease of operation of the MFK and DK for each task, only the first task, that of entering the flight plan, yielded a significant preference for the DK.

In terms of mental effort, four pilots responded that the DK and MFK required the same amount of mental effort, three responded that the DK required more, and five responded that the MFK required more. (All three pilots that thought the DK required more mental effort, were unfamiliar with FMC operation.) There was no significant preference.

For overall workload, 10 out of 12 pilots felt that the workload was greater on the multifunction keyboard as compared to the dedicated keyboard. This tested significant.

4.2.4 Error Potential

When the pilots rated the DK on error potential, all of the responses were borderline, good, or very good, and tested significant. For the MFK, 93% of the responses were borderline, good, or very good, and all but the "likelihood of making errors" category on the MFK questionnaire tested significant.

There was no significance shown in the responses regarding error potential on the comparison questionnaire. Five pilots reported that there was about the same error potential on the DK versus the MFK. Five pilots reported that they were more likely to make errors on the MFK, and two reported that they were more likely to make errors on the DK. No pilot thought that the error potential was too high for either unit.

4.2.5 Multifunction Keyboard CDU Design

In the test situation, the MFK display blanks upon returning to the top level keyboard configuration. Five pilots preferred this arrangement, four would rather see the previous display retained, and three had no preference. This did not test significant.

Six pilots indicated that the keyboard should remain in its most recent configuration when the information in the scratch pad is transferred into the display (scratch pad is emptied), one indicated that the keyboard should return to the next higher level, and five had other comments or no preference.

Having dedicated keys (e.g., NEXT PAGE, PREV PAGE, CLEAR) in addition to multifunction keys was considered acceptable by ten pilots (two did not answer the question). This was a significant result.

4.2.6 Training

The majority of the pilots saw no problem for pilots proficient on the dedicated keyboard CDU to transition to the MFK, and reported no other potential training problems for the MFK.

4.2.7 General Considerations

All pilots considered the DK somewhat suitable or very suitable for the purpose of controlling the FMC, which tested significant on the 0.05 level on the DK postflight questionnaire. Although the result was not significant for the MFK, nine out of the twelve pilots considered the MFK somewhat suitable or very suitable for that purpose. Many comments regarding possible improvements for both units were made.

As reported on the comparison questionnaire, for the tasks performed during the test, six pilots greatly preferred using the DK, three slightly preferred using the DK, one slightly preferred using the MFK, and two greatly preferred using the MFK. This did not result in significance at the 0.05 level. It is interesting to note that none of the pilots liked both equally. It is also interesting that of the pilots unfamiliar with FMC operation, four greatly preferred the DK, and two greatly preferred the MFK. Several pilots preferring the DK explained that they disliked the number of keystrokes on the MFK, and that familiarity made it easier for them to operate the DK. Comments from pilots preferring the MFK cited the simpler and less cluttered keyboard as reasons for their choice.

4.3 TIMELINE ANALYSIS RESULTS

The Timeline Analysis Program (TLA) was used to examine the workload differences in using the MFK versus the DK during a flight. TLA is a computer model that has been used extensively to study crew workload in general. In particular, it is used to examine such workload aspects as ease of equipment operation, how well the operator will be able to perform the tasks, and task sequencing. Full description of TLA usage can be found in the TLA User's Guide (ref. 7).

The TLA comparison was done on an advanced system utilizing a dedicated keyboard CDU and a multifunction keyboard CDU as the interface between the pilot and a flight management system (FMS). The FMS was designed to represent the "fully integrated" next-generation aircraft. This FMS, therefore, had additional capabilities over current FMC operation, such as navigation and communication radio tuning and checklist processing.

The mission scenario used in this analysis was developed under Phase II of the Advanced Flight Management CDU Study performed under NASA Contract NAS1-16300, TR B-4 (ref. 8). Two of the three mission segments, cruise and descent, were analyzed. The location of the CDU was established as centered and forward of the pilot, and assumes that the copilot is operating the CDU with his right hand.

Appendix D contains the graphical output from the TLA analysis. The multifunction keyboard CDU is designated "15-KEY CDU" and the dedicated keyboard CDU is designated "DEDICATED KYBD CDU." The four output types are described below.

Mission timeline: The mission timeline provides a description of each task in a procedure and of each event (milestone) in a flight phase. It defines the duration of each task, and presents an interval bar along the timeline to show when a task situation is in effect. Tasks are listed from top to bottom of the chart in chronological order of occurrence within the mission. Mission timelines for both the MFK and the DK CDUs for the cruise and descent phases are contained in Appendix D.

Workload histogram: The histogram report is a plot of a channel or of the weighted average workload as a function of elapsed time for the entire mission. Workload histograms for each CDU included in Appendix D are for the right hand, internal vision, and cognitive channels, and for the weighted average workload.

Channel activity: This is a bar graph that defines the average and standard deviation of the workload for each of nine channels, and a weighted channel average workload. The right hand, internal vision, and cognitive channels are of the most interest in the present analysis. There are two channel activity reports for each CDU type; one for the cruise segment and one for the approach segment.

Workload summary: The workload summary is a comparison between the two CDU types of the average workload for each channel group of the weighted average. Two summaries are included in Appendix D; one for each flight phase (cruise and descent).

The mission timelines contained in Appendix D show how the multifunction and dedicated CDU types could be utilized in an advanced flight deck. The cruise segment consists of inserting a new 4-D flight plan to return to Atlanta via RNAV route, J-815J, STAR transition, MACEY 02, which was changed from SHINE 01, and insertion of Planned Time of Arrival (PTA) at the outer marker to runway 08, Lakeside (CATTA). The cruise segment runs from 0 to 165 seconds. The descent segment consists of a revision of the PTA at Lakeside and a handoff to Atlanta approach control. This segment runs from 165 to 245 seconds. As can be seen in the timelines, neither the cruise nor descent phase requires the entry of alpha characters.

The workload histograms for the multifunction and dedicated keyboard CDUs show similar patterns of workload on the internal vision, right hand, and cognitive channels. The weighted channel average histograms show both CDUs well below the 80% workload limit. The multifunction CDU weighted channel average histogram shows that the workload is more evenly distributed over the mission as compared to the dedicated CDU histogram. The MFK does not exceed 40% workload at any given point, while the DK peaks at over 70% workload.

The channel activity summaries for the multifunction and the dedicated CDUs show very similar percent workload values for the different workload channels. Similarly, the workload summaries, which compare the totals of the workload groups for the DK and the MFK, reveal little difference between the two CDU types. In the cruise segment, the total vision for the MFK is slightly higher than that for the DK, but this difference is cancelled by the slightly lower value on the MFK as compared to the DK for total communications, resulting in approximately the same weighted average. In the descent phase, the workload summary shows very little difference between the MFK and DK for the workload groups and for the weighted average.

5.0 DISCUSSION AND CONCLUSIONS

For the operations performed in this test, the multifunction keyboard CDU required more keystrokes, in general, than did the dedicated keyboard CDU. This was a direct result of the double keystroke required to input alpha information. The pilots performed tasks faster on the DK than on the MFK. There was no significant interaction between pilot familiarity and CDU type, however, which indicates that even for pilots new to both units and unfamiliar with the overall FMC operation, there is no advantage gained by using the MFK for this particular operation.

In evaluating the differences between the multifunction and dedicated keyboards for tasks in general, the average time per keystroke was analyzed. There was no significant difference between the DK and the MFK for pilots, in general. Pilots who were unfamiliar with the FMC operation, however, had a lower average keystroke time on the MFK than on the DK; the opposite was true for the familiar pilots. This result, however, is confounded by the fact that whereas the pilots who were not familiar with FMC operation were equally familiar with the two CDU types, the pilots familiar with the FMC operation were much more familiar with the DK than with the MFK. Several familiar pilots commented that they knew the keyboard on the DK and were more comfortable with it. It is possible that after experience with the MFK to equal their experience with the DK, these pilots would show the same tendency as the others (i.e., they would have a lower average keying time on the MFK than on the DK).

There was no significant difference in terms of average keying times due to the type of CDU (MFK versus DK). The interaction of pilot familiarity with CDU type may have masked any difference in average keying times between the two CDU types, however. If in fact all pilots were equally familiar with both units, there may have been a significantly lower average keystroke time on the MFK as opposed to the DK.

Familiarity with the conventional control is an important consideration. Pilots who were familiar with the DK tended to prefer it to the MFK. Some commented that they liked it better because they were used to it and could anticipate their next action as they were completing the current action. Although the keyboard configuration on the MFK is changing constantly, the same keys pop up in the same location, thus enabling a pilot to "memorize" key location as they have done with the DK. If they were able to use the MFK until they attained the same degree of familiarity as on the DK, more pilots may have preferred the MFK.

The demands of flight activity had a significant effect on the pilot performance on both CDUs. Average keying time when hand flying during turbulence was almost twice that which occurred on the ground. Performance on the MFK and the DK CDU seem to be affected equally by flight activity, as there was no significant interaction between flight activity and CDU type. The relatively higher average keying times for the unfamiliar pilots during the high flight activity conditions is not easily explained. It may be that the high level of activity placed greater stress on those pilots who were not extremely familiar with FMC operation.

Errors could not be analyzed properly due to the fact that the MFK CDU was not programmed to provide error correction. There was however, some indication that there was no significant difference between the two units in terms of error probability, as the number of error sequences per keystroke on the MFK was not significantly different from the number of error sequences per keystroke on the DK.

No differences were found between the two units when the pilot flight performance (as measured by the RMS error of the flight parameters) was analyzed. These parameters may not be sensitive to small differences in performance due to the factors of interest. A recent study showed that primary task measurements, such as control movement and the mean square of pitch and roll, did not exhibit reliable changes as a function of mediational (e.g., cognitive) load (ref. 9).

It may also be that the pilots were concentrating mostly on operating the CDU as opposed to flying. One recent study compared data manually entered (via multifunction control and dedicated keyboard) to vocally entered. "In the situation when data entry was done manually the pilots would concentrate most of their information processing on the data entry task and flying performance would suffer; however, when data entry was done vocally the pilots could still concentrate on the flying task and enter data while maintaining good flight control" (ref. 10). Several pilots in the present study commented that the experimental design was not realistic in the sense that data would "never" be entered manually by the pilot flying. This however, is a standard technique in measuring increases in workload, i.e., the performance on a secondary task (flying) is evaluated with respect to changes in a primary task (FMC input). Also, the flying qualities of the simulator may have aided in masking any differences between the two units.

For the examination of input type, Task 6 was chosen for analysis. Pilot familiarity and key type were found to be significant. Numeric input time was less than alpha input time, which in turn was less than system command or line select input times. Interestingly, CDU type was not found to be significant. It was expected that there would be a significant interaction between the CDU type and key type, showing a relative difference between the MFK and the DK in terms of input type (in particular, input of alpha information). Although the F value of this interaction is fairly high, it does not meet the criteria level of $p<.05$. It may be that because the task chosen for analysis was the high flight activity, high task complexity condition, this interaction was masked.

Pilot opinion reported through the questionnaires revealed some problems with the MFK. Hardware characteristics were considered good for both units, with the exception of the MFK key operating forces. The MFK switches hinged at the top and worked best if pressed near the bottom of the switch. Pressing too close to the hinge required excessive force. The logic and task structure on the MFK were not rated significantly favorable in general. Only the categories of entering system commands and numeric information were rated favorably. A significant number of pilots preferred the DK to the MFK in terms of the number of steps required, and for entering alpha information or a combination of alpha and numeric information. Also, overall workload was perceived as higher on the MFK than on the DK.

The results of the timeline analysis shows that the MFK and the DK, when used in an advanced flight deck concept, impose similar workload levels. The advanced flight deck concept did not contain any alpha input. The workload was more evenly distributed over the mission for the MFK than for the DK, although it may be possible to shift the timing of operations on the DK to smooth out the workload peaks. Thus, in terms of workload on the advanced flight deck, the MFK performs as well as or better than the DK.

The results of this test indicate that not all tasks performed on a dedicated unit are amenable to direct translation to a multifunction unit. Although the task used for comparison in this test may not be a suitable candidate for a multifunction keyboard, several possible means of improving the function and pilot acceptance of multifunction keyboards are evident. The number of choices of top level and in subsequent configurations could possibly be reduced depending on the phase of flight. This has been recommended by previous studies as a design guideline and was discussed in Section 3.3. For the FMC tasks used as a comparison in this test, a reduction depending on flight phase would be very limited. In operations requiring numerous levels of keyboard paging, reducing the number of choices could make a significant improvement.

It is possible to use the line select keys adjacent to sections of the display area to call up the keyboard appropriate for that selection. This method was used in Phase II of the Advanced Flight Management CDU Study. For tasks such as the FMC operation, where the keyboard was programmed to bring up the alpha configuration automatically when appropriate, this would actually add keystrokes to the scenarios. For other applications requiring the use of a variety of entry keyboard configurations, however, this method could be easier than paging through to the desired configuration. When asked about this method, overall pilot opinion was neither significantly favorable nor significantly unfavorable.

It is also possible to mix dedicated keys with multifunction keys; the appropriate number of each type is dependent on the task. There were three keys in FMC operation that would have generally appeared on the multifunction keyboard (e.g., CLEAR, NEXT PAGE, and PREV PAGE). It was felt appropriate to place keys of this nature on dedicated keys. Although they were not functional during this test, this arrangement served to free up keys on the multifunction keyboard. A significant number of pilots responded favorably when asked about this.

An increasing use of artificial intelligence would increase the desirability of multifunction keyboards over dedicated keyboards. A multifunction keyboard would allow a "smart system" to be used to its best advantage, i.e., to reduce the amount of irrelevant data confronting the pilot.

Functions chosen for implementation on a multifunction CDU should be selected on the basis of how the tasks will be structured as compared to the traditional dedicated controls. As in the case of the FMC operation, tasks that require significantly more keystrokes to accomplish on the MFK should be avoided. Inclusion of a large amount of alpha entry increases the number of keystrokes to a level where performance times are significantly higher on the MFK than on the DK. Average time per keystroke was not significantly different between units, and pilots unfamiliar with FMC operation had a lower average keystroke on the MFK. Thus, if a function can be accomplished without a substantial increase in the number of keystrokes on an MFK as compared to a DK, it is a suitable candidate for MFK implementation.

APPENDIX A

QUESTIONNAIRE SUMMARY

Appendix A contains the summary of the responses and comments of all 12 pilots. Responses for familiar and unfamiliar pilots are listed separately. For a given response category, the total number of familiar pilots with that response is listed first and the total number of unfamiliar pilots is listed second, separated by a slash. The Kolgomorov-Smirnov D statistic is listed in a column on the right-hand side of the page. Written comments are listed by pilot number below each question. Comments written by familiar and unfamiliar pilots are designated with an F and a U, respectively, after the pilot number.

MULTIFUNCTION KEYBOARD CDU—POSTFLIGHT QUESTIONNAIRE

INSTRUCTIONS

The following questions pertain to the multifunction keyboard CDU. Please mark your answers to the questions as indicated. Space is provided at the bottom of each page for comments. Any comments or suggestions you would like to make would be appreciated. Also, use the comments space to enumerate any operational difficulties encountered during the test. Please be as specific as possible. If you have any questions, ask one of the test conductors.

HARDWARE CHARACTERISTICS

For questions 1 through 6, mark your answers by putting X in the appropriate column.

1. Rate the following factors for the multifunction keyboard CDU.

	Very Poor	Poor	Border-line	Good	Very Good	D
Keyboard:						
Key arrangement	0/1	1/0	1/2	3/1	1/2	.23
Key operating forces	1/0	1/0	2/2	1/3	1/1	.23
Key separation	___	___	1/0	2/3	3/3	.52*
Keyboard location	1/0	___	1/1	2/4	2/1	.35
Key legend readability	___	___	0/1	___	6/5	.72*
Key legend abbreviations	___	___	0/1	3/3	3/2	.52*
Display:						
Display readability	___	___	___	2/5	4/1	.60*
Display format	___	___	0/1	6/4	0/1	.52*
Display information density	___	___	___	5/5	1/1	.60*
Display brightness+	___	___	___	5/3	1/2	.60*
Control/display features:						
Relationship of controls to dfisplay	___	0/1	0/1	6/3	0/1	.43*
CDU location	1/1	___	1/0	3/5	1/0	.35
Appearance of character on the display when a key is pressed	___	___	___	4/4	2/2	.60*

+ No answer from one pilot
* $p < .05$

COMMENT:

Subject 4 (U): Display format—It seems to me that there could be better differentiation between heading labels on the display and selected data. Keyboard display—would be better on middle console, as it is on aircraft.

Subject 8 (U): Relationship of controls to display—parallax problem.

Subject 10 (F): With experience my acceptability of this keyboard would improve dramatically.

LOGIC AND TASK STRUCTURE

2. Rate the following information entry factors for the multifunction keyboard CDU.

	Very Poor	Poor	Border-line	Good	Very Good	D
Entering information:						
Locating the desired key	____	1/0	2/3	3/2	0/1	.32
Entering system commands	____	1/0	0/1	5/3	0/2	.52*
Entering alpha information	1/2	1/1	1/1	2/0	1/2	.05
Entering numeric information	____	1/0	0/1	3/3	2/2	.52*
Entering a combination of alpha and numeric	1/2	3/0	1/2	1/1	0/1	.15

3. Rate the overall task structure for the multifunction keyboard.

	Very Poor	Poor	Border-line	Good	Very Good	D
Logical steps	____	1/0	1/2	3/2	1/2	.32
Task complexity	2/0	0/1	2/1	1/2	1/2	.15
Number of steps required	2/1	0/1	0/1	4/4	____	.20
"Knowing where you are" in the logic+	____	1/0	4/3	0/2	1/0	.30

+ No answer from one pilot
*p < .05

COMMENT:

Subject 4 (U): The number of steps required to enter alpha data is really unacceptable. There should be at least 26 keys. This concept has a disadvantage in that switches change function, so you can't "memorize" the keyboard. But the advantage is that only a few key possibilities are presented at a time, and they are large and clearly labeled.

Subject 6 (U): With a little practice I felt (surprisingly rapidly so, to me, in view of my limited previous exposure to the multifunction keyboard) basically comfortable operating the system.

Subject 7 (F): In time would recall the use of L and R keys after a numeric entry (i.e., RW13R).

Subject 8 (U): Locating the desired key would rapidly increase with use. Double entry of alpha is not an easy task while flying.

Subject 9 (F): Should have "A" and "B" on numeric page for above and below altitudes.

Subject 11 (U): Entering alpha information required two steps. Also required two different keys most of the time. This increased chance for errors, takes more time. Entering alpha numerics even more cumbersome because you had to switch down from the alpha page to numeric page.

4. Rate the difficulty level of operating the multifunction keyboard CDU while maintaining piloting functions during the following test phases.

	Very Poor	Poor	Border-line	Good	Very Good	D
Preflight:						
Enter flight plan	___	1/0	1/0	3/3	1/3	.52*
Performance initialization	___	___	2/0	2/3	2/3	.43*
Cruise:						
Modify route	1/0	0/1	1/1	3/3	1/1	.27
Enter altitude restriction	2/0	___	1/1	2/4	1/1	.27
Approach:						
Set up approach	1/0	0/1	2/0	2/4	1/1	.27
Time/distance to crossing radial	1/0	0/1	1/1	3/3	1/1	.27

5. Rate the acceptability of workload factors for the multifunction keyboard.

	Very Poor	Poor	Border-line	Good	Very Good	D
Mental effort required	1/0	1/1	1/0	2/4	1/1	.27
Overall workload	1/0	1/2	1/0	2/4	1/0	.27

* $p < .05$

COMMENT:

Subject 4 (U): Requiring two or three switch actuations for each letter input is a serious pilot distraction.

Subject 6 (U): I mark very good and good in view of the rapidity with which one gains comfort with the system.

Subject 8 (U): Without an instructor alongside there would be a lot of confusion with the little knowledge I have of the system.

ERROR

6. Rate the multifunction keyboard on error potential.

	Very Poor	Poor	Border-line	Good	Very Good	D
Likelihood of making errors+	____	2/0	4/1	0/4	____	22
Ease of error detection+	____	____	2/3	3/1	1/1	.40*
Ease of error correction++	____	____	2/2	2/0	1/3	.40*

\+ No answer from one pilot
++No answer from two pilots
* $p < .05$

COMMENTS:

Subject 4 (U): The extra switch activations required detracts from flying the aircraft, and leaves less time to double-check.

Subject 8 (U): Unable to evaluate as the test would take no errors would definitely like some sort of check method to verify that entered data is correct. The initial flight plan would not be a problem but making changes on Arr/Dep could get a bit confusing and subject to wrong route flying or being directed toward wrong Route/Act restrictions.

Subject 10 (F): Did not try error correction.

7. How familiar were you with multifunction keyboard CDUs prior to participating in this study?

___ Very familiar
1/0 Somewhat familiar
5/6 Unfamiliar

8. How suitable is the multifunction keyboard CDU for the purpose you saw demonstrated today?

2/2 Very suitable
2/3 Somewhat suitable
1/0 Borderline
1/0 Somewhat unsuitable
0/1 Very unsuitable

9. What improvements should be made to the multifunction keyboard CDU?

Subject 2 (F): Less pressure on keys. Make a next page selection available for alpha instead of three per key. Have keys in preflight, in flight, and approach sequence.

Subject 4 (U): Have 12 to 15 large keys, and enough small ones to fill out an entire alphabet.

Subject 5 (F): Another alphanumeric selection scheme
Lower touch pressure
More and smaller keys are possible
Some dedicated high use keys

Subject 6 (U): Perhaps a little less pressure required to activate. I see this in relation to turbulence and chop conditions, not in the on-the-ground regime.

Subject 7 (F): Softer touch on keyboard
Larger letters to numbers in keys
More than one way to switch from one function to another without "being wrong."

Subject 8(U): Alpha selection—double key push especially while flying is unsatisfactory. +/– key confusing but would clear up with use.

Subject 10 (F): Have the page blink when you make an entry.

Subject 11 (U): Simplify alpha keyboard to one step—one letter capability.

Please use the space below to write any additional comments you might have for the multifunction keyboard CDU.

Subject 1 (F): Unnecessary pilot workload—a simple alpha and numeric entry requires several inputs to the CDU as opposed to DAKs.

Subject 3 (U): The line select keys were hard for me to see which line they lined up with.

Subject 7 (F): I think I could learn to like it.

Subject 9 (D): In general, very good and easy to learn to use.

Subject 11 (U): The keyboard seems quite large. This makes it easy to read and operate, but cockpit panel space is really limited in commercial airplanes.

DEDICATED KEYBOARD—CDU POSTFLIGHT QUESTIONNAIRE

INSTRUCTIONS

The following questions pertain to the dedicated keyboard CDU. Please mark your answers to the questions as indicated. Space is provided at the bottom of each page for comments. Any comments or suggestions you would like to make would be appreciated. Also, use the comments space to enumerate any operational difficulties encountered during the test. Please be as specific as possible. If you have any questions, ask one of the test conductors.

HARDWARE CHARACTERISTICS

For questions 1 through 6, mark your answers by putting an X in the appropriate column.

1. Rate the following factors for the dedicated keyboard CDU.

	Very Poor	Poor	Border-line	Good	Very Good	D
Keyboard:						
Key arrangement	___	___	0/1	5/4	1/1	.52*
Key operating forces	___	___	___	4/2	2/4	.60*
Key separation	___	___	1/1	5/3	0/2	.43*
Keyboard location	___	___	2/0	4/6	___	.43*
Key legend readability	___	___	2/2	4/4	___	.40*
Key legend abbreviations	___	___	___	6/5	0/1	.60*
Display:						
Display readability	___	___	1/1	2/5	3/0	.43*
Display format	___	___	0/1	6/4	0/1	.52*
Display information density	___	___	0/1	5/4	1/1	.52*
Display brightness	___	___	___	5/4	1/1	.60*
Control/display features:						
Relationship of controls to display	___	___	0/1	6/5	___	.52*
CDU location	0/1	1/0	1/1	4/4	___	.27
Appearance of character on the display when a key is pressed	___	___	___	6/5	0/2	.60*

* $p < .05$

COMMENT:

Subject 3 (U): It would help to have the CDU on the pedestal so the flight instruments would be in your scan.

Subject 4 (U): Display readability would be better if labels and data were better differentiated. Key legend readability function keys are too small for labels.

Subject 8 (U): First looking at the dedicated CDU screen did not like the char. pres. but after using found it OK. Changed size of altered data very desirable.

LOGIC AND TASK STRUCTURE

2. Rate the following information entry factors for the dedicated keyboard CDU.

	Very Poor	Poor	Border-line	Good	Very Good	D
Entering information:						
Locating the desired key	___	___	0/1	6/4	0/1	.52*
Entering system commands	___	___	___	6/4	0/2	.60*
Entering alpha information	___	___	2/1	4/2	0/3	.40*
Entering numeric information	___	___	1/0	4/3	1/3	.52*
Entering a combination of alpha and numeric	___	___	2/1	2/2	2/3	.40*

3. Rate the overall task structure for the dedicated keyboard.

	Very Poor	Poor	Border-line	Good	Very Good	D
Logical steps	___	___	0/2	4/4	2/0	.43*
Task complexity	___	___	0/1	5/4	1/1	.52*
Number of steps required	___	___	___	5/5	1/1	.60*
"Knowing where you are" in the logic	___	0/1	___	5/5	1/0	.52*

* $p < .05$

COMMENT:

Subject 4 (U): It would help in your handout to know where one is flying (route, etc.) to make the entries more logical.

Subject 4 (U): The dedicated keyboard seemed to be a little more complex in operation or functions. However, I believe that this would improve rapidly with practice.

Subject 8 (U): Knowing where you are in the logic is a little tough doing just bits and pieces.

WORKLOAD

4. Rate the difficult level of operating the dedicated keyboard CDU while maintaining piloting functions during the following test phases.

	Very Poor	Poor	Border-line	Good	Very Good	D
Preflight:						
Enter flight plan	___	___	___	3/2	3/4	.60*
Performance initialization	___	___	___	3/2	3/4	.60*
Cruise:						
Modify route	___	0/1	1/0	4/3	1/2	.43*
Enter altitude restriction	___	0/1	___	5/4	1/1	.52*
Approach:						
Set up approach	___	0/1	1/1	5/3	0/1	.35
Time/distance to crossing radial+	___	0/1	1/1	3/3	1/1	.33

5. Rate the acceptability of workload factors for the dedicated keyboard.

	Very Poor	Poor	Border-line	Good	Very Good	D
Mental effort required	___	___	0/2	5/4	1/0	.43*
Overall workload	___	___	0/2	6/4	___	.43*

+ No answer from 1 pilot
* $p < .05$

COMMENT:

Subject 3 (U): The workload would be reduced if one was more familiar with not only the dedicated keyboard but also the routing one is to fly.

Subject 8 (U): Found this keyboard much preferred to the multifunction for data entry.

ERROR

6. Rate the dedicated keyboard on error potential.

	Very Poor	Poor	Border-line	Good	Very Good	D
Likelihood of making errors	____	____	2/1	4/5	____	.40*
Ease of error detection	____	____	1/3	5/1	0/2	.40*
Ease of error correction	____	____	____	6/4	0/2	.60*

* $p < .05$

COMMENT:

Subject 3 (U): I feel the errors encountered are due largely to being unfamiliar with the unit.

Subject 10 (F): Error likelihood high when you first start, less when you gain experience with the system.

7. How familiar were you with dedicated keyboard CDUs prior to participating in this study?

5/0 Very familiar
1/0 Somewhat familiar
0/6 Unfamiliar

8. How suitable is the dedicated keyboard CDU for the purpose you saw demonstrated today?

6/4 Very suitable
0/2 Somewhat suitable
___ Borderline
___ Somewhat unsuitable
___ Very unsuitable

*$p < .05$

9. What improvements should be made to the dedicated keyboard CDU?

Subject 4 (U): Make function keys selectable to illustrate suitable functions for the task at hand. Also, make them larger with better labels.

Subject 5 (F): More prominent lettering on the keys (i.e., brighter paint, larger letters, etc.).

Subject 6 (U): I found the alpha key locating to be a little difficult in comparison to the multifunction keyboard.

Subject 7 (F): Highlight page on CRT.

Subject 10 (F): Progress page is too cluttered.

Please use the space below to write any additional comments you might have for the dedicated keyboard CDU.

Subject 1 (F): Simple direct entry keys are fast and simple in operation. Less workload than multientry keys.

Subject 6 (U): I found the key pressure required to be ideal as contrasted to the multifunction.

Subject 8 (U): Am probably biased against excessive automation of flying functions. Removing too many tasks reduces the pilots to computer operators except when some part is inoperable and then it is back to manual.

Subject 12 (U): With experience, this operation should be easy. I like it.

FLIGHT MANAGEMENT COMPUTER CDU PROGRAM QUESTIONNAIRE

INSTRUCTIONS

The following questions pertain to both the multifunction keyboard CDU and the dedicated keyboard CDU. Please mark your answers to the questions as indicated. Space is provided at the bottom of each page for comments. Any comments or suggestions you would like to make would be appreciated. Also, use the comments space to enumerate any operational difficulties encountered during the test. Please be as specific as possible. If you have any questions, ask one of the test conductors.

HARDWARE CHARACTERISTICS

For questions 1 through 4, place an X in the column which best describes the statements comparing the dedicated keyboard CDU (DK) to the multifunction keyboard CDU (MFK).

1. How do the dedicated keyboard CDU and the multifunction keyboard CDU compare in terms of the following hard characteristics?

	DK Much Better	DK Slightly Better	DK & MFK Equal	MFK Slightly Better	MFK Much Better	D
Keyboard:						
Keyboard arrangement	2/2	1/1	0/1	3/0	0/2	.13
Key operating forces	3/3	3/1	0/2	___	___	.43*
Key separation	___	0/1	2/1	1/2	3/2	.32
Key legend readability	___	0/1	0/2	5/2	1/1	.35
Key legend abbreviations	0/1	___	2/1	3/2	1/2	.20
Display:						
Display readability	___	2/1	3/3	1/2	___	.20
Display brightness	___	0/1	6/3	0/2	___	.32
Control/display features:						
Appearance of character on the display when a key is pressed	___	1/1	5/4	0/1	___	.31

* $p < .05$

COMMENT:

Subject 4 (U): Both displays need more differentiation between headings and data.

Subject 8 (U): I did not like the touch of the MFK as it seemed to take too much pressure to activate the key, especially if the key was pressed too close to its hinge. I could also be biased against the MFK as I was involved with it during the other test (Flight Status Monitor) and see an attempt to have one keyboard serve two very different functions, which could be a real operational problem if multifunction problems were being attended to as well as a navigation problem.

Subject 11 (U): DK key arrangement better than the MFK because the MFK alpha keyboard requires too many steps.

LOGIC AND TASK STRUCTURE

2. How do the dedicated keyboard CDU and the multifunction keyboard CDU compare for the following information entry factors?

	DK Much Better	DK Slightly Better	DK & MFK Equal	MFK Slightly Better	MFK Much Better	D
Locating the desired key	2/3	1/0	1/0	2/1	0/2	.21
Entering system commands	2/1	1/2	3/1	0/2	____	.23
Entering alpha information	3/4	3/0	____	0/1	0/1	.43*
Entering numeric information	2/2	2/1	1/1	1/2	____	.20
Entering a combination of alpha and numeric	3/4	3/0	____	0/1	0/1	.43*

3. How did the overall task structure compare for the dedicated keyboard CDU versus the multifunction keyboard CDU?

	DK Much Better	DK Slightly Better	DK & MFK Equal	MFK Slightly Better	MFK Much Better	D
Logical steps	2/0	1/1	3/3	0/1	0/1	.23
Task complexity	2/0	1/2	2/3	1/0	0/1	.23
Number of steps required	3/3	2/2	1/0	0/1	____	.43*
"Knowing where you are" in the logic	1/1	1/1	4/3	0/1	____	.23

* $p < .05$

COMMENT:

Subject 8(U): The alpha data entry for the MFK is unsatisfactory due to requiring a double entry for each character.

Subject 11 (U): Alpha and numeric keyboards were on different pages on the multifunction. This was awkward to enter 16L.

4. Compare the ease of operating the dedicated keyboard CDU and the multifunction keyboard CDU while maintaining piloting functions during the following test phases:

	DK Much Better	DK Slightly Better	DK & MFK Equal	MFK Slightly Better	MFK Much Better	D
Preflight:						
Enter flight plan	2/0	2/3	2/3	___	___	.40*
Performance initialization	2/0	1/3	3/2	0/1	___	.31
Cruise:						
Modify route	2/1	3/1	1/3	___	0/1	.31
Entering altitude restriction	2/0	3/2	1/3	___	0/1	.31
Approach:						
Set up approach	2/2	1/1	3/1	0/2	___	.23
Time/distance to crossing radial	2/1	1/2	3/1	0/2	___	.23

* $p < .05$

COMMENT:

Subject 3 (U): The MFK with the larger keys and printing seem to make it easier to operate in flight. It takes less attention and concentration to operate.

Subject 4(U): The added keystrokes needed to utilize the MFK, while hand flying the aircraft made the operation unsafe.

For questions 5 through 13, place an X before the statement that best describes your answer to the question.

5. Which unit required greater mental effort during operation?

0/1 Dedicated keyboard CDU required much more mental effort than the multifunction keyboard CDU
0/2 Dedicated keyboard CDU required slightly more mental effort than the multifunction keyboard CDU
3/1 Both required about the same amount of mental effort
2/0 Multifunction keyboard CDU required slightly more mental effort than the dedicated keyboard CDU

1/2 Multifunction keyboard CDU required much more mental effort than the dedicated keyboard CDU

Was the mental effort required excessive for either unit?+

0/2 Yes
6/3 No

+ No answer from one pilot

COMMENT:

Subject 3 (U): I felt the mental effort with the DK was too distracting while one is flying.

Subject 4 (U): It became a dangerous distraction while hand flying, particularly the MFK.

Subject 10 (F): No, but with the MFK it might be harder to come back to after a long distraction.

6. Which of the following statements on the overall workload applies:

___ Workload on the dedicated keyboard CDU was much greater as compared to the multifunction keyboard CDU.
0/1 Workload on the dedicated keyboard CDU was slightly greater as compared to the multifunction keyboard CDU.
0/1 Workload was about the same for the dedicated keyboard CDU and the multifunction keyboard CDU.
4/3 Workload on the multifunction keyboard CDU was slightly greater as compared to the dedicated keyboard CDU.
2/1 Workload on the multifunction keyboard CDU was much greater as compared to the dedicated keyboard CDU.

Was the overall workload required excessive for either unit?+

2/2 Yes
3/3 No
1/0 Other:

Subject 3 (U): Both require distraction from flying when some of the operations (such as altitude and speed restrictions) could be accomplished with the autopilot.

+ No answer from one pilot
*$p < .05$

COMMENT:

Subject 1 (F): Multifunction for some entries requires three separate key functions. Example—entering RW13R.

Subject 2 (F): MFK would be for some operators.

Subject 4 (U): Entering alpha information on the MFK was unreasonably complicated.

Subject 5 (U): Combination alpha/numeric on multifunction keyboard took longer.

Subject 8 (U): It is possible that changes in approaches, etc., made in the terminal phase of a flight would not be entered into the system. While flying the DK I know where I am, as compared to entering a last minute change and then being concerned if the "machine" is giving me proper guidance. An enroute change in altitude would be no problem. It is the changes in departure or arrival routings made in congested areas that cause me concern as far as having to enter the information.

7. Which of the following statements on error potential applies:

___ Much more likely to make errors on the dedicated keyboard CDU than on the multifunction keyboard CDU
0/2 Somewhat more likely to make errors on the dedicated keyboard CDU than on the multifunction keyboard CDU
4/1 About the same error potential for the dedicated keyboard CDU and the multifunction keyboard CDU.
2/2 Slightly more likely to make errors on multifunction keyboard CDU than on the dedicated keyboard CDU
0/1 Much more likely to make errors on multifunction keyboard CDU than on the dedicated keyboard CDU

Do you think the error potential was too high for either unit?+

___ Yes
6/4 No
0/1 Other:

Subject 3 (U): Not being familiar with the use of either unit, I cannot make an accurate comment.

+ No answer from one pilot
*p < .05

COMMENT:

Subject 4 (U): As a first-time user, I made only a couple of errors. On the DK, the errors tended to be in selecting modes. The MFK helps avoid this, but the 2-stroke alpha inputs are confusing and error producing, so I must rate this a draw.

8. Although the multifunction keyboard CDU was not programmed to provide realistic error scenarios, which of the following statements applies concerning error detection during this test:

1/0 Much easier to detect errors on dedicated keyboard CDU
0/2 Slightly easier to detect errors on dedicated keyboard CDU
4/3 About the same ease of error detection for the dedicated keyboard CDU and the multifunction CDU
1/0 Slight easier to detect errors on the multifunction keyboard CDU
0/1 Much easier to detect errors on the multifunction keyboard CDU

COMMENT:

Subject 5 (F): Line select keys on multifunction CDU were not aligned visually with the display lines and probably contributed to my error(s) in line select entry. Multifunction keys required too high a force even using the lower edge.

9. Which of the following statements on error correction applies+:

2/1 Much easier to correct errors on dedicated keyboard CDU
0/1 Slightly easier to correct errors on dedicated keybard CDU
2/2 About the same ease of error correction for the dedicated keyboard CDU and the multi-function keyboard CDU
1/2 Slightly easier to correct errors on the multifunction keyboard CDU
___ Much easier to correct errors on the multifunction keyboard CDU

+ No answer from one pilot

COMMENT:

Subject 7 (F): Clear key was not functional on the MFK.

Subject 8 (U): I don't like the MFK because of the double key press requirement.

Subject 10 (F): Didn't correct any errors on the MFK, therefore no error correction comparison possible.

MULTIFUNCTION KEYBOARD CDU DESIGN

The design of the multifunction keyboard CDU in this test reflects the current operation of the 737-300 CDU. There are many changes that could be made to the operation of the multifunction keyboard. The questions below are being asked to obtain your insights and preferences regarding multifunction keyboard operation.

10. In the design for this test, the display blanks upon returning to the top level keyboard configuration. Did you find this helpful or would you prefer the previous information to remain in the display?

2/3 Should blank upon returning to top level
3/1 Should retain previous display
0/2 No preference
1/0 Other (specify):

Subject 5 (F): Would probably have a preference with more experience of unit in the field.

11. What should happen to the keyboard configuration when information entered into the scratch pad is transferred into the display (i.e., the scratch pad is emptied)?

3/3 The keyboard should remain in its most recent configuration (i.e., alpha or numeric)
0/1 The keyboard should return to the next higher level
0/2 No preference
3/0 Other (specify):

Subject 5 (F): Need more experience.

Subject 7 (F): The keyboard should return to the top level.

Subject 10 (F): The answer is different for different phases of flight. In some cases (PERF), stay in recent configuration; in others maybe go to next higher level.

COMMENT:

Subject 4 (U): I would much prefer a 26 through 28 key keyboard with both alpha and numerals on the key faces, with a shift button to select one or the other. This display should remain when the scratch pad is emptied.

Subject 5 (F): More artificial intelligence is probably possible than was used in the demonstration. This might improve the multifunction ratings.

12. One possible method of reconfiguring the keyboard for data entry to the scratch pad is to use the line select key next to the data field to be filled. Pressing the line select key would change the keyboard to the appropriate configuration (i.e., alpha, numeric, or a choice if data can be entered both ways for that particular field). Would this design be:

2/0 Very satisfactory
1/4 Satisfactory

1/1 Borderline
2/0 Unsatisfactory
___ Very unsatisfactory

Subject 1 (F): Increased workload.

13. The functions of NEXT PAGE, PREV PAGE, and CLEAR were located on dedicated keys beneath the display area, rather than on multifunction keys. Did you find this arrangement to be:

2/4 Very satisfactory
2/2 Satisfactory
___ Borderline
___ Unsatisfactory
___ Very unsatisfactory

+ No answer from two pilots
$^*p < .05$

COMMENT:

Subject 6 (U): While we did not use these keys to any extent in this program, I can see their "dedicated" status to be appropriate especially in an online, inflight, actual situation.

14. The prompt area and its associated line select key on the dedicated keyboard CDU is used as a "multifunction" area. For example, the ACTIVATE> prompt appears on the Route page at the bottom of the display; pressing the line select key next to it tells the FMC to activate the data. Can you think of any functions that should be treated in this manner on the multifunction keyboard CDU display?

Subject 2 (F): Use same idea to prompt sequence (i.e., Pos Init, Rte, Perf, Dpt).

Subject 4 (U): Yes, similar function. It is useful as a signal to the pilot that the needed input is completed.

Subject 5 (F): Why not instead eliminate the ACTIVATE and use the execute key? Why do we need to do both?

Subject 10 (F): There might be some climb modes or descent modes that would be better off as a line select key.

COMMENT:

Subject 5 (F): On both displays, it is difficult to immediately find the alpha characters. Perhaps a different alpha layout would help (e.g., two long rows of keys A-M, M-Z, or vowels colored, or alpha keys bordering the CDU keyboard, etc.). The numeric keys were in a familiar layout and were easy to find for both. The multifunction numeric was extremely easy to use.

15. Do you think there would be any problem for pilots proficient on the dedicated keyboard CDU to transition to a multifunction keyboard CDU?

1/1 Yes
5/5 No

16. Are there any other training problems apparent for the multifunction keyboard CDU?

0/1 Yes
4/5 No
2/0 Other:

Not suitable to a two-man cockpit. (2)
Learning the ABCs! (7)

COMMENT:

Subject 8 (U): As with any new system of this type the training concentrates far too much on operating the "new toy" and the basic operation of the DK takes a backseat. The basic operation of the DK should be comfortable first and the "new toy" brought in.

17. For the tasks performed today, which unit do you prefer to use?

2/4 Much prefer the dedicated keyboard CDU
3/0 Slightly prefer the dedicated keyboard CDU
___ Like both equally
1/0 Slightly prefer the multifunction keyboard CDU
0/2 Much prefer the multifunction keyboard CDU

Please explain your choice:

Subject 1 (F): Ease of entry with DAKs.

Subject 2 (F): MFK too slow to operate and requires finding key not in logical order.

Subject 3 (U): The presentation and size of keys made the MFK unit seem less cluttered.

Subject 4 (U): Too many keystrokes on the MFK! Both in choosing functions and inputting data!

Subject 5 (F): Primarily because of alphanumeric work requirement on the MFK and previous experience (bias) with the dedicated CDU.

Subject 6 (U): Much easier to select appropriate keys on MFK. A simpler display with easier logic and faster alpha key selection. It strikes me as a "new improved" version of the dedicated unit. While two steps are required, I nonetheless preferred it overall.

Subject 7 (F): I've been using it for years.

Subject 9 (F): More experience using the dedicated keyboard.

Subject 10 (F): I'm much more familiar with the DK's operations and expect changes as they occur.

Subject 12 (U): DK requires less mental effort.

18. Do you think the simulation was adequate to present the flying tasks?

3/4 Yes
2/1 No
1/1 Other:

Subject 3 (U): The entries to the CDUs were good. The actual flying while using the CDUs was not adequate due to the location of the CDU.

Subject 5 (F): Normally, the copilot would be programming. Also, some questions require more experience with the units and a prior orientation to example questions to follow.

COMMENT:

Subject 4 (U): The three modes were good choices. Flight tasks were none (preflight), low (CWS climb), and high (hand flying in turbulence). The simulation featured high breakout forces and displacements, with poor aircraft static stability. This provided an excellent task loading for the test.

Subject 8 (U): No, full simulation should be used and fly a segment without the system, and fly it with the system to give a more realistic evaluation.

Subject 10 (F): No, normally the pilot flying does not make FMC changes.

Subject 11 (U): Yes. It would, however, be a good idea to familiarize the test subject with the units, and then let the test subject program and change the display as need be, instead of reading a step by step.

19. Please use the space below to write any additional comments you might have for the dedicated keyboard CDU and the multifunction keyboard CDU.

Subject 1 (F): Multientry keys increase "heads down" time in the cockpit. Procedures require a pilot to search for correct entry keys (i.e., to select the single letter, press, then select multi-choice).

Subject 2 (F): I see no improvement to cockpit safety or crew efficiency in the MFK.

Subject 3 (U): I felt there was a problem with using the line select keys on both unit. The MFK CDU seemed to be a bit more of a problem.

Subject 4 (U): The MFK badly needs 26 to 28 keys. As it is, it is a threat to flight safety. I am not used to any CDU at all. I have a feeling that with practice the dedicated keyboard increases in superiority because a pilot memorizes key positions through usage. I am sure that data entry speed is probably twice as high as that using the MFK once experience is gained. This means the dedicated keyboard is safer because it distracts the pilot less. Unless the MFK adopts 26 to 28 keys, it can't compare.

Subject 5 (F): The dedicated keys on the multifunction CDU were not labeled or used. Perhaps using a combination of multi and dedicated keys combined on the same display unit would prompt different comments. I liked the large and very legible keys on the multifunction CDU.

Subject 6 (U): I feel that the MFK would be better than the DK during turbulence and low light conditions. I suspect that locating the keyboard 2 or 3 inches aft on its location and pitched upward at, perhaps, 10 to 15 degrees, would facilitate its use. I found myself tending to lean forward to operate it. Why would I not then just move the seat forward? Because then I'd be improperly seated for flying the aircraft.

Subject 7 (F): Needs a little work, but I think I could grow to like it.

Subject 11 (U): Checklist.

APPENDIX B

TRAINING MANUAL FOR FLIGHT MANAGEMENT COMPUTER CDU TEST

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Manual Description

This training manual is to be used as part of training and familiarization for pilots participating in the Flight Management Computer (FMC) Control Display Unit (CDU) test. It provides you with information about the dedicated keyboard CDU (737-300 FMC) and the multifunction keyboard CDU concept. Read over this manual to familiarize yourself with the two CDU concepts. An instructor pilot will show the CDU operation to you prior to the test, and you will be given as much time as is needed to practice using both the dedicated keyboard and multifunction keyboard CDUs.

This manual is divided into four sections; the first section describes the purpose for the test and serves as an introduction to multifunction and dedicated keyboards. The second section describes the dedicated keyboard and the multifunction keyboard to be used in this test. Keyboard operations for both concepts are described in detail. The third section describes the laboratory setup and the data collection process. The fourth section describes a typical test session.

1.2 Test Purpose

The flight management computer CDU test is being conducted to compare two types of input devices: a dedicated keyboard and a multifunction keyboard. The task that will be used in this test for evaluation purposes is operation of the flight management computer (FMC) for the Boeing 737-300. The FMC control display unit (CDU) is the interface between the crew and the FMC. You will be asked to perform the same tasks on the FMC CDU configured with a multifunction keyboard and with the currently used 737-300 dedicated keyboard.

A dedicated keyboard has keys, or switches, that always perform the same function. Activation of a given key will always give the same results. A multifunction keyboard has keys that are capable of changing their function. The current function of a particular key is displayed on its programmable legend keyface. It requires fewer keys than the dedicated keyboard to accomplish the same functions. The multifunction keyboard is an attempt to reduce the crew's workload and manage the information flow by restricting the information presented to only that which is relevant to the current task or operation, while having other information available on request. This data management could reduce the clutter and cross-checking problems that can occur when unnecessary information is combined with that which is presently required.

This test will investigate the use of a multifunction keyboard in the place of the currently used dedicated keyboard for the operation of the 737 FMC. Using the Flight Deck Integration Research cab to allow simulation of flying tasks, a set of operations will be performed on the FMC CDU with both the multifunction keyboard and the dedicated keyboard. A brief questionnaire will be administered after the session with each keyboard type, and a program questionnaire will be filled out at the end of the test sessions. Data will be recorded automatically during the session.

2.0 DEDICATED KEYBOARD AND MULTIFUNCTION KEYBOARD CDUs

2.1 Dedicated Keyboard CDU

The dedicated keyboard CDU to be used in this test as shown in Figure B-1 is currently used for the 737-300 FMC. It is divided into a keyboard section and a display section. The CDU data displays are shown on a 5-inch, cathode-ray tube (CRT). The general format of the CRT display is also given in Figure B-1. The basic display format consists of an array of 14 24-character lines. A variety of alphanumeric characters and symbols can be presented on each line. The basic display format is subdivided by specifically defined display data blocks that are reserved in all displays for certain types of usage.

The first five character spaces in the first line of the display are reserved for a data status indicator. This is a prefix to the page identifying title, which indicates whether the information currently on the display is the active executed flight plan (ACT) or a modification (MOD) to the active plan. If this data status block is blank, the data on the display is either not plan specific or not active.

When flight plan data is entered, it needs to be activated and executed before it becomes an active route. When the system has an active route, all of the displays associated with that route have an "ACT" prompt in the title line of the page. Modifications in the data status area to any route plan can be made at any time. If changes are made to an active route, the "ACT" will be changed to "MOD." The "MOD" designation goes away when the modifications are erased or when the modifications are executed, and "ACT" reappears in the display title line.

The next 14 character spaces of the first line of the display are reserved for an identifying title for the display. The title may be a simple one that identifies the type of information presented in a data display (PROGRESS, for instance), or it may be more complex, perhaps identifying a display which corresponds to a particular flight phase and the mode of operation in that phase at the same time (ECON CRZ CLB).

The remaining five character spaces in the first line are reserved for the page number for each display. This tells the operator the position of the current display in a string of pages that might exist for some FMCS functions.

The entire 24 character spaces at the bottom (the 14th line) of the display are used as a scratch pad block for entry of data from the keyboard, or for display of failure messages, operational alerts, and advisory prompts.

The remainder of the display (12 24-character lines) is available for use in displaying data without restriction. This data can consist of information directly applicable to operation of the aircraft, a menu allowing selection of system functional options, or a combination of the two.

The data area is partitioned into specific data fields that are dependent on the display page. Entered data must be in the correct format, or else entry cannot occur. There are situations where certain data is required (e.g., the destination on the route page). This is indicated by the use of box prompts. If prompts are present on a display they must be filled in before you can go on.

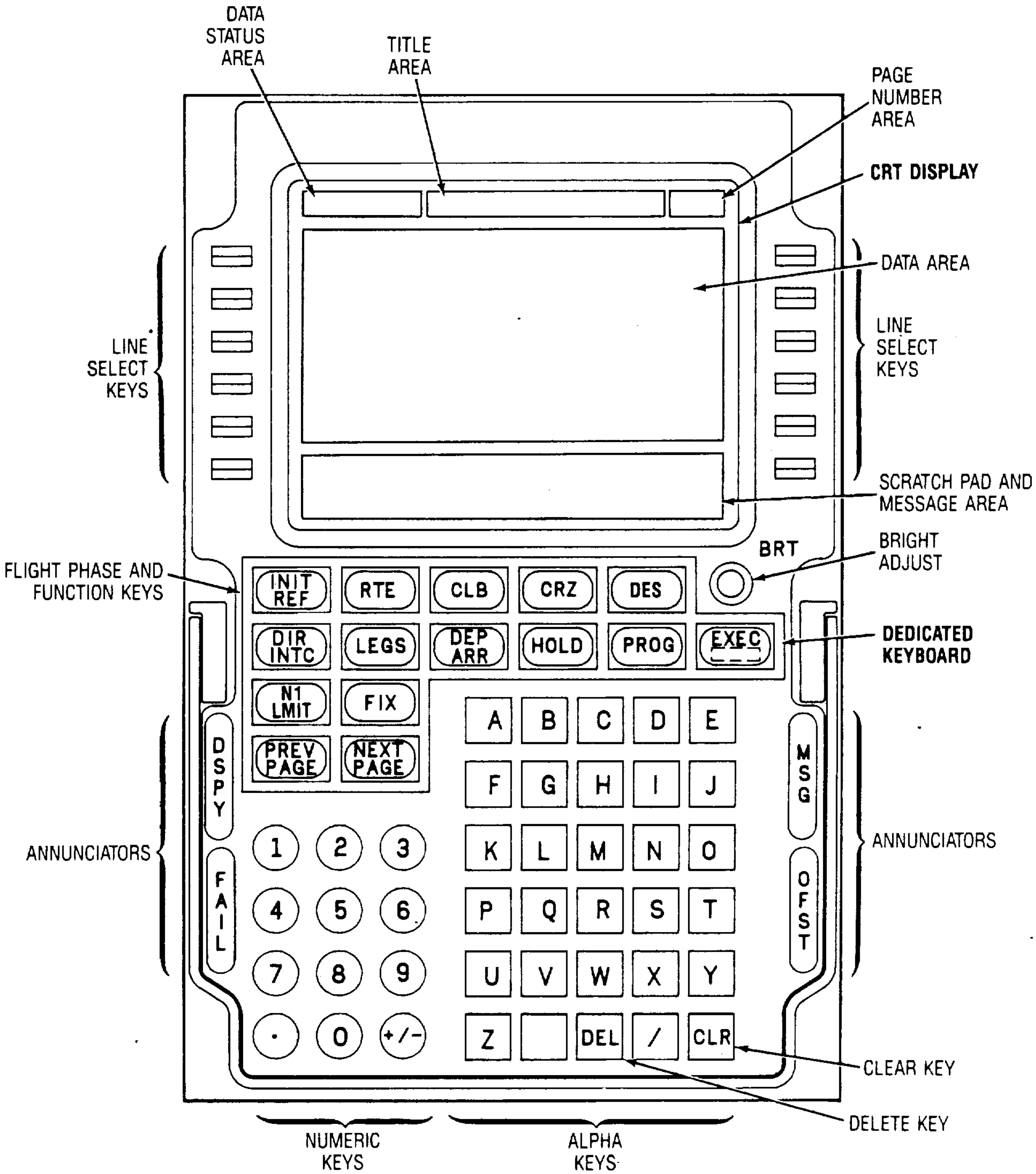

Figure B-1. Dedicated Keyboard CDU

2.1.1 Alphanumeric Key Group

The CDU alphanumeric keyboard provides the crew with a means of entering data into the system for initialization of the navigation and guidance modes, and for modification of flight plans. All entries initiated by operation of the alphanumeric keyboard initially appear in the scratch pad area of the display. The scratch pad contents can be edited or cleared by pressing the CLR key. When an entry is present in the scratch pad, a brief depression of the CLR key will clear the last character in the entry. If the CLR key is held down for more than 1 second, the entire entry in the scratch pad will be cleared.

The alphanumeric key group also includes the special-purpose slash (/), change sign (+/-), decimal point (.), and clear (CLR) keys. The slash key serves to separate data fields where multivariable entries are employed. An example of this type of entry is the definition of a climb speed schedule target airspeed and mach number (300/.780). The decimal point key inserts a decimal point into the scratch pad character string when pressed. The change sign key alternately changes the entry in the scratch pad from a positive to a negative quantity and back again. Repeated depressions of the change sign key simply toggle the positive or negative sense of the scratch pad entry.

2.1.2 Flight Phase and Function Keys

This group of 13 keys are the flight planning and flight phase keys. These keys provide the means for crew access to the flight planning functions of the FMCS. The specifics of flight phases (CLB, CRZ, and DES) can also be selected, once initially addressed, for display by using keys of this group.

The phases of flight that can be preplanned and controlled by the FMCS are climb, cruise, and descent. The keys used to access the flight mode displays are:

CLB (climb)—Displays current or alternate climb mode for assessment and selection. Cruise altitude (CRZ ALT) is enterable, as are speed/altitude restrictions.

CRZ (Cruise)—Displays current or alternate cruise mode for assessment and selection. Information about optimum altitude-climb savings, and turbulence penetration N1 targets is also available.

DES (descent)—Displays current or alternate descent mode for assessment and selection. End-of-descent (E/D) altitude is displayed and the airport-related speed/altitude restrictions are enterable. Flightpath angle (FPA), vertical speed (V/S), and vertical bearing (V/B) information is provided for crew reference.

The flight planning keys are:

INIT/REF (initialization/reference)—Allows access to data pages required for start-up of the FMCS and IRS. Also, the operator may select various reference data and maintenance pages.

N1 LIMIT—Permits manual selection of the active N1 limit, and selection of any Climb N1 Limit thrust reduction that may apply.

DEP/ARR (departures/arrivals)—Used for selection of the procedures and runways at the origin and destination airports entered by the crew.

RTE (route)—Gives access to flight plan data selections and entries into the FMC in clearance language. This will probably be the primary key for entry of lateral flight plan information.

LEGS (route legs)—Displays and accepts entries of detailed data concerning each leg of the flight plan for both the lateral and vertical paths.

HOLD—Permits planning or initiation of holding at a designated waypoint.

FIX (fix information)—Displays range and bearing data from the present position to an entered fix.

PROG (flight progress)—Displays current flight status information such as ETA, fuel remaining at waypoint, navigation radio tuning status, wind, and path errors.

The remaining key of this category is the EXEC (execute) key. This key is used to incorporate displayed data in the FMC as part of the active flight plan. The EXEC key is operable when its annunciator bar is illuminated. The key is used for activating the flight plan, changing the active flight plan, changing the active guidance mode, or inserting data that affect the active flight plan, guidance mode, or data base. Illumination of the white annunciator bar indicates that a valid set of data is on display and may be made active for guidance of the aircraft.

2.1.3 Page Select Keys

If a function has more than one page of display data associated with it, the page number block at the upper right corner of the CRT display will indicate this. The page number actually consists of two numbers separated by a slash. The first number indicates what page is currently displayed, and the second number indicates total number of pages in the string. Pressing the NEXT PAGE key advances the display to the next higher numbered page, while pressing the PREV PAGE key backs up the display to the next lower numbered page. The page strings are continuous, however, in that advancement past the last page in a string (beyond 9/9, for example) would take the display back to the first page in the string (1/9, in this case). The same sort of thing occurs if the first page of a string is displayed and the PREV PAGE key is pressed (i.e., the display shows the last page in the string).

2.1.4 Line Select Keys and Scratch Pad Usage

Twelve line select keys are provided on the CDU panel, as shown in Figure B-1, six each to the left and right of the display screen. The line select keys perform three functions. They can be used to transfer information from the scratch pad area up into the appropriate display area. They can be used to copy information from the display to the scratch pad. Finally, they can be used to designate a chosen item in a displayed list (e.g., selecting a specific runway from a list of candidate runways.) These functions are explained below.

All manual data entries appear initially in the scratch pad area. In the scratch pad, they can be verified and, if necessary, edited. Entry of the data into the operational display is accomplished by pressing an appropriate line select key.

In addition to transferring data from the scratch pad up to the data area of the display, the line select keys can be used to duplicate data from a data area line into the scratch pad. This is done when the scratch pad is blank, simply by pressing the line select keys associated with the data desired for duplication in the scratch pad. The data appears in the scratch pad and, by use of the line select keys may then be transferred up to another data line of the display. If the display page is changed while there is an item in the scratch pad, the contents of the scratch pad will carry over and can then be inserted into any data line on the new page for which it is valid.

At certain times during the FMC CDU operation, the data area will show several options from which the pilot can choose. An example is a list of runways for a given departure airport. A depression of the line select key next to a runway will designate that runway as chosen.

2.1.5 Delete Key

The delete (DEL) key is a special purpose key that is used to remove data from a display (and thus a flight plan) after it has been line selected and accepted into a data field. If the scratch pad is empty, pressing the DEL key will write "DELETE" into the scratch pad. The delete process is then completed by the operator's line selecting the data item he desires removed. If the deletion is a valid one, the data field reverts to its default value (box prompts, dashes, or a system-generated value). When use of the DEL key would be incorrect, the system will prevent the operator from making mistakes. Selection of the wrong line select key on a page in which the delete operation is valid for at least one display parameter brings up an INVALD DELETE message in the scratch pad. Pressing the DEL key when the displayed page has no valid delete operation evokes no response. The DEL key must be pressed once for each parameter to be deleted.

2.2 Multifunction Keyboard CDU

The multifunction keyboard CDU is shown in Figure B-2. As can be seen, the CDU is divided, like the dedicated keyboard, into the display section and the keyboard section. The display and the pages shown during the operation are identical to the dedicated keyboard CDU. The keyboard area is very different from the 737 CDU, as there are only 15 keys on the multifunction CDU versus over 50 on the dedicated keyboard CDU. The functions displayed on the multifunction keys will, in this test, virtually be identical to the 737 FMC dedicated keyboard. Only selected functions will be available at any one time, however. The keyboard configuration shown in Figure B-2 is the top level configuration. It comprises the flight phase and function keys, and the step back key. Selection of any key will cause the keyboard to reconfigure.

Three of the four dedicated keys immediately below the display area will be used during this test. They are the CLEAR, NEXT PAGE, and PREV PAGE keys. The CLEAR key affects only contents of the scratch pad line and operates the same as on the dedicated keyboard. A brief press of the CLEAR clears the last-entered character and moves the data entry marker back one space. A longer press of the CLEAR key clears the entire scratch pad. NEXT PAGE advances one page as described for the dedicated keyboard. PREV PAGE goes back one page, as described for the dedicated keyboard.

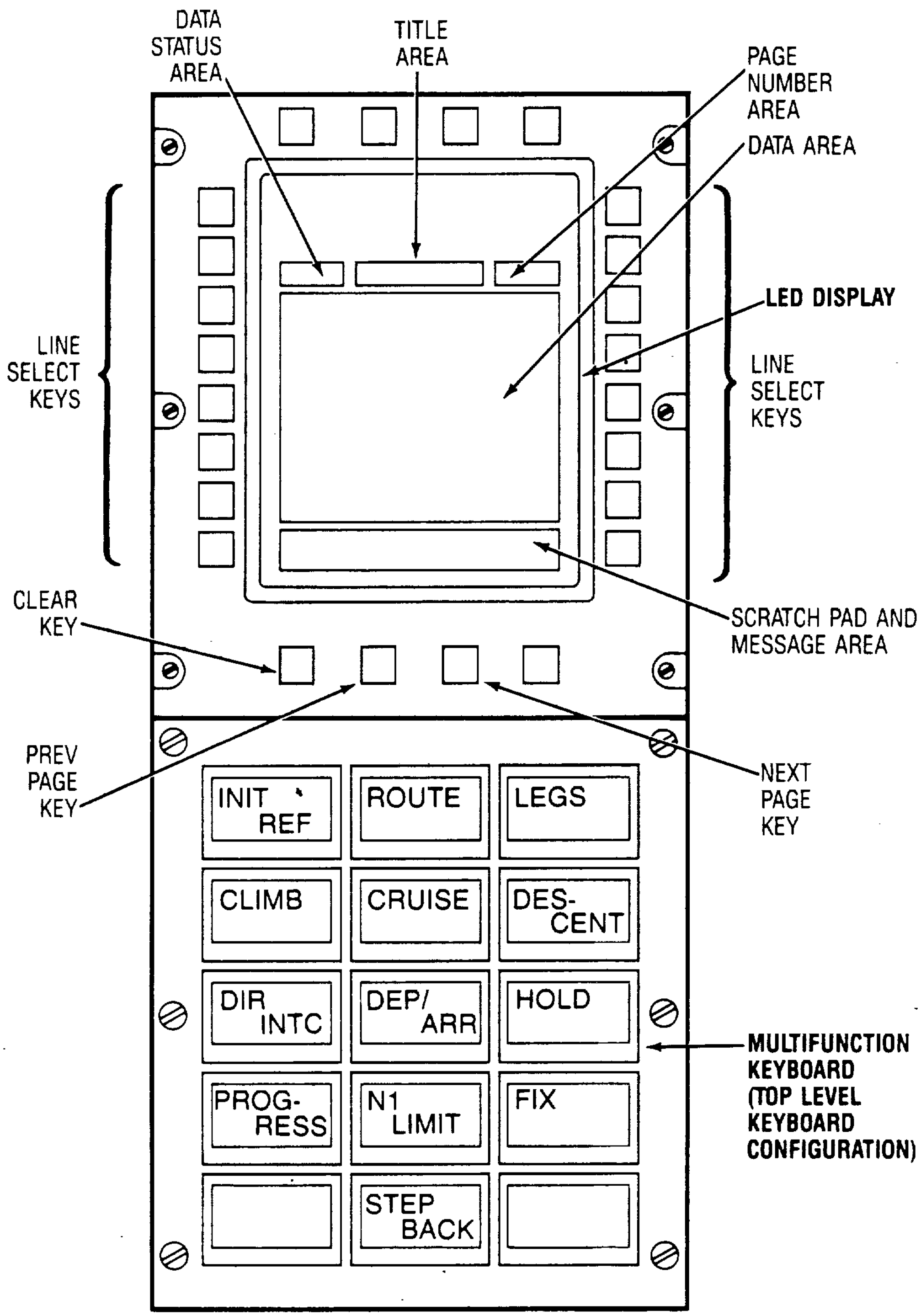

Figure B-2. Multifunction Keyboard CDU (Top Level Keyboard Configuration)

The multifunction keys are software controlled to reformat (change legend and function) in accordance with previous operation(s). These keys may reformat when any of the multifunction keys are operated, or when line select keys are operated. The key legends and associated functions described are below.

a) The numeric keys enter the selected number, decimal (.), or sign (+/-) into the position in the scratch pad indicated by the data entry marker.

b) The alphabetic keys require two operations for alpha entry. The first alphabetic keyboard has three letters per key, similar to the telephone keyboard arrangement (ABC, DEF, etc.). Selection of a letter set will result in a reformat of the keys in that row to display the three letters (i.e., A, B, and C, on individual keys). The individual alpha keys enter the selected letter into the position in the scratch pad indicated by the data entry marker.

c) The TOP LEVEL key returns the keyboard to the highest logic level. Any provisional entered data will be deleted when this key is selected unless it is recalled by using the STEP BACK key on the next key stroke.

d) The STEP BACK key negates the previous key operation.

e) The EXECUTE key is the "command" key and operates like the EXECUTE key on the dedicated keyboard. When provisional data is ready for entry, the EXECUTE key will become available to send the data to the flight management computer.

f) Actuation of a flight phase and function key causes display of the first (or only) page in that mode. Flight phase and function keys are identical to those for the dedicated keyboard CDU.

g) The index key returns the keyboard to the highest level configuration for a particular mode (i.e., one level down from the top level configuration).

Most of the FMCDU modes allow data entry. Entries are performed in the same manner as for the dedicated keyboard CDU, using the scratch pad area and line select keys. Alpha or numeric entries are made by selecting the appropriate alpha and numeric keys. After the new line is in the scratch pad, it is entered in the data line by a press of the line select key. The data must be a valid entry with the correct format before entry will occur.

Hands-on training prior to testing will be given on the dedicated keyboard and the multifunction keyboard CDUs described above. This will allow you to see how the CDUs actually operate.

3.0 LABORATORY SETUP, DATA COLLECTION, AND TEST SCENARIOS

3.1 Laboratory Setup

The FMC CDU test will be conducted in the Renton Simulation Center with the research cab as the test vehicle. The research cab does not represent a specific aircraft configuration, but will be running software to simulate the 737-300. The aircraft model is being used solely to provide a flight task and should not be evaluated with respect to actual flight characteristics.

The test setup will accommodate both the multifunction keyboard CDU and the dedicated keyboard CDU. You will use both configurations during the course of the test. Flying tasks will be performed concurrently with the operation of one of the CDUs. This will allow for a realistic comparison of the two CDUs.

3.2 Data Collection

Data collected during the session will include flight performance data, eye view monitor data, and subjective data. Flight performance data includes several parameters automatically recorded during the flying tasks. These will be specifically related to flying the airplane (e.g., altitude deviations).

A second method of collecting data involves the eye view monitor. The eye view monitor is a device that collects real time data on where you are looking. It consists of a tracking mirror mounted on the instrument panel, a head tracking module, and a camera unit that feeds information into the computer. The head tracking module consists of a headband with a light weight unit attached. You will be asked to wear this during the test. The eye view monitor is a noninterference unit; care has been taken to assure that its use will be comfortable and will not distract you from performance of the tasks.

The third data collection device is pilot questionnaires. A brief questionnaire will be filled out after each CDU is used. A program questionnaire will be the final step in the testing process. You will be asked to provide your comments and impressions about the two keyboard configurations via the questionnaires.

3.3 Test Scenarios

Six scenarios will be performed on each CDU. Two scenarios, Flight Plan Route Entry and Performance Initialization, will be performed preflight. Modify Route and Enter Altitude Restriction will be performed during cruise. During the approach phase, Set Up Approach and Time/Distance to Crossing Radial will be performed. Appendix C lists the six scenarios, and presents the general steps in each scenario. The exact sequence of key presses will differ between the dedicated keyboard CDU and the multifunction keyboard CDU. You do not need to memorize the specific entries in each scenario; an instructor pilot will be present during the testing to give you the necessary information.

4.0 TEST PROCEDURE

A typical test session will be conducted as described below.

Upon arrival at the test location, time will be taken to explain the test setup and data collection process. You will be given an introduction to the simulator and have an opportunity to become familiar with flying the airplane. You will be positioned at the eye reference point in the simulator. The eye view monitor will be calibrated at this time, which will allow eye tracking data to be recorded during the subsequent testing.

A period of familiarization with the first CDU (either the dedicated keyboard or the multifunction keyboard) will be conducted. This time can be used to practice using the CDU. Any questions you have about the CDU or about how the test will be run can be answered at this time. An instructor pilot will show each scenario. You can run through the scenarios until you are able to complete them with no errors. The instructor pilot will be present during training and during the test to tell you each specific entry (e.g., enter KYKM for destination). After you practice operating the CDU while performing the flying tasks, the next step will be a test of the first CDU. This will consist of performing the six scenarios listed in Appendix C; two operations during three flight phases.

The scenarios will be presented in random order, and you will be informed of which flight phase you are in prior to each test trial. Each operation will last several minutes. At the beginning of each operation, the simulation will be started. A period of time will be given to allow stable flying (except for those two scenarios performed during preflight). When you are comfortable with flying, the CDU operation will be performed. At the end of the CDU operation the simulation will be stopped. Data will be collected automatically on the flight parameters and with the eye view monitor.

A brief questionnaire on the first CDU will be given to you when all six scenarios are completed. This questionnaire will cover features of the first CDU to elicit a subjective evaluation of the CDU operation. Any observations, suggestions, and comments that you might have will be appreciated.

After a short break to change CDU configuration, a familiarization period will be conducted with the second CDU. A test on the second CDU will be run next, and will consist of the same six scenarios as the first CDU. A brief questionnaire on the second CDU will be given to you, followed by a program questionnaire. The program questionnaire is longer than the others, and contains comparative questions about the dedicated keyboard and multifunction keyboard CDUs.

The entire session is expected to last approximately four hours.

APPENDIX C

TRAINING AND TEST SCENARIOS

TEST SCENARIO 1: ENTER FLIGHT PLAN

Flight Phase—Preflight

Go to ROUTE page .

Enter KBFI into "ORIGIN"

Enter KMWH into "DEST"

Enter RW13R into "RUNWAY"

Enter ELN for first waypoint

Enter EPH for second waypoint

Activate

Execute

Go to KBFI DEPARTURE page

Select LACRE3 for "SID"

Select VAMPS for "TRANS"

Execute

Go to LEGS page

Line Select ELN into "THEN"

Execute

Verbal instructions to pilot:

Positioned on Runway 13R at Boeing Field prior to flight plan entry.

TEST SCENARIO 2: PERFORMANCE INITIALIZATION

Flight Phase—Preflight

Go to INIT REF page

Select INDEX

Go to PERF INIT page

Enter 110 into "Gross wt."

Enter 5 into "Reserves"

Enter 35 into "COST INDEX'

Enter 18000 into "TRP/CRZ ALT"

Execute

Enter 270/55 into "CRZ WIND"

Enter -5 INTO "ISA DEV"

Execute

Verify transition altitude

Verbal instructions to pilot:

Position is on Runway 13R at Boeing Field prior to performance initialization.

TEST SCENARIO 3: MODIFY ROUTE

Flight Phase—Climb

Go to ROUTE page

Enter KYKM into "Dest"

Execute

Go to LEGS page

Enter HUMPP for first waypoint

Enter RADDY for second waypoint

Execute

Go to KYKM ARRIVAL page

Select ILS 27 for "Approaches"

Select SUNED for "Trans"

Execute

Verbal instructions to pilot:

Position is 4 miles from VAMPS, 7000 ft. and climbing at 250 knots. Route modification consisting of new destination. Climb out at 250 knots using CWS; maintain constant airspeed and heading.

TEST SCENARIO 4: ENTER ALTITUDE RESTRICTION

Flight Phase—Climb

Go to LEGS page

Enter 7000B into VAMPS waypoint

Enter 210/ into LACRE

Execute

Verbal instructions to pilot:

Position is 400 ft. and climbing just after liftoff from KBFI. Speed is 200 knots. Speed and altitude restrictions received. Climb out at 200 knots and flaps 1 using CWS. Maintain constant speed and heading.

TEST SCENARIO 5: SETUP APPROACH

Flight Phase—Top of Descent

Go to KMWH ARRIVAL page

Select ILS 32R for "APPROACH"

Select MOSES1 for "STAR"

Execute

Go to LEGS page

Line select CF32R into "THEN"

Execute

Verbal instructions to pilot:

Position is approximately 10 miles prior to top of descent in moderate turbulence. Speed 320 knots, altitude 18,000 ft. Approach clearance received. Maintain heading and 18,000 ft. altitude.

TEST SCENARIO 6: TIME/DISTANCE TO CROSSING RADIAL

Flight Phase—Top of Descent

Go to FIX page

Enter MWH into "Fix"

Enter 120/ into "DNTKFX"

Bring second line of information into scratchpad

Go to LEGS page

Enter scratchpad into "THEN"

Line Select CF32R into "THEN"

Execute

Verbal instructions to pilot:

Position is approximately 10 miles prior to top of descent in moderate turbulence. 320 knots, altitude 18,000 ft. Time and distance to the crossing of the MWH 120 radial requested. Maintain heading and level flight.

TRAINING SCENARIO 7: ENTER FLIGHT PLAN

Flight Phase—Preflight

Go to ROUTE page.

Enter KSEA into "ORIGIN"

Enter KPDX into "DEST"

Enter RW16R into "RUNWAY"

Enter PUW for first waypoint

Enter ALW for second waypoint

Activate

Execute

Go to KSEA DEPARTURE page

Select MOUNT1 for "SID"

Select GEG for "TRANS"

Execute

Go to LEGS page

Select PUW into "THEN"

Execute

TRAINING SCENARIO 8: PERFORMANCE INITIALIZATION

Flight Phase—Preflight

Go to INIT REF key

Select INDEX

Go to PERF INIT page

Enter 130 into "Gross wt."

Enter 3 into "Reserves"

Enter 40 into "COST INDEX'

Enter 25000 into "TRP/CRZ ALT"

Execute

Enter 185/30 into "CRZ WIND"

Enter 7 INTO "ISA DEV"

Execute

Verify transition altitude

TRAINING SCENARIO 9: MODIFY ROUTE

Flight Phase—Climb

Go to ROUTE page

Enter KBOI into "Dest"

Execute

Go to LEGS page

Enter LWS for first waypoint

Enter MYL for second waypoint

Execute

Go to KBOI ARRIVAL page

Select ILS 10R for "Approaches"

Select PARMO for "Trans"

Execute

TRAINING SCENARIO 10: ENTER ALTITUDE RESTRICTION

Flight Phase—Climb

Go to LEGS page

Enter 18000B into ELN waypoint

Enter 290/ into ELN

Execute

TRAINING SCENARIO 11: SET UP APPROACH

Flight Phase—Top of Descent

Go to KPDX ARRIVAL page

Select ILS 10R for "APPROACH"

Select DLS1 for "STAR"

Execute

Go to LEGS page

Line select SAUVI into "THEN"

Execute

TRAINING SCENARIO 12: TIME/DISTANCE TO CROSSING RADIAL

Flight Phase—Top of Descent

Go to FIX page

Enter PDT into "Fix"

Enter 350/ into "DNTKFX"

Bring second line of information into scratch pad

Go to LEGS page

Enter scratchpad into "Then"

Execute

APPENDIX D

TLA OUTPUT

SHIFTED

MISSION TIMELINE
MISSION - FROM SCEN.3A - ILS
WITH 15-KEY CDU
CONFIGURATION - NASA 515 -AFD
FLIGHT PHASE - CRUISE - AREA NAV
COMPARE CDU'S (EXP)
15-KEY MULTI-FUNC
CREWMEMBER - CO-PILOT

MAR 5, 1986

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
19X001		
8AX 1	MON. EXT. VIS.	47.00
130010	SET UP NEW 4-D FLIGHT PLAN	
02X030	SELECT ATC CLEARANCE PAGE	
2LX 109	PRESS TOP LEVEL KEY (X)	1.68
2LX 81	PRESS FLT PLAN KEY (X)	1.77
2LX 111	PRESS ATC CLEARANCE KEY (X)	1.77
2L 08	MON ATC CLR MODE DATA	2.34
13X018	DESTINATION NAME -	
2LX 160	LINE SELECT ORIGIN (X)	1.83
2LX 161	LINE SELECT DESTINATION (X)	1.83
2L 08	MON ATC CLR MODE DATA	2.34
13X034	ATC CLR PAGE - ROUTE INPUT	
2LX 162	LINE SELECT V/A (X)	1.83
2LX 163	PRESS RNAV KEY (X)	1.77
2LX 175	LINE SELECT J-815R TO SP	1.83
2LX 164	LINE SELECT J-815R (X)	1.83
2L 08	MON ATC CLR MODE DATA	2.34
13X035	ATC CLR PAGE - TO INPUT	
2LX 176	LINE SELECT SH1 01 TO SP	1.83
2LX 165	LINE SELECT TO (X)	1.83

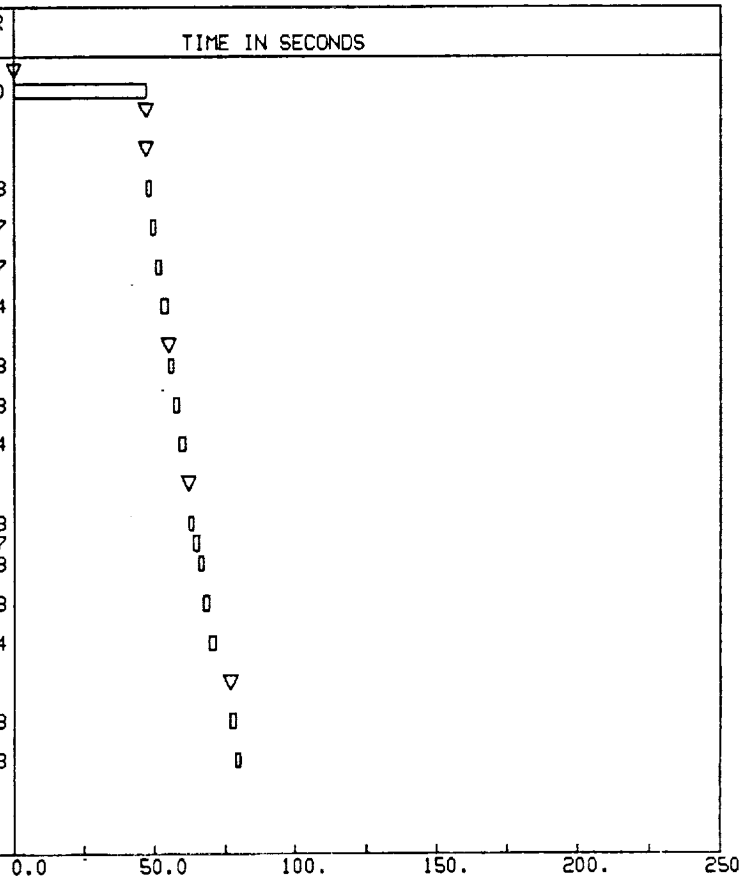

Figure D-1. Mission Timeline—Multifunction Keyboard, Cruise

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
2LX 120	PRESS GRP KEY (X)	1.77
2LX 166	LINE SELECT MACEY (X)	1.83
2L 08	MON ATC CLR MODE DATA	2.34
13X032	ARRIVALS PAGE - STAR INPUT	
2LX 104	PRESS ARRIVAL KEY (X)	1.52
2LX 167	LINE SELECT MACEY2 (X)	1.83
13X033	LEGS 1 PAGE - PTA INPUT	
2LX 99	PRESS LEGS 1 KEY (X)	1.52
2LX 168	LINE SELECT LAKESIDE PTA (X)	1.83
2LX 26	PRESS NO. 1 KEY (X)	1.18
2LX 35	PRESS NO. 0 KEY (X)	0.83
2LX 27	PRESS NO. 2 KEY (X)	0.83
2LX 26	PRESS NO. 1 KEY (X)	0.83
2LX 168	LINE SELECT LAKESIDE PTA (X)	1.83
02X043	REVIEW PROVISIONAL FLT PLAN DATA	
2L 09	MON FLT PLN 1 MODE DATA	2.08
2K 17	MON MAP VIDEO	2.27
2LX 169	LINE SELECT STEP KEY (X)	1.83
02X043	REVIEW PROVISIONAL FLT PLAN DATA	
2L 09	MON FLT PLN 1 MODE DATA	2.08
2K 17	MON MAP VIDEO	2.27
2LX 169	LINE SELECT STEP KEY (X)	1.83
02X043	REVIEW PROVISIONAL FLT PLAN DATA	
2L 09	MON FLT PLN 1 MODE DATA	2.08
2K 17	MON MAP VIDEO	2.27
2LX 169	LINE SELECT STEP KEY (X)	1.83
020044	ACCEPT PROVISIONAL FLIGHT PLAN	

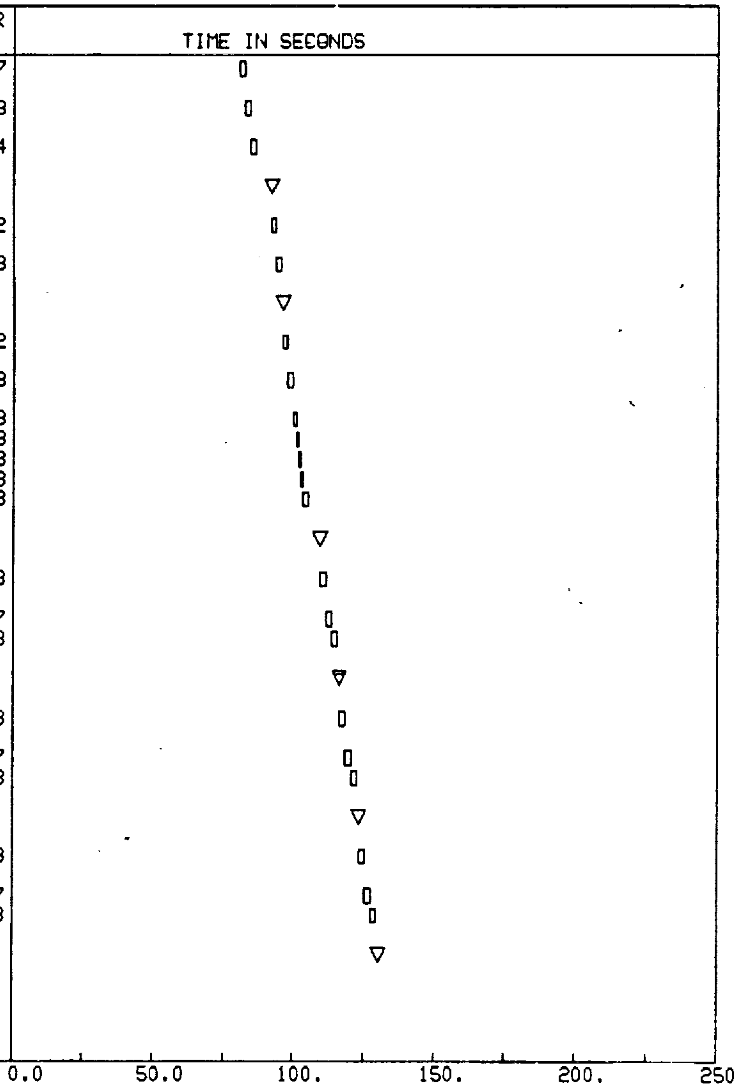

Figure D-1. Mission Timeline—Multifunction Keyboard, Cruise (Continued)

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)	TIME IN SECONDS
2L 21	PRESS EXEC KEY	1.52	
2L 09	MON FLT PLN 1 MODE DATA	2:08	
2K 17	MON MAP VIDEO	2.27	
1P020007	CALL OUT-[FLIGHT PLAN ENTERED AND CHECKED]	2.00	
02X044	FL INPUT - 320		
2LX 109	PRESS TOP LEVEL KEY (X)	1.68	
2LX 80	PRESS PERF DATA KEY (X)	1.77	
2LX 94	PRESS DESCEND KEY (X)	1.77	
2L 09	MON FLT PLN 1 MODE DATA	2.34	
2LX 170	LINE SELECT TARGET ALT KEY (X)	1.83	
2LX 140	PRESS FL KEY (X)	1.77	
2LX 28	PRESS NO. 3 KEY (X)	0.83	
2LX 27	PRESS NO. 2 KEY (X)	0.83	
2LX 35	PRESS NO. 0 KEY (X)	0.83	
02X045	GS INPUT - 250		
2LX 170	LINE SELECT TARGET ALT KEY (X)	1.83	
2L 09	MON FLT PLN 1 MODE DATA	2.34	
2LX 171	LINE SELECT CMD SPEED (X)	1.83	
2LX 27	PRESS NO. 2 KEY (X)	1.18	
2LX 30	PRESS NO. 5 KEY (X)	0.83	
2LX 35	PRESS NO. 0 KEY (X)	0.83	
2LX 171	LINE SELECT CMD SPEED (X)	1.83	

0.0 50.0 100. 150. 200. 250.

Figure D-1. Mission Timeline—Multifunction Keyboard, Cruise (Concluded)

SHIFTED

MISSION TIMELINE
MISSION - FROM SCEN.3A - ILS WITH 15-KEY CDU
CONFIGURATION - NASA 515 -AFD
FLIGHT PHASE - DESCENT - AFD COMPARE CDU'S (EXP) 15-KEY MULTI-FUNC
CREWMEMBER - CO-PILOT

MAR 5, 1986

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)	TIME IN SECONDS
150023	RECEIVE INSTRUCTIONS TO CHANGE LAKESIDE PTA TO 10 22 15		
1R 35	MON VHF-2 COMM AUDIO	8.00	
1P150009	MON RADIO COMM - [NASA 515, DUE TO TRAFFIC YOUR PLANNED TIME OF ARRIVAL AT	4.00	
1P150010	LAKESIDE IS NOW 10 22 15 , OVER]	4.00	
1R 39	COMM VIA VHF-2	4.50	
1P150011	RADIO COMM - [515, ROGER, TIME OF ARRIVAL NOW 10 22 15]	4.50	
1R 30	ACT PUSH-TO-TALK SW ON CONTROL HANDGRIP	4.50	
15X024	REVISE FLIGHT PLAN TO CHANGE LAKESIDE PTA		
2LX 109	PRESS TOP LEVEL KEY (X)	1.68	
2LX 81	PRESS FLT PLAN KEY (X)	1.77	
2L 09	MON FLT PLN 1 MODE DATA	2.34	
2LX 168	LINE SELECT LAKESIDE PTA (X)	1.83	
2LX 26	PRESS NO. 1 KEY (X)	1.18	
2LX 35	PRESS NO. 0 KEY (X)	0.83	
2LX 27	PRESS NO. 2 KEY (X)	0.83	
2LX 27	PRESS NO. 2 KEY (X)	0.83	
2LX 26	PRESS NO. 1 KEY (X)	0.83	
2LX 30	PRESS NO. 5 KEY (X)	0.83	
2LX 168	LINE SELECT LAKESIDE PTA (X)	1.83	
2L 09	MON FLT PLN 1 MODE DATA	2.34	

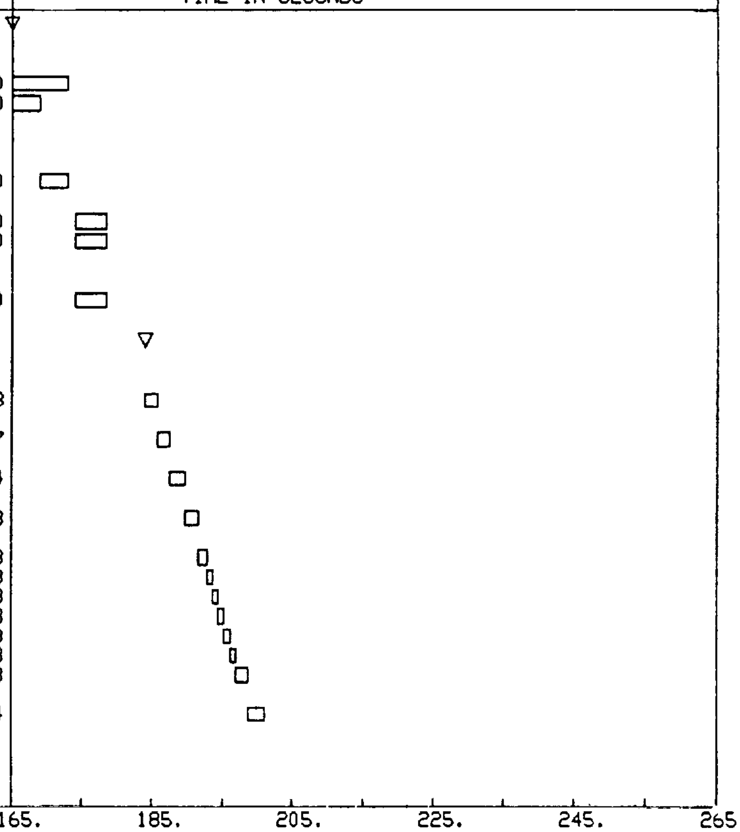

Figure D-2. Mission Timeline—Multifunction Keyboard, Descent

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
00EV09	C/P EXT VIS SCAN	
8A 12	PILOT EXTERNAL VISION SCAN	45.00
2LX 108	PRESS EXECUTE KEY (X)	1.52
1P150014	CALL OUT -[FLIGHT PLAN UPDATED WITH NEW PTA AT LAKESIDE]	3.00
150027	HANDOFF TO ATLANTA APPROACH CONTROL -126.9	
1P140039	MON RADIO COMM - [NASA 515, CONTACT APPROACH CONTROL ON ONE TWO SIX POINT	4.00
1R 16	MON VHF-2 COMM AUDIO	5.00
1P140040	NINER, OVER]	1.00
150026	REACH 220 KIAS	
1P140041	RADIO COMM -[NASA 515, ROGER, APPROACH ON ONE TWO SIX POINT NINER]	4.00
1R 24	ACT PUSH-TO-TALK SW ON CONTROL HANDGRIP	4.00
1R 40	COMM VIA VHF-2	4.00

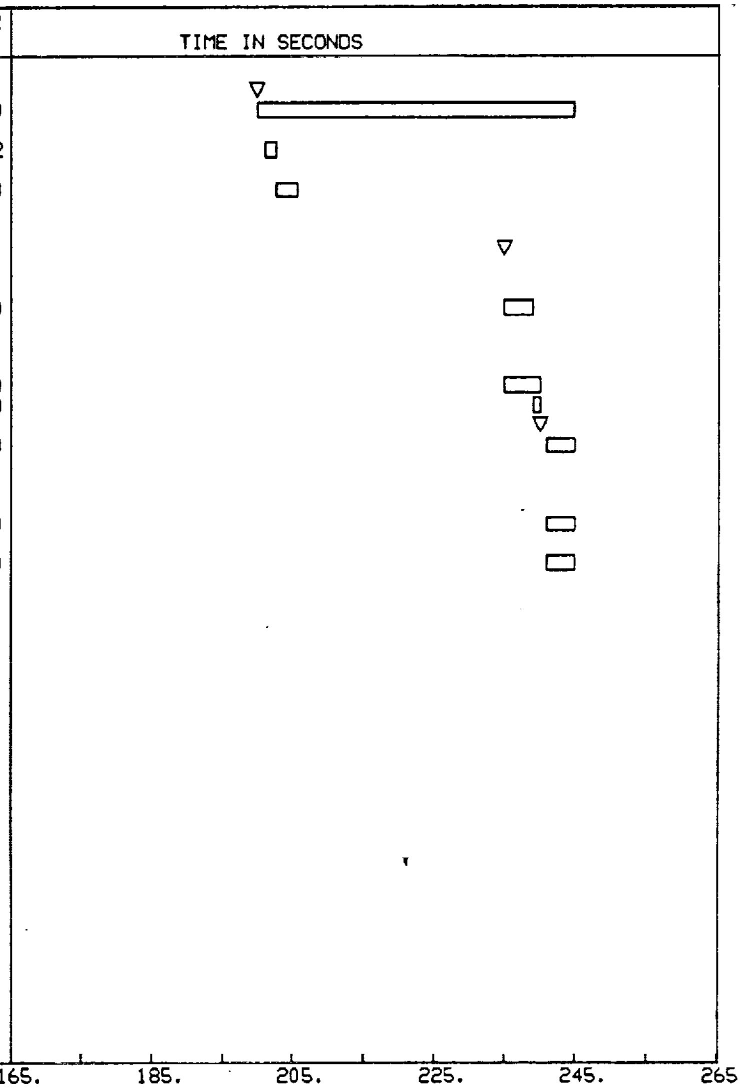

Figure D-2. Mission Timeline—Multifunction Keyboard, Descent (Concluded)

UNSHIFTED

MISSION TIMELINE
MISSION - FROM SCEN.3A - ILS
DEDICATED KEYBD. CDU
CONFIGURATION - NASA 515 -AFD
FLIGHT PHASE - CRUISE - AREA NAV
COMPARE CDU'S
DEDICATED KEYBOARD
CREWMEMBER - CO-PILOT

MAR 5, 1986

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
19X001	MONITORING	
8AX 1	MON. EXT. VIS.	47.00
130010	SET UP NEW 4-D FLIGHT PLAN	
020048	SELECT RTE PG	
2L 165	PRESS ROUTE KEY	1.48
2L 08	MON CDU DISPLAY	2.08
130030	SELECT ORIG TO DEST	
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
2L 08	MON CDU DISPLAY	2.08
2L 21	PRESS EXEC KEY	1.42
2L 08	MON CDU DISPLAY	2.08
19X002	MONITORING	
8AX 2	MON EXT VIS	8.00
130031	RTE STRUCTURE DESTINATION	
2L 161	PRESS DIR/INIT KEY	2.03
2L 44	PRESS H/RTE KEY	1.35
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
2L 44	PRESS H/RTE KEY	1.48
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
130032	ENTER FLT. LEVEL 320	
2L 28	PRESS NO.3 KEY	1.35
2L 27	PRESS NO.2 KEY	1.35
2L 35	PRESS NO.0 KEY	1.35
2L 175	LINE SEL - KEY	2.08
020051	XEQ CHG	
2L 08	MON CDU DISPLAY	2.08
2L 21	PRESS EXEC KEY	1.42
2L 08	MON CDU DISPLAY	2.08
19X002	MONITORING	
8AX 2	MON EXT VIS	8.00

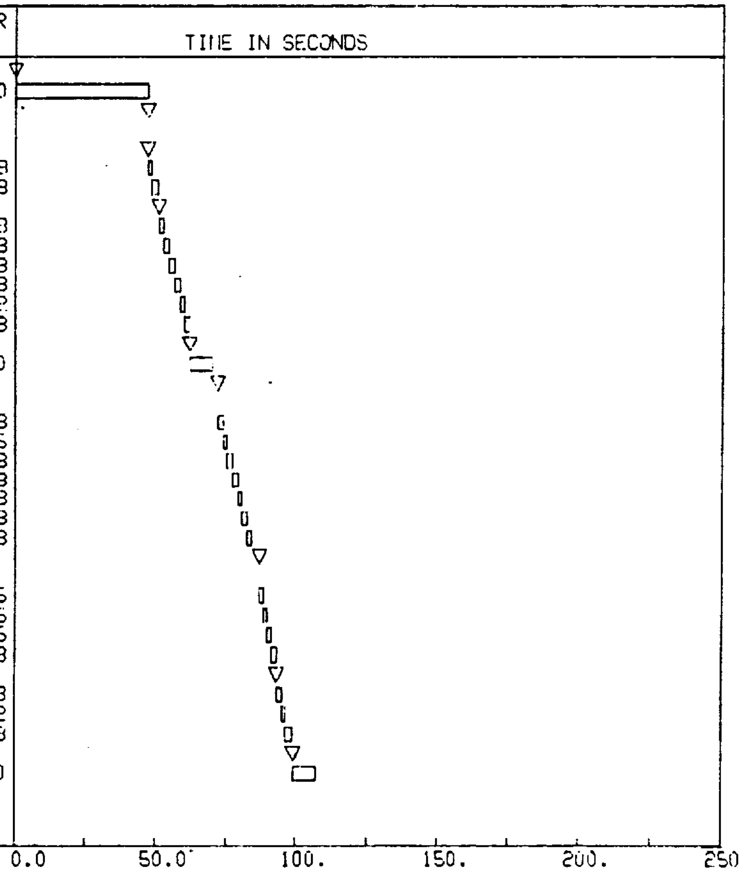

Figure D-3. Mission Timeline—Dedicated Keyboard, Cruise

C-2

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
020052	ESTABLISH ARRIVAL INFO	
2L 52	PRESS P/STAR KEY	1.35
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
130033	ENTER SPD.	
2L 27	PRESS NO.2 KEY	1.35
2L 30	PRESS NO.5 KEY	1.35
2L 35	PRESS NO.0 KEY	1.35
2L 175	LINE SEL - KEY	2.08
020051	XEQ CHG	
2L 08	MON CDU DISPLAY	2.08
2L 21	PRESS EXEC KEY	1.42
2L 08	MON CDU DISPLAY	2.08
19X002	MONITORING	
8AX 2	MON EXT VIS	8.00
020053	ESTABLISH LAKESIDE LOM ARRIVAL CLEARANCE	
2L 169	PRESS DES KEY	2.03
2L 175	LINE SEL - KEY	1.83
2L 26	PRESS NO.1 KEY	1.35
2L 35	PRESS NO.0 KEY	1.35
1P010071	SION TO PUSHBACK. WE HAVE INFORMATION KILO. OVER]	3.00
2L 27	PRESS NO.2 KEY	1.35
2L 26	PRESS NO.1 KEY	1.35
1Q 16	MON VHF-1 COMM AUDIO	6.00
1P010072	MON RADIO COMM-[NASA 515. ATLANTA GROUND. ROGER. CLEAR TO PUSHBACK. ADVISE	4.50
2L 08	MON CDU DISPLAY	2.34
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
1P010075	WHEN READY TO TAXI. OVER.]	1.50
2L 175	LINE SEL - KEY	1.83
1P010064	RADIO COMM-[NASA 515. ROGER]	1.70
1Q 24	ACTUATE PUSH-TO-TALK SW ON CONTROL HAND-GRIP	1.70
1Q 15	COMM VIA VHF-1	1.70
2L 08	MON CDU DISPLAY	2.08
2L 175	LINE SEL - KEY	1.83

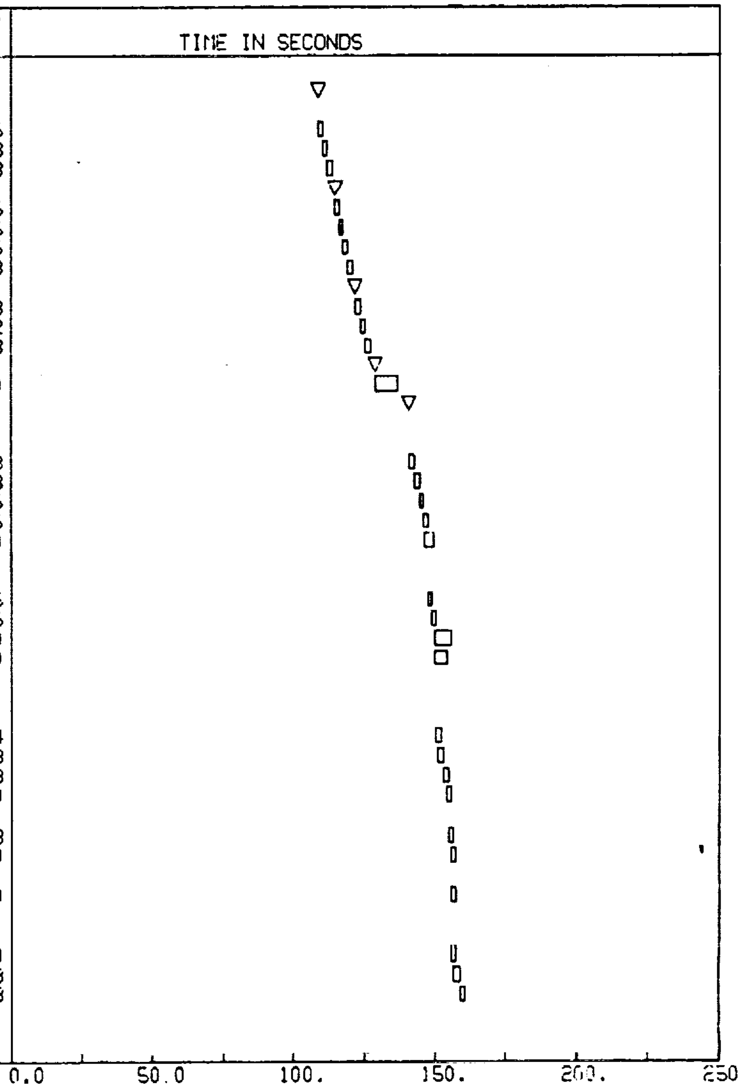

Figure D-3. Mission Timeline—Dedicated Keyboard, Cruise (Continued)

CODE		EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)	TIME IN SECONDS
2L	21	PRESS EXEC KEY	1.52	
2L	08	MON CDU DISPLAY	2.08	

0.0 50.0 100. 150. 200. 250.

Figure D-3. Mission Timeline—Dedicated Keyboard, Cruise (Concluded)

UNSHIFTED

MISSION TIMELINE
MISSION - FROM SCEN.3A - ILS
DEDICATED KEYBD. CDU
CONFIGURATION - NASA 515 -AFD
FLIGHT PHASE - DESCENT - AFD
COMPARE CDUS
DEDICATED KEYBD.
CREWMEMBER - CO-PILOT

MAR 5, 1986

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)
150023	RECEIVE INSTRUCTIONS TO CHANGE LAKESIDE PTA TO 10 22 15	
1R 35	MON VHF-2 COMM AUDIO	8.00
1P150009	MON RADIO COMM - [NASA 515, DUE TO TRAFFIC YOUR PLANNED TIME OF ARRIVAL AT	4.00
1P150010	LAKESIDE IS NOW 10 22 15 , OVER]	4.00
1R 39	COMM VIA VHF-2	4.50
1P150011	RADIO COMM - [515, ROGER, TIME OF ARRIVAL NOW 10 22 15]	4.50
1R 30	ACT PUSH-TO-TALK SW ON CONTROL HANDGRIP	4.50
150030	REVISE LOM PTA (LAKESIDE)	
2L 169	PRESS DES KEY	2.03
2L 175	LINE SEL - KEY	1.83
2L 26	PRESS NO.1 KEY	1.45
2L 35	PRESS NO.0 KEY	1.35
2L 27	PRESS NO.2 KEY	1.35
2L 27	PRESS NO.2 KEY	1.35
2L 26	PRESS NO.1 KEY	1.35
2L 30	PRESS NO.5 KEY	1.35
2L 175	LINE SEL - KEY	1.83
2L 175	LINE SEL - KEY	1.83
2L 09	MON FLT PLN 1 MODE DATA	2.34
2L 21	PRESS EXEC KEY	1.52
00EV09	C/P EXT VIS SCAN	
8A 12	PILOT EXTERNAL VISION SCAN	45.00
150027	HANDOFF TO ATLANTA APPROACH CONTROL -126.9	

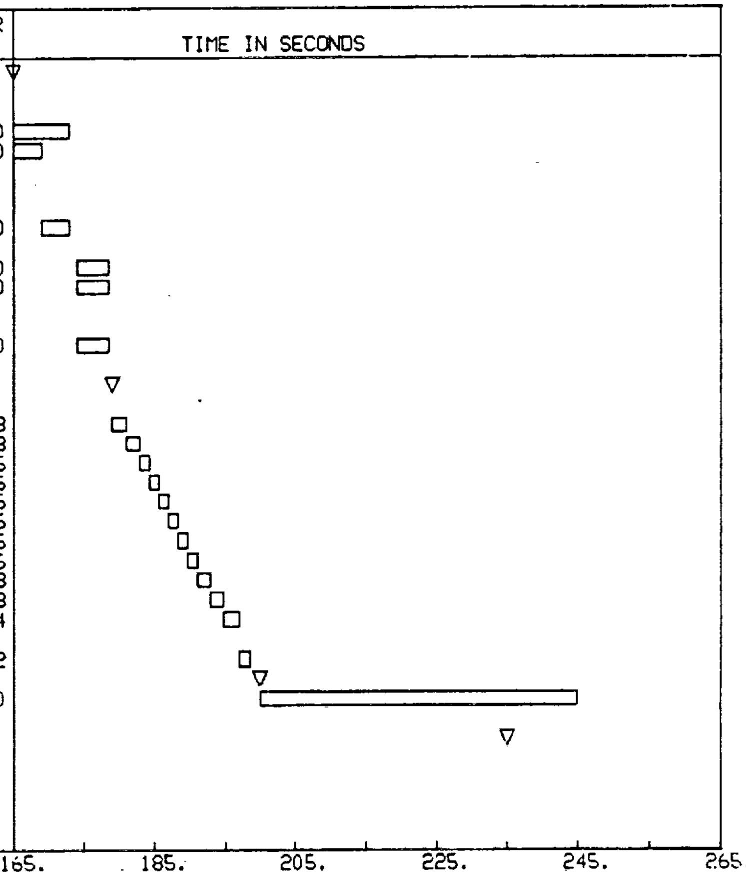

Figure D-4. Mission Timeline—Dedicated Keyboard, Descent

CODE	EVENT/PROCEDURE OR TASK DESCRIPTION	TASK DUR (SEC)	TIME IN SECONDS
1P140039	MON RADIO COMM - [NASA 515, CONTACT APPROACH CONTROL ON ONE TWO SIX POINT	4.00	
1R 16	MON VHF-2 COMM AUDIO	5.00	
1P140040	NINER, OVER]	1.00	
150026	REACH 220 KIAS		
1P140041	RADIO COMM - [NASA 515, ROGER, APPROACH ON ONE TWO SIX POINT NINER]	4.00	
1R 24	ACT PUSH-TO-TALK SW ON CONTROL HANDGRIP	4.00	
1R 40	COMM VIA VHF-2	4.00	

165. 185. 205. 225. 245. 265.

Figure D-4. Mission Timeline—Dedicated Keyboard, Descent (Concluded)

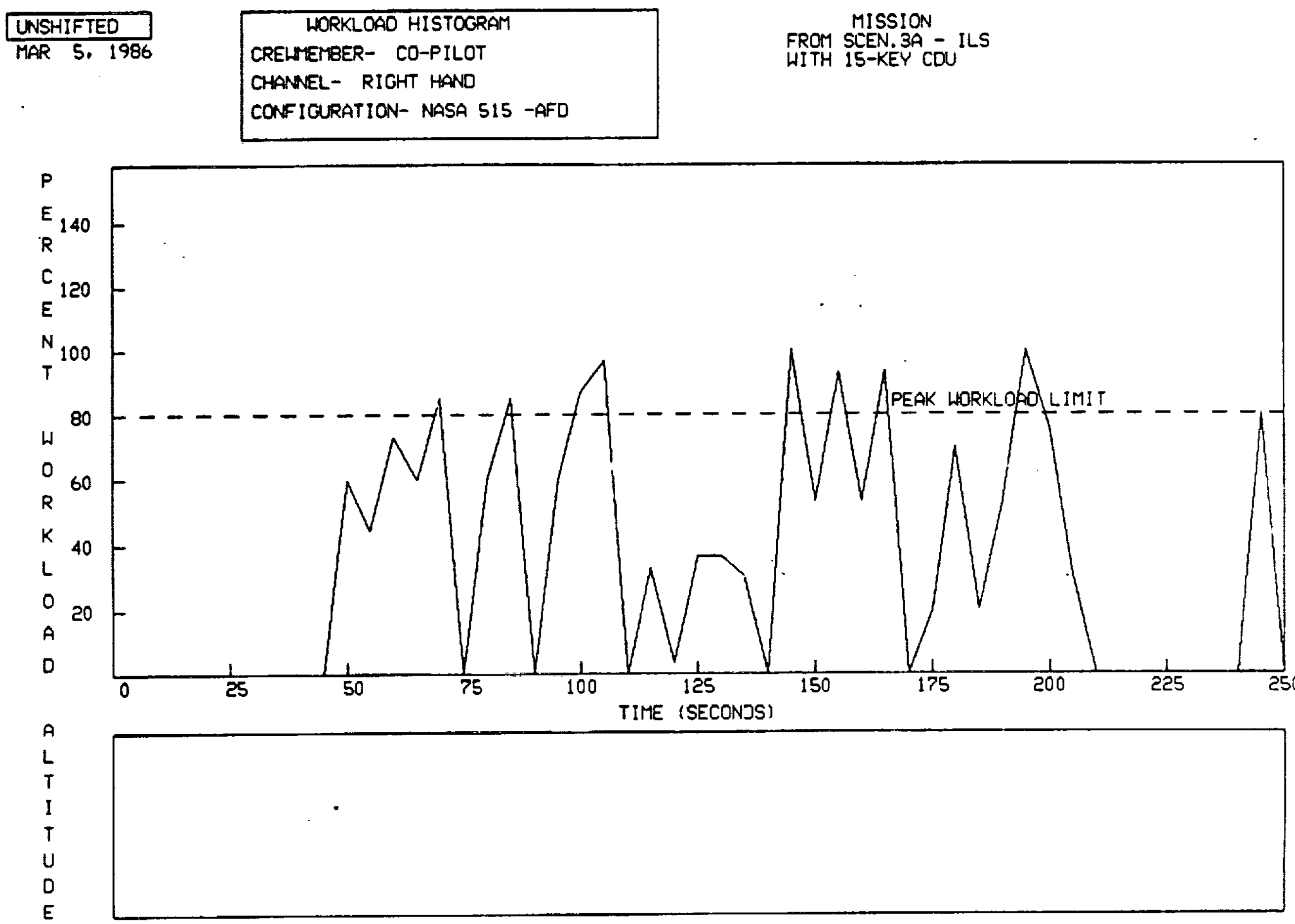

Figure D-5. Workload Histogram—Multifunction Keyboard, Right Hand

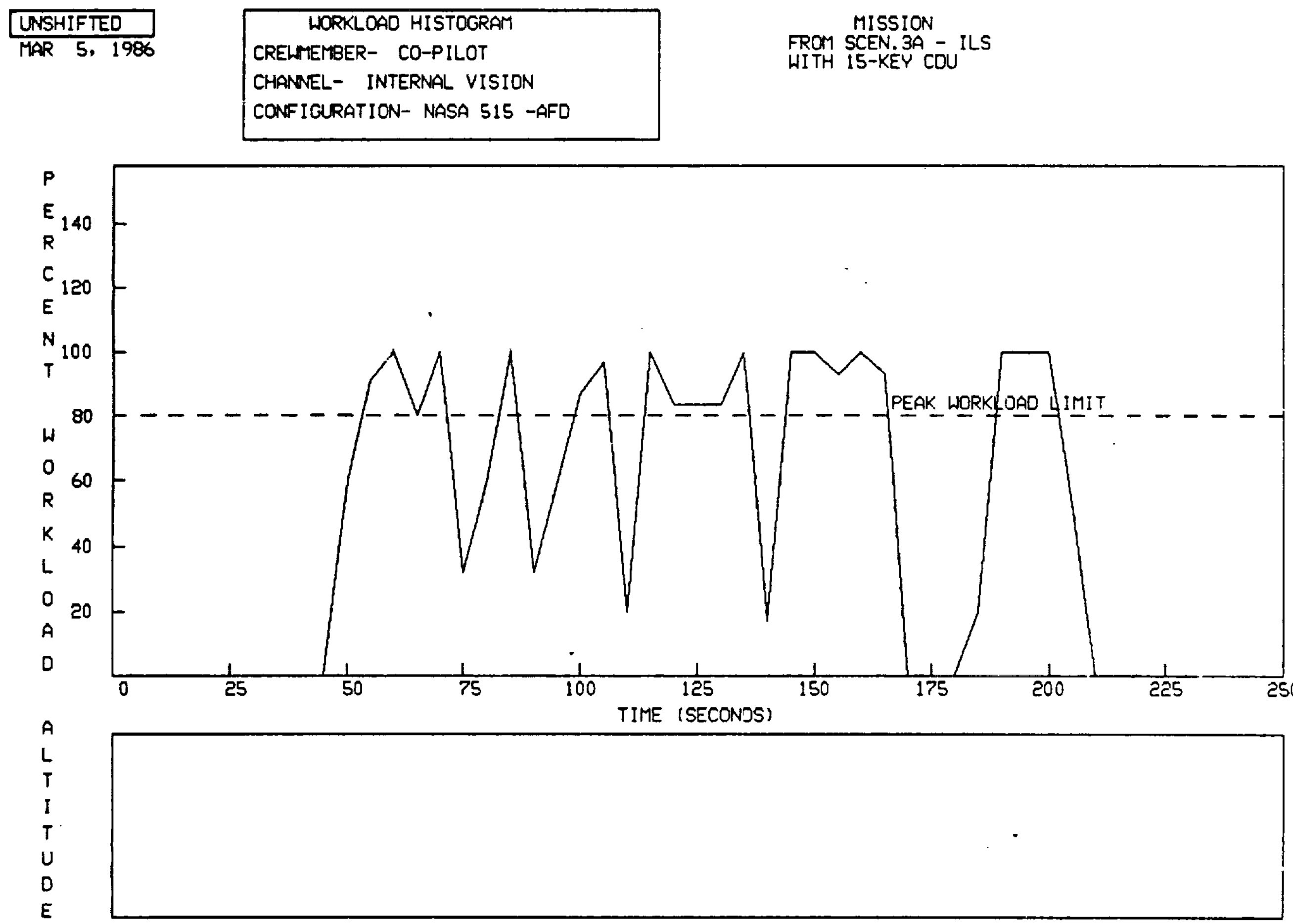

Figure D-6. Workload Histogram—Multifunction Keyboard, Internal Vision

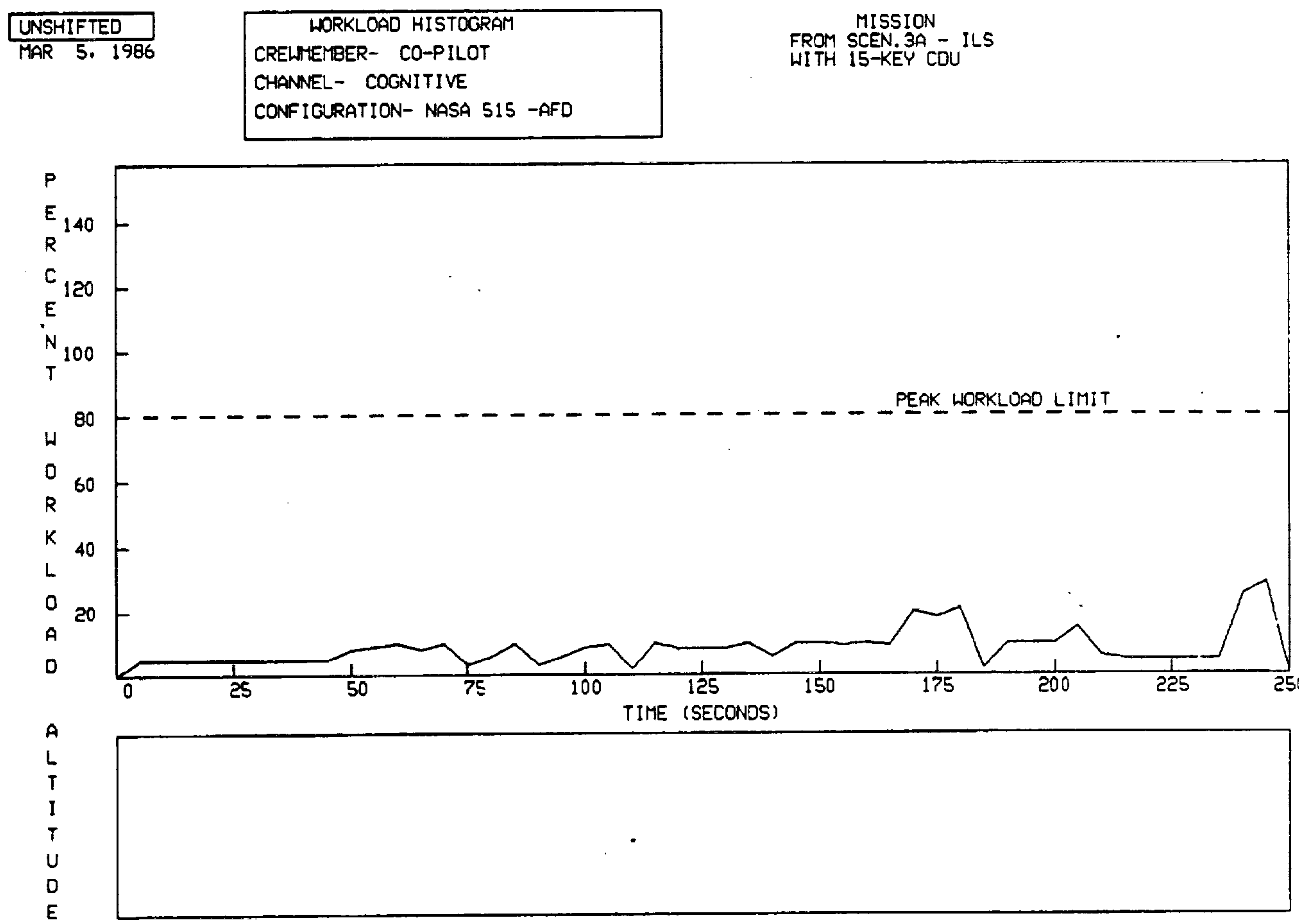

Figure D-7. Workload Histogram—Multifunction Keyboard, Cognitive

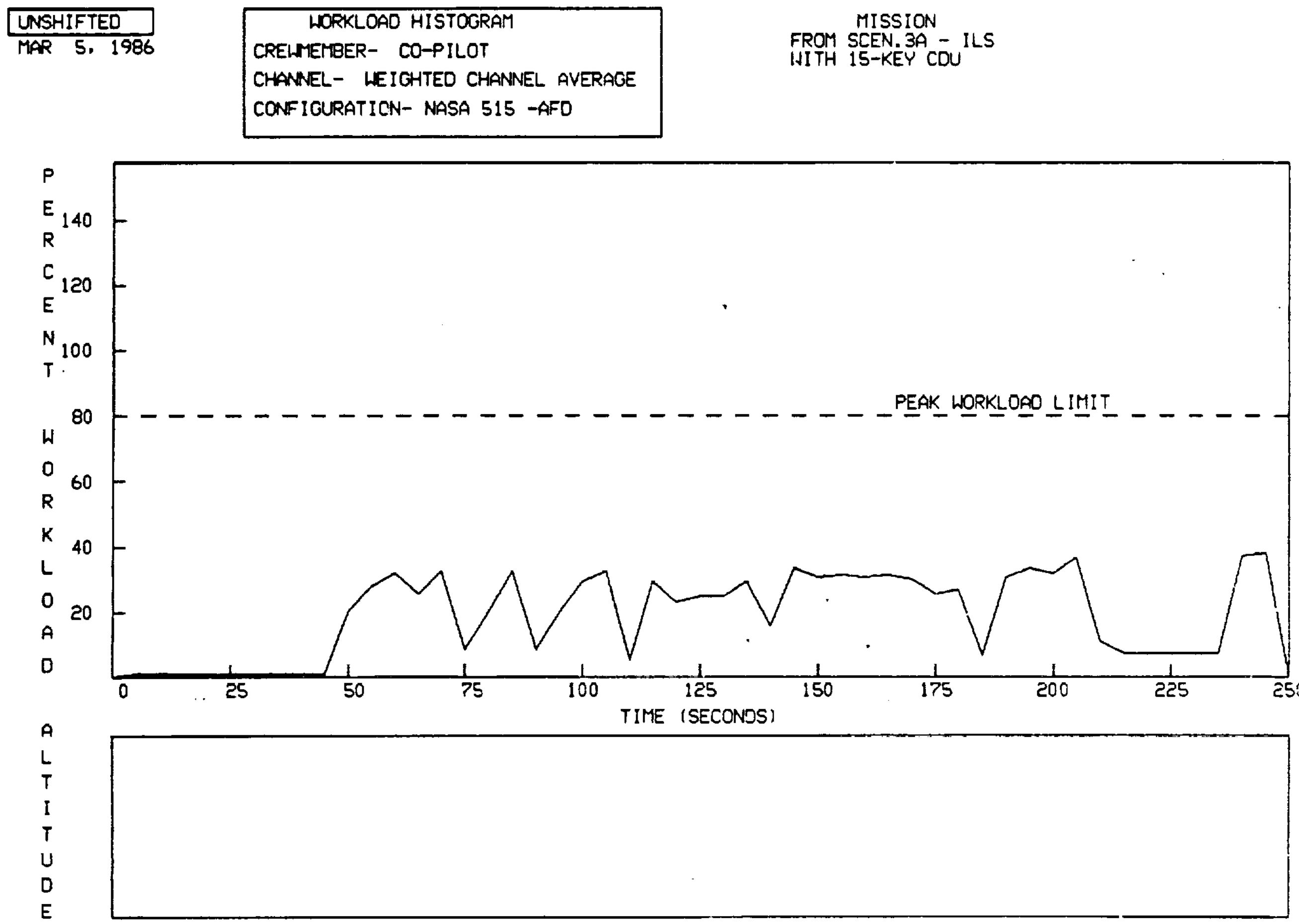

Figure D-8. Workload Histogram—Multifunction Keyboard, Weighted Channel Average

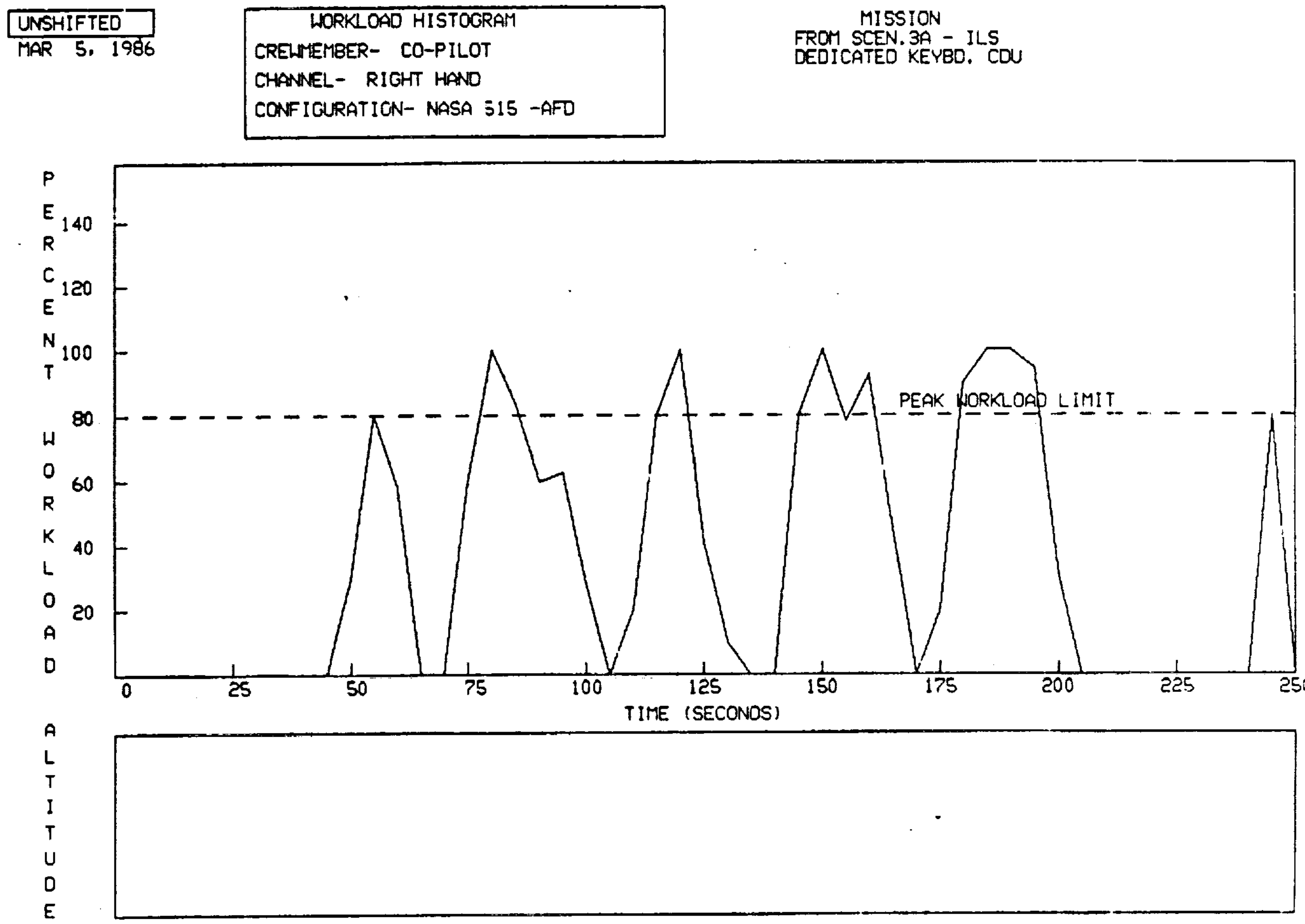

Figure D-9. Workload Histogram—Dedicated Keyboard, Right Hand

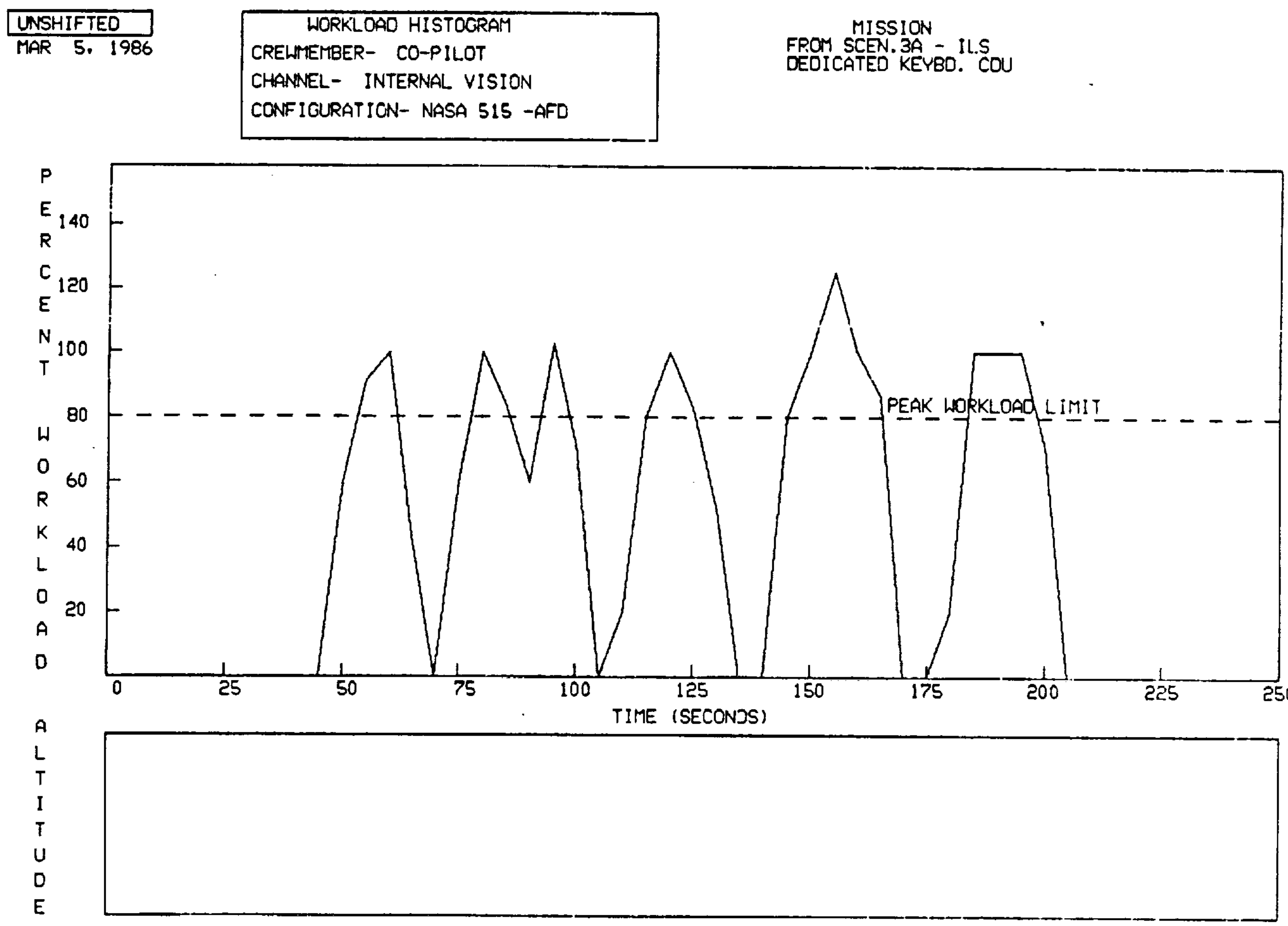

Figure D-10. Workload Histogram—Dedicated Keyboard, Internal Vision

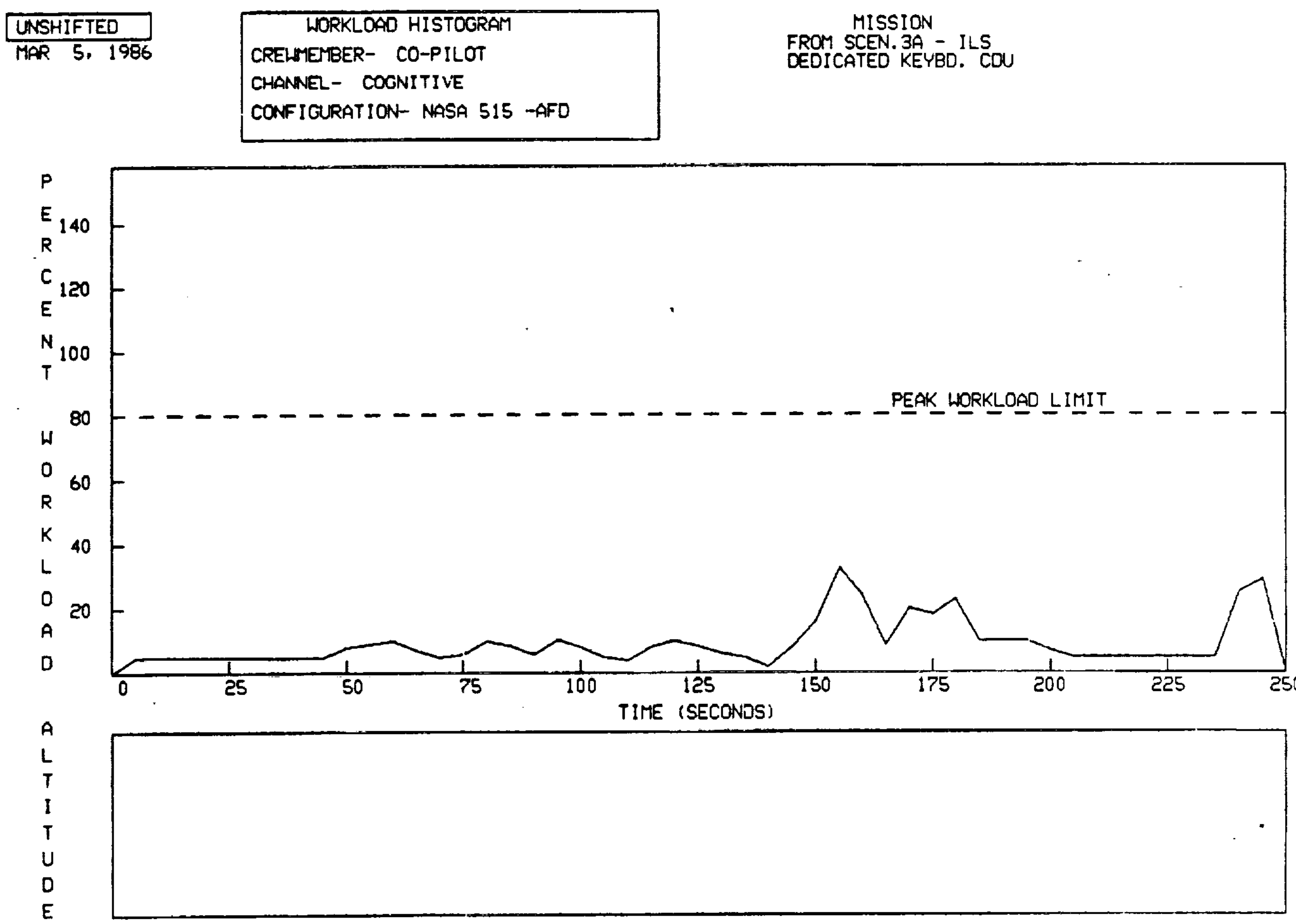

Figure D-11. Workload Histogram—Dedicated Keyboard, Cognitive

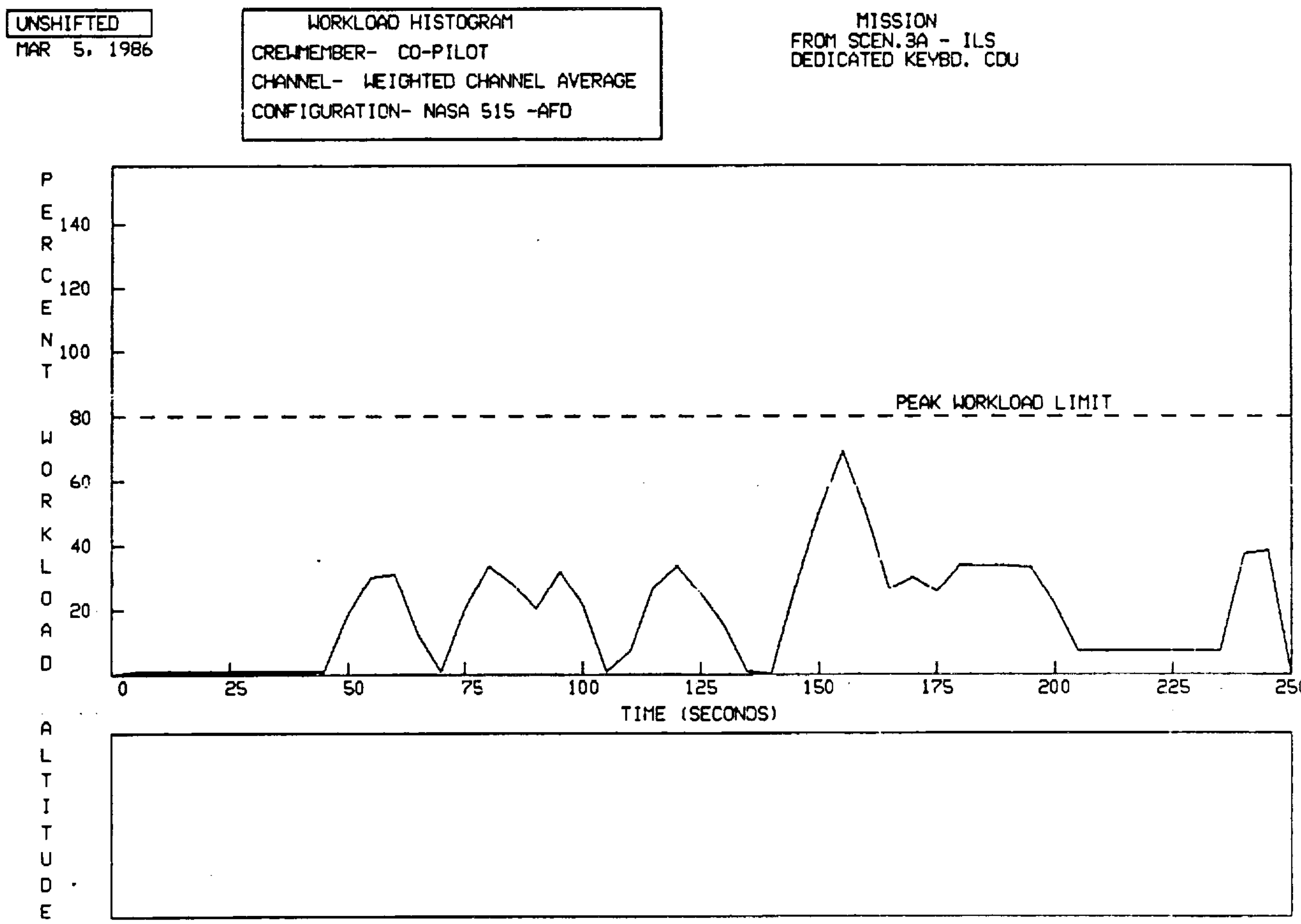

Figure D-12. Workload Histogram—Dedicated Keyboard, Weighted Channel Average

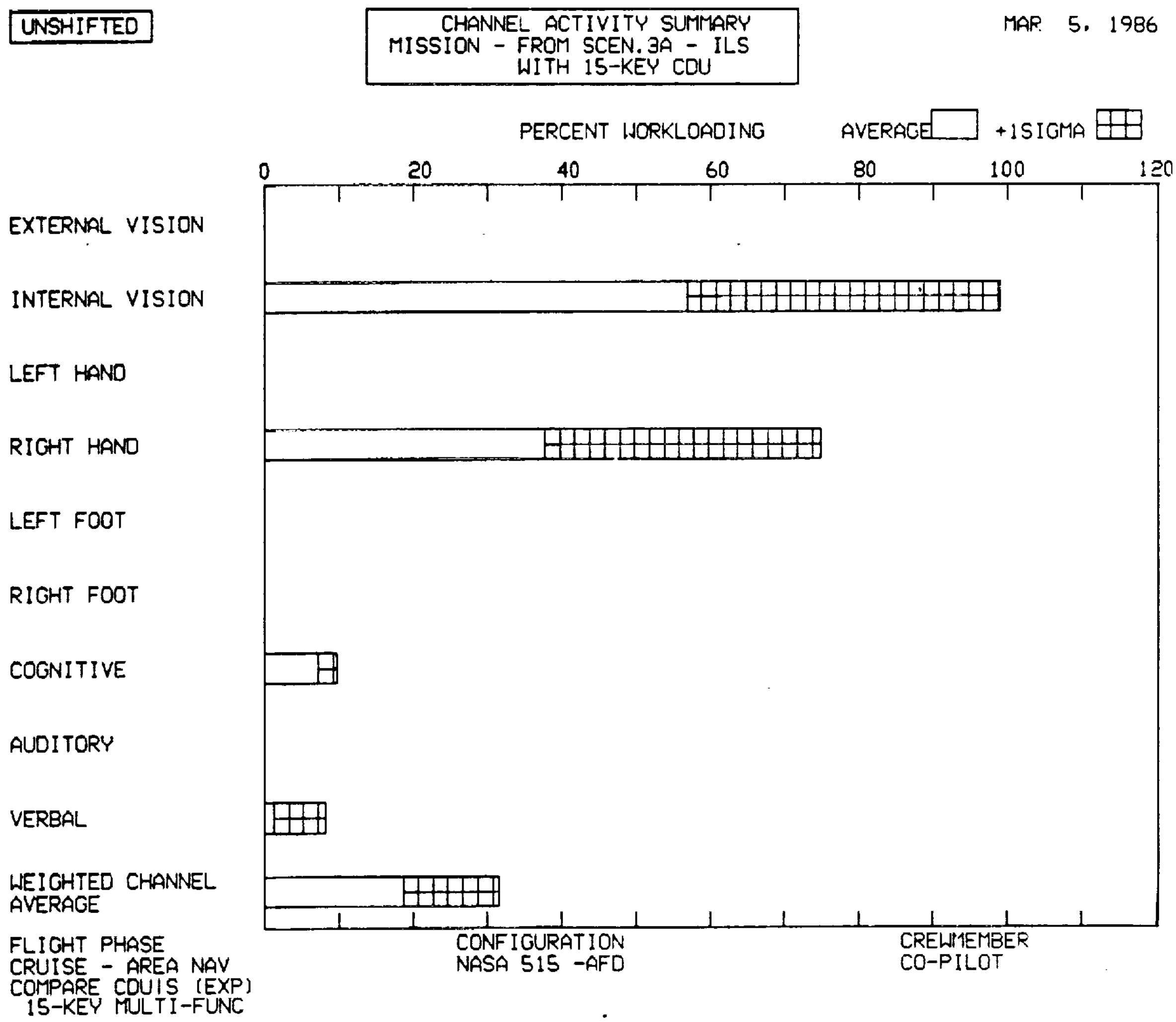

Figure D-13. Channel Activity Summary—Multifunction Keyboard, Cruise

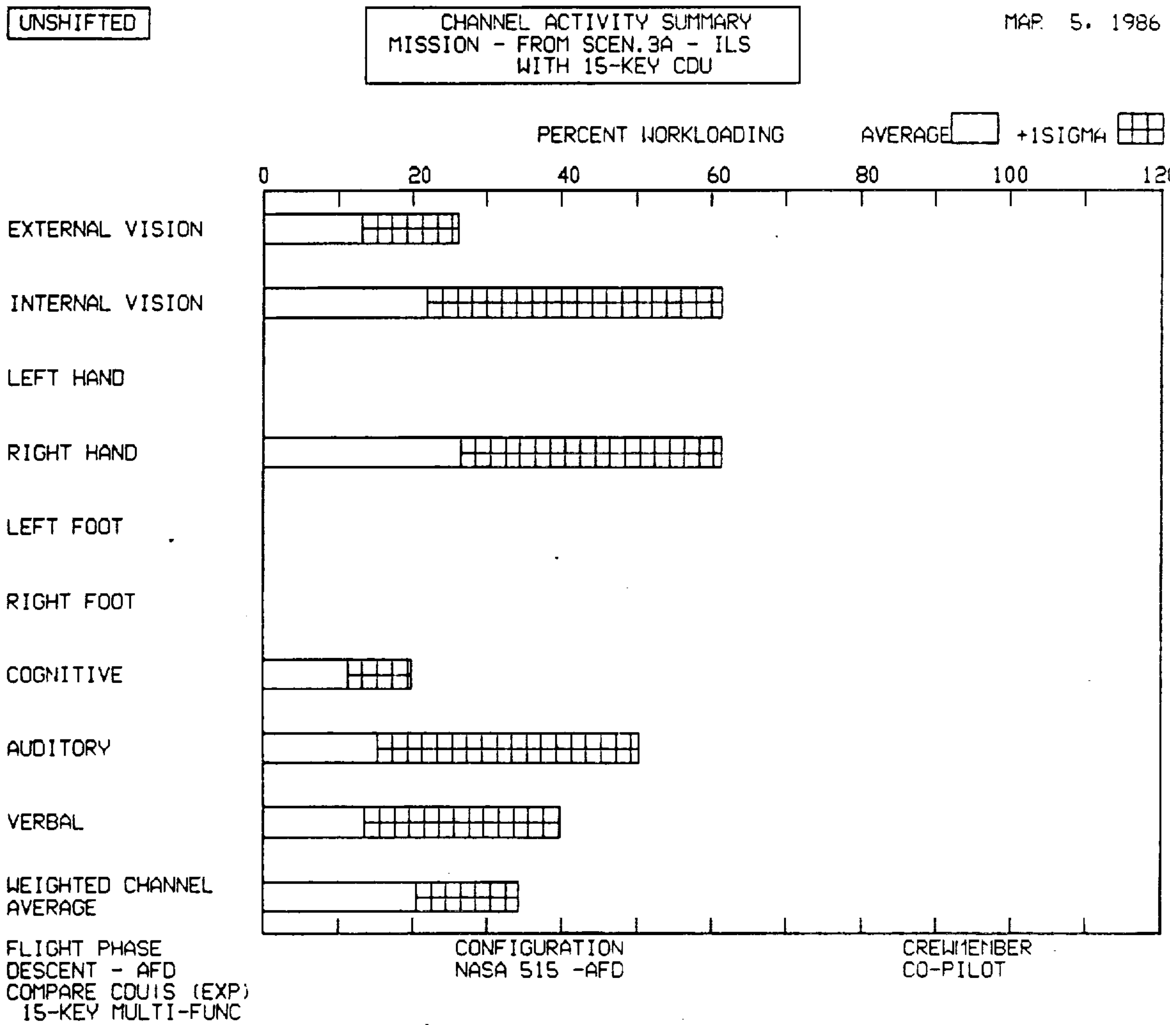

Figure D-14. Channel Activity Summary—Multifunction Keyboard, Descent

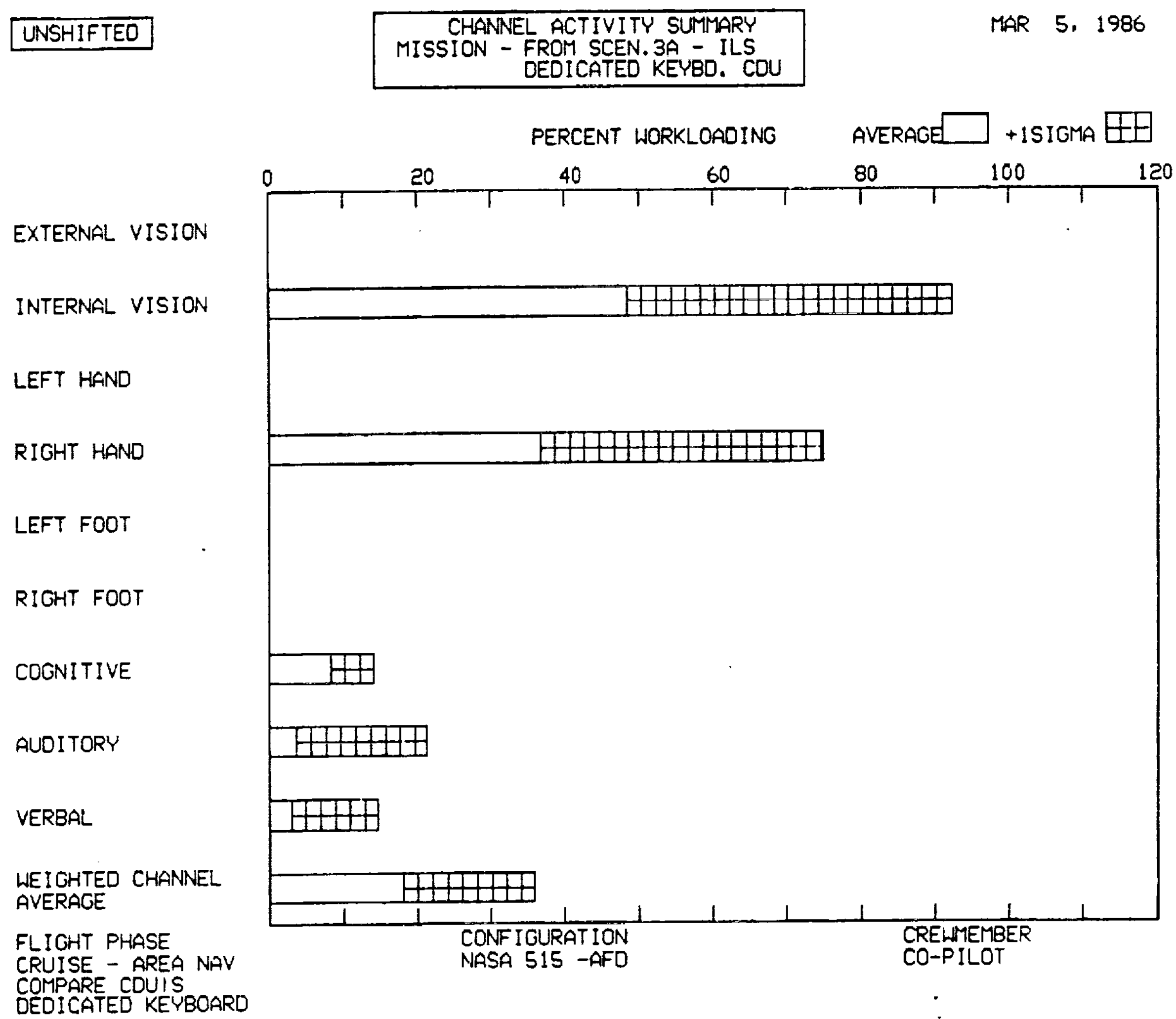

Figure D-15. Channel Activity Summary—Dedicated Keyboard, Cruise

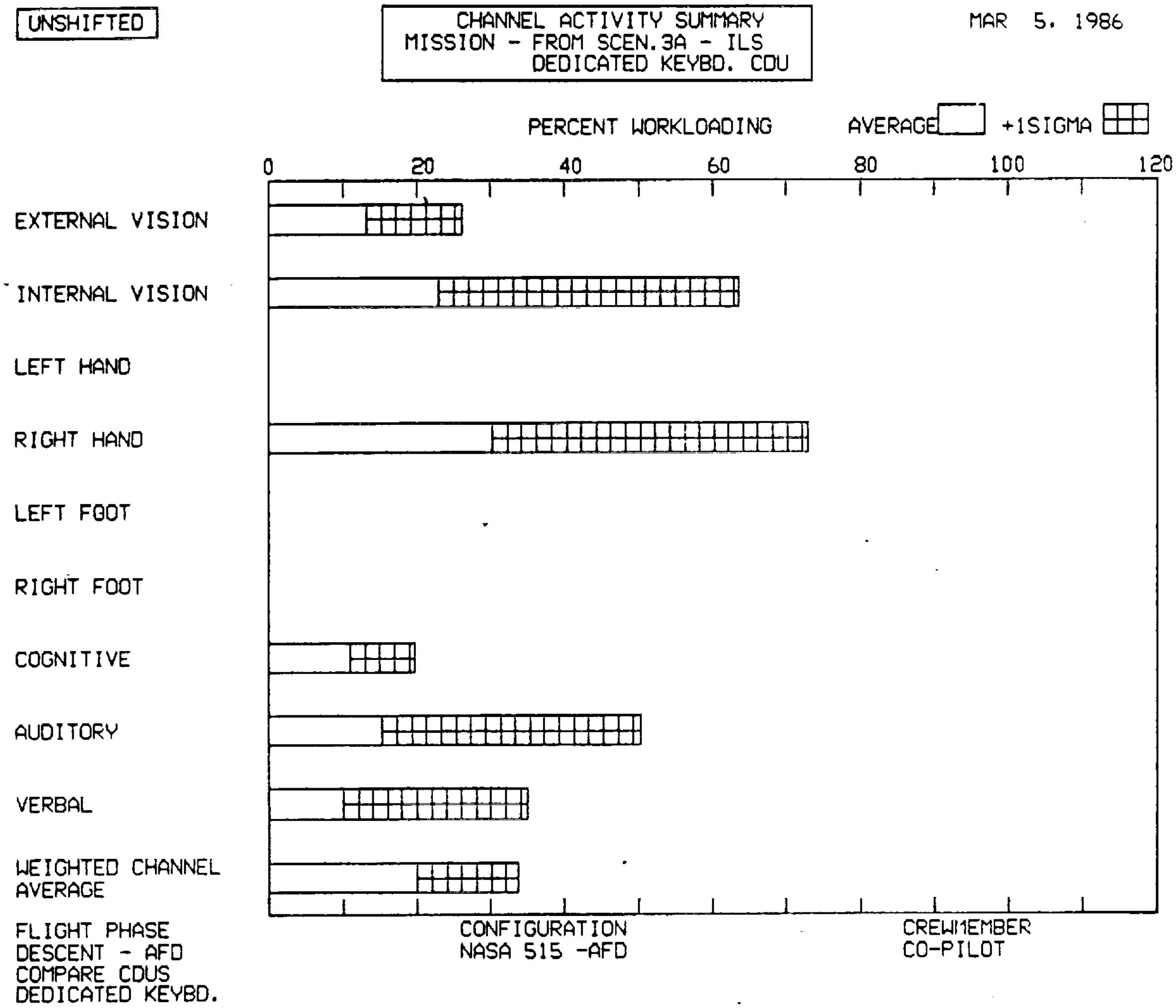

Figure D-16. Channel Activity Summary—Dedicated Keyboard, Descent

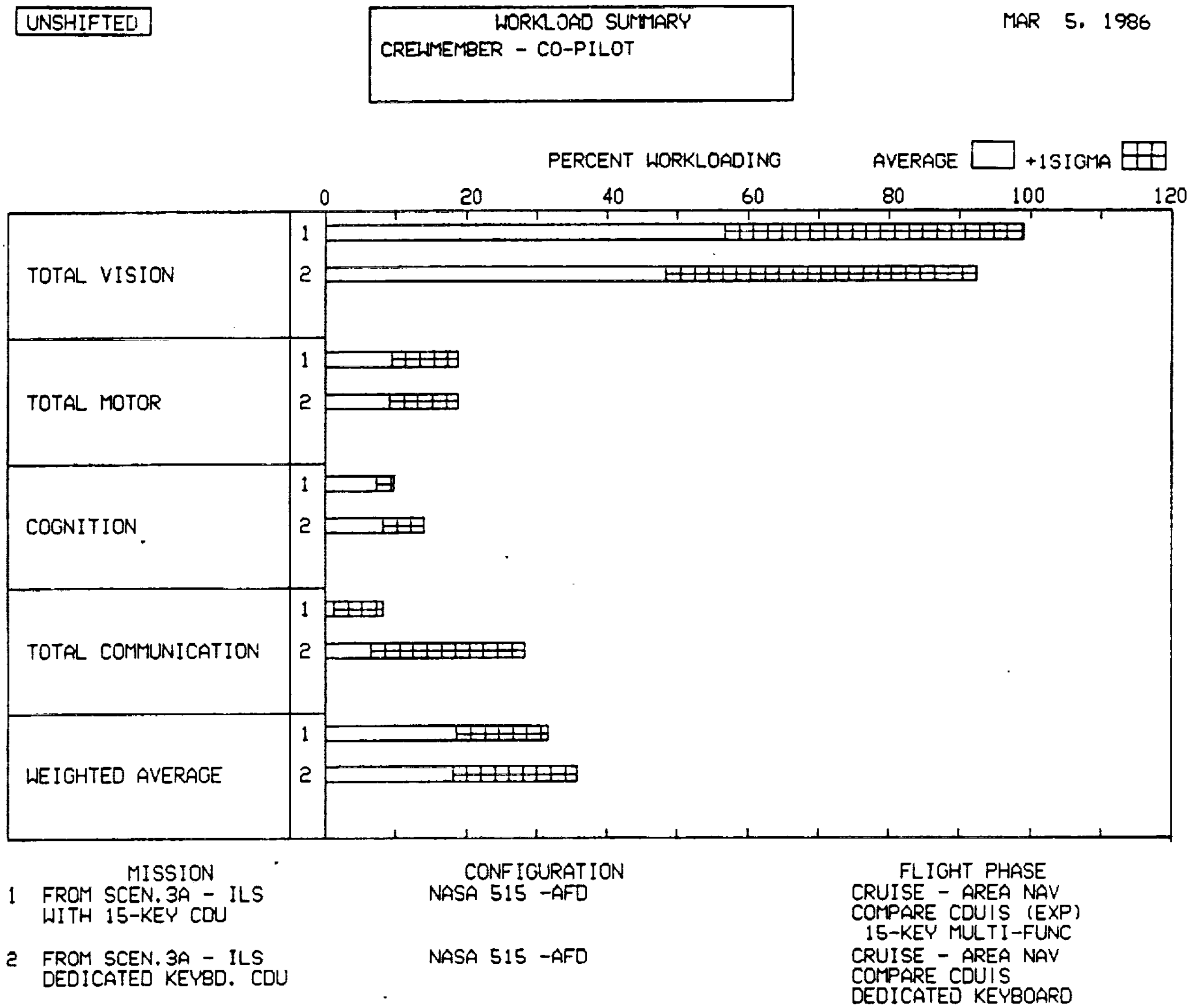

Figure D-17. Workload Summary—Multifunction Versus Dedicated Keyboard, Cruise

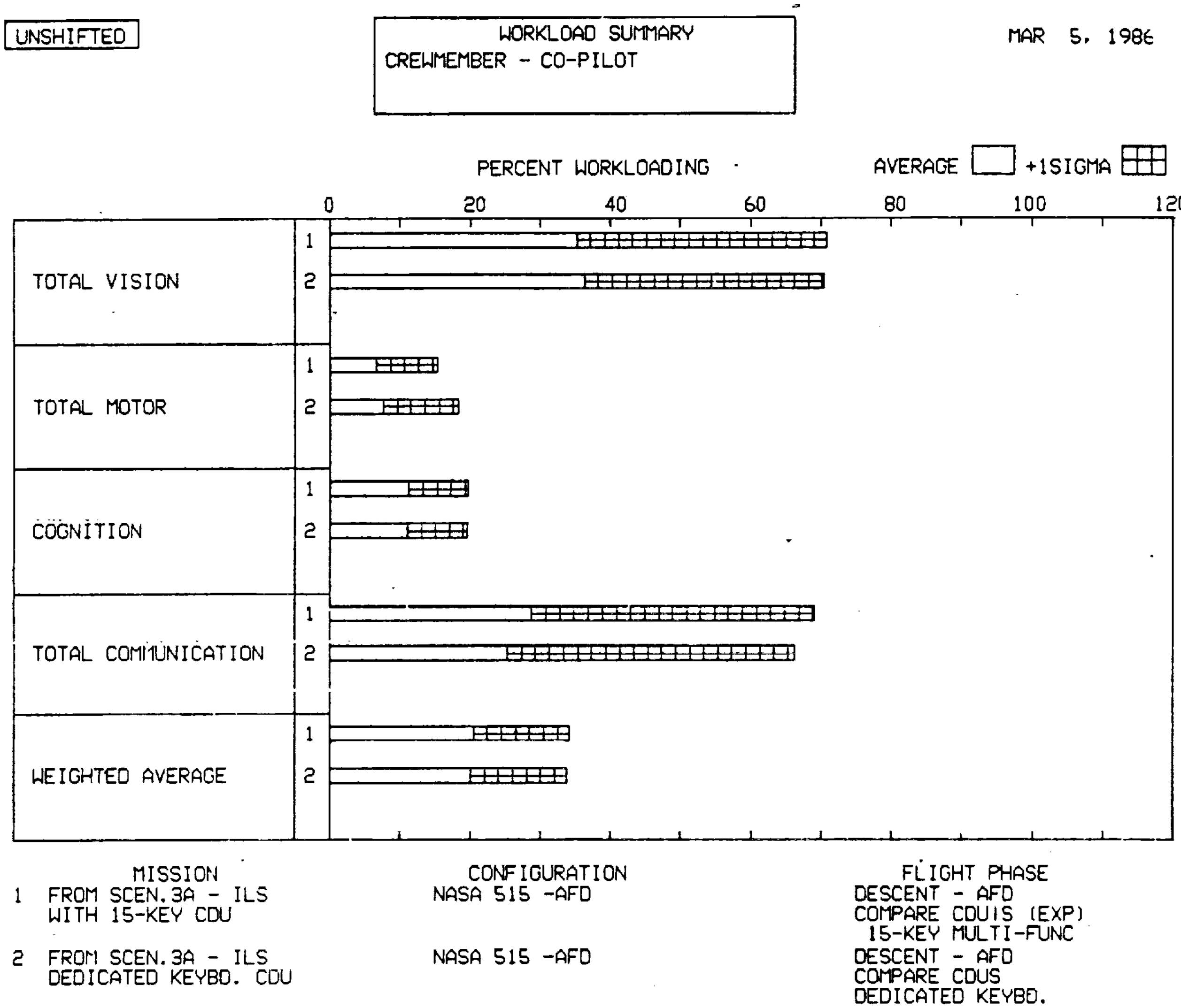

Figure D-18. Workload Summary—Multifunction Versus Dedicated Keyboard, Descent

REFERENCES

REFERENCES

1. Calhoun, G. L., "Multifunction Control Panel Design Considerations for Information Systems," SID International Symposium, Digest of Technical Papers, 19-21 April 1977.

2. Miller, K. H., "Operator Workload Reduction Techniques Applied to Control Panel Design," Boeing Document D6-44193, 1976.

3. Calhoun, G. L., and Herron, E. L., "Pilot-Machine Interface Considerations for Advanced Aircraft Avionics Systems," AGARD CP 329, 1982.

4. Reising, J. M., "Multifunction Keyboard Configuration for Single-Seat, Air-to-Ground Fighter Cockpits," Proceedings of the Human Factors Society, 21st Annual Meeting, 1977.

5. Herron, E. L., "Two Types of System Control With an Interactive Display Device," SID International Symposium, Digest of Technical Papers, 1978.

6. Calhoun, G. L., et al., "Evaluation of Factors Unique to Multifunction Controls/Displays Devices," AFWAL-TR-80-3131, November 1980.

7. Anderson, A. F., and Miller, K. H., "Timeline Analysis Program (TLA) User's Guide, TLA-Mod 2," Boeing Document D6-44646, 1977.

8. Pfaff, T. A., "Advanced Flight Management CDU Study, Phase II, TRB-4," Boeing Document D6-51319, 1981.

9. Wierville, W. W., et al., "Evaluation of 16 Measures of Mental Workload Using a Simulated Flight Task Emphasizing Mediational Activity," Human Factors, Vol. 27, No. 5, October 1985.

10. Aretz, A. J., "A Comparison of Manual and Vocal Response Modes for the Control of Aircraft Subsystems," AFWAL-TR-83-3005, March 1983.

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16. Abstract

A flight management computer (FMC) control display unit (CDU) test was conducted to compare two types of input devices: a fixed legend (dedicated) keyboard and a programmable legend (multifunction) keyboard. The task used for comparison was operation of the flight management computer for the Boeing 737-300. The same tasks were performed by twelve pilots on the FMC control display unit configured with a programmable legend keyboard and with the currently used B737-300 dedicated keyboard. Flight simulator work activity levels and input task complexity were varied during each pilot session. Half of the pilots tested were previously familiar with the B737-300 dedicated keyboard CDU and half had no prior experience with it. The data collected included simulator flight parameters, keystroke times and sequences, and pilot questionnaire responses. A timeline analysis was also used for evaluation of the two keyboard concepts.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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