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AUTHOR Cooper, Fred R.; And Others
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ABSTRACT

Naval researchers studied the effects of delay in the presentation of visual information on pilot performance. Simulated carrier landing tasks were performed by subjects using a visual display generated by a computer. In one part of the experiment pilots were asked to "fly" carrier approaches with and without a 0.1 second delay in the visual scene presented to them. In the second part of the experiment, pilots were asked to "fly" carrier approaches several times during which six pilot control inputs were recorded. Statistical analysis of the data generated by the experiment indicated that the differences between mean performance with delay and with no delay were not significant. Variances of lateral control deflection and force were significantly different for the delayed presentation and the nondelayed presentation, but the analysis of the other four control inputs did not reveal statistically significant differences. (CH)

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TECHNICAL REPORT: NAVTRAEQUIPCEN IH-250

THE EFFECT OF DELAY IN THE PRESENTATION OF VISUAL INFORMATION ON PILOT PERFORMANCE

Analysis and Design Branch,
Computer Laboratory, and
Human Factors Laboratories
Naval Training Equipment Center
Orlando, Florida 32813

Final Report for Period April 1974 - July 1975

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NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

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THE EFFECT OF DELAY IN THE PRESENTATION OF VISUAL INFORMATION ON PILOT PERFORMANCE

Fred R. Cooper
Analysis and Design Branch

William T. Harris
Computer Laboratory

Vincent J. Sharkey
Human Factors Laboratory

December 1975

Approved:

GLENN W. HOHMAN
Head, Analysis and Design Branch

DR. L. D. HEALY
Acting Head, Computer Laboratory

JAMES S. DUVA
Head, Human Factors Laboratory

HUGH HALPIN, CDR, USN
Deputy Director
Research and Technology Department

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA
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The effects of delay in the presentation of visual information on pilot performance during simulated carrier landing tasks were investigated. The TRADEC research flight simulator was used in conjunction with an Evans and Sutherland LDS 1 calligraphic visual display system for several different initial conditions, with and without delayed visual presentation, in conducting evaluations of pilot learning performance and piloting technique. The experimental construction, conduction, data analysis and results are presented herein.

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SUMMARY

A considerable effort has been undertaken at the Naval Training Equipment Center's Analysis and Design Branch, Computer and Human Factors Laboratories toward answering three questions regarding computer generated visual system technology. The questions were:

a. Do visual system presentation delays on the order of 0.1 seconds have any adverse effects on pilot trainee learning ability?

b. Do the presentation delays cause the pilot subjects to exercise their piloting skills differently than when their visual stimuli are not delayed?

c. What is the nature of the differences in piloting techniques utilized when the pilot's visual stimuli have been delayed, if any?

Questions a, b, and c have been answered by a two experiment study for the specific task of landing an aircraft simulator, with performance similar to an F-4, on an aircraft carrier visual display generated by computer generated imagery.

Experiment 1 of the study addressed the first question posed. Twelve pilot subjects of varying age and background were asked to "fly" carrier approaches both with and without a 0.1 second delay in the visual scene presented to them. The performance criterion of merit was the number of trials required for the subjects to complete three successive carrier arrestments.

Experiment 2 of the study addressed the second and third questions posed. For Part 1 of Experiment 2, twelve pilot subjects were asked to "fly" carrier approaches until five successful carrier arrestments were made. Real time data recording was used to record six pilot control inputs. A statistical unit of measure known as the variance was computed for each of the control inputs. These variances were compared for the delay and no-delay cases using some standard statistical analytical procedures known as multivariate analyses.

Part 2 of Experiment 2 addressed question c and utilized the data gathered under Part 1. Fast Fourier transforms were performed on the pilot control inputs for the delay and no-delay conditions transforming the seemingly random time histories to the frequency domain for easier interpretation. The frequency spectra for the delayed environment of the recorded control parameters were compared to those for the non-delayed environment.

The results of this study indicated:

a. In Experiment 1, the difference between the mean number of trials required by the pilot subjects to reach criterion performance in the delay condition and the mean number in the no-delay condition was not statistically significant. In fact, except for the earliest trials, the differences between mean performance with no delay and mean performance with delay were practically non-existent.

PREFACE

Appreciation is expressed to the following individuals who were persistent and faithful enough to complete the flying tasks involved in this study. Their contributions of time and talent as pilot subjects provided valuable performance data used in the analyses presented herein.

NAME	AFFILIATION
LCDR C. E. Lipford	USN (Ret.)
Lt. Col. H. Phillips	Independent Businessman, USAF (Ret.)
CAPT R. W. Green	USN (Ret.)
CDR G. R. Norrington	NAVTRAEQUIPCEN, Code N-334
CDR T. E. Curry	NAVTRAEQUIPCEN, Code N-33
Lt. Col. J. G. Cowart	NOOM(A), U.S. Marine Corps
Maj. E. Bodenheimer	USAF
Capt. J. Jordan	U.S. Marine Corps
LTJG Stan Snavely	USNR
Mr. Mitchell Bradner	Singer Link
Mr. Robert Browning	NAVTRAEQUIPCEN, Code NOOT
Mr. Harvey Adkins	Goodyear
Mr. Phillip Carley	Xerox Data Systems
Mr. Kenneth F. Muse	NAVTRAEQUIPCEN, Code N-2211
Mr. Wallace F. Flitter	NAVTRAEQUIPCEN, Code N-322
Mr. Francis H. McClellan	NAVTRAEQUIPCEN, Code N-2233

Very special acknowledgement is made to Steve Jackson, Florida Technological University graduate student, employed under contract with the NAVTRAEQUIPCEN, Code N-214, who provided programming expertise supporting the conduct of the experiments and resulting data analysis, and who did the lion's share of gathering, on magnetic tape, the performance of the subject pilots.

Acknowledgement is also given to Mr. Gary Killian, Florida Technological University student, and Mr. Harvey C. Saltzman of the Computer Laboratory for programming assistance rendered.

Finally, acknowledgement is given to Dr. Charles Dziuban of Florida Technological University for statistical consultation services.

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SECTION I

INTRODUCTION

Because of the current national economy, the fuel shortage, concern for ecology, and the ever increasing complexity and cost of modern weapon systems, there is, and will likely continue to be, emphasis on the development and utilization of sophisticated flight simulators. Military and commercial aircraft users are investing heavily in flight simulators equipped with visual systems and in visual systems to be attached to existing flight simulators.

In general, visual simulators are conceived as add-on systems to flight trainers. Investigation of interfacing such systems has been, historically, and typically, less than rigorous. Addition of one system to another seems inevitably to affect the operation of the combination. Such is the case with visual systems when attached to flight simulators.

An inherent delay exists between the time a visual system receives its inputs and the time a visual presentation is displayed. For example, the Computer Generated Image Advanced Development Model visual system attached to Device 2F90, a TA-4J OFT, at Kingsville Naval Air Station (NAS), Texas, in late 1973, required a little in excess of 100 ms[1] to generate a visual scene. This time delay added to the 50 ms update cycle time of the 2F90, represented a 200 percent change in time related effects on the pilot's control responses.[2]

The question naturally arose as to what effect this additional delay is likely to have on the training effectiveness of a flight simulator system.

---

[1]Healy, L. D. and Cooper, F. R., "Verification of Simulator Performance by Frequency Response Measurement," Proceedings of the 6th NAVTRAEQUIPCEN/Industry Conference, Nov 13-15, 1973, NAVTRAEQUIPCEN IH-226.

[2]O'Connor, F. E., CAPT USN, Dr. B. J. Schinn, and Dr. W. M. Bunker, "Prospects, Problems, and Performance: A Case Study of the First Pilot Trainer Using CGI Visuals," Proceedings of the 6th NAVTRAEQUIPCEN/Industry Conference, Nov 13-15, 1973, NAVTRAEQUIPCEN IH-226.

SECTION II

STATEMENT OF THE PROBLEM

The purpose of the experiment was to attempt to answer the following questions:

a. Does a 100 ms delay of a visual presentation affect pilot learning performance?

b. Do pilots perform their piloting skills differently when their visual stimuli have been delayed for 100 ms?

c. If pilots do perform their skills differently when visual stimuli are delayed 100 ms, in what way(s) is their performance different?

SECTION III

EXPERIMENT DESCRIPTION

APPROACH

The previous questions were addressed by two experiments. Experiment 1 was designed to answer Question a. Experiment 2 was designed to answer Questions b and c.

The approach taken to answer Question a was to design specific carrier approach tasks which incorporated both delay and no-delay conditions to be learned by pilot subjects. The pilot subjects were then required to fly the tasks. An analysis of the number of carrier approach trials taken to achieve an established successful criterion of performance was then conducted.

The approach taken to answer Questions b and c was to focus the investigation on the pilot/simulator interface -- the flight controls. Pilot control displacements and forces were measured while flying specific carrier approach tasks with and without 100 milliseconds (ms) delay. An analysis of the recorded measurements was accomplished to determine if pilots manipulated the controls with more or less displacements and/or with more or less forces when their visual stimuli were delayed. Finally, the measurements of control displacements and forces were subjected to a Fourier analysis to examine, in the frequency domain, the effects of the 100 ms visual presentation delay on flight control activity.

HARDWARE AND SIMULATION SOFTWARE USED

The experiments were conducted with the Naval Training Equipment Center's (NAVTRAEQUIPCEN's) TRADEC F-4 Flight Simulator. This simulator system consists of a Xerox Data System Sigma 7 digital computer with a full complement of general purpose digital computer peripheral equipment (figures 1 and 2), a four-degree-of-freedom motion platform (figure 3), a variable configuration simulated aircraft cockpit (figure 4), and an operator's control console (figure 5).

The computer system hardware consists of 48,000 words of core storage, 13.7 million bytes of random access disc memory, four magnetic tape drives, a high-speed line printer, card reader, card punch, paper tape reader/punch, and a Calcomp incremental plotter. The simulator software is a program which simulates the F-4 aircraft. The F-4 simulator is utilized in the conduct of research in various aspects of simulation techniques and of human factors relating to simulation. The program is written to support operator's console functions such as establishing modes of flight, recording of data, aiding in conducting tests and establishing different conditions and configurations of flight. The program allows recording of up to 165 selectable parameters on magnetic tape each program iteration cycle, i.e., every 50 ms.

The simulation program was modified to provide appropriate operator control of the conduct of this experiment. Program modifications provided for:

Figure 1. Xerox Data Systems Sigma 7 Computer

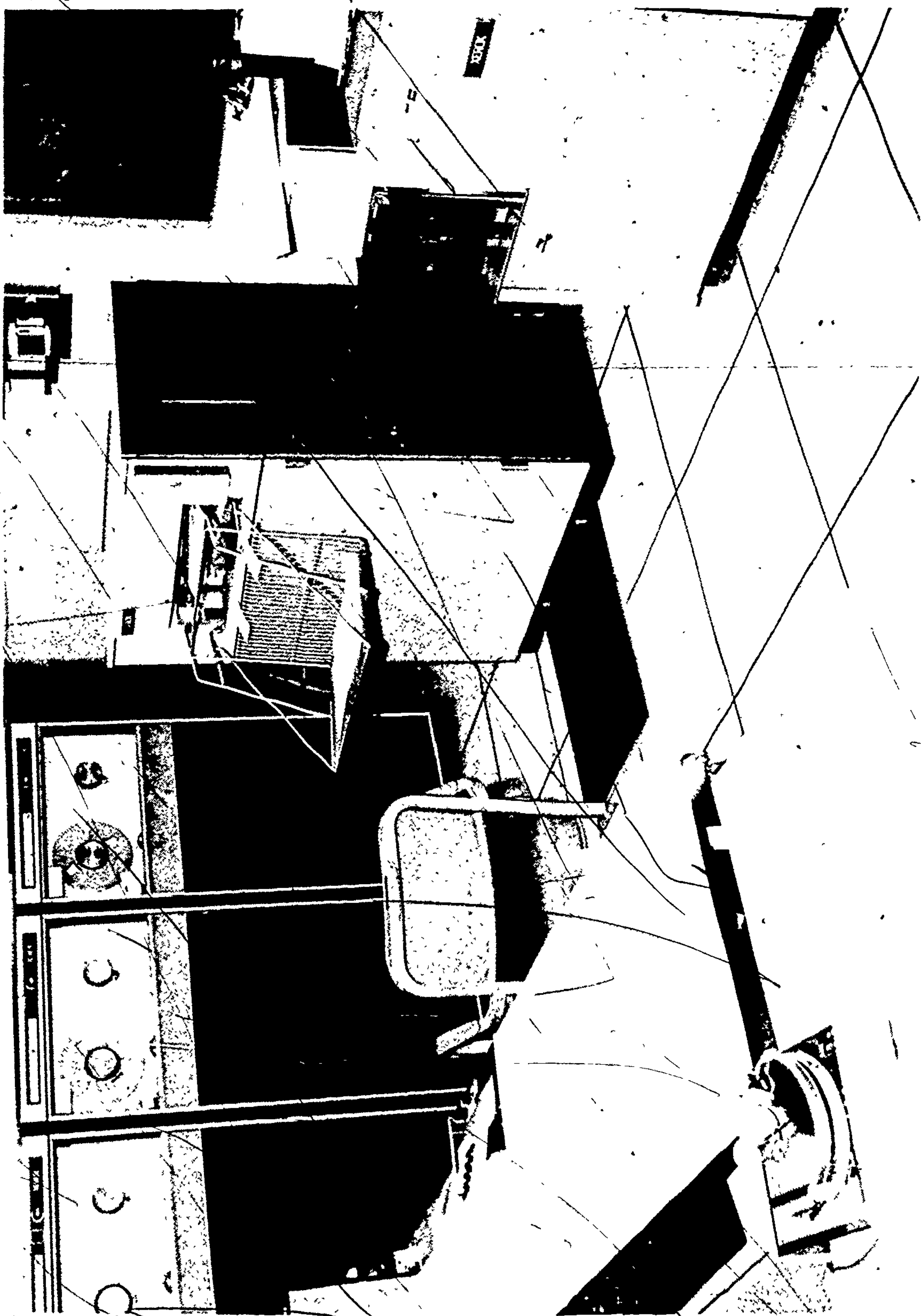

Figure 2. Xerox Data Systems Sigma 7 Computer

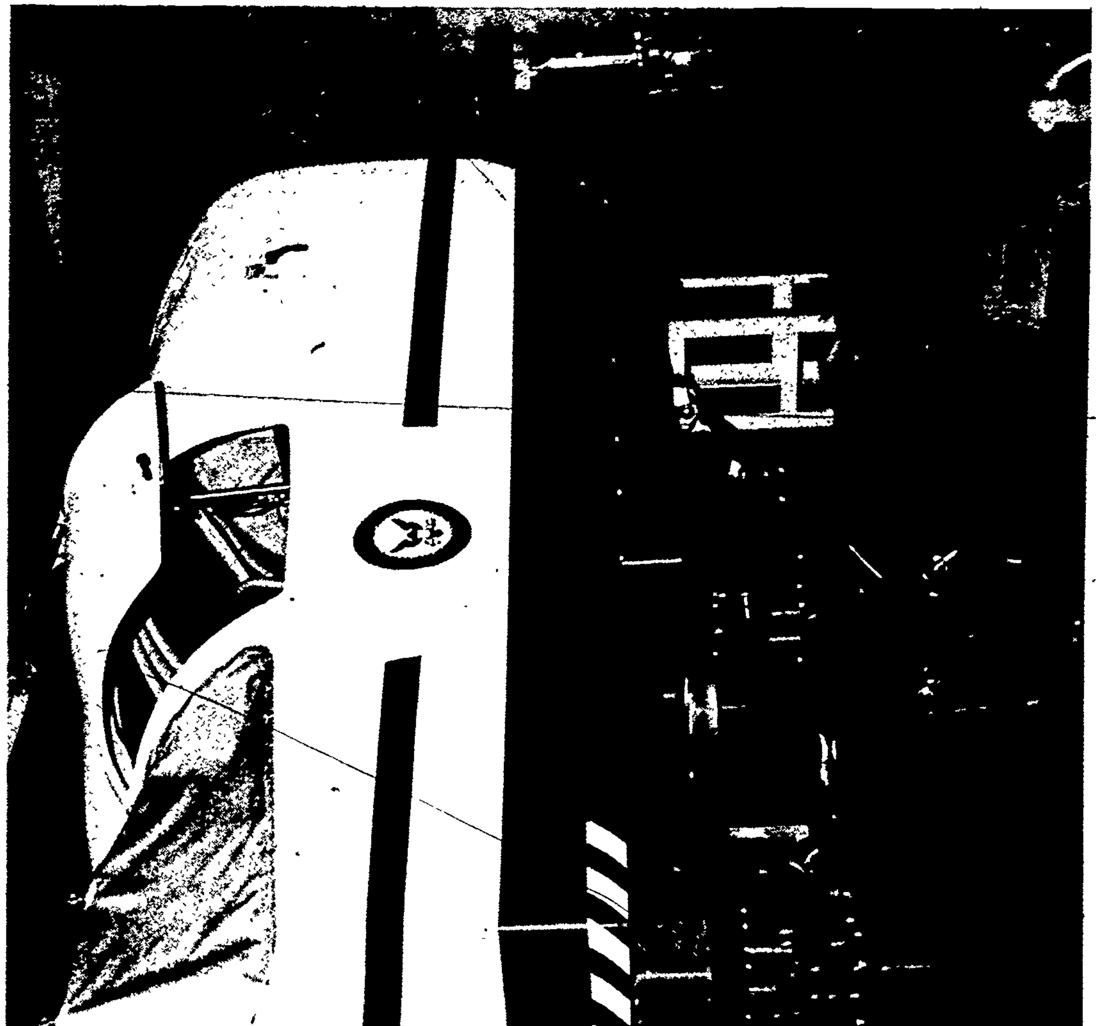

Figure 3. TRADEC Four Degree of Freedom Motion System

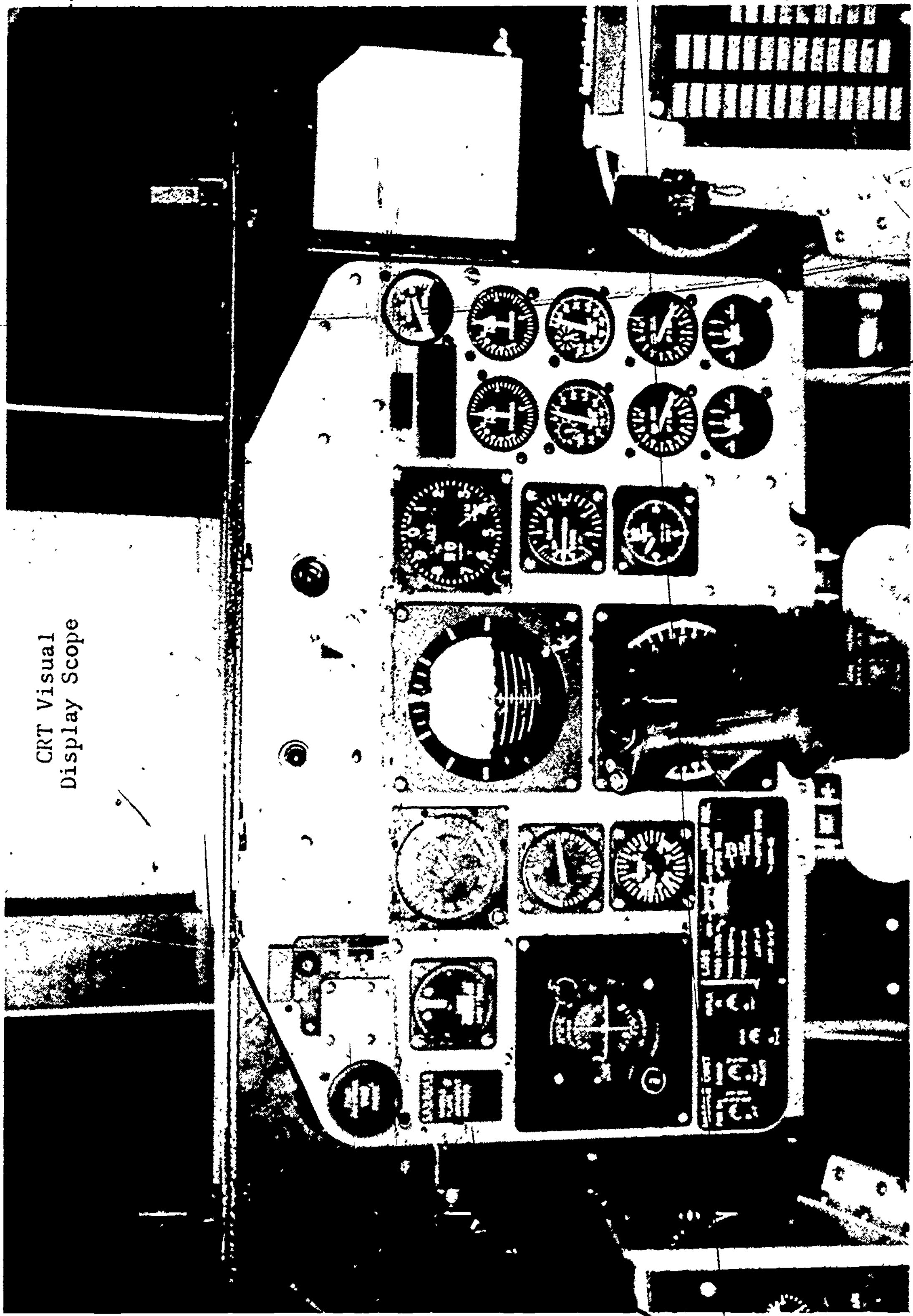

Figure 4. Simulated Aircraft Cockpit

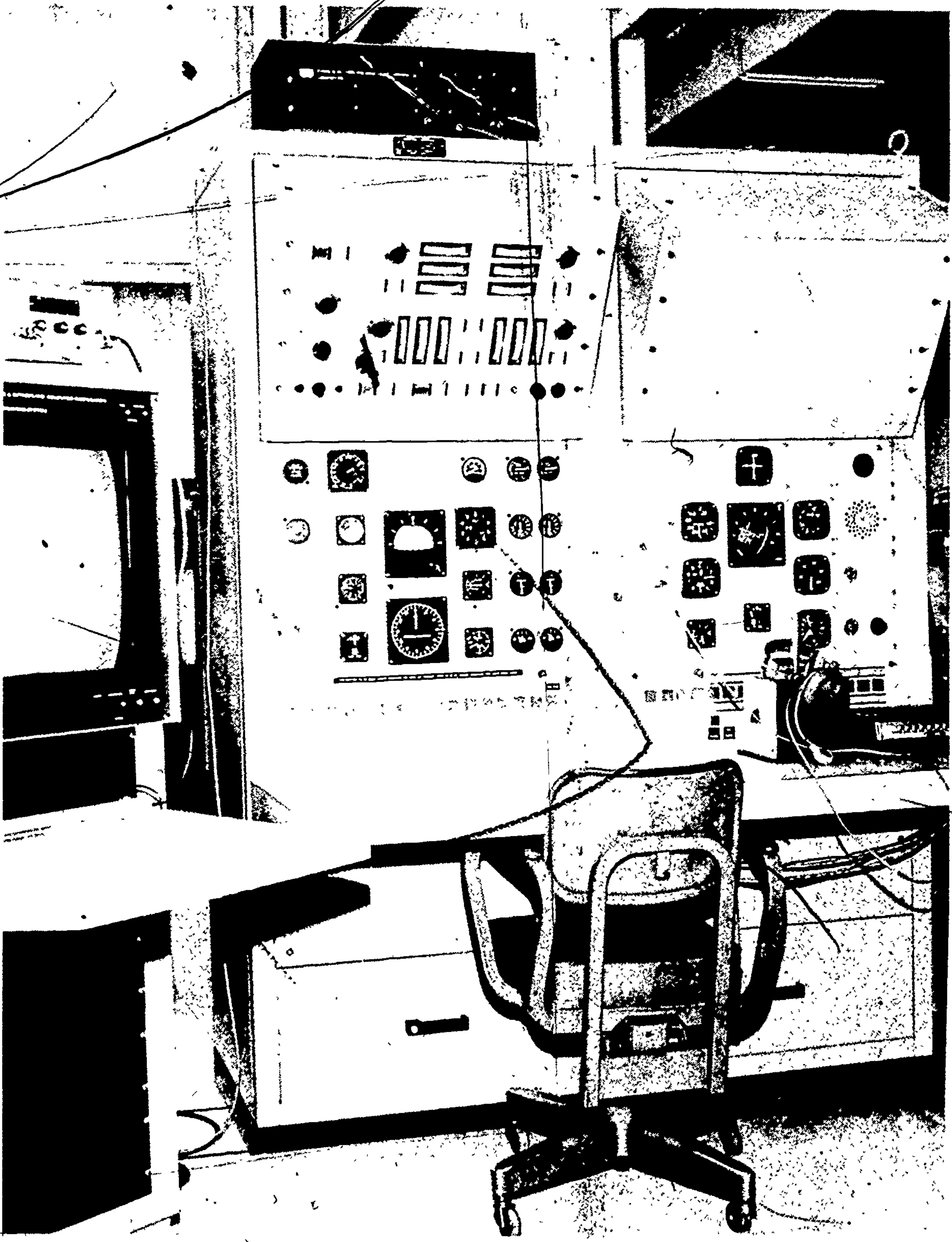

Figure 5. Operator's Control Console

a. Operator insertion of test subject identification and carrier approach task conditions (e.g., Delay/No-Delay, Task Selection, etc.).

b. Presetting the position of the simulated aircraft to one of three selectable points in space from which carrier approaches began.

c. Operator release of control of the simulator to a pilot subject enabling him to fly an approach and attempted arrestment on a visually depicted carrier.

d. Appropriate termination of each carrier approach.

e. Control of recording selected data on magnetic tape during each approach.

The F-4 simulator was interfaced with an Evans and Sutherland Line Drawing System (LDS) I line drawing visual CRT display system[3] which provides a 19° horizontal by 19° vertical field of view. This monochromatic visual system consists of a line drawing scope shown in figure 5, a special purpose high-speed processor, figure 6, and an associated slave scope located in the simulated cockpit in view of the pilot, shown in figure 4. The special purpose high-speed processor accepts aircraft and aircraft carrier position and orientation information from the simulator computer and produces the correct perspective picture at the two display stations in real time. The time required for the visual system to compute and display the aircraft carrier scene used in these experiments varies from 12.5 ms to 25 ms. The time taken within this range depends upon the number of lines that are in view of the pilot's eyepoint, which is dependent upon the distance between the aircraft and the aircraft carrier as the approach to arrestment progresses.

The F-4 simulator program's iteration cycle is 50 ms. Position and orientation of the aircraft and aircraft carrier are computed each program iteration. The method of simulating 100 ms additional delay in the visual system was accomplished by withholding, from the Evans and Sutherland visual system, this aircraft and carrier positional information for two program iteration cycles (2 iterations x 50 ms per iteration = 100 ms). This was accomplished by software, the implementation of which is illustrated in figure 7. Carrier and aircraft positioning information was stored in buffers, the first buffer containing the position information calculated during the preceding program iteration cycle, (therefore 50 ms old), the second buffer the iteration cycle before that (100 ms old), etc., with the 9th buffer holding the information calculated during the 9th previous iteration (i.e., 450 ms old).

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[3] Sutherland, Ivan E. and Dan Cohen, "Display Techniques for Simulation," Technical Report: NAVTRADEVCEN 70-C-0025-1.

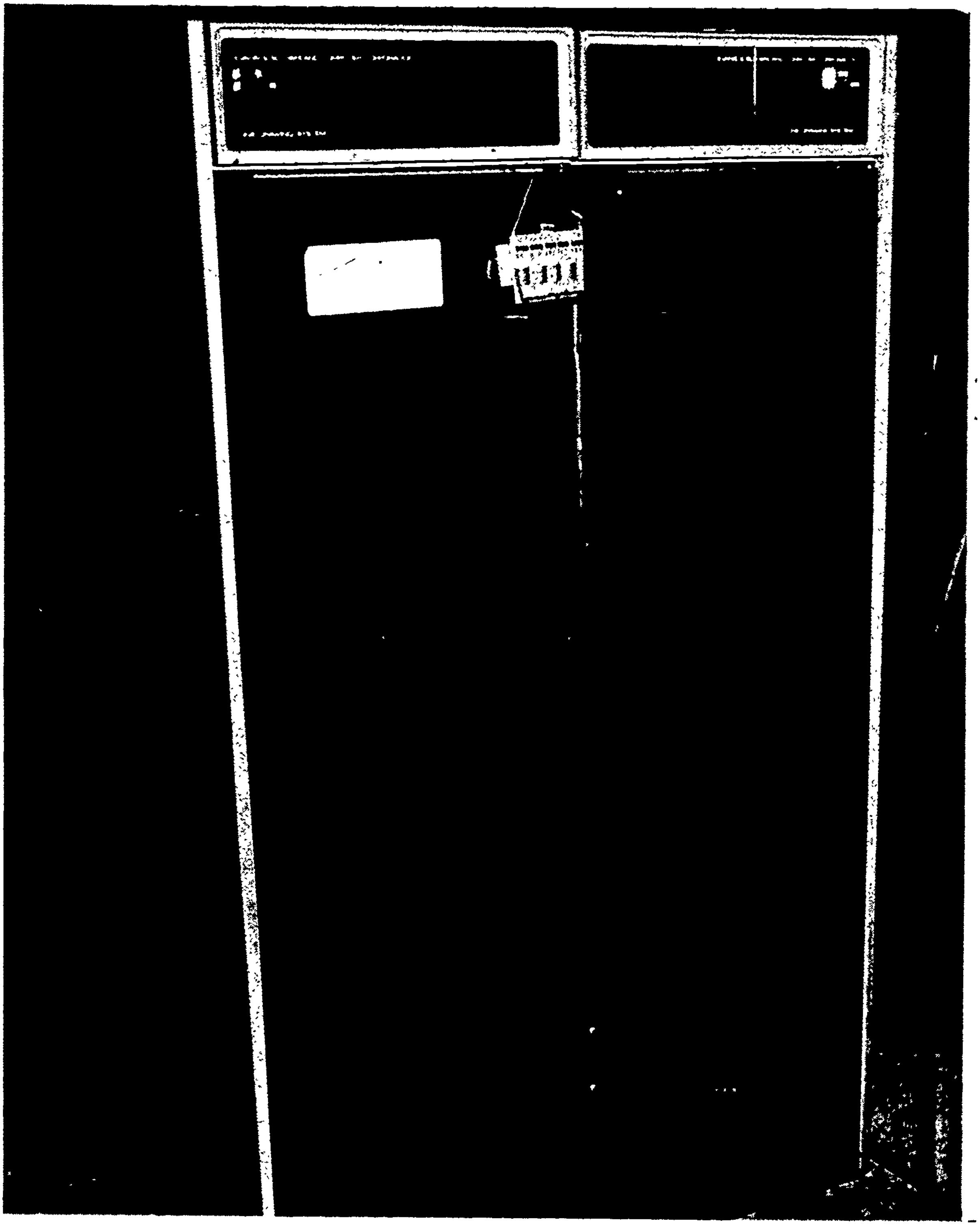

Figure 6. Evans and Sutherland Special Purpose High-Speed Processor. LDS I

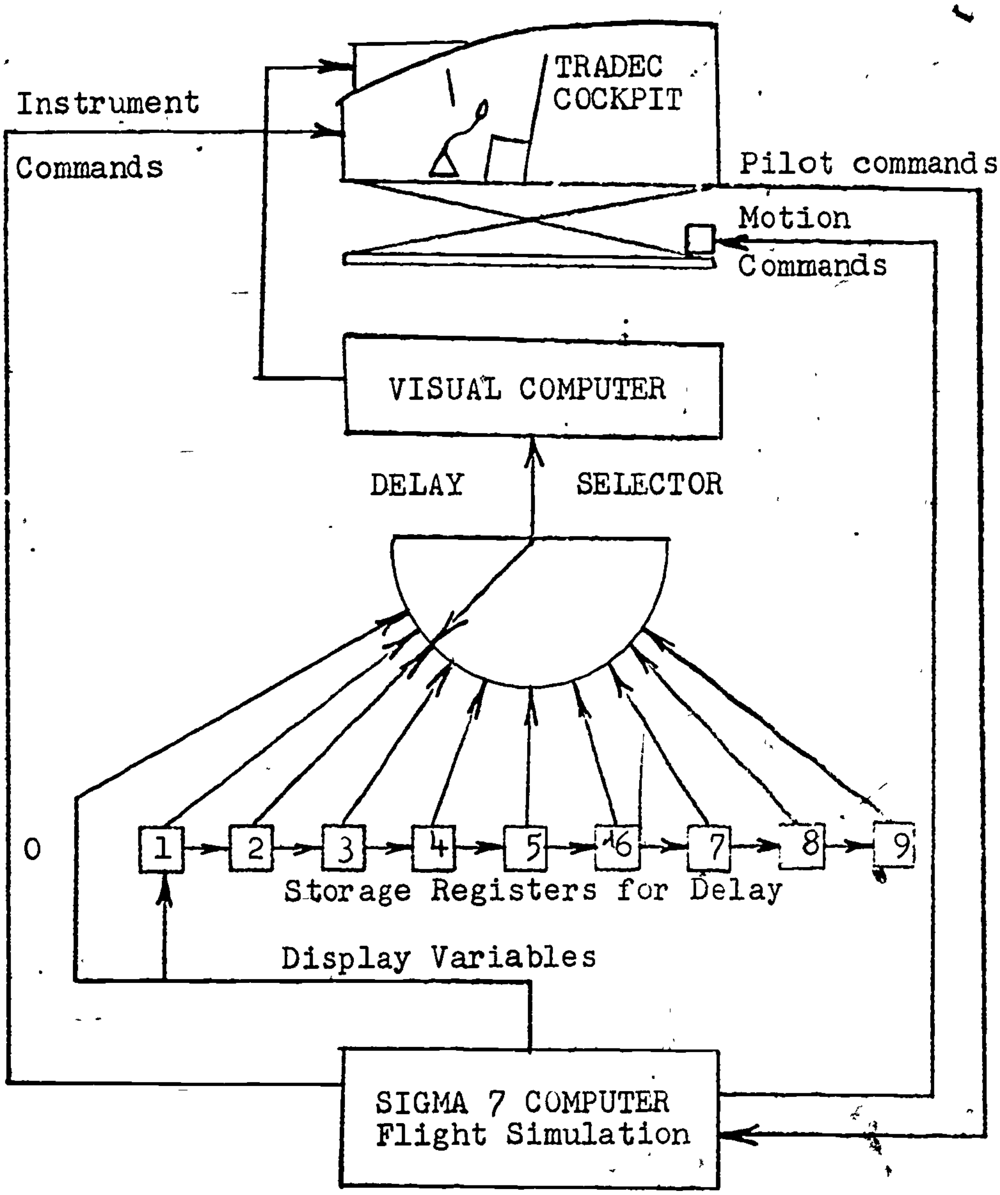

Figure 7. Time Delay Implementation and Signal Interfacing

At the end of each simulation program iteration cycle the contents of buffers 0 through 9 were transferred, or shifted to the adjacent buffer. Information in the 9th buffer was discarded. Selection of a given buffer to be presented to the Evans and Sutherland visual system therefore determined the amount of visual system time delay simulated. The subject experiment utilized the selection of "buffer" 2 when a delayed task was to be flown and "buffer" 0 when a no-delay task was to be flown.

The implementation just described resulted in effectively adding 100 ms time delay to the actual time required by the Evans and Sutherland system to produce and display the position of the aircraft carrier scene. Therefore, the actual visual cue delays presented to the pilot subjects was 12.5 ms to 25 ms for the no-delay condition and 112.5 ms to 125 ms for the delayed condition.

PILOT SUBJECTS USED

Sixteen Navy, Marine and Air Force pilots and former pilots, assigned to or employed as civilians by the NAVTRAEQUIPCEN, or employed and self-employed in industry in the Orlando area, volunteered their time to serve as pilot subjects in the experimentation. (Table 1 contains a summary of their flying experience.) All but two were carrier qualified from two and one-half years to twenty-five years ago.

TASKS PERFORMED BY PILOT SUBJECTS

The tasks selected were rather exacting and purposely so, for it was thought that if an artificial delay of 100 ms were to have an effect, it would show up more readily in the more difficult parts of the flight training regimen.

The basic task for the pilot subject was to learn to land a simulated aircraft on the carrier deck displayed on a Cathode Ray Tube (CRT) screen. Six variations of this basic task were used. Two were considered *a priori* to be of least difficulty, comparatively speaking, two of moderate difficulty and two, the most difficult. This was done in order to afford the pilot subjects some early opportunity of success to prevent possible discouragement on their part and also in the later analysis to determine if an interaction existed between Delay and Task Difficulty.

Certain initial conditions were common to all six task variations. In each case, the carrier moved at a rate of thirty-five (35) knots. The aircraft was always positioned one (1) nautical mile from the carrier at an altitude of three hundred ninety (390) feet and at an airspeed of one hundred thirty-five (135) knots (i.e., on the glide slope and at the correct airspeed). Except for pilot control positions, initial conditions were the same for each approach trial. Each successful approach trial required about 30 seconds flight from the time the pilot subject was given control until approach termination occurred.

The six task variations were as follows:

Task A (Least Difficult)

Table 1. PILOT SUBJECT QUALIFICATIONS

SUBJECT IDENT.	EXPERIMENT PARTICIPATION PART I	EXPERIMENT PARTICIPATION PART II	TOTAL FLIGHT TIME	AIRCRAFT TYPE	NUMBER OF TRAPS ON CARRIER	YEARS SINCE CARRIER QUALIFIED
1010	*	*	3000	T-33, F-86	0	-
1111	*		2400	A-4, A-5, TF-9	150	6
2020		*	Unknown	Navy, A-6	Unknown	Unknown
2121	*	*	4200	F-80, F-84 F-86, F-101	0	-
3030		*	5000	RF-8, F-6 F-9, SNJ, T-2	311	14
3333	*	*	2000	F-8, A-4	50	16
4444	*	*	1000	F-3H, F-9F, TV-2	18	18
5555	*	*	1300	F-4	194	2.5
6666	*	*	4500	A-3	140	5
7070	*		6000	P-2, P-3	6	22
9999	*	*	1500	SNJ	10	25
AAAA	*	*	2250	F-6, F-8, S-2	200	18
DDDD	*	*	4000	A-4, A-6, F-8	100	9
EEEE	*	*	5000	F-4, S-2F, TBM	200	18

The aircraft was set 600 feet to the right of the center line of the carrier's angle deck, figure 8. The pilot subject was required to make a left turn to line up on the center line of the carrier's angle deck.

Task B (Least Difficult)

The aircraft was set directly on the glide slope and on the center line of the carrier's angle deck, figure 9. No turns were required and the pilot subject's objective was to hold the aircraft on the glide slope until arrestment.

Task C (Moderately Difficult)

This task was the same as Task B, figure 9, except that an arbitrary level of turbulence representative of "light turbulence" flying conditions was added to the simulator motion system.

Task D (Moderately Difficult)

The aircraft was set 600 feet to the left of the center line of the carrier's angle deck, figure 10. The pilot subject was required to make a right turn to line up on the angle deck's center line.

Task E (Most Difficult)

This was the same as Task D, figure 10, (right turn required from 600 feet to the left of the angle deck center line) with an arbitrarily selected more severe level of turbulence, representative of "heavy turbulence" flying conditions, added to the simulator motion system.

Task F (Most Difficult)

This was the same as Task A, figure 8, (left turn required from 600 feet to the right of the angle deck center line) with the more severe level of turbulence added to the problem.

There were five conditions which had to be met in order for a trap (aircraft arrestment) to be successful:

a. The trap area on the carrier deck was rectangular in shape and simulated a carrier deck area 50 feet wide by 80 feet long. A trap was possible if the aircraft center of gravity was in an altitude range of 64 to 69 feet above sea level and within the trap area.

b. The landing gear had to be down.

c. The rate of descent of the aircraft had to be less than or equal to 1000 feet per minute as it entered the space defined in paragraph a. above.

d. The aircraft could not be pitched down more than two degrees from horizontal and not be pitched up more than eighteen degrees from horizontal as it entered the space defined in paragraph a.

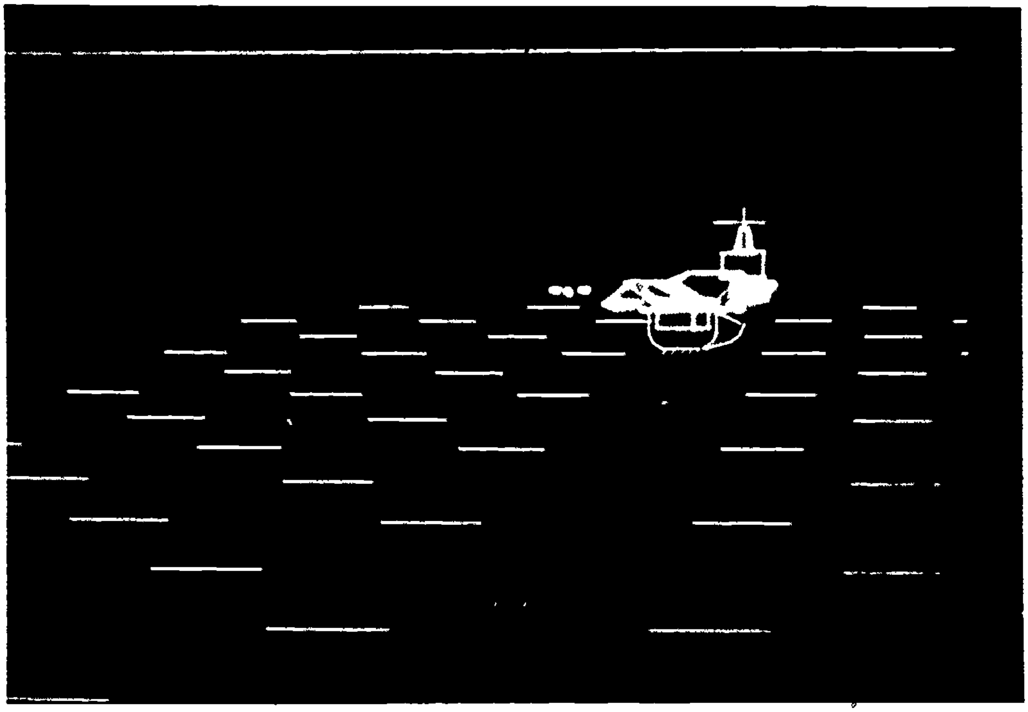

Figure 8. Visual Display Starting Position (Left)

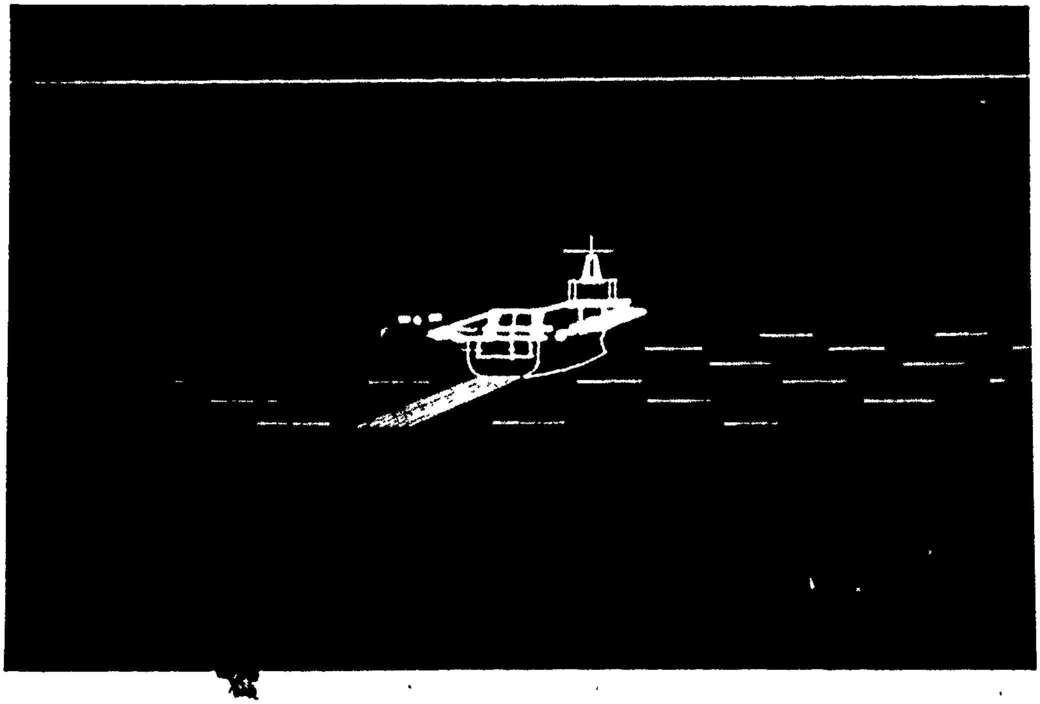

Figure 9. Visual Display Starting Position (Center)

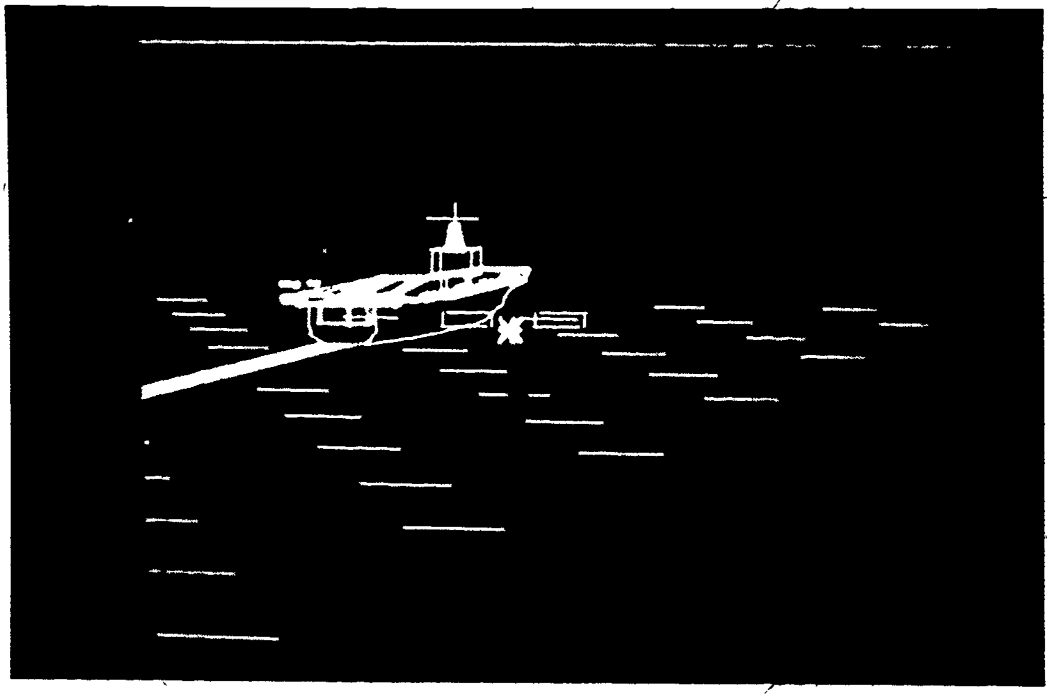

Figure 10. Visual Display Starting Position (Right)

e. The aircraft could not be rolled to the left or right more than fifteen degrees from horizontal as it entered the space defined in paragraph a.

DESCRIPTION OF EXPERIMENTS

Two experiments were designed to answer the questions stated in Section II, Statement of the Problem. The first experiment was designed to address Question a of Section II. The second experiment was designed to address Questions b and c of Section II.

The procedure common to both experiments was as follows. Each pilot subject was briefed before entering the simulator cockpit. After the briefing and while the pilot subject was buckling into the cockpit seat, the operator entered the pilot's identification code, task selection, and delay/no-delay control code into the simulator program. The operator then preset the simulated aircraft's position to a point in space associated with the selected task. The pilot at this time could see a visual display of an aircraft carrier as seen from 390 feet altitude, at a distance of one mile, and either 600 feet left of, 600 feet right of, or directly aligned with the center line of the carrier's angle deck, figures 10, 9, and 8 respectively. The simulated flight airspeed was set at 135 knots. When the pilot subject indicated he was ready, the operator released control of the simulator to the pilot. The pilot was then completely in control of the flight simulator. Recording of the pilot's flight control activity on magnetic tape began at the instant the operator released control to the pilot. The pilot was then required to fly the approach visually to the displayed carrier and attempt an arrestment. Automatic data recording every 50 ms on magnetic tape continued until the approach terminated with an arrestment, a bolter, a wave off, or a crash. Upon conclusion of the approach, the operator reset starting conditions as described previously so that the pilot could attempt another approach. The pilot subject continued making approaches in this fashion until successfully completing the established success criterion for the experiment. After successfully completing a task, the operator inserted appropriate task selection and delay codes into the program to set up the subsequent task.

EXPERIMENT 1

PROCEDURE. Twelve of the pilot subjects practiced each task until each was proficient in task performance. A pilot subject was considered to have learned a task if he made three successful arrestments in a row in that task. The dependent variable was number of trials to criterion performance for each task.

The tasks were always presented in the *a priori* order of difficulty, that is, Tasks A and B preceded Tasks C and D and the latter preceded Tasks E and F. Within this general order, however, the Delay vs No-Delay condition was interleaved so that one condition may not have an obvious advantage over the other due to "practice effects." The order in which the pilot subjects learned the tasks is summarized in table 2. Each pilot subject was assigned to a presentation order at random with the restriction that the last pilot subjects were assigned to orders to maintain the overall

Table 2. ORDER OF TASK PRESENTATION

PILOT SUBJECT I.D.	SEQUENCE NUMBER	TASK B D	TASK B ND	TASK A D	TASK A ND	TASK D D	TASK D ND	TASK C D	TASK C ND	TASK E D	TASK E ND	TASK F D	TASK F ND
1010	I	2			1		4	3			5	6	
2121	I	2			1		4	3			5	6	
6666	I	2			1		4	3			5	6	
1111	II		2	1		4			3	5			6
7070	II		2	1		4			3	5			6
5555	II		2	1		4			3	5			6
4444	III		1	2		3			4	6			5
9999	III		1	2		3			4	6			5
EEEE	III		1	2		3			4	6			5
3333	IV	1			2		3	4			6	5	
DDDD	IV	1			2		3	4			6	5	
AAAA	IV	1			2		3	4			6	5	

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balance in table 2. The numbers in the body of table 2 specify the order in which each pilot subject learned the tasks under the two (Delay/No-Delay) conditions.

Table 2 indicates that six pilot subjects learned Task B first, three in the Delay condition and three in the No-Delay condition. Those three that had learned Task B in the No Delay condition then learned Task A in the Delay condition. Those three that had learned Task B in the Delay condition then learned Task A in the No-Delay condition. The other six pilot subjects learned Task A first, three with No-Delay and three with Delay, and then learned Task B second with the conditions reversed. Tasks C and D, and then E and F were learned in the orders indicated in table 2. The pilot subjects were not informed of the Delay or No-Delay conditions.

Overall then, each of the twelve pilot subjects learned six tasks, two tasks at each of the three Difficulty levels, and at each Difficulty level, one under the No-Delay condition and one under the Delay condition. Each pilot subject was considered to have learned each task when he performed three successful entrapments in a row (successful performance). The dependent variable was the number of trials on each task required to reach successful performance.

DATA RECORDED. A log was kept of each pilot subject's carrier approach trials for each task and each delay condition. The log contained the results of each approach, i.e., trap, bolter, wave off, or crash. Figure 11 is a sample of the log.

The date, pilot identification code, and task sequence designation were recorded on each page of a subject's record. The approach trial number, the approach outcome (e.g., wave off, bolter, crash, or trap), the number of wire caught (wire 1 through 4), the task designation (tasks A through F, with indication of delay or no-delay), and remarks, as applicable, were recorded for each approach trial. The remarks column was intended primarily to note spontaneous, off-hand comments from the subject pilot that may have supported, or been relevant to, the analysis of the experiment.

As indicated in figure 11, a task was flown until the subject achieved three successive traps. The next task called for in the given pilot's task sequence was then set up. The subject continued in this fashion until completing all six tasks.

DATA ANALYSIS AND RESULTS. The analysis of variance model used in the data analysis is a special case of three-way classification mixed model in which the Delay/No-Delay condition and the Task conditions are fixed constants and the assignment of the pilot subjects was a random variable.[4]

[4]See McNamar, Quinn: Psychological Statistics, John Wiley & Sons, N.Y., N.Y., 1969, pp 364-371

Date: 10 June 1974 Pilot ID 1010 Sequence I

Approach	Bolter	Crash	Trap	Task	Remarks
1.			X	B(D)	1 MI on Center Fuel 6000
2.			X		
3.			X		
4.	X			A(ND)	1 MI 600' Right
5.			X		
6.			X		
7.			X		
8.			X	D(ND)	1 MI 600' Left
9.		X			
10.		X			
11.	X				
12.	X				
13.			X		
14.		X			
15.	X				
16.		X			
17.	X				
18.			X		
19.			X		
20.		X			
21.			X		
22.	X				
23.		X			
24.	X				
25.			X		
26.			X		
27.			X		
28.		X		C(D)	Center, Rough Air
29.			X		
30.		X			
31.			X		
32.	X				
33.			X		
34.			X		
35.			X		
36.					
37.					

Figure 11. Experiment Part 1, Sample Log

The results of the analysis of variance are presented in table 3. The main interest was testing for effects of the two manipulated variables (Delay/No-Delay and Task Difficulty) and their interaction. For the influence of the Delay/No-Delay condition on pilot subject performance, F = 0.53 which is obviously not significant. For the effect of Task Difficulty, F = 6.666 which is a statistically significant ratio (.05>p>.01, df = 2.22). The Delay by Task interaction, F = 0.89, is also not a significant result.[5] No further tests are available in this model.

The fact that task condition has a significant effect on pilot subjects' learning performance is not surprising. Recall that the Tasks were presented roughly in the order of difficulty that was agreed upon *a priori*. Thus, two factors influenced the pilot subjects' learning performance from task to task throughout the experiment. The first factor (task difficulty, presented in the order - relatively easy to difficult) tended to cause a greater number of trials-to-criterion to be required for the more difficult task. The second factor, practice effect, operated in the opposite direction and tended to cause fewer trials-to-criterion as time went by after longer practice. The effect of the first factor, difficulty (perhaps because the range was narrow), was overshadowed by the effect of the second factor, practice, and the general diminution of the trials-to-criterion on the latter tasks is evidenced by the significance of the Task factor in the analysis of variance.

Further evidence on this point is presented in table 4. Each average in table 4 is based on the performance of twelve pilots. The diminution of the average number of trials-to-criterion is especially noticed in progression from the least difficult to the moderately difficult tasks. Performance levels off thereafter so that the "most difficult" tasks were learned in approximately the same number of trials as were the "moderately difficult."

Within each "Difficulty" level, however, the differences between the Delay and the No-Delay conditions are of no statistical nor practical significance. The only possible exception from the practical point of view lies in the "Least Difficult" task level where the average number of trials-to-criterion was greater under the Delay conditions. This difference was due solely to the performance of one pilot who took 157 trials-to-criterion in the Delay condition (his first task) and then made only one subsequent error during the remainder of the experiment.

The main conclusion from this part of the study is that, overall, the introduction of a 100 ms delay in presentation of the visual information had no effect on the learning by the pilot subjects.

[5] For the choice of the error terms in these tests see McNamar, Quinn, ibid., pp 377-378.

Table 3. ANALYSIS OF VARIANCE FOR PERFORMANCE SCORES FOR 12 PILOT-SUBJECTS FOR TWO "DELAY" CONDITIONS AND THREE LEVELS OF TASK DIFFICULTY

SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	VARIANCE ESTIMATE	F RATIO
Delay (D)	234.72	1	234.72	0.53
Task (T)	4,649.69	2	2,324.85	6.66
Pilot-Subject	4,890.94	11	444.63	
Interaction				
D X T	852.03	2	426.02	0.89
D X S	4,884.95	11	444.09	
T X S	7,684.98	22	349.32	
D X T X S	10,537.30	22	478.97	
TOTAL	33,734.61	71		

Table 4. MEAN NUMBER OF TRIALS TO CRITERION

	TASKS A&B LEAST DIFFICULT	TASKS C&D MODERATELY DIFFICULT	TASKS E&F MOST DIFFICULT
No Delay	20.8	11.0	11.2
Delay	34.2	9.4	10.3
Both	27.5	10.2	10.7

EXPERIMENT 2

PROCEDURE. All pilot subjects were quite proficient after completion of Experiment 1. The flight tasks and operating procedures were familiar to them at the beginning of Experiment 2.

The object of Experiment 2 was to record, for later analysis, each pilot subject's flight control activity while flying assigned carrier approaches with and without the delay condition. Twelve pilots completed these tasks. Task B, an easy task, Task D, a moderately difficult task, and Task F, a difficult task used in Experiment 1 were chosen for use in Experiment 2.

It was found to be convenient to refer to Tasks D, B and F as Left, Center and Right Tasks, respectively, each with Delay (D) and with No-Delay (ND). Subsequent references to tasks will be made in this manner.

Experiment 2 required each pilot subject to make five successful arrestments for each of the Left, Center, and Right Tasks with and without the delay condition. This resulted in a total of 30 successful arrestments required of each pilot subject. Successive arrestments were not required. Typically, a subject would make 40 to 60 approach attempts in achieving 30 successful traps. The pilot's control activity was recorded on magnetic tape during all of his approaches, however, only that recorded during successful approaches, i.e., resulting in arrestment, were subjected to later analysis. The sequence of tasks flown by each pilot subject was identical. The sequence was as follows:

(1) C (D) - Center with Delay

(2) L (ND) - Left with No-Delay

(3) R (ND) - Right with No-Delay

(4) L (D) - Left with Delay

(5) R (D) - Right with Delay

(6) C (ND) - Center with No-Delay

DATA RECORDED. Six (6) pilot control parameters were recorded on magnetic tape each program cycle. These are:

DDS - Stabilator Control Stick Deflection

DSA - Aileron Control Stick Deflection

DRP - Rudder Pedal Deflection

FSSA - Force Applied to Stabilator Control Stick

FSAA - Force Applied to Aileron Control Stick

FRPA - Force Applied to Rudder Pedal

The three parts of figure 12 are time histories of the six parameters recorded during an approach by one of the pilot subjects. These plots are typical of all approaches made by all pilot subjects.

DATA ANALYSIS- VARIANCES IN CONTROL FORCES AND DISPLACEMENTS. The first step in the analysis of variance was to compute the means and variances of each of the six control parameters (DSS, FSSA, DSA, FSAA, DRP, FRPA) recorded for each successful carrier approach made during the experiment. The results of these calculations were recorded on magnetic tape and were listed.

The next step in the analysis of Experiment 2 data was to average the five values of variance for the five successful approaches of a given task (Left, Center or Right, Delay or No-Delay) for each of the six control parameters (DSS, FSSA, DSA ..., FRPA). To aid in explaining this and subsequent steps in the process followed in analyzing the data, consider the three dimensional model shown in figure 13. Figure 13 is a sample model structure of one of a typical recorded control parameter. Each cell indicated on the model represents the average variance of the given control parameter taken over five successful approaches by one of twelve pilot subjects, flying one of three basic approach tasks (Left, Center, Right) with one of two visual presentation time delay conditions (Delay or No-Delay). For example, the upper left-hand cell entry shown on figure 13 represents the average of the variances in a variable for five successful approaches made by one pilot subject for the left task with delayed visual presentation. Table 5 contains the computed average variance values for each of the six control variables (DSS, FSSA, ..., FRPA) for each pilot subject (12 pilots) for each task (Left, Center, and Right) for the two delay conditions (Delay or No-Delay).

At this point, it is important to draw attention to what may be subtle enough to confuse. Note that the analysis discussed in the remainder of this section is an analysis of variance in variances.

An Average of Statistics program, figure 14 (4 parts), calculated an average variance for each cell of the model. The same program was used to compute the average variance of the variances of each control parameter for all pilot subjects in each of the three tasks (Left, Center, Right) with and without delay. The results are summarized in figures 15, 16, and 17.

Since the entries in cells are the average variance in the control parameters for a specific pilot and flight condition, the differences in these entries represent the effect of the flight conditions on the manner in which pilots exercise their piloting skills.

The results of averaging the cell entries, shown in figure 13, over all pilot subjects are given in tables 6, 7, and 8, and are plotted in figures 15, 16, and 17. Notice that for all three starting positions the delayed visual task had greater variance than the non-delayed for the following parameters: longitudinal control deflection (DSS), lateral control deflection (DSA) and lateral control force (FSAA). In fact, in only four of the eighteen comparisons of variance (Left, Center and Right

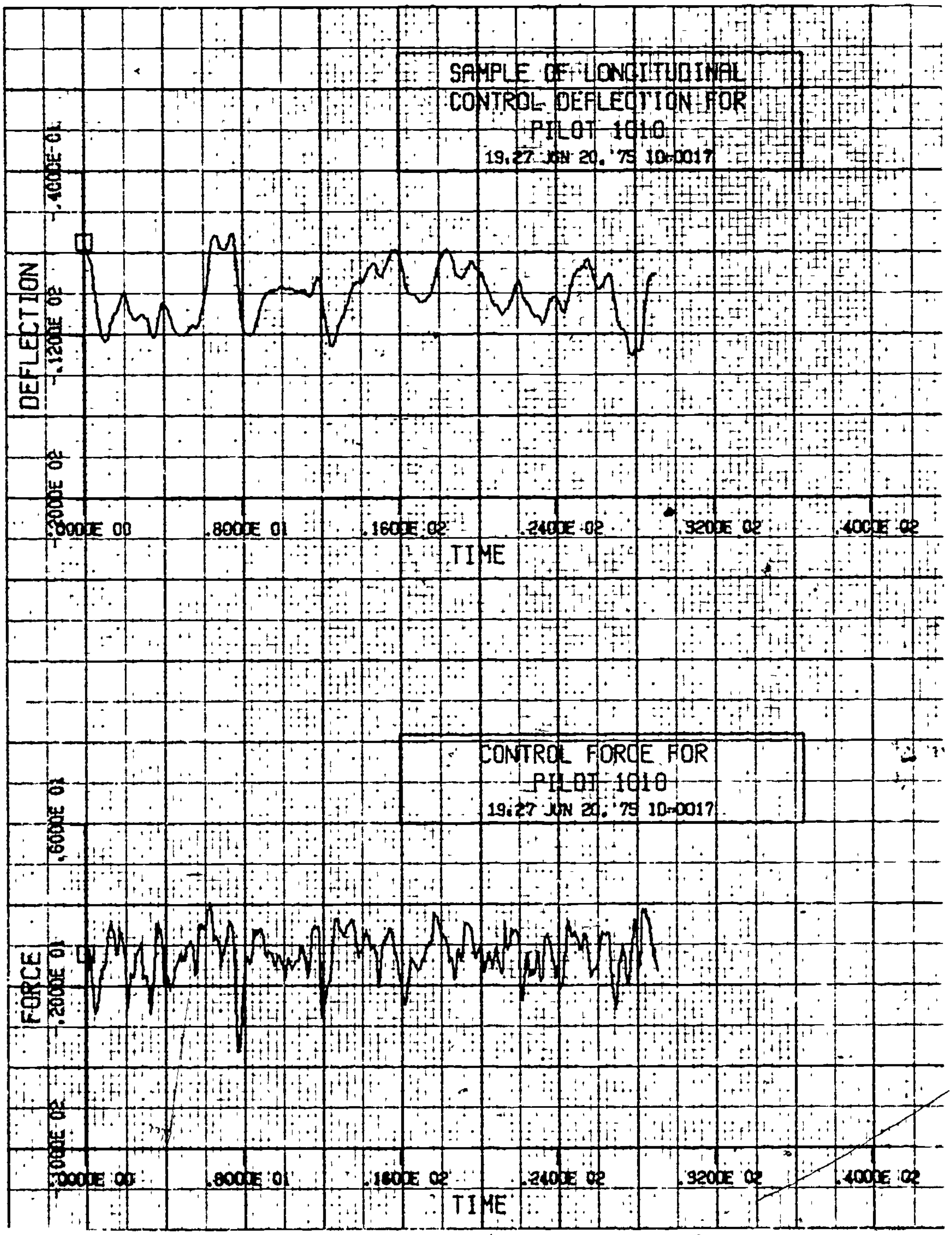

Figure 12. Sample Time History (Longitudinal)

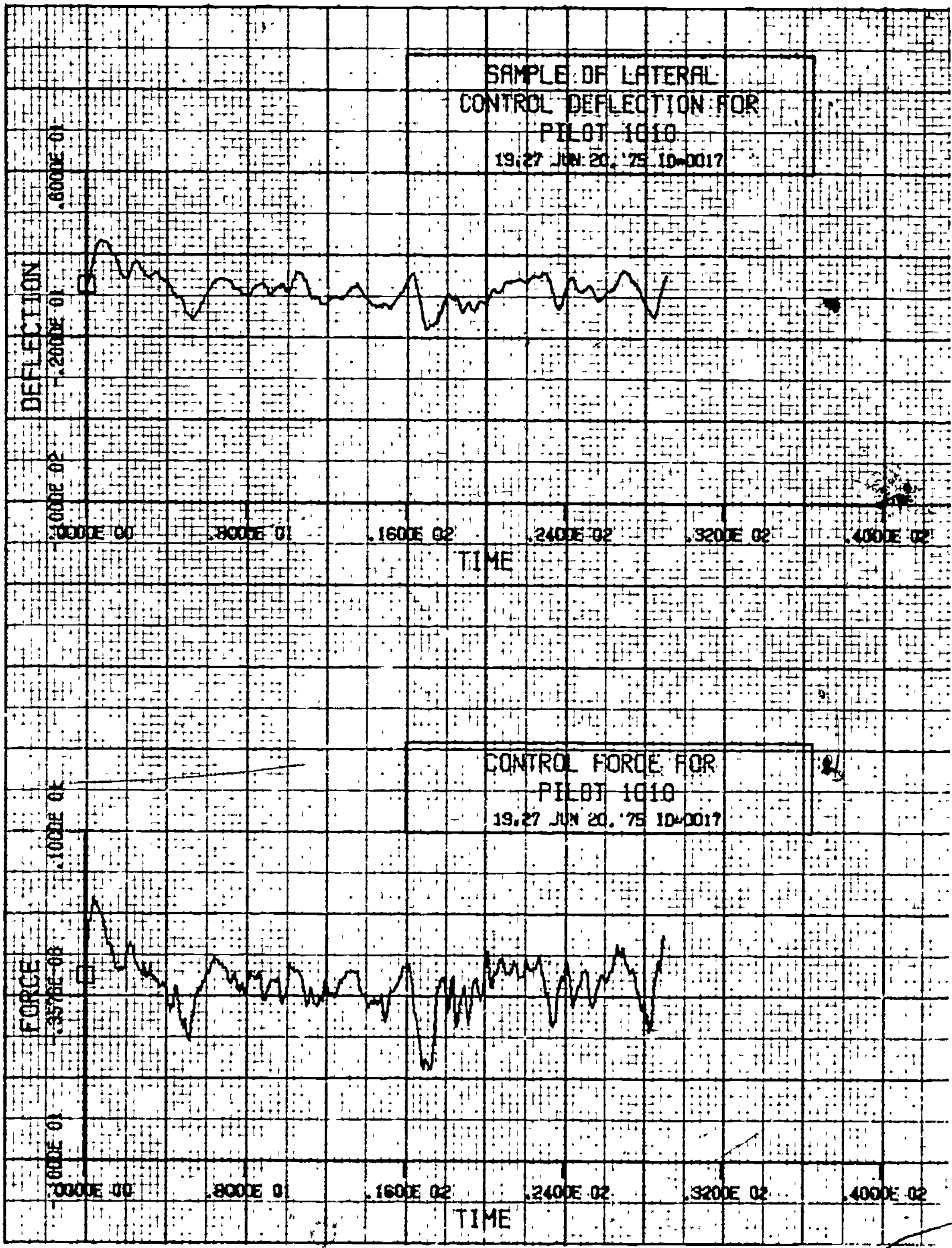

Figure 12. Sample Time History (Lateral) (CONT)

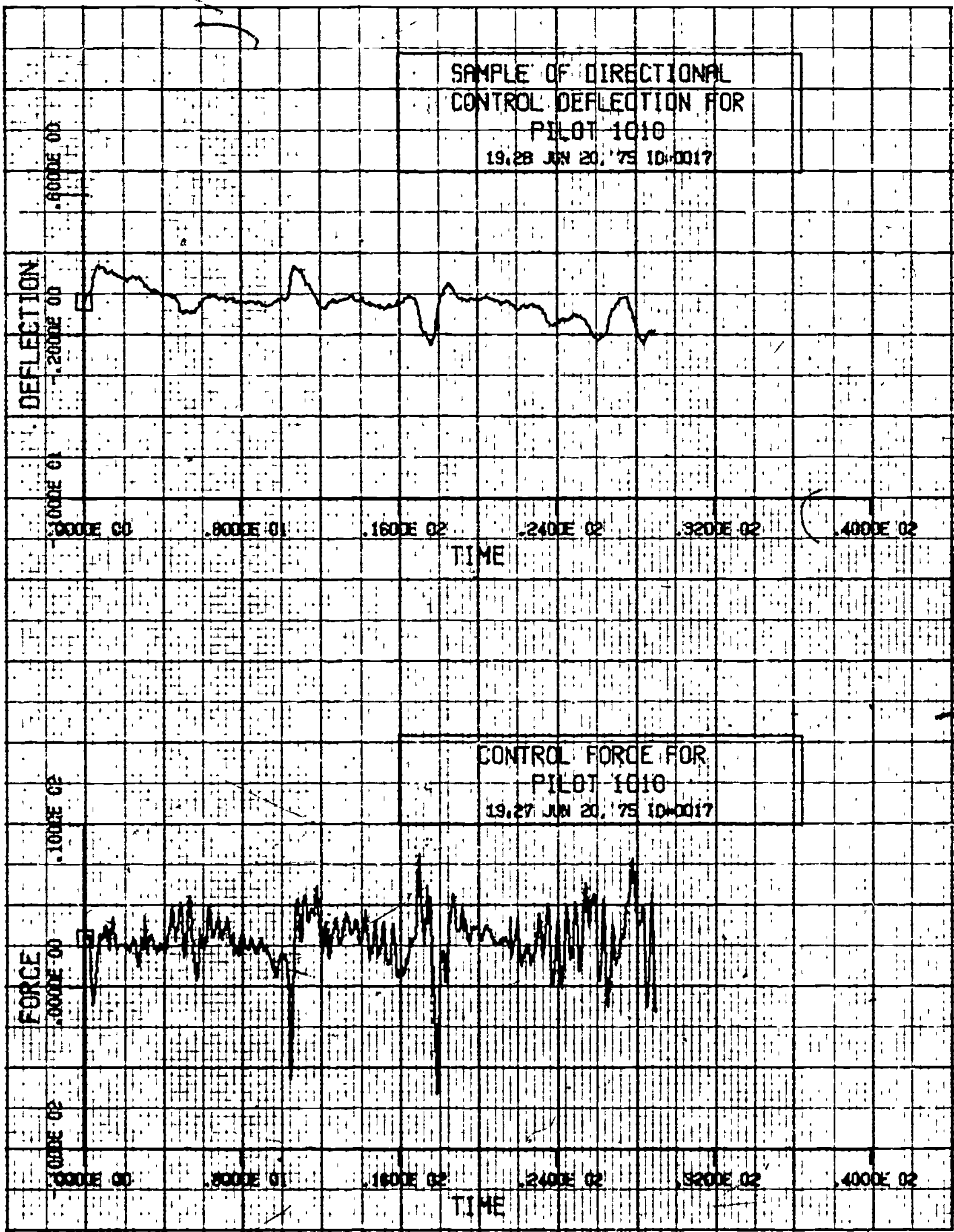

Figure 12. Sample Time History (Directional) (CONT)

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Longitudinal Control Deflection (DSS)

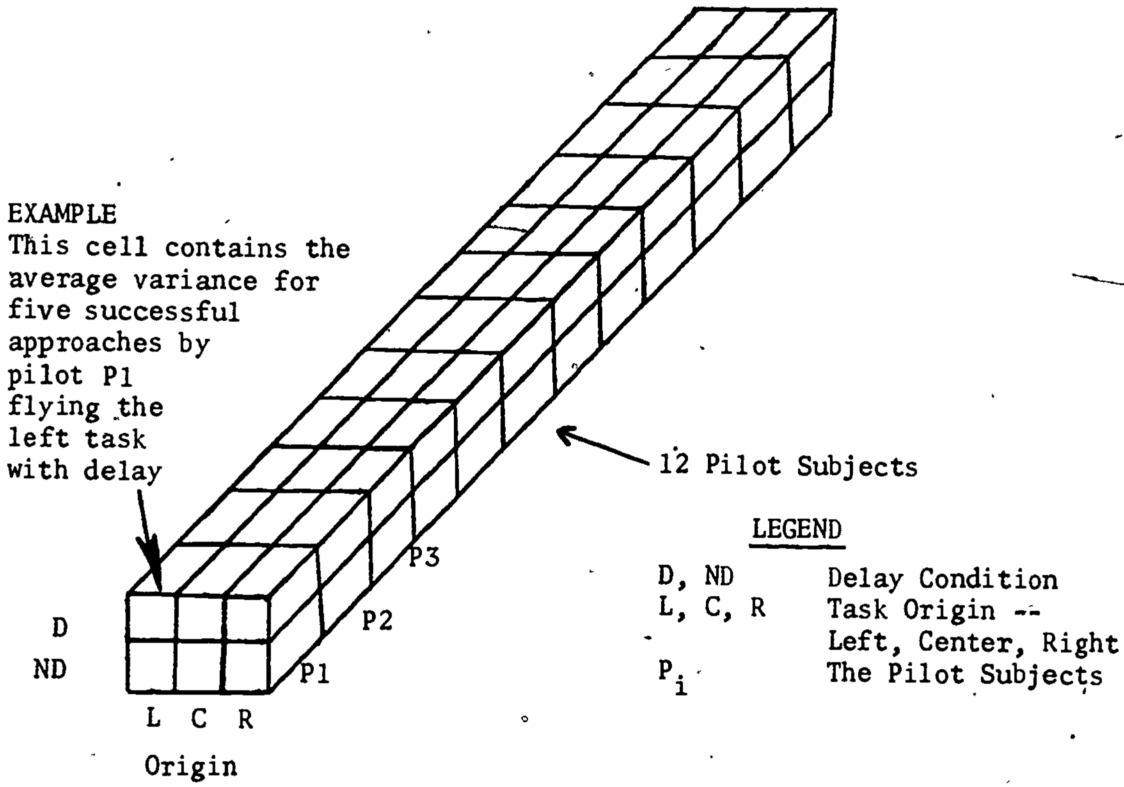

Figure 13. Analysis of Variance Model Sample, Experiment Part 2

TABLE 5

PILOT SUBJECT AVERAGE VARIANCE
BY TASK, DELAY AND
CONTROL PARAMETERS

PILOT CODE	DELAY OR NO DELAY	AVERAGE VARIANCE LEFT	CENTER	RIGHT	PARAMETER
AAAA	D	1.79549	.47004	1.02865	DSS
AAAA	ND	.73351	.74278	.69769	DSS
DDDD	D	1.35142	.61510	1.40882	DSS
DDDD	ND	1.32648	1.34906	1.87705	DSS
EEEE	D	2.02129	.96918	3.40512	DSS
EEEE	ND	1.75535	.74058	2.07053	DSS
1010	D	1.29266	.63332	1.81826	DSS
1010	ND	1.05626	.76829	1.44591	DSS
2020	D	1.24214	1.13251	1.51636	DSS
2020	ND	.77980	.71921	2.29756	DSS
3333	D	1.12134	.79752	1.60450	DSS
3333	ND	1.04482	.45345	1.09790	DSS
2121	D	1.34445	1.01772	1.46072	DSS
2121	ND	1.26780	1.18925	2.39694	DSS
3030	D	.95005	.55928	1.41465	DSS
3030	ND	.85852	.37598	1.38624	DSS
4444	D	1.56314	3.15023	2.07885	DSS
4444	ND	2.26062	.50685	2.49766	DSS
5555	D	2.14684	.92066	.97841	DSS
5555	ND	1.69141	.98044	1.16494	DSS
6666	D	1.36420	2.19783	2.69249	DSS
6666	ND	1.27649	2.58591	2.24018	DSS
9999	D	.68824	.76724	.88086	DSS
9999	ND	1.18478	1.56636	.50832	DSS
AAAA	D	.98797	.68062	1.91662	FSSA
AAAA	ND	.75771	.94036	2.03897	FSSA
DDDD	D	.60775	.46503	.98656	FSSA
DDDD	ND	.65372	.63657	1.42301	FSSA
EEEE	D	1.09655	.95884	3.15772	FSSA
EEEE	ND	1.31048	.58176	2.33103	FSSA

TABLE 5 (CONT)

PILOT SUBJECT AVERAGE VARIANCE
BY TASK, DELAY AND
CONTROL PARAMETERS

PILOT CODE	DELAY OR NO DELAY	AVERAGE VARIANCE LEFT	CENTER	RIGHT	PARAMETER
1010	D	.62122	.51924	1.38129	FSSA
1010	ND	.61950	.46303	1.54758	FSSA
2020	D	.85058	1.49083	1.38756	FSSA
2020	ND	.71787	.58641	3.04751	FSSA
2121	D	.62951	.34999	.77852	FSSA
2121	ND	.54690	.27284	.91618	FSSA
3030	D	.82738	.71748	1.77233	FSSA
3030	ND	.81291	.46073	1.87121	FSSA
3333	D	.88782	.66710	1.84463	FSSA
3333	ND	.73936	.35880	1.02932	FSSA
4444	D	.93118	2.01811	1.39633	FSSA
4444	ND	1.64432	.44698	2.26562	FSSA
5555	D	1.16170	.66272	1.06948	FSSA
5555	ND	.84389	.53764	1.19831	FSSA
6666	D	1.07044	1.36543	2.19842	FSSA
6666	ND	.75133	1.27535	2.45267	FSSA
9999	D	.59769	.76084	1.19169	FSSA
9999	ND	.66211	.33515	.96243	FSSA
AAAA	D	1.97776	.36394	1.83983	DSA
AAAA	ND	2.35853	.18444	1.84610	DSA
DDDD	D	1.59281	.25501	1.77968	DSA
DDDD	ND	1.46045	.08837	1.24926	DSA
EEEE	D	1.34147	.25549	2.08146	DSA
EEEE	ND	1.32301	.09409	1.40155	DSA
1010	D	2.08590	.08501	3.40622	DSA
1010	ND	1.60034	.32100	2.51206	DSA
2020	D	1.64234	.32596	1.54867	DSA
2020	ND	.87779	.17638	1.79266	DSA
2121	D	1.47694	.06181	.79037	DSA
2121	ND	1.13744	.07705	.59372	DSA

TABLE 5 (CONT)

PILOT SUBJECT AVERAGE VARIANCE
BY TASK, DELAY AND
CONTROL PARAMETERS

PILOT CODE	DELAY OR NO DELAY	AVERAGE VARIANCE LEFT	CENTER	RIGHT	PARAMETER
3030	D	.61606	.12407	1.11321	DSA
3030	ND	.45128	.07605	.99740	DSA
3333	D	2.96739	.97257	4.36092	DSA
3333	ND	2.63645	.10219	2.60337	DSA
4444	D	.81062	.15485	1.06539	DSA
4444	ND	.77929	.10321	.93032	DSA
5555	D	2.92754	.48891	2.98728	DSA
5555	ND	2.72424	.38583	2.24545	DSA
6666	D	1.47121	.55691	1.83386	DSA
6666	ND	1.24865	.56519	2.19428	DSA
9999	D	1.27997	.23360	1.12737	DSA
9999	ND	.77931	.24390	.73552	DSA
AAAA	D	.09632	.02950	.10315	FSAA
AAAA	ND	.11475	.01565	.11719	FSAA
DDDD	D	.04998	.01294	.07455	FSAA
DDDD	ND	.05123	.00366	.06062	FSAA
EEEE	D	.05434	.00916	.10348	FSAA
EEEE	ND	.05440	.00329	.08170	FSAA
1010	D	.09776	.00965	.16201	FSAA
1010	ND	.08043	.02168	.13331	FSAA
2020	D	.06835	.01410	.06051	FSAA
2020	ND	.03337	.00669	.09268	FSAA
2121	D	.07135	.00498	.04314	FSAA
2121	ND	.06586	.00313	.03407	FSAA
3030	D	.01900	.00560	.04682	FSAA
3030	ND	.01490	.00338	.04652	FSAA
3333	D	.13739	.04865	.20382	FSAA
3333	ND	.12144	.01173	.12710	FSAA
4444	D	.02514	.00899	.04942	FSAA
4444	ND	.02625	.00374	.04477	FSAA

TABLE 5 (CONT)

PILOT SUBJECT AVERAGE VARIANCE
BY TASK, DELAY AND
CONTROL PARAMETERS

PILOT CODE	DELAY OR NO DELAY	AVERAGE VARIANCE LEFT	CENTER	RIGHT	PARAMETER
5555	D	.13377	.03065	.15858	FSAA
5555	ND	.11940	.02252	.12288	FSAA
6666	D	.05965	.02991	.10222	FSAA
6666	ND	.05698	.03801	.11338	FSAA
9999	D	.07210	.01982	.07731	FSAA
9999	ND	.05316	.01786	.06365	FSAA
AAAA	D	.00466	.00132	.00327	DRP
AAAA	ND	.00271	.00107	.00338	DRP
DDDD	D	.00030	.00047	.00042	DRP
DDDD	ND	.00040	.00030	.00040	DRP
EEEE	D	.00732	.00263	.01003	DRP
EEEE	ND	.01148	.00049	.01080	DRP
1010	D	.05384	.00121	.06762	DRP
1010	ND	.04678	.00643	.04623	DRP
2020	D	.03182	.00120	.05038	DRP
2020	ND	.01119	.00163	.01839	DRP
2121	D	.04752	.00123	.01249	DRP
2121	ND	.07009	.00217	.02113	DRP
3030	D	.02145	.00639	.03259	DRP
3030	ND	.02019	.00377	.04126	DRP
3333	D	.00181	.00021	.00157	DRP
3333	ND	.00097	.00101	.01463	DRP
4444	D	.00879	.00082	.00558	DRP
4444	ND	.00830	.00051	.01207	DRP
5555	D	.00261	.00035	.00128	DRP
5555	ND	.00161	.00070	.00173	DRP
6666	D	.04344	.00190	.05229	DRP
6666	ND	.02510	.02437	.04510	DRP
9999	D	.07378	.00270	.02514	DRP
9999	ND	.03750	.01150	.03298	DRP

TABLE 5 (CONT)

PILOT SUBJECT AVERAGE VARIANCE
BY TASK, DELAY AND
CONTROL PARAMETERS

PILOT CODE	DELAY OR NO DELAY	AVERAGE VARIANCE LEFT	CENTER	RIGHT	PARAMETER
AAAA	D	1.85349	1.92938	3.77790	FRPA
AAAA	ND	1.05358	2.13049	3.98979	FRPA
DDDD	D	.39132	.29441	1.04083	FRPA
DDDD	ND	.94108	.31726	.50718	FRPA
EEEE	D	1.41365	.76066	2.64650	FRPA
EEEE	ND	4.94633	.26100	3.13841	FRPA
1010	D	5.00461	.32454	7.74743	FRPA
1010	ND	2.71575	1.76732	5.40544	FRPA
2020	D	3.27354	.83384	4.59249	FRPA
2020	ND	1.79528	.86144	4.21057	FRPA
2121	D	3.81890	.93259	5.41606	FRPA
2121	ND	9.38484	.93558	12.36712	FRPA
3030	D	8.98165	5.20424	18.69986	FRPA
3030	ND	10.17906	2.56332	30.16136	FRPA
3333	D	1.53074	.35595	1.26641	FRPA
3333	ND	.47149	.73860	2.50758	FRPA
4444	D	1.45813	.46640	1.75607	FRPA
4444	ND	1.41689	.48263	4.77768	FRPA
5555	D	.44855	.24418	.74423	FRPA
5555	ND	.40873	.29296	.47750	FRPA
6666	D	8.00043	1.43678	19.17819	FRPA
6666	ND	.91654	12.32790	11.41264	FRPA
9999	D	18.68991	1.43205	11.75544	FRPA
9999	ND	5.75441	7.66180	12.90260	FRPA

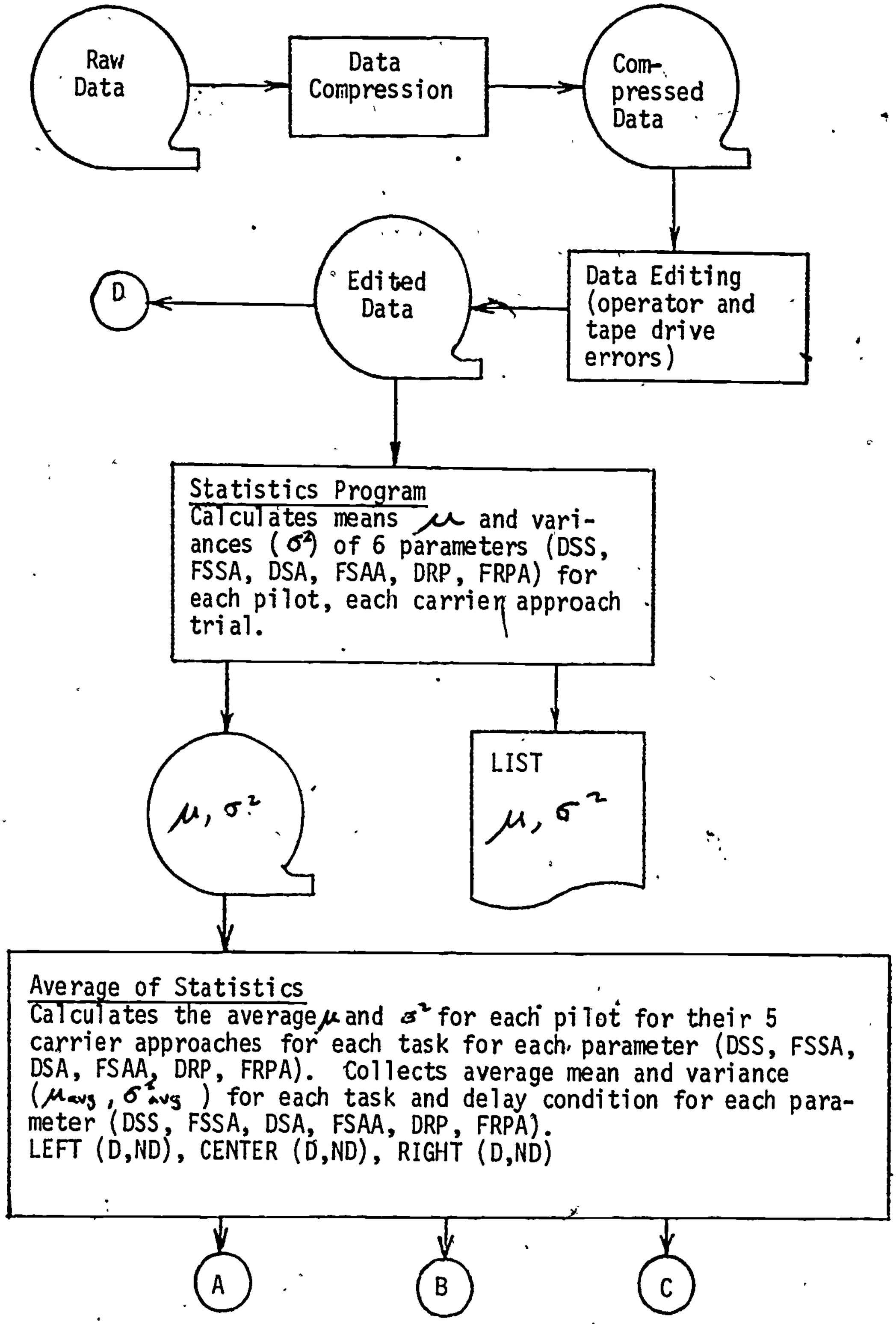

Figure 14. Flow Diagram of Experiment Part 2 Data Processing

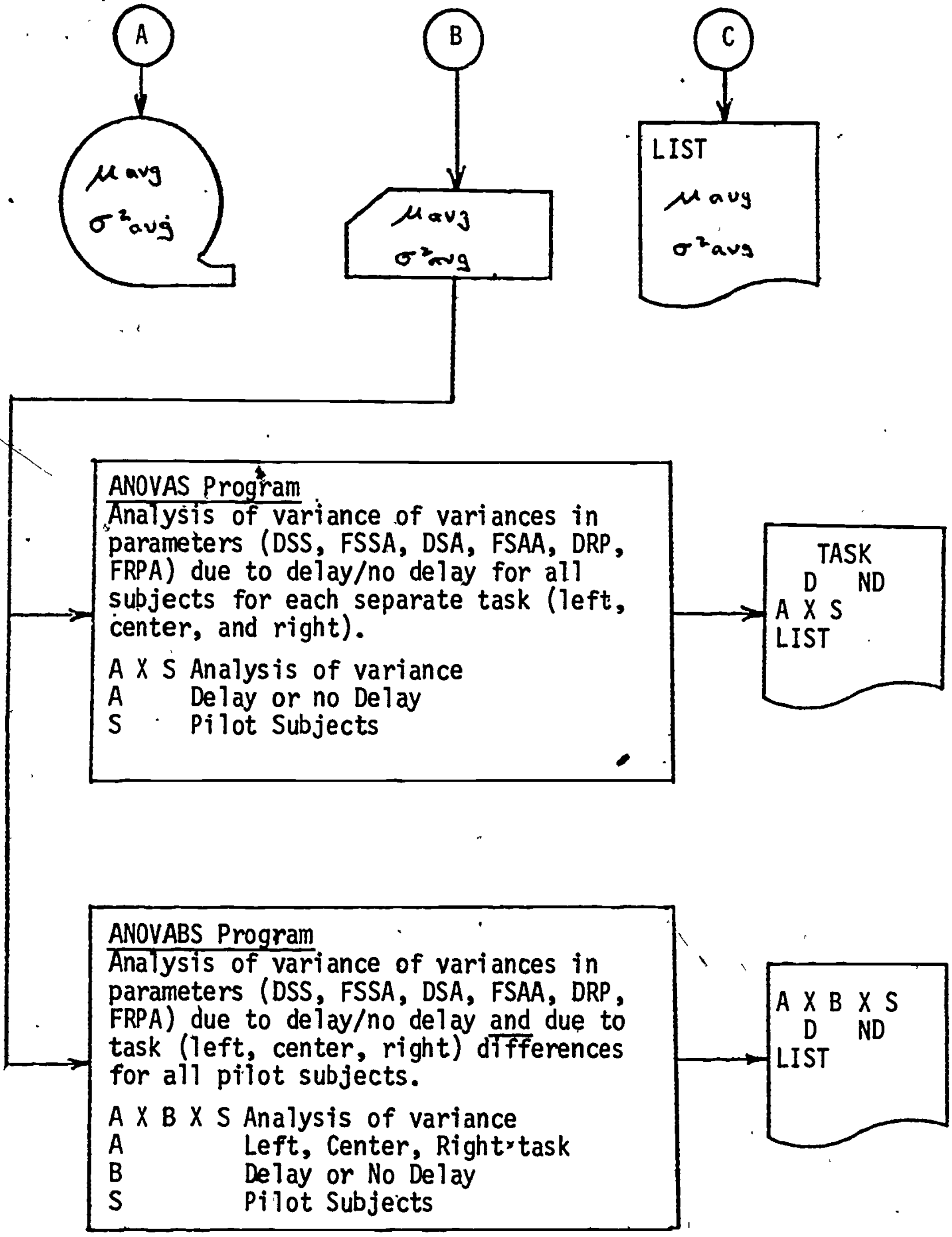

Figure 14. Flow Diagram of Experiment Part 2
Data Processing (CONT)

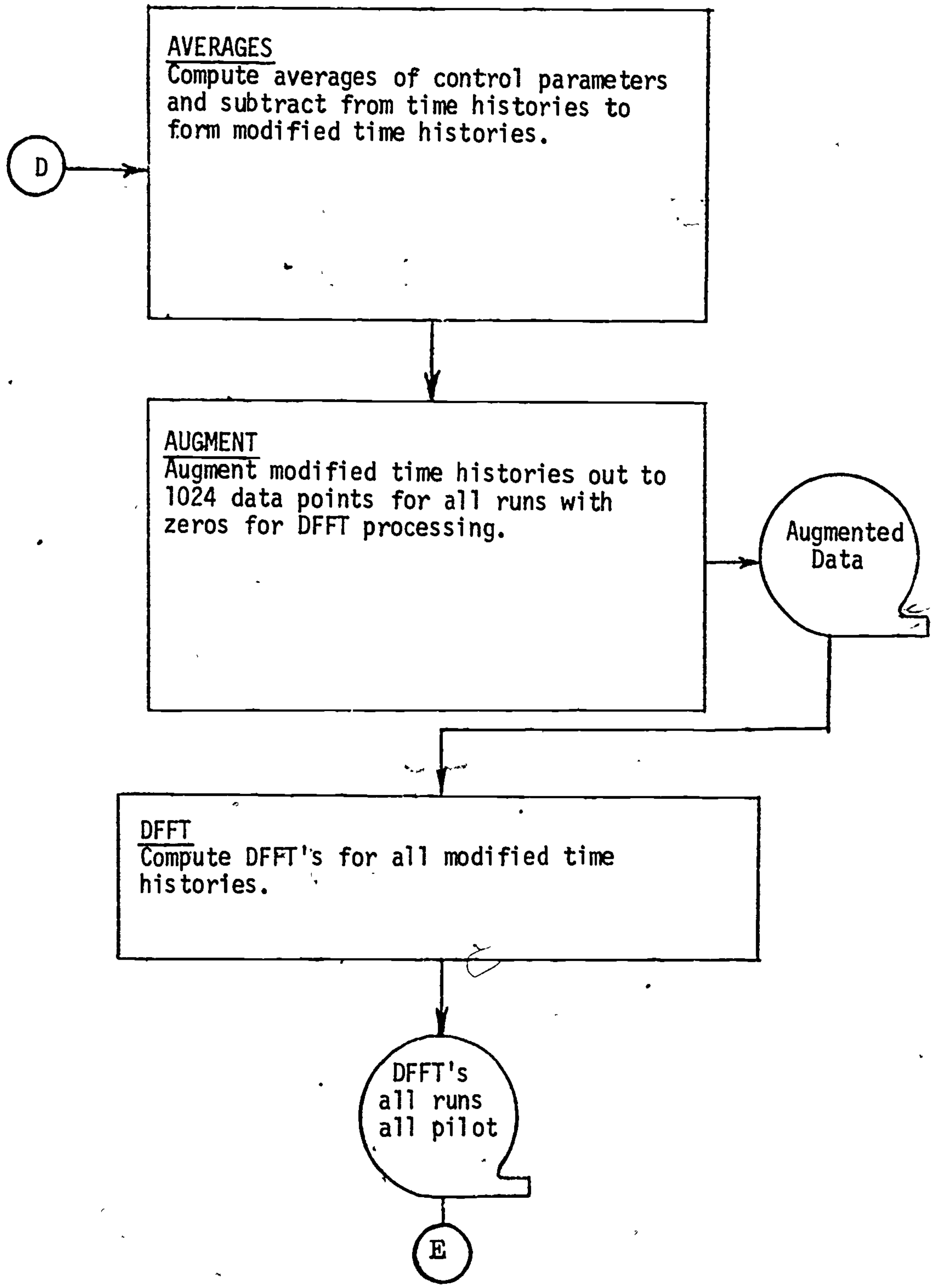

Figure 14. Flow Diagram of Experiment Part 2 Data Processing (CONT)

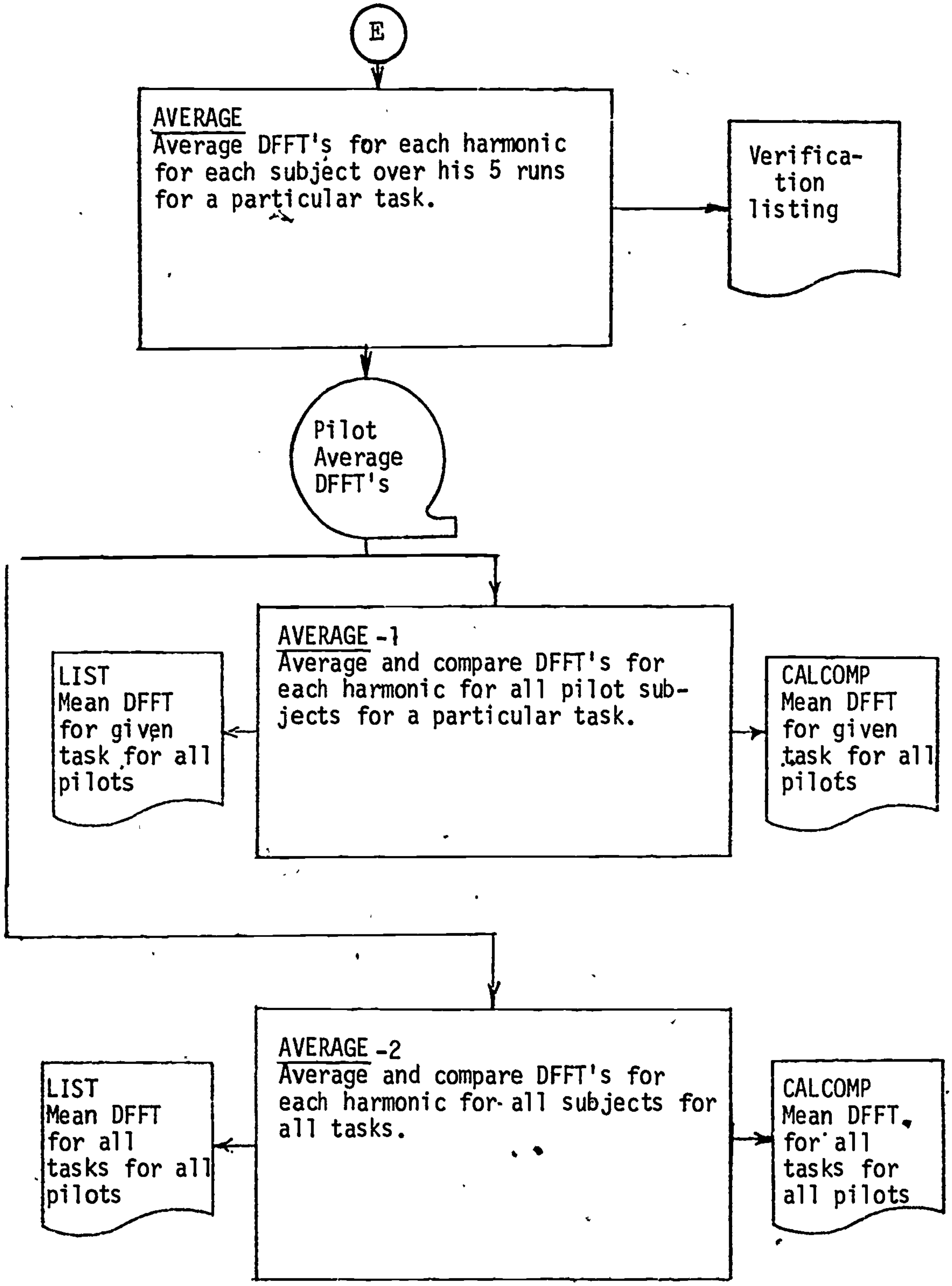

Figure 14. Flow Diagram of Experiment Part 2 Data Processing (CONT)

Table 6. STATISTICAL SUMMARIES LONGITUDINAL AVERAGE VARIANCES-12 SUBJECTS

DISPLACEMENT (DSS)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	1.4068	1.1192	1.6906	1.4055
NO DELAY	1.2698	1.0398	1.6401	1.3166
COLUMN MEANS	1.3383	1.0795	1.6654	

F_{Task} = 6.2534**
P_{Task} = .0072
F_{Delay} = .8934
P_{Delay} = .3674
$F_{Task\ X\ Delay}$ = .0428
$P_{Task\ X\ Delay}$ = .9585

FORCE (FSSA)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	.8546	.8666	1.5983	1.1065
NO DELAY	.8395	.6460	1.7487	1.0781
COLUMN MEANS	.8471	.7563	1.6735	

F_{Task} = 39.7728**
P_{Task} = .0000
F_{Delay} = .1210
P_{Delay} = .7332
$F_{Task\ X\ Delay}$ = 1.0796
$P_{Task\ X\ Delay}$ = .3582

* STATISTICALLY SIGNIFICANT AT .05 LEVEL

** STATISTICALLY SIGNIFICANT AT .01 LEVEL

Table 7. STATISTICAL SUMMARIES LATERAL AVERAGE VARIANCES-12 SUBJECTS

DISPLACEMENT (DSA)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	1.6824	.3232	1.9945	1.3334
NO DELAY	1.4481	.2015	1.5918	1.0804
COLUMN MEANS	1.5652	.2623	1.7932	

F_{Task} = 40.5225**
P_{Task} = .0000
F_{Delay} = 10.2748**
P_{Delay} = .0083
$F_{Task\ X\ Delay}$ = 1.8443
$P_{Task\ X\ Delay}$ = .1804

FORCE (FSAA)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	.0738	.0187	.0988	.0637
NO DELAY	.0660	.0126	.0865	.0550
COLUMN MEANS	.0699	.0156	.0926	

F_{Task} = 42.6083**
P_{Task} = .0000
F_{Delay} = 5.3550*
P_{Delay} = .0392
$F_{Task\ X\ Delay}$ = .4156
$P_{Task\ X\ Delay}$ = .6701

* STATISTICALLY SIGNIFICANT AT .05 LEVEL

** STATISTICALLY SIGNIFICANT AT .01 LEVEL

Table 8. STATISTICAL SUMMARIES DIRECTIONAL AVERAGE VARIANCES-12 SUBJECTS

DISPLACEMENT (DRP)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	.0248	.0017	.0219	.0161
NO DELAY	.0197	.0045	.0207	.0150
COLUMN MEANS	.0222	.0031	.0213	

F_{Task} = 8.4328**
P_{Task} = .0022
F_{Delay} = .3393
P_{Delay} = .5775
$F_{Task\ X\ Delay}$ = 1.2694
$P_{Task\ X\ Delay}$ = .3007

FORCE (FRPA)

	LEFT	CENTER	RIGHT	ROW MEANS
DELAY	4.5721	1.1846	6.5518	4.1028
NO DELAY	3.3319	2.5284	7.6548	4.5055
COLUMN MEANS	3.9520	1.8565	7.1033	

F_{Task} = 8.0062**
P_{Task} = .0028
F_{Delay} = .5977
P_{Delay} = .4613
$F_{Task\ X\ Delay}$ = 1.0052
$P_{Task\ X\ Delay}$ = .3839

* STATISTICALLY SIGNIFICANT AT .05 LEVEL

** STATISTICALLY SIGNIFICANT AT .01 LEVEL

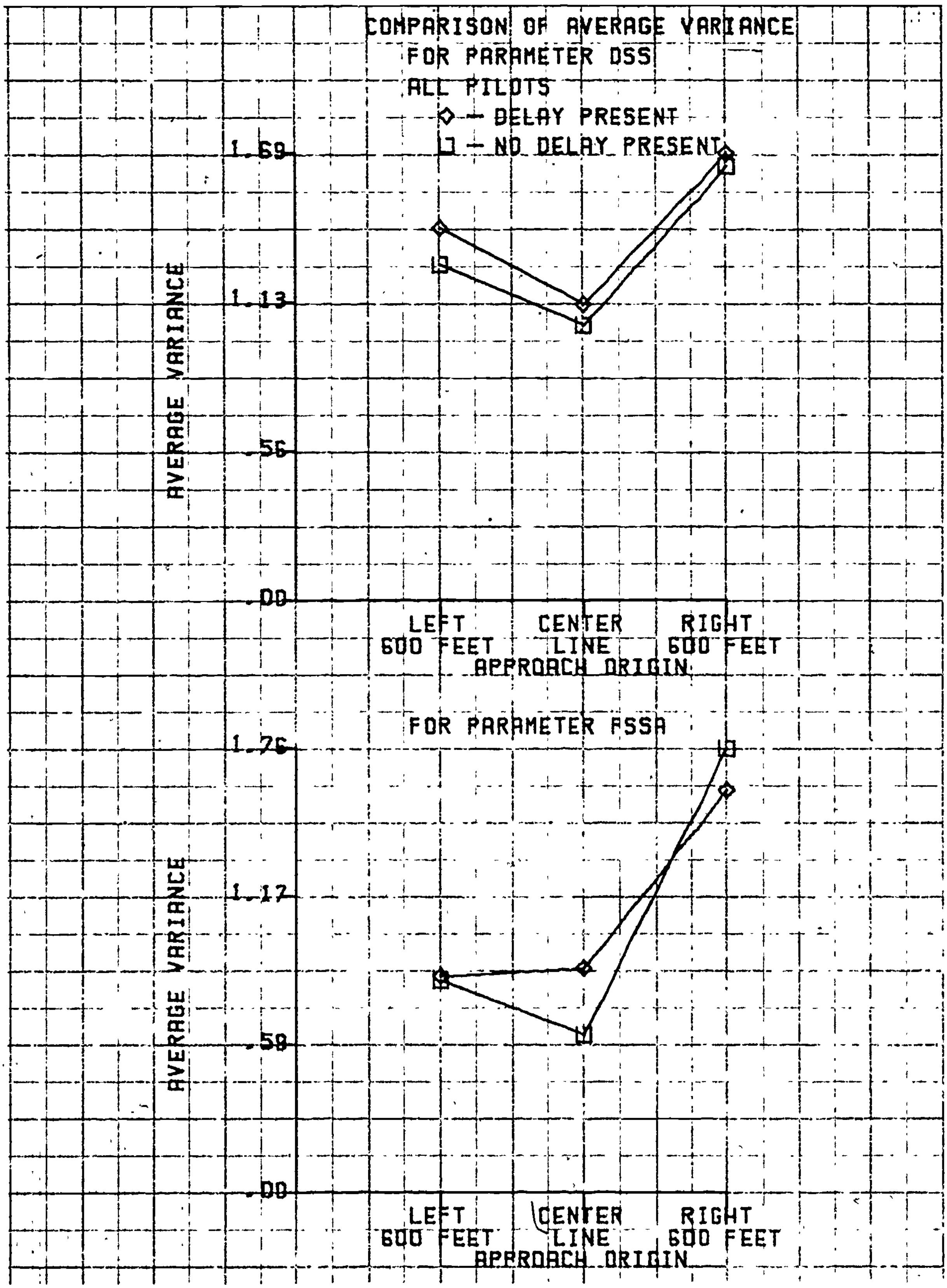

Figure 15. Comparison of Variances - Longitudinal

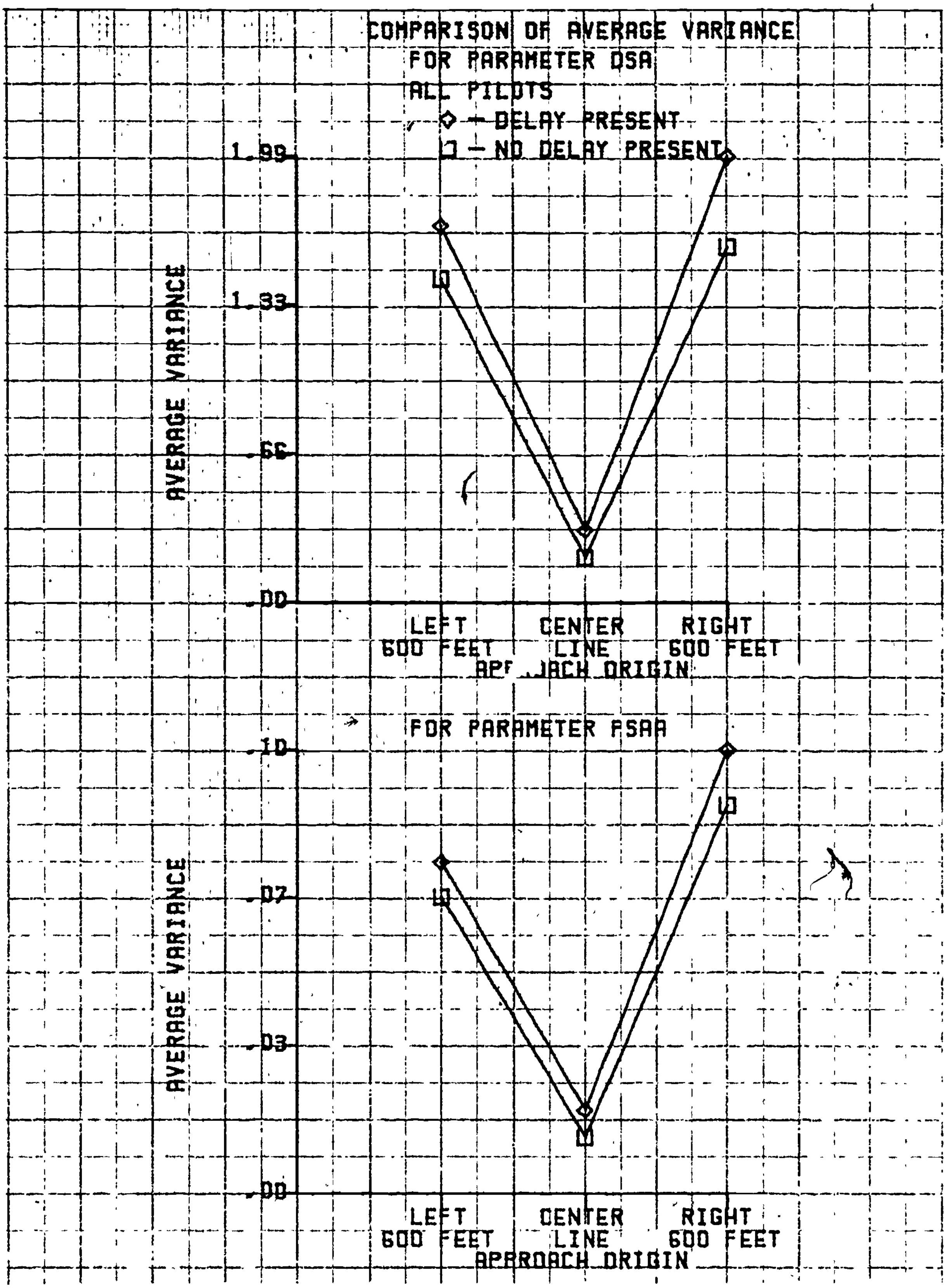

Figure 16. Comparison of Variances - Lateral

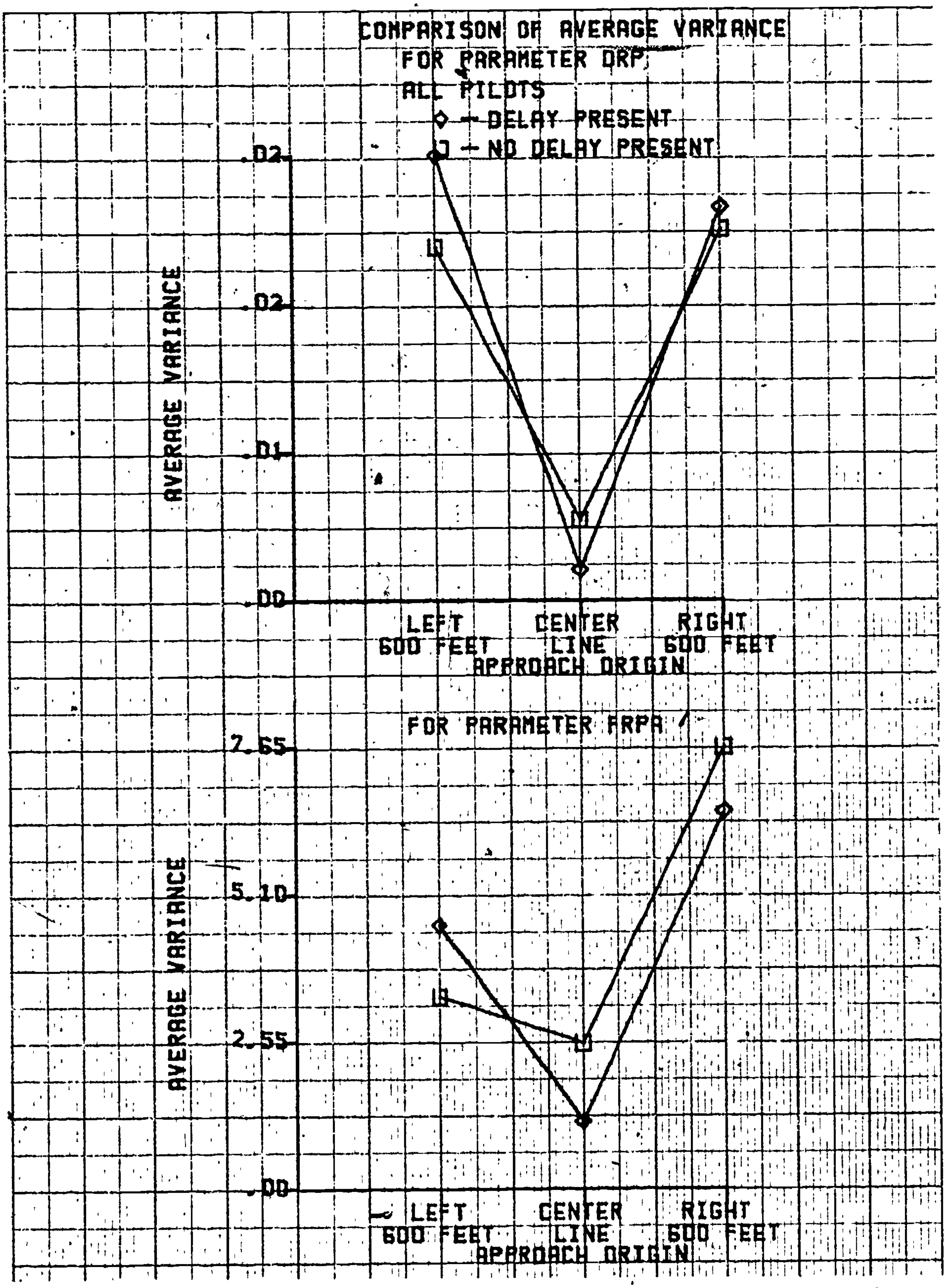

Figure 17. Comparison of Variances - Directional

Tasks for six control parameters) did the non-delayed variance exceed the delayed variance. Of these, three were for the rudder control variables (Center Task, rudder pedal deflection (DRP) and Center and Right Tasks, rudder control force (FRPA)).

There is some chance that the differences in average variance observed between the different conditions are due to chance or happenstance. One accepted method for determining the probability that the observed phenomena are due to chance is known as the multivariate analysis of variance. Therefore, a multivariate analysis of variance in the average variances of the six control parameters was performed to determine statistical significance of the differences in average variance of the control parameters due to both the task and the delay factors. For our purposes, two levels of statistical significance are considered and are defined to be those situations in which the F ratios[6] resulting from delay effects being due to chance, are less than .05 or less than .01.

The analysis of variance program was obtained from what is known as VUL2, the Vanderbilt Statistical Package[7], written by Dr. Laird W. Heal. The program, called ANOVABS (figure 14, part 2), calculates an analysis of variance with two "within" factors, or repeated measures.

The differences in variances of the control inputs (DSS, FSSA, DSA, FSAA, DRP, FRPA) for the two basic conditions of Delayed and Non-Delayed visual presentation are shown in figures 15, 16, and 17. The results of the multivariate analysis on the differences are presented in tables 6, 7, and 8. The F ratios for the task origins are statistically significant for all tasks. This indicates that all of the observed control parameters were exercised differently for each task. This is not surprising since the tasks are all different. The center task required the fewest control manipulations of the three tasks. The principal difference in left and right task was the addition of the turbulent air variable to the right task. The F ratio based on the differences of variances due to delayed or non-delayed visual presentation for the lateral control parameter is statistically significant at P = .0083 for the lateral control deflection and at P = .0392 for the lateral control force.

FOURIER ANALYSIS OF CONTROL INPUTS. The question "If pilots do perform their skills differently when visual stimuli are delayed 100 ms, in what way(s) is their performance different?" is difficult to answer by examining the time histories of the pilot's control activity. One time history appears

[6] Mendenhall, William, "Introduction to Probability and Statistics", Third Edition, Duxbury Press, pp. 243f.

[7] Heal, Laird W., "VUL2 Vanderbilt Statistical Package", Xerox Computer Users' Group Exchange Program Library, Catalog No. 890400-11B00.

much the same as another and in particular, the time histories for the Delayed and Non-Delayed cases also appear to be very similar. The results of the multivariate analysis of variance in Control Forces and Displacements, indicate that clear differences exist in the variances of the various control parameters, but not what the nature of those differences might be. One method of examining time histories is to investigate their frequency content. The time histories were mapped into the frequency domain to better evaluate the exact nature of the differences which occur in piloting technique when the pilot subject's visual stimuli have been delayed. The Fourier transformation to the frequency domain was accomplished by using a published program package.[8]

The Discrete Fast Fourier Transform (DFFT) is one convenient tool for performing the required mapping from the time domain into the frequency domain. One computer program, FOURT, processes the Cooley-Tukey Fast Fourier Transform as defined by:

$$X_n = \sum_{m=0}^{N-1} X_m e^{\frac{-i2\pi mn}{N}} \qquad 0 \leq n \leq N-1$$

Where:
- i = imaginary
- m = summation index on the number of data points
- n = harmonic
- N = number of data points in the recorded time history
- X_m = m th value of the untransformed data
- X_n = amplitude of the n th harmonic of the transform

An error analysis of this program appears in a related publication.[9] The various time histories were of differing length making comparisons of the results of the Fourier processing difficult. The different lengths were all augmented with zeros to make their lengths 1024 data points, (figure 14, page 44, Augment) allowing faster program execution and a commonality of fundamental frequencies of the Discrete Fourier Transform (DFT). So as not to introduce major harmonic content into the DFT's, the average value of each time history was removed before augmentation of the data strings.

[8] Brenner, N. M., "Three Fortran Programs that Perform the Cooley-Tukey Fourier Transformation," MIT Lincoln Laboratory Publication AD 657019, 28 July 1967.

[9] Ferris, James F., and Nuttall, Albert H., "Comparison of Four Fast Fourier Transform Algorithms," NUSC Report No. 4113, 3 June 1971, Naval Underwater Systems Center, Newport, R.I.

The choice of data string size and the 50 ms sampling period results in a fundamental frequency of .0195 Hz per frequency cell. Since preliminary analysis of selected time histories of each control parameter representing each task indicated no appreciable energy in the spectra at frequencies above 4 Hz, the calculations were halted at 200 harmonics.

The following spectra were calculated for each control parameter.

a. For each pilot subject, the spectra for five successful approaches for each task in each delay condition were averaged.[10] (Figure 14, page 45, Average 1.) This produced three (one for each task) spectra for each delay condition for each pilot subject.

b. Each of the six spectra thus produced per pilot subject were then averaged over all the pilot subjects, providing six spectra for the entire group of pilot subjects, one for each task for each delay condition (figure 14, page 45, Average 2).

Thus, thirty-six spectra were prepared for the entire group of pilot subjects; three (Tasks) x two (Delay Conditions) x six (Control Input Parameters). These are presented in figure 18. Figure 18 also displays the differences in the spectra discussed above, i.e., the differences in the spectra for the Delayed visual presentation condition minus the Non-Delayed visual presentation condition. These differences were computed by subtracting the real and imaginary amplitudes for each frequency cell of the delayed spectrum from the real and imaginary amplitudes of the same frequency cell of the Non-Delayed spectrum. Figure 18 shows the general trend of the results of pilot activity in the frequency domain. Notice that the control input spectra have decreasing amplitude with increasing frequency and that the difference spectra (Delay spectra minus the No-Delay spectra) have the same general trend. This suggests that the delay effects (as indicated by the difference spectra) are functions of frequency and that the effects are greater at around .6 Hz. The results of the frequency analysis are summarized in table 9. The principle frequency and approximate amplitude refer to the difference spectra of the delayed condition minus the non-delayed condition. The control input limit refers to either the delayed or non-delayed case and merely states the approximate upper frequency limit of information content.

[10] The spectrum averaging discussed herein is the arithmetic mean of the contents of each frequency cell (multiple of the fundamental frequency).

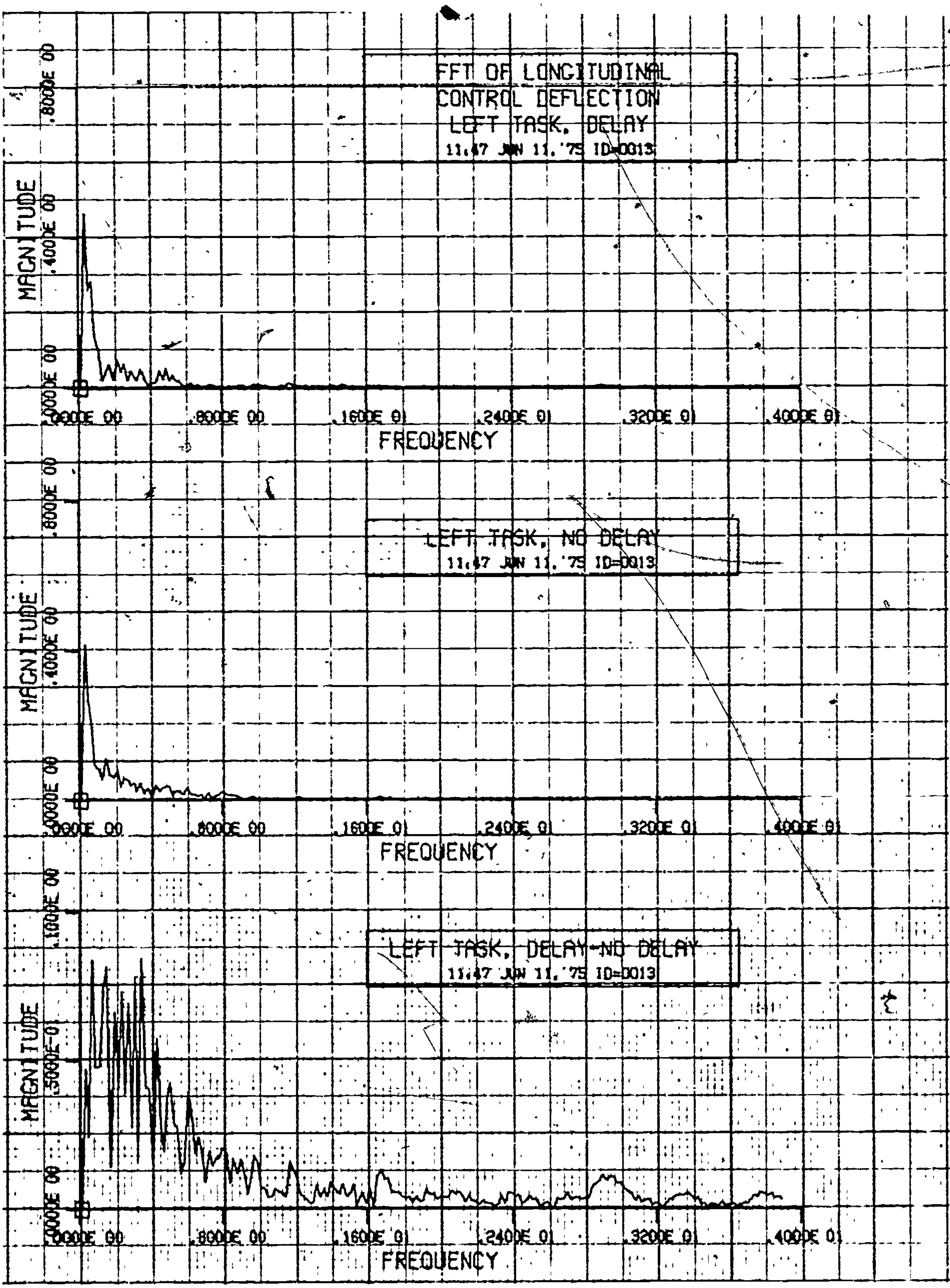

Figure 18. Fast Fourier Transforms of Control Inputs by Task

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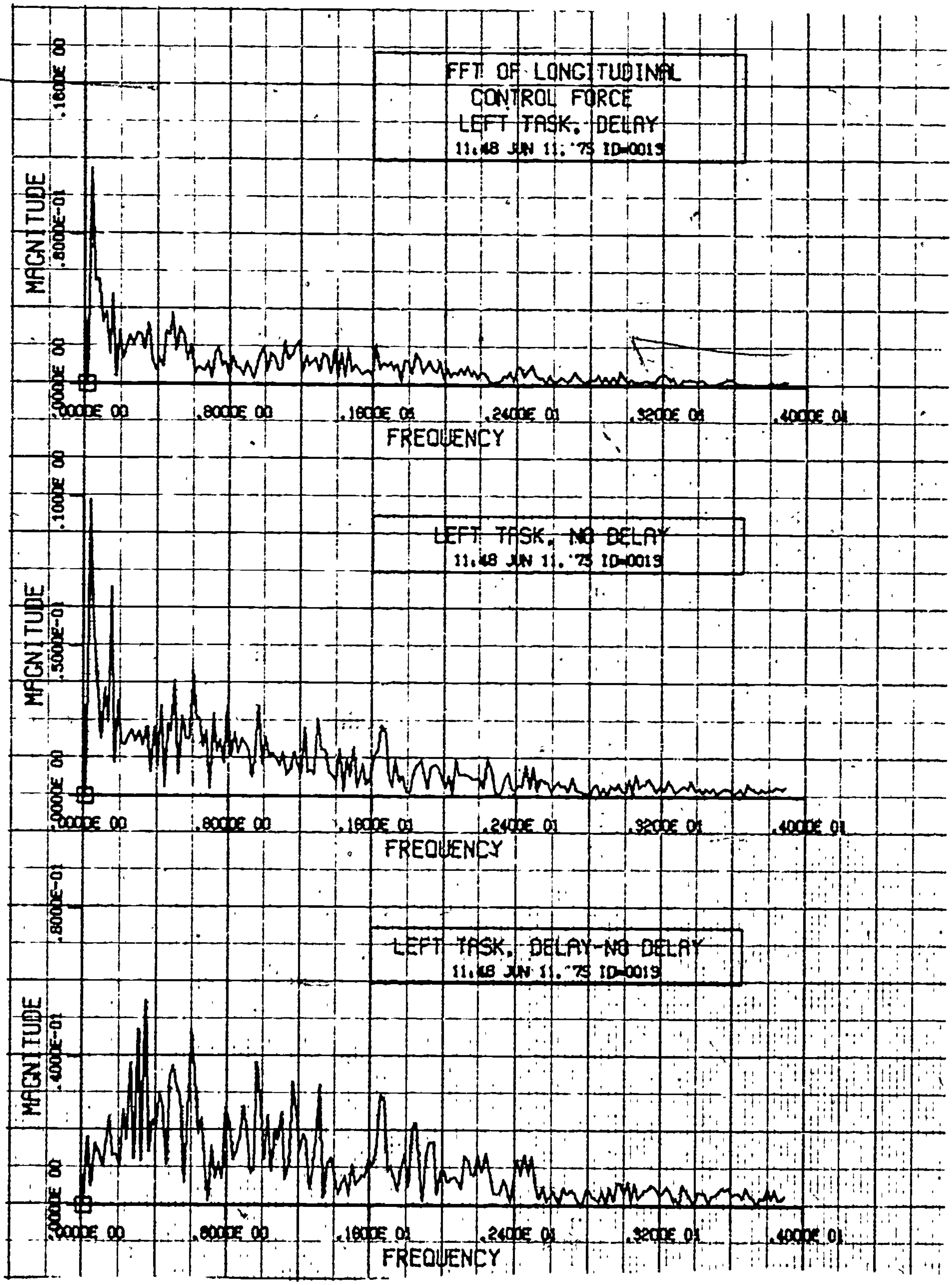

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

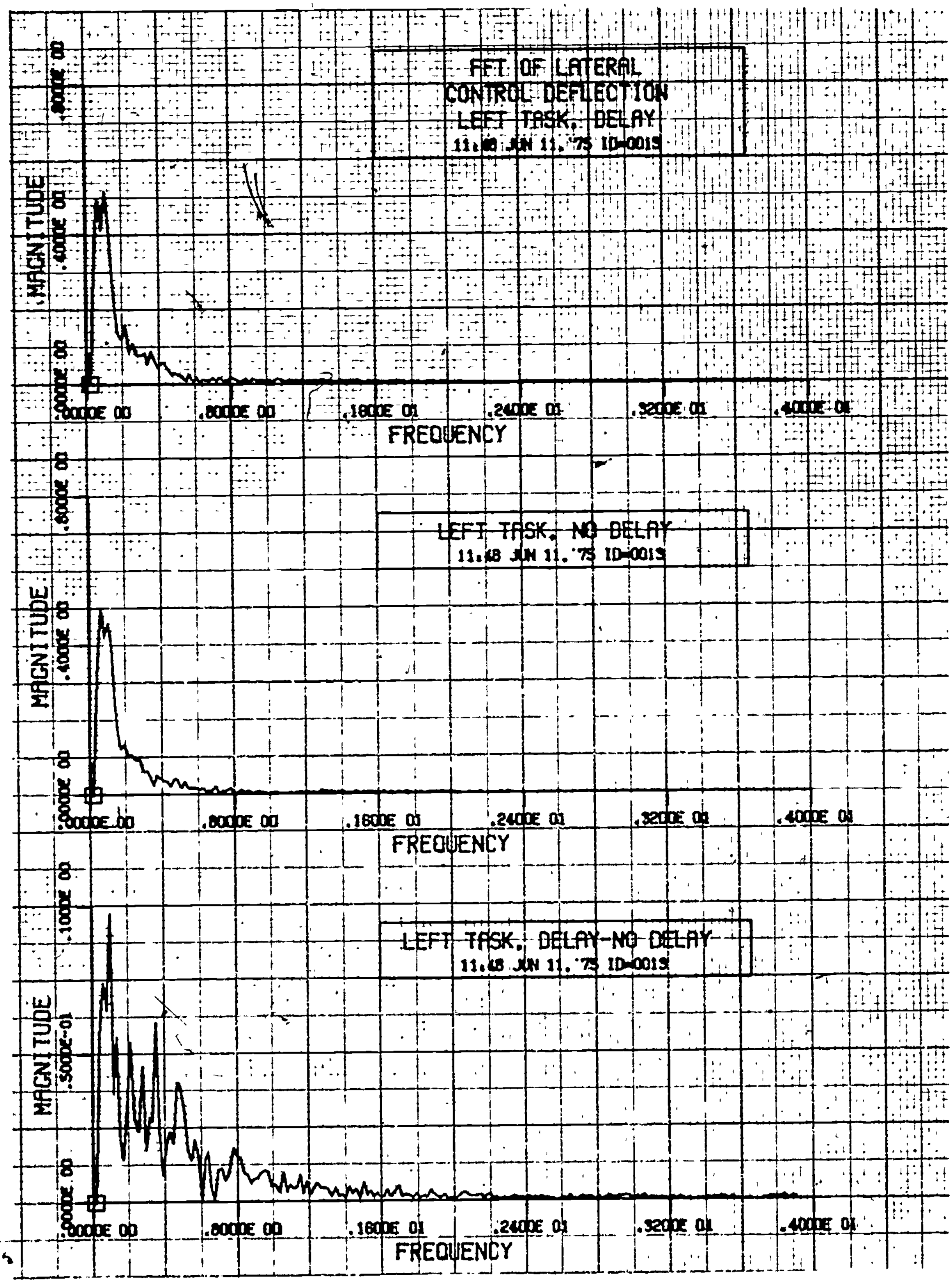

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

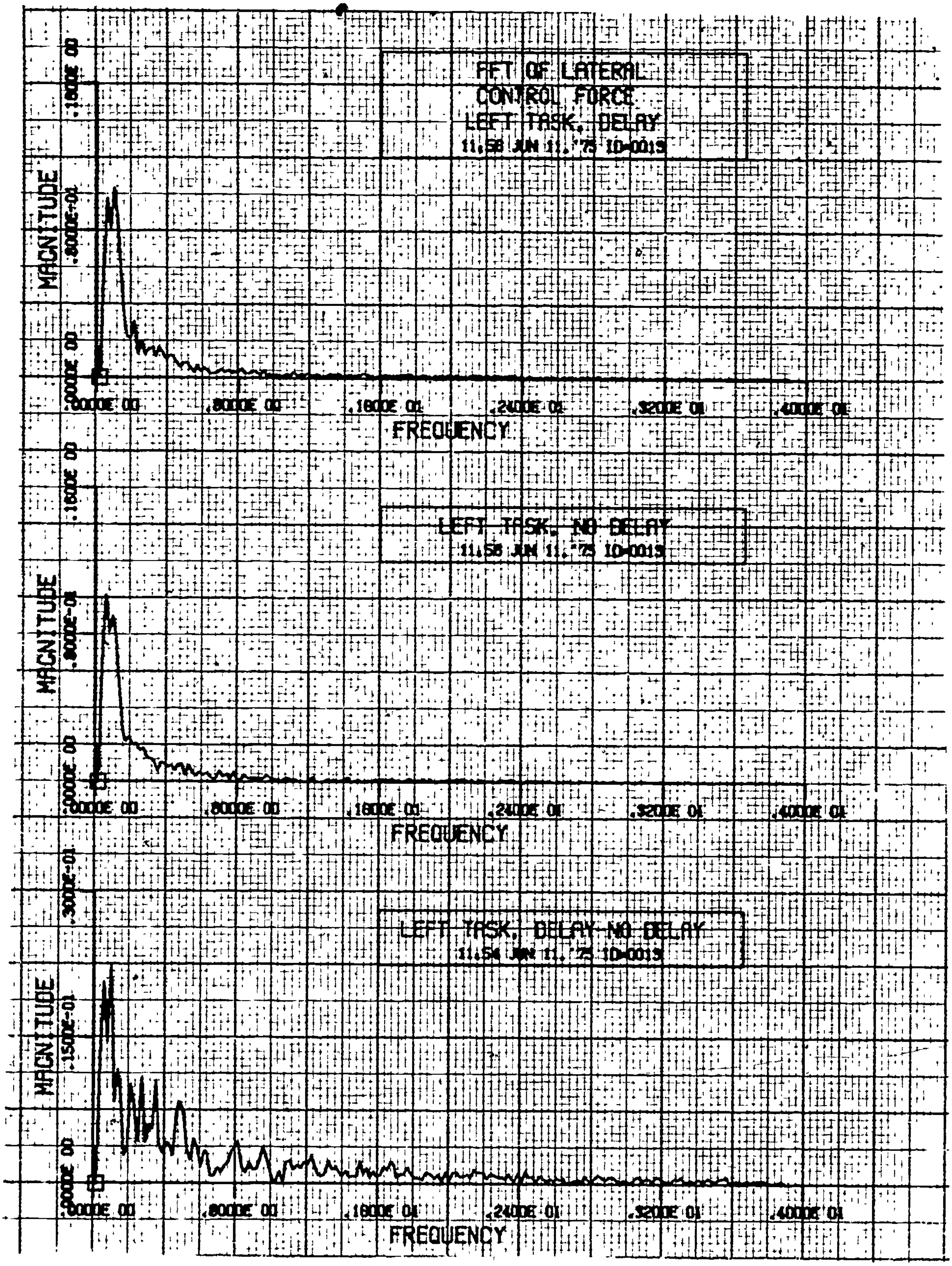

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

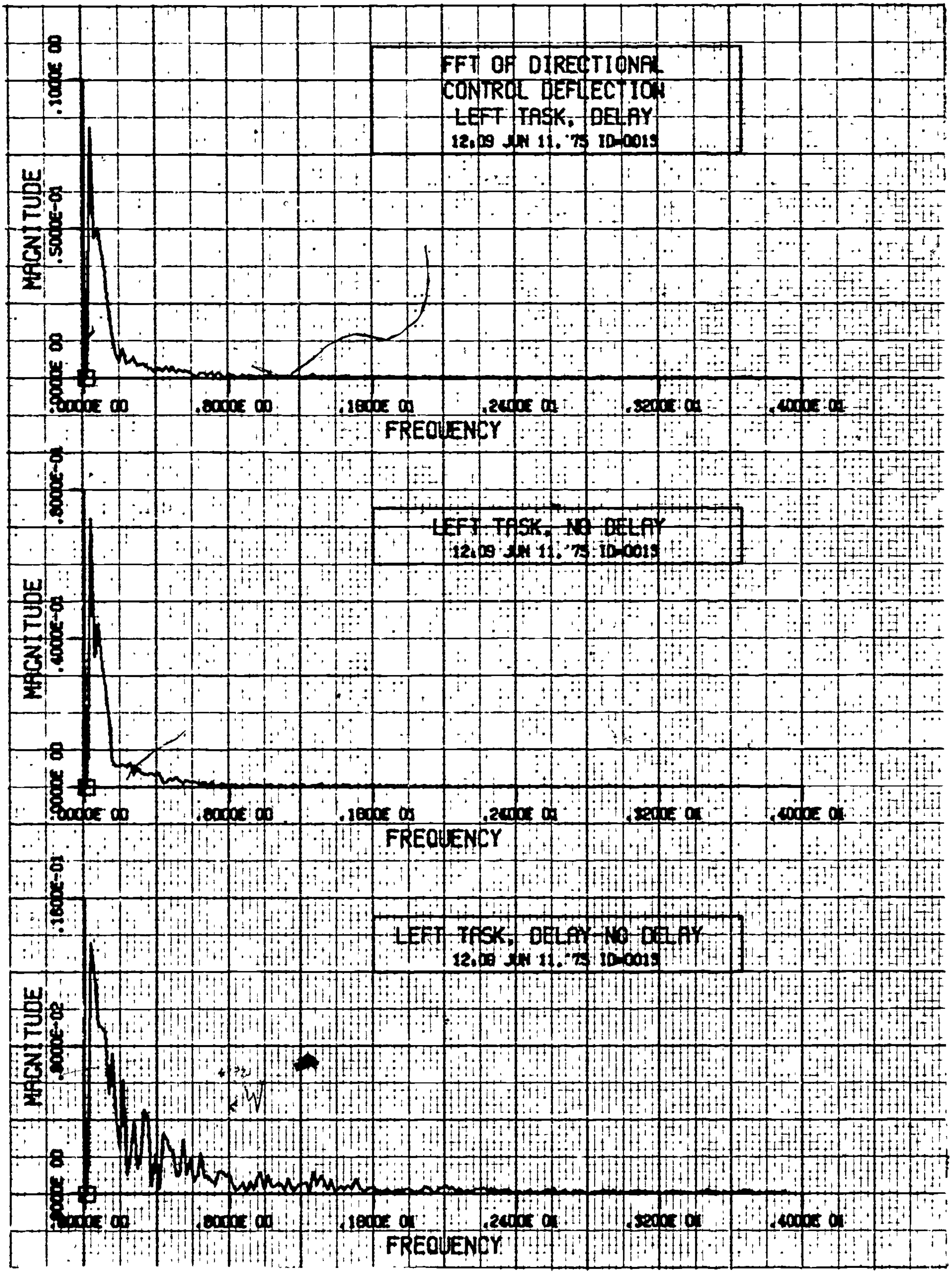

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

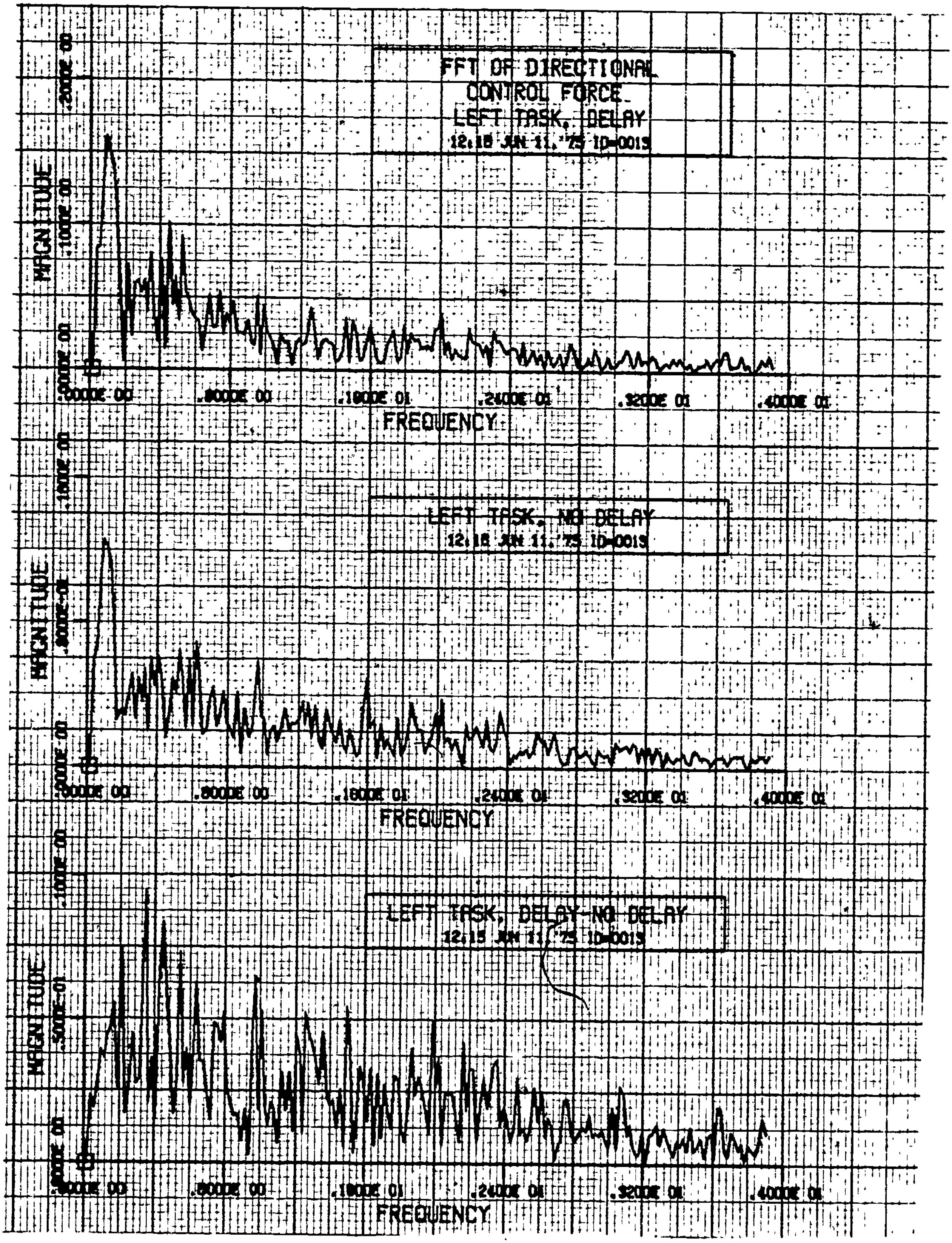

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

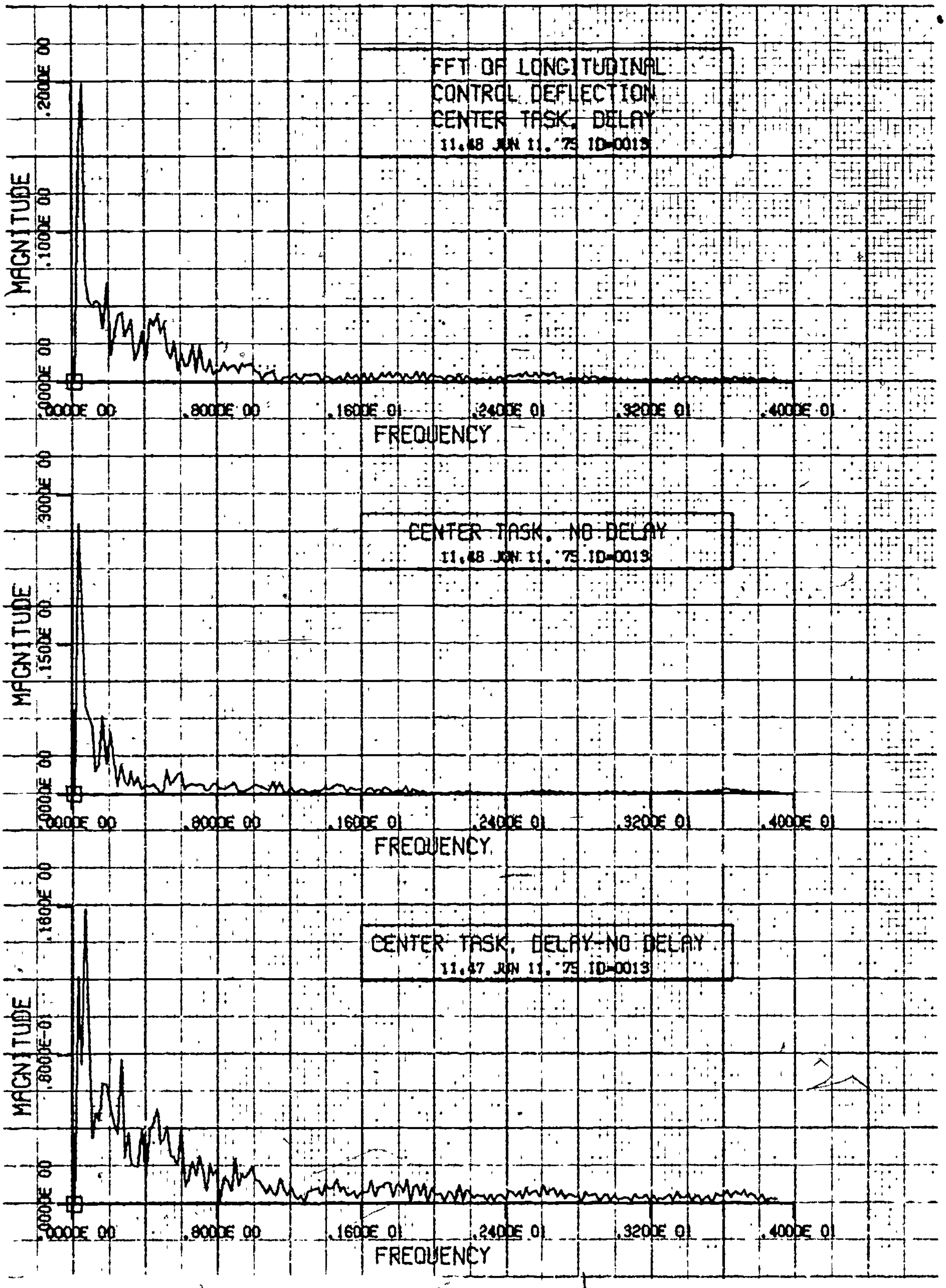

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

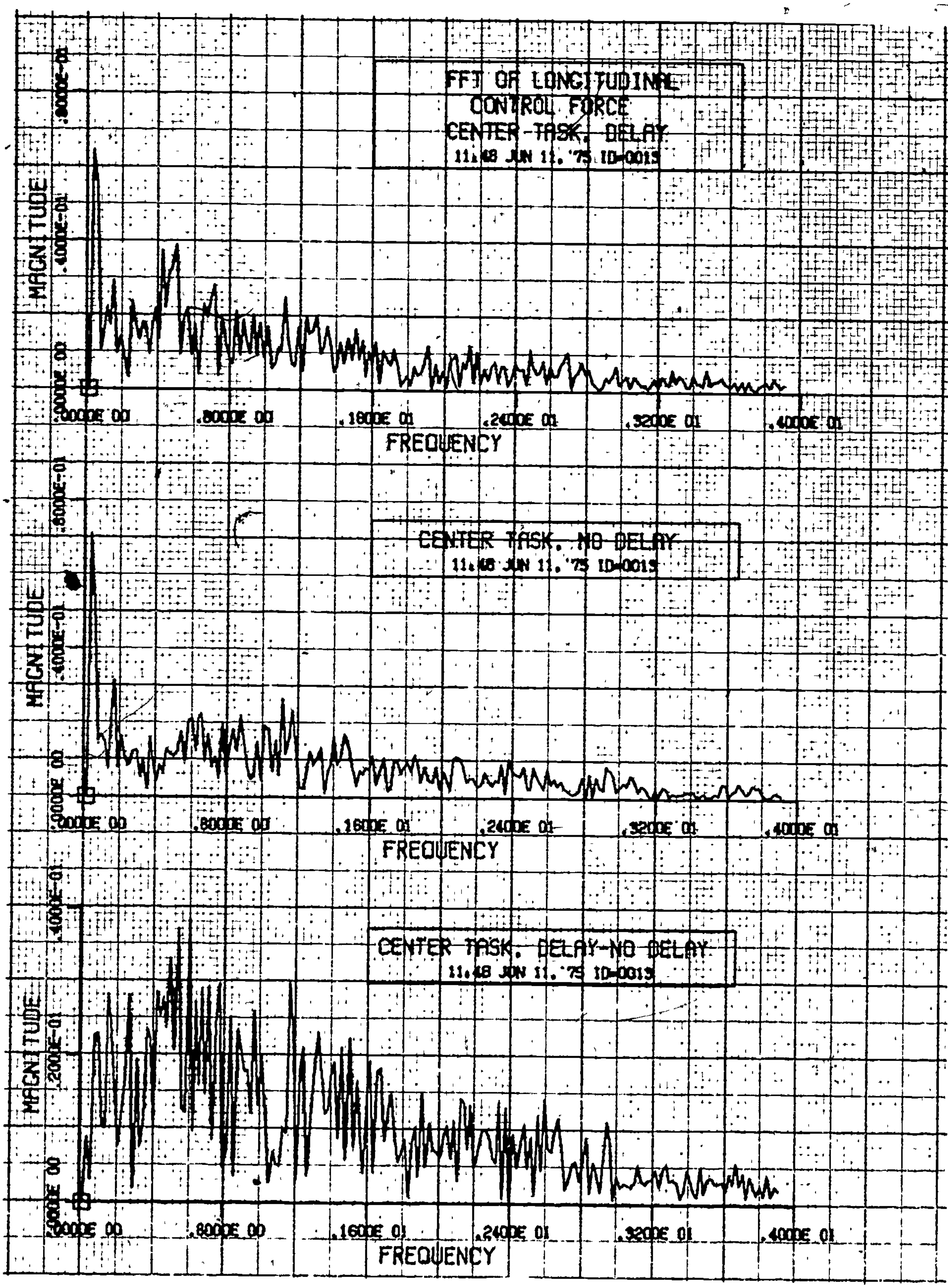

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

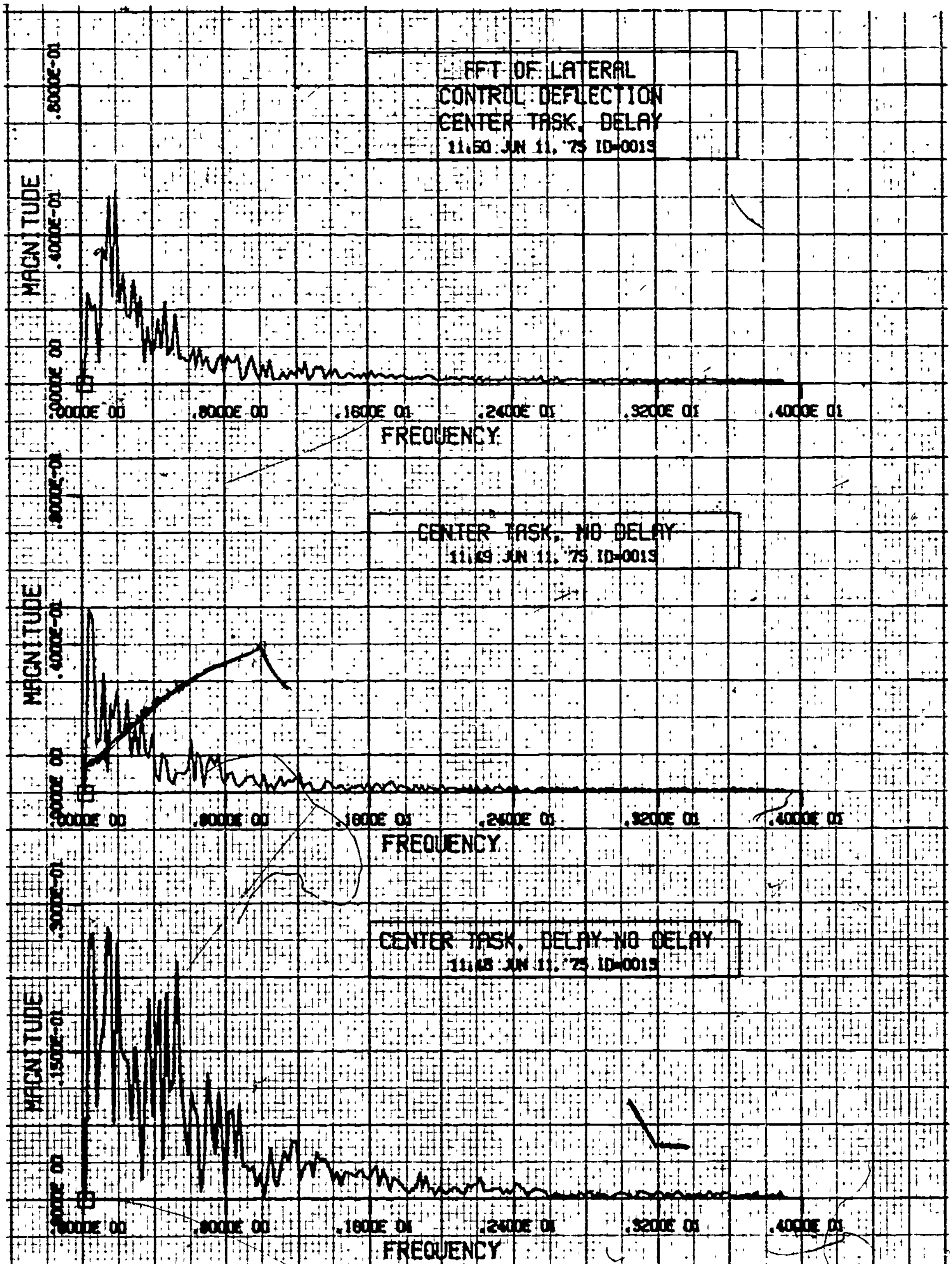

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

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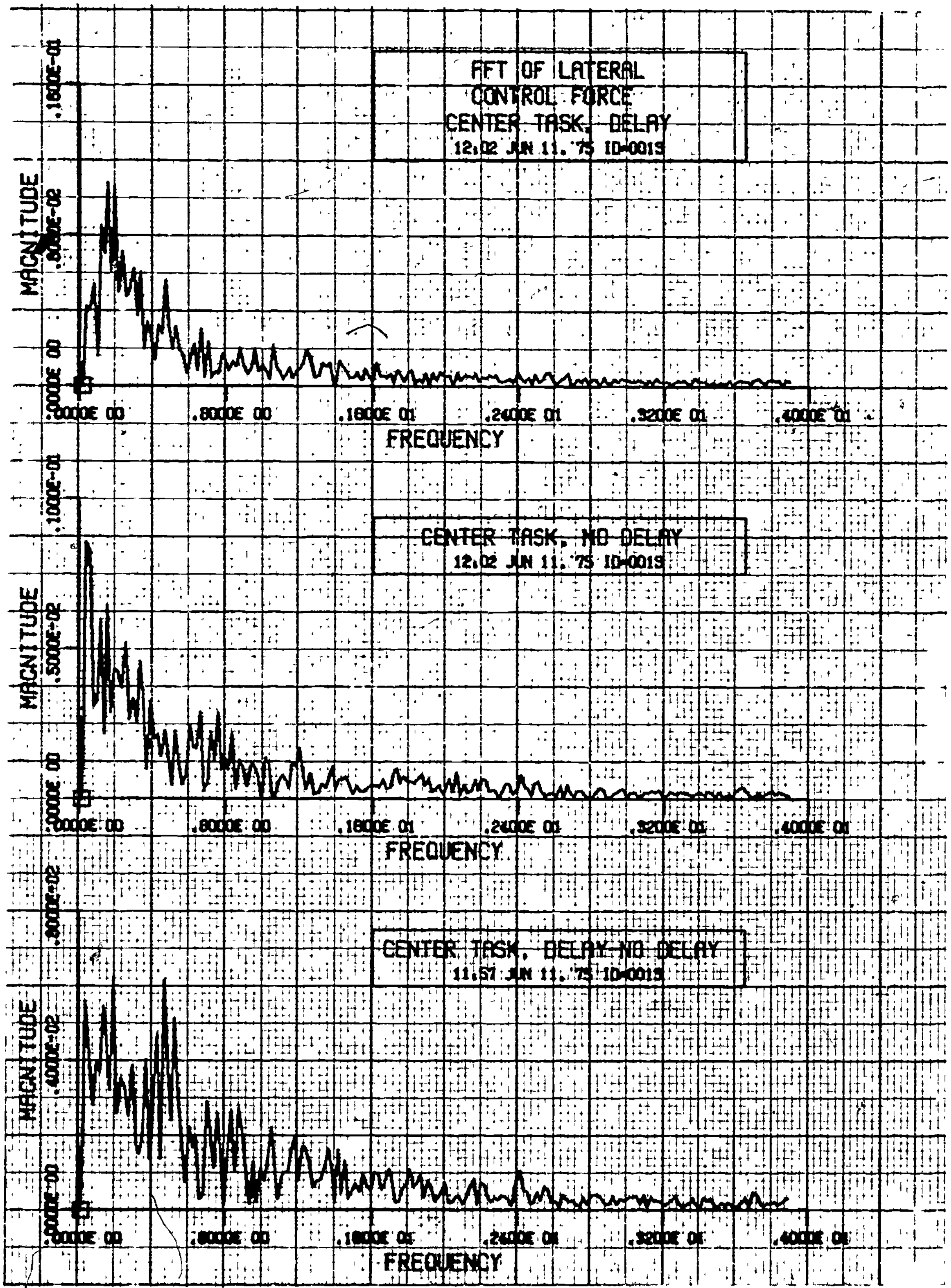

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

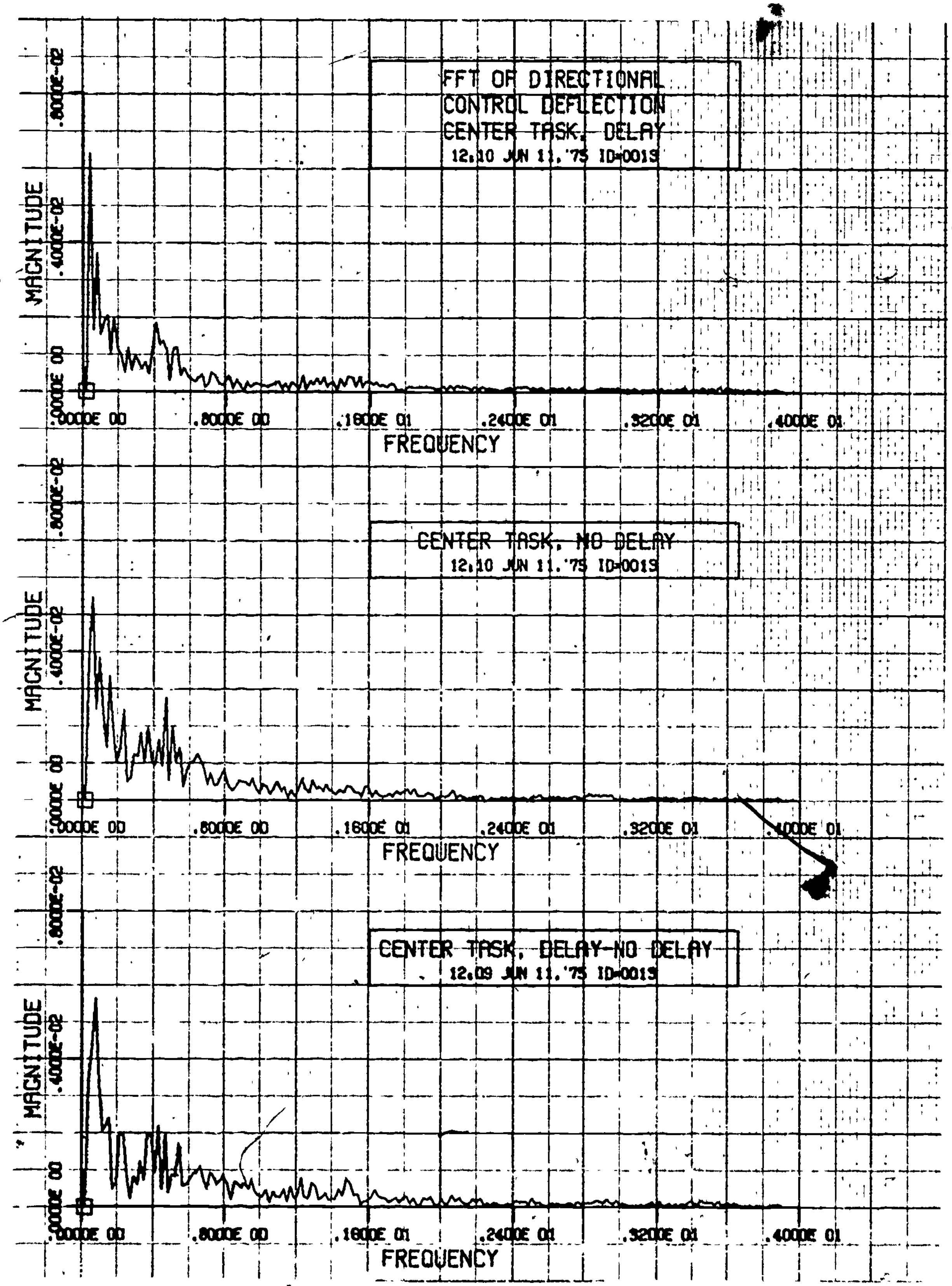

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

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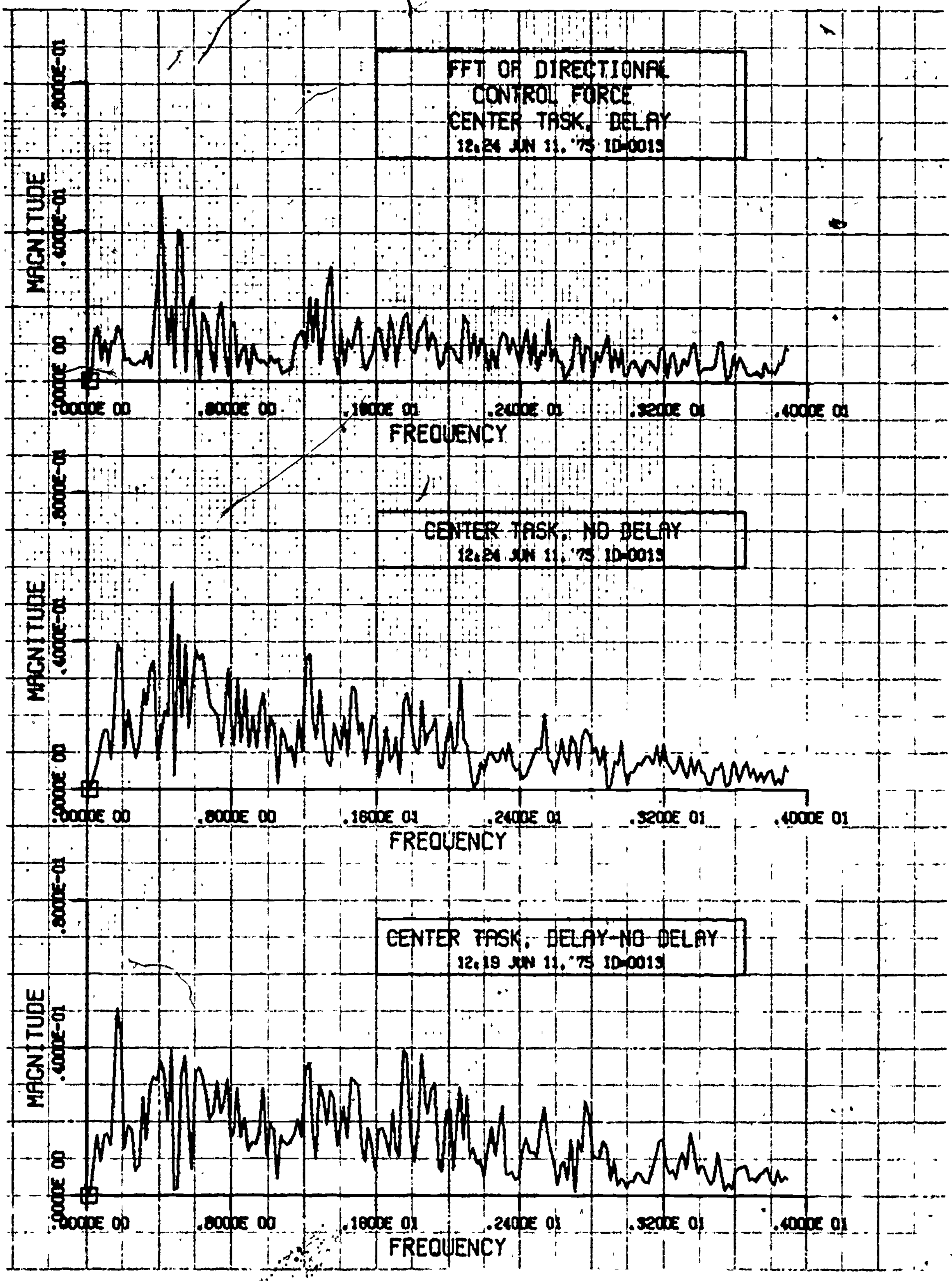

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

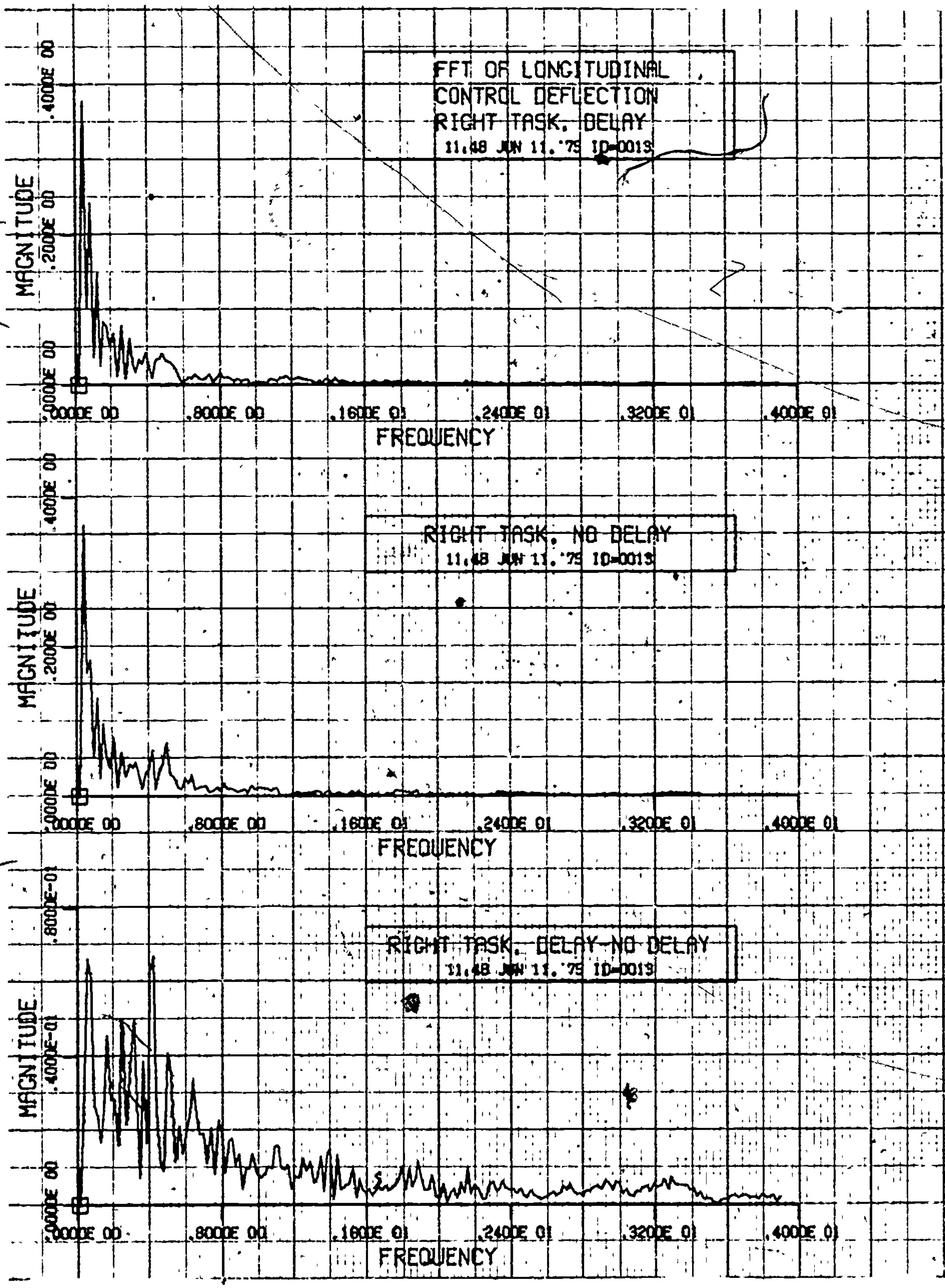

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

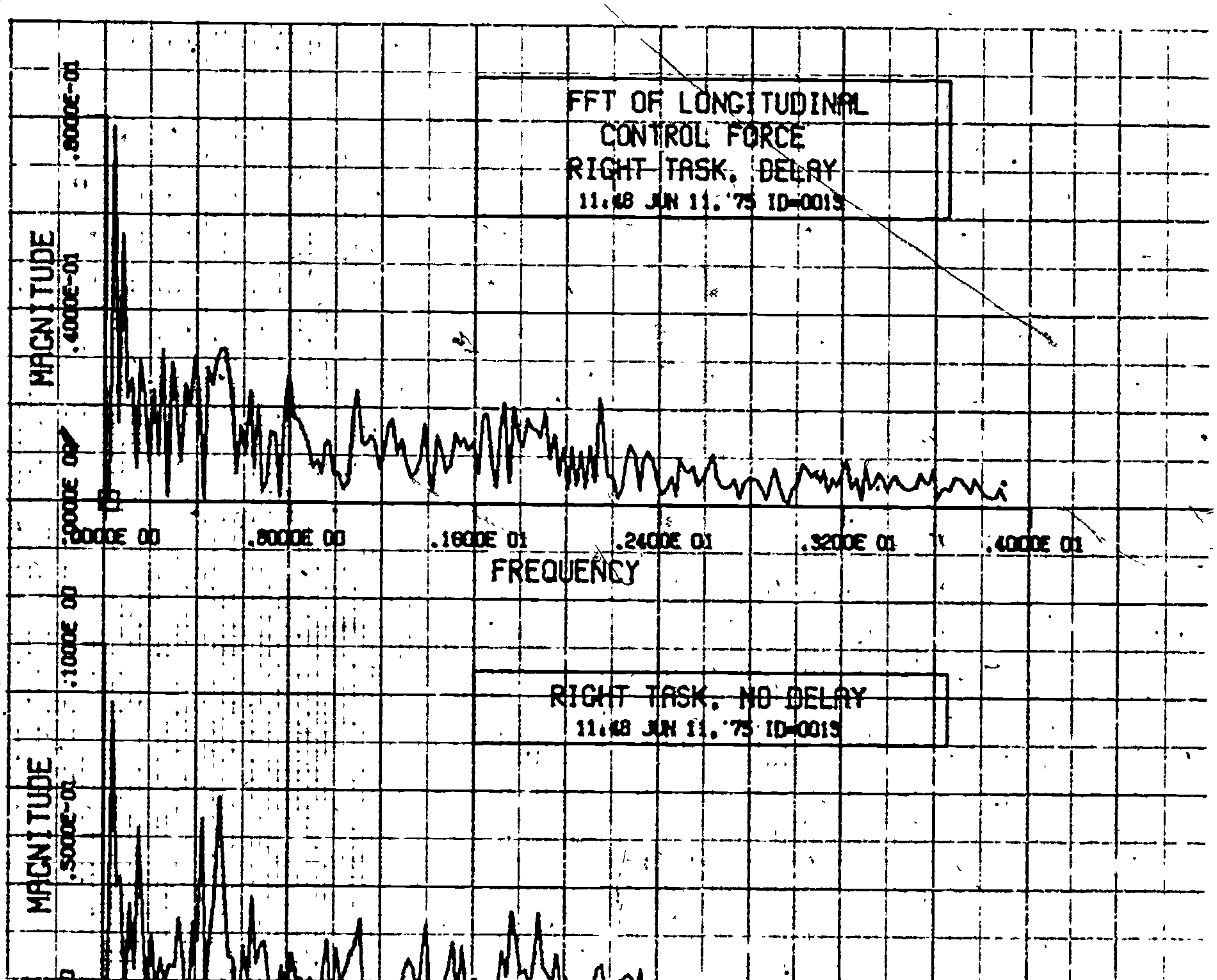

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

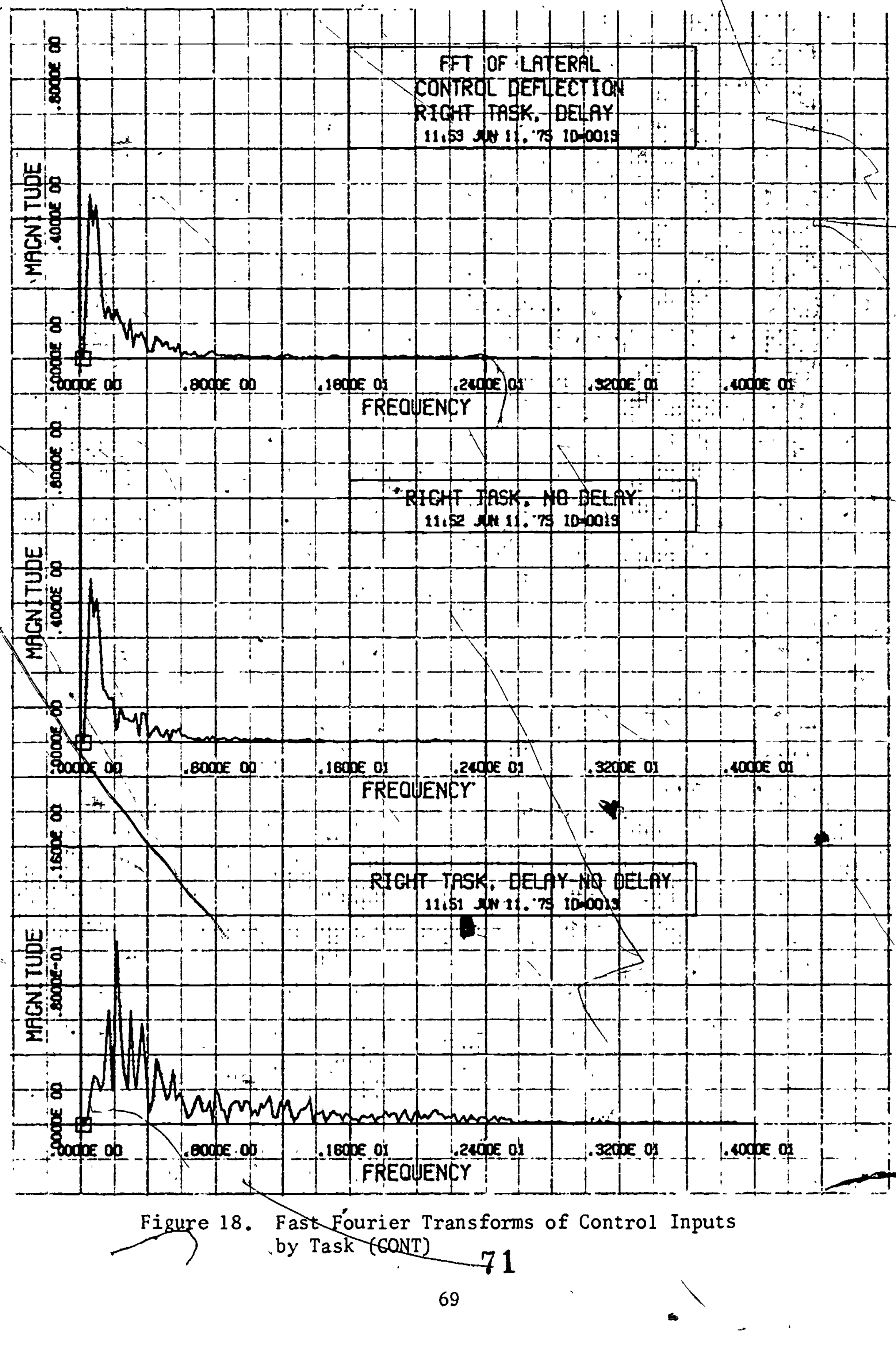

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

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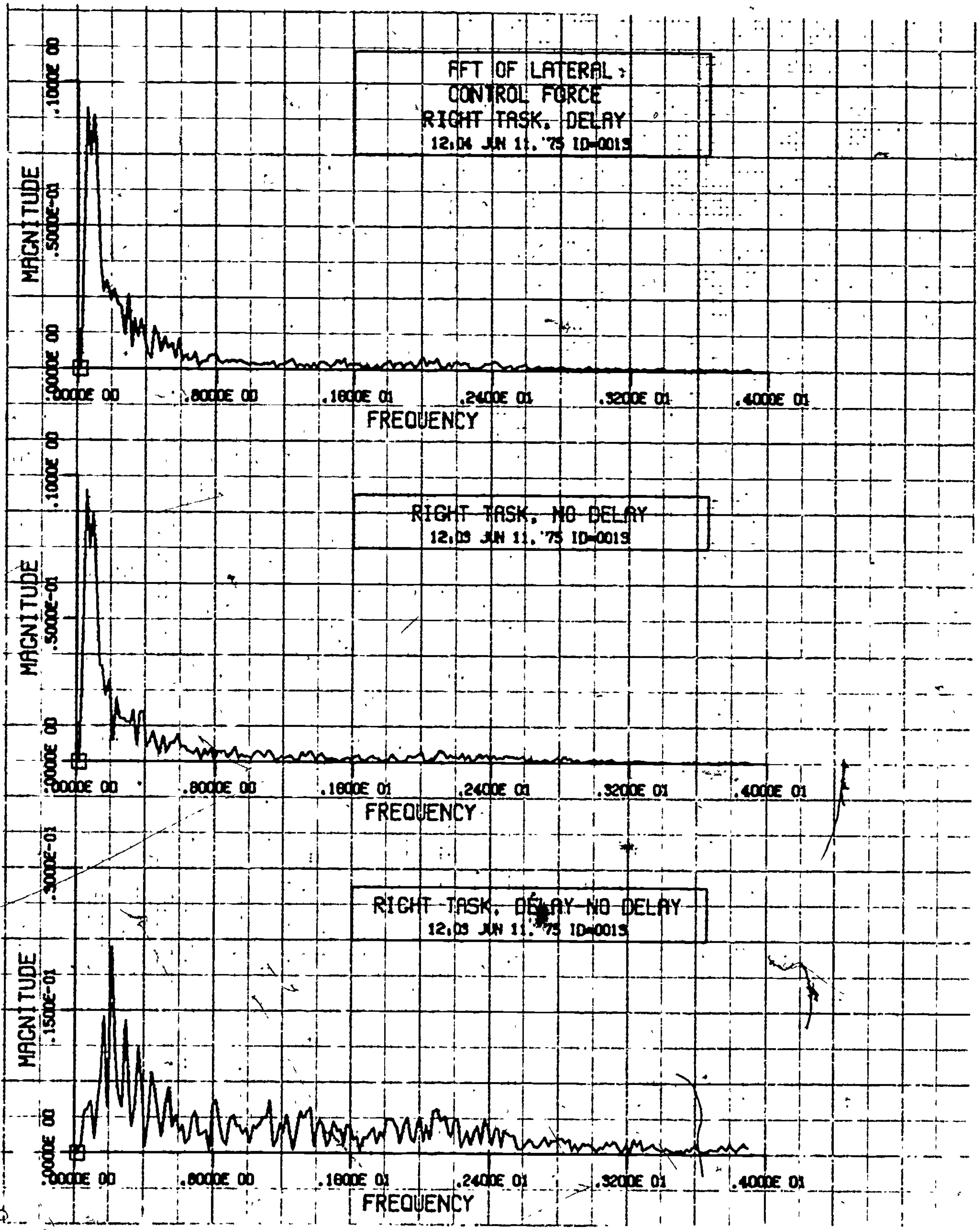

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

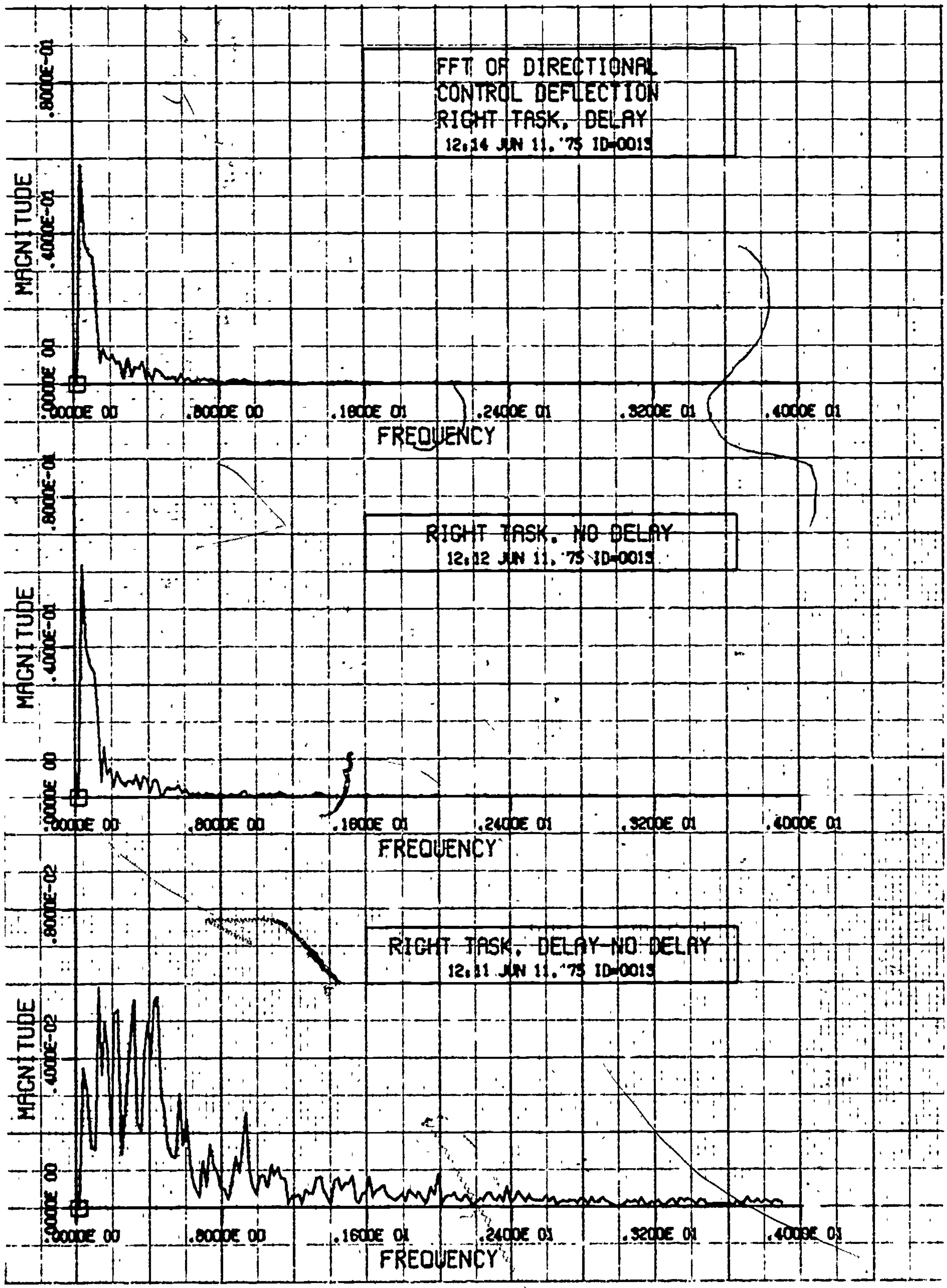

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

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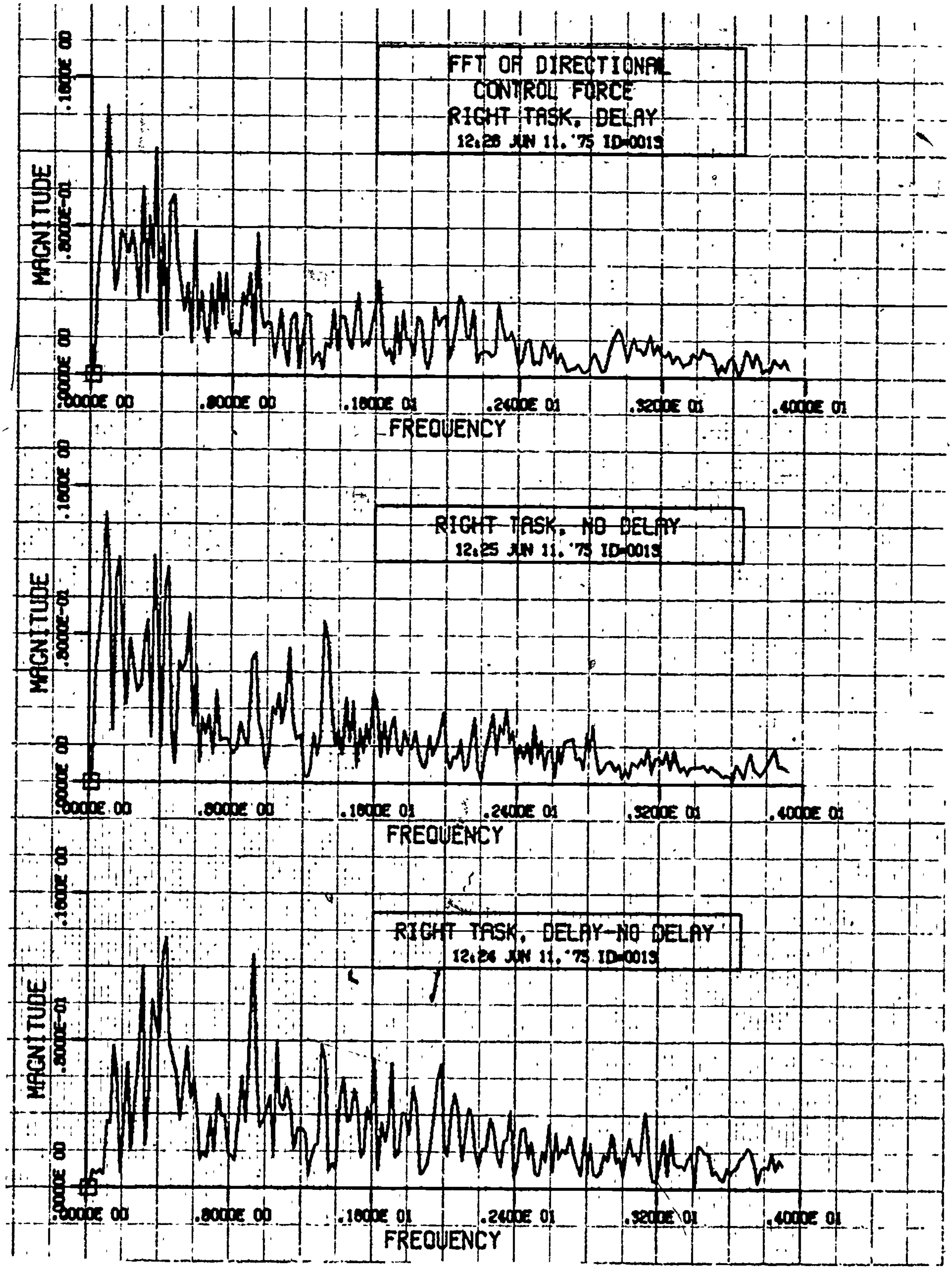

Figure 18. Fast Fourier Transforms of Control Inputs by Task (CONT)

Table 9. SUMMARY OF ANALYSIS OF FAST FOURIER PROCESSING

CONTROL PARAMETER	LEFT	TASK CENTER	RIGHT
DSS			
Principle Frequencies (Hz)	.2 to .4	.1	.1, .4
Approx. Amplitudes	.08	.16	.07
Control Input Limits (Hz)	.8	.8	.8
FSSA			
Principle Frequencies (Hz)	.4	.2 to 1, Peak .6	.4
Approx. Amplitudes	.05	.04	.05
Control Input Limits (Hz)	1.6	2.4	2.4
DSA			
Principle Frequencies (Hz)	.1	.1 to .6	.2
Approx. Amplitudes	.1	.025	.1
Control Input Limits (Hz)	.8	1.2	.8
FSAA			
Principle Frequencies (Hz)	.1	.2, .4	.2
Approx. Amplitudes	.02	.006	.02
Control Input Limits (Hz)	.8	.8	.8
DRP			
Principle Frequencies (Hz)	.1	.1	.1 to .4
Approx. Amplitudes	.015	.006	.006
Control Input Limits (Hz)	1.6	1.6	1.6
FRPA			
Principle Frequencies (Hz)	.4	.4, 1.2, 1.8	.4, .9
Approx. Amplitudes	.1	.04	.12
Control Input Limits (Hz)	2.4	3.4	3.4

SECTION IV

CONCLUSIONS AND DISCUSSION

The first question posed in the statement of the problem "Does 100 ms delay of a visual presentation affect pilot learning performance?" was answered by Experiment 1. No statistically significant differences were found between the "trials-to-criterion" (three successive traps) in the Delayed condition and in the Non-Delayed condition.

The second question posed in the statement of the problem "Do pilots perform their piloting skills differently when their visual stimuli have been delayed for 100 ms?" has been answered in the affirmative insofar as the pilot control inputs in the lateral control parameters (displacement and force) are concerned. The effect of delay was found to be statistically significant at the .0083 level for aileron control displacement (DSA) and at the .0392 level for aileron control force (FSAA). The effect of delay on the remaining four control parameters (DSS, FSSA, DRP, FRPA) was found to be not statistically significant.

While the differences in the mean scores for all tasks for the remaining four pilot control input parameters for the Delay compared with the No-Delay condition were all statistically not significant, it is interesting to note that of the eighteen mean comparisons made (see tables 6, 7, and 8), four average variance values were less for the Delay condition than for the No-Delay condition. (They were elevator control force (FSSA) during the Right Task, rudder pedal deflection (DRP) during the Center Task, and rudder pedal force (FRPA) during the Right and Center Tasks.)

It is believed that these four average variance values can be explained. Three of the four comparisons involved rudder control force and/or deflection. Several approaches by subject pilots were made with high angle of attack, sufficient to activate the rudder pedal stall warning shaker. It is believed that the directional displacements and forces recorded due to the shaker masked the effect of the delay condition on pilot subject induced control displacements and forces. The fourth comparison, elevator control force during the Right Task, is believed to be similarly masked by the rough air turbulence used in this task. None of the other tasks utilized rough air turbulence.

The third question, "If pilots do perform their skills differently when visual stimuli are delayed 100 ms, in what way is their performance different?" has been resolved by transforming the pilot control inputs to the frequency domain and comparing the frequency spectra of the control inputs for the delayed visual presentation to the spectra for the non-delayed visual presentation case. These comparisons are summarized in table 9.

The time histories of each control parameter for all successful approaches were transformed to the frequency domain using the discrete Fourier transform. The transformations were averaged for each given task and each delay condition over all pilot subjects. The difference spectra were formed by subtracting the average delayed spectrum from the average non-delayed spectrum for each task and each control parameter, (figure 18). The difference spectra show the effect of delay to decrease with increasing frequency. The major difference between the Delayed and No-Delayed spectra typically occurred in the range 0 to 2 Hz.

The results of these experiments are applicable to a high performance simulation (F-4) using a narrow field of view visual presentation. However, caution should be exercised before any attempt is made to extrapolate the results to visual systems with wider fields of view or to aircraft having different frequency modes such as large bomber or transport aircraft.

In conclusion, it has been determined that learning performance of pilot subjects, executing the tasks specified for Experiment 1 and in the simulator system utilized, was not affected by 100 ms delay in visual stimuli. Perhaps this result could be due to pilot subjects responding, with extra effort, to the delayed task conditions, i.e., they may have "tried harder." It was determined that, in general, pilot subjects manipulated their flight controls differently both in displacements and in control force when their visual stimuli were delayed 100 ms. These differences are indicated both by the general trend toward a greater variance in control activity (in some cases the differences were statistically significant) and by the differences in the frequency spectra for the Delayed and Non-Delayed conditions.

SECTION V

RECOMMENDATIONS

In view of the findings of Experiments 1 and 2, the following studies are recommended:

a. A similar study be conducted which would allow both a variable time delay and variable task as independent arguments. Sample areas of interest would include: learning performance and input control variance as functions of length of delay time and task type. Since the present experiments considered only the carrier landing task, other task types might be aerial refueling, air-to-ground weapon delivery, and formation flying.

b. A similar study should be conducted for a large field of view visual presentation system.

c. A similar study should be conducted for large multi-engine transport type aircraft whose natural frequencies are vastly different than the strike type of aircraft (the F-4) used in these studies.

d. The study should be repeated utilizing predictive filters designed based upon the frequency spectra of the differences in the delayed and the non-delayed pilot control input performance. The prediction could be expected to reduce the effects of the delayed visual presentation.

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