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An experiment was conducted to evaluate the performance and workload characteristics of six types of control system configurations during simulated IFR approaches. The six types were, (1) manual ILS, (2) manual approach with flight director, (3) semi-automatic approach with flight director in which the pitch, roll, and yaw axes of the autopilot were controlled by the pilot through force wheel steering, (4) and (5) two workload sharing approaches with force wheel steering and flight directors where, in one case, the pilot

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controlled pitch and power while the co-pilot controlled roll and yaw and, in the other case, the roles of the pilot and co-pilot were interchanged, and finally (6) a fully automatic approach.

General conclusions were that the full automatic mode provided the best performance and lowest workload while the manual ILS mode and the semi-automatic mode provided the worst performance and the highest workload. The two workload sharing conditions and the manual flight director condition fared well in both performance and workload measurements, ranking second only to the full automatic mode.

FOREWORD

This report was written in partial fulfillment of Air Force Contract No. F33615-75-C-3050 under the direction of Mr. W. Klotzback, contract monitor, of the Terminal Area Control Branch (FGT) of the Air Force Flight Dynamics Laboratory (AFFDL). The research was conducted under Project 8226 Task 01 during the period of January 1971 through December 1974. This report was submitted in April 1975 by:

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Sincere appreciation is hereby expressed for the cooperation of the following individuals who contributed to the success of this program.

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LIST OF ABBREVIATIONS AND ACRONYMS

ADI	Attitude Director Indicator
AFCS	Automatic Flight Control System
AFFDL	Air Force Flight Dynamics Laboratory
AGL	Above Ground Level
ANOVA	Analysis of Variance
AVRI	Altitude/Vertical Rate Indicator
CDI	Course Deviation Indicator
FD	Flight Director
FPA	Flight Path Angle
FWS	Force Wheel Steering
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IP	Instructor Pilot or Copilot
IPIS	Instrument Pilot Instructor School
LOC	Localizer
MSL	Mean Sea Level
NM	Nautical Miles

SUMMARY

An evaluation was performed to assess the performance and work load characteristics of six modes of aircraft control during simulated instrument flight rule (IFR) approaches. The six modes included manual instrument landing system (ILS), manual with the use of a flight director, pilot/copilot work load sharing, flight director with autopilot stability augmentation ("semi-automatic"), and fully automatic. Force Wheel Steering (FWS) was used during all approaches except those in the manual mode.

Eight pilots, experienced in instrument flying and reciprocating multi-engine aircraft, flew four flights each. During the first flight each pilot flew all six modes for familiarization. In the other three flights, pilots flew three approaches in each of two modes. The first approach was for practice; the last two were for data collection. The order of modes was counterbalanced across subjects. Both subjective and objective data were recorded; objective data was subjected to an analysis of variance to determine statistical significance. Conclusions and recommendations were advanced.

SECTION I

INTRODUCTION

Automatic landing systems provide more precise aircraft performance than manual control during IFR approaches to touchdown under normal operating conditions. However, exceptions to the normal operating conditions do occur and can present serious problems to the pilot and crew when the automatic system is engaged. Examples of these exceptions are (1) phenomena which may provide the autopilot with erroneous information (e.g., bends in the glide slope) (2) partial or total autopilot failures, and (3) events necessitating go-around (e.g., intervening aircraft, engine failure, wind shear).

When the pilot and copilot are removed from the aircraft control loop, as with automatic landing systems, they may require an unacceptably long period of time to get back into the loop when an emergency arises. Consequently, investigations were undertaken to find methods of keeping the pilot and copilot in the loop while reducing mental and physical work load, and/or of allowing easy entry into and exit from the loop.

In 1963, IPIS demonstrated that if the pilot uses forces, as in force wheel steering (FWS), instead of control displacements, he can make corrective inputs to the autopilot quickly and accurately.[1] In 1964, IPIS showed that the pilot, copilot, and autopilot can share aircraft control (each controlling or stabilizing one or more axes) via FWS to reduce both pilots' work load during an approach.[2]

At Wright-Patterson Air Force Base an automatic flight control system approved for category II weather minimums, and FWS were installed in a JC-131B test aircraft. This provided the means to investigate FWS and work load sharing using a simulated flare at 100 feet AGL and go-around initiation at 50 feet AGL.

A new instrument panel was installed in the test aircraft for two purposes: (1) to improve the standard aircraft instruments by providing such things as radar altitude, flight director commands, etc,; and (2) to provide the information needed to determine if a situation has developed which necessitates pilot take-over from the autopilot, due to a graceful/catastrophic autopilot failure.

1. USAF Instrument Pilot Instructor School, Project No. 63-1 December 1963.

2. USAF Instrument Pilot Instructor School, Project No. 64-1A, November 1965.

Six modes of aircraft control were evaluated during this project. Some of these modes implemented the concepts of work load sharing and force wheel steering. Work load was shared between pilot, copilot, and autopilot. The autopilot was coupled to the ILS for one mode and was used for stability augmentation in three other modes.

SECTION II

METHOD

Test Item

In order to provide the information necessary to enable the pilot and/or copilot to monitor autopilot performance, and to fly the aircraft with greater precision during manual control, the pilot's instrument panel was modified to permit the addition of a Sperry Z-14 flight director, an altitude vertical rate indicator (AVRI), a radar altimeter indicator, and an autopilot trim indicator (see Figure 1). The copilot's instrument panel was modified to contain a Sperry Z-14 flight director and an AVRI (see Figure 2). The instruments which are standard on the JC-131B testbed aircraft were retained.

The AVRI was installed because the standard rate of climb indicator was not responsive to frequent changes in the rate of climb which often occur near touchdown. The radar altimeter was installed to permit the setting of an automatic flare at any altitude, and to provide altitude information during flare and go-around.

Force sensors were installed in both control wheels and the rudder pedals and were coupled to the Sperry SP-50A/Z-14 category II, "state-of-the-art", automatic flight control system. This flight control system is standard equipment on the DC-9 aircraft, but was modified for this evaluation in order to permit the autopilot to be integrated with FWS and the flight director. A control box was used to set the force level required by either the pilot or copilot in order to make an input to the autopilot. Work load sharing was implemented by "deleting" selected axes via high force levels for those axes. One work load sharing mode permitted the pilot to fly the roll and yaw axes while the copilot flew the pitch axis. The minimum forces required to make an input to each axis of the autopilot are listed in Table 1.

TABLE I. FORCES REQUIRED TO MAKE AUTOPILOT INPUTS VIA FWS

Axis	Lbs
Pitch	4
Roll	5
Yaw	10

NOTE: The servo for any axis could be overridden by making a force input of at least 20 pounds.

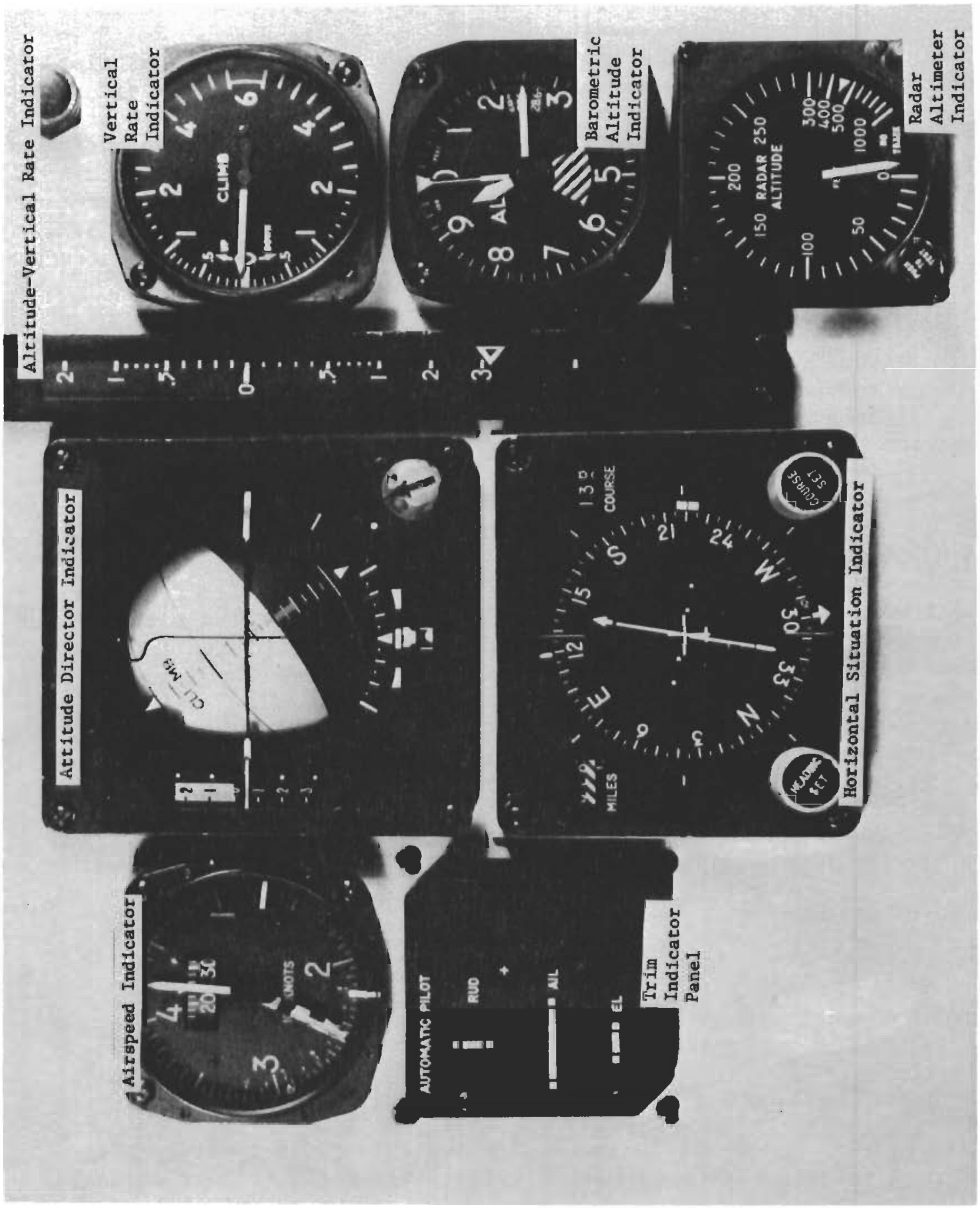

Figure 1. Pilot's Instrument Panel.

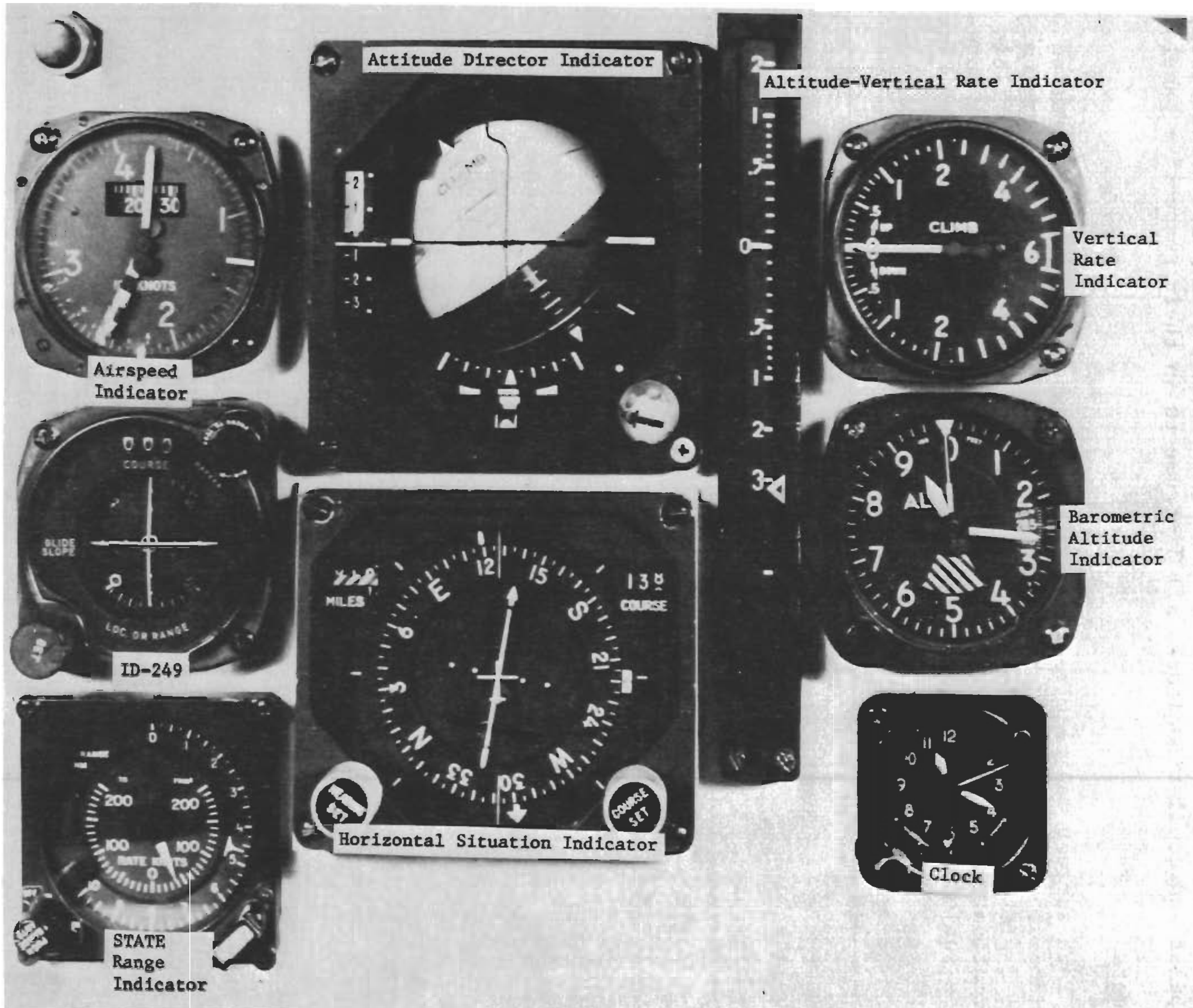

Figure 2. Copilot's Instrument Panel.

A more thorough description of the test item is provided in another document.[3]

The flight director command bars were not visible in Mode A (Manual ILS) for either the pilot or copilot. The autopilot trim indicator functioned in only those modes in which the autopilot was used. Otherwise, the pilot and copilot monitored all instruments in their respective panels.

Subjects

Each subject was required to have flight experience in reciprocating multiengine aircraft and to have experience with a flight director system. Table 2 presents information about each subject's flying experience. This information was obtained from the Pilot Personal Data Questionnaire. None of the subjects wore glasses or contact lenses to correct a vision deficiency.

TABLE 2. PILOT FLYING EXPERIENCE

Subject No.	Total Flying Time (Hrs)	Total Instrument Flying Time (Hrs)	Total Flight Director System Time (Hrs)
1	1100	300	100
2	1100	250	300
3	500	200	100
4	600	200	125
5	3000	750	16
6	1000	200	100
7	4300	1400	700
8	7600	1000	1000
Mean (approx)	2400	538	268

Flight Profile

Every approach had the same profile. Each subject was required to intercept the centerline of the localizer beam at an angle of 45° and to be tracking the localizer at 8NM from the runway threshold. Subjects were also required to intercept the glide slope beam at a fixed altitude of 2200 feet MSL, to track the glide slope and the localizer down to 100 feet AGL, flare to 50 feet as a simulated touchdown, and then go around. This profile is presented in Figure 3. For data reduction purposes, the profile was divided into four segments as described in the Data Reduction and Analysis section.

3. Systems Research Laboratories, Inc., Project 6737-05, August 1974.

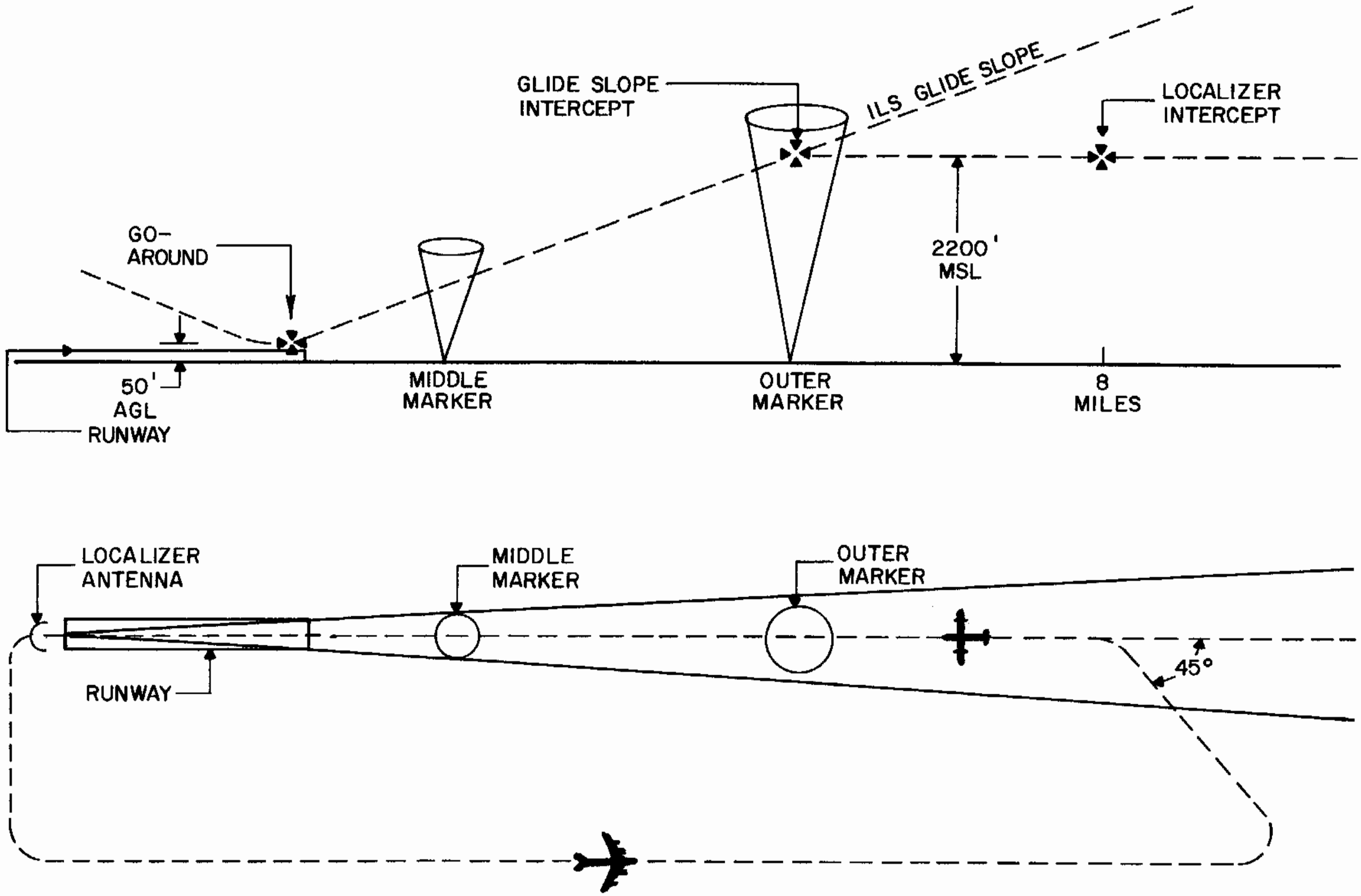

Figure 3. Vertical and Horizontal Views of the Flight Profile for Test Approaches.

TABLE 3. DIVISION OF AIRCRAFT CONTROL FOR EACH MODE

MODE	PILOT	COPILOT	AUTOPILOT add FWS
A (Manual ILS)	Pitch Roll Yaw Power		Not Used
B (Manual with Flight Director)	Pitch Roll Yaw Power		Not Used
C (Semi-Automatic)	Pitch Roll Yaw Power		Stability augmentation for pitch, roll and yaw.
D (Work Load Sharing - Pitch & Power	Pitch Power	Roll Yaw	Stability augmentation for pitch, roll and yaw.
E (Work Load Sharing - Roll & Yaw	Roll Yaw	Pitch Power	Stability augmentation for pitch, roll and yaw.
F (Full Automatic)	Power		Coupled to ILS for control of pitch, roll and yaw.

Experimental Design

The modes used in this evaluation are described in Table 3. The hypothesis was to determine if there were significant differences in performance and/or work load among any of these modes. Performance and work load were defined by the arithmetic mean, absolute mean, and mean standard deviation of the dependent variables in Table 4. The means were measures of central tendency while the standard deviation was a measure of variability.

TABLE 4. DEPENDENT VARIABLES

PERFORMANCE		WORK LOAD	
glide slope error		pitch force	Data not pertinent to Mode F since autopilot controlled these axes.
localizer error		roll force	
pitch steering bar error	Data not recorded for Mode A since flight director was not used.	yaw force	
bank steering bar error			

Subjects flew all six modes in the counterbalanced sequences shown in Table 5. These sequences were used to control for practice, fatigue, and order effects which could have caused progressive changes in subjects' performance and work load. Each subject flew four flights with six approaches per flight. The first flight was for familiarizing the subject with (1) the test aircraft's controls, displays, and handling characteristics, (2) flight profile and procedures, (3) division of crew responsibilities, and (4) the various modes of operation of the test system. All subjects flew the same sequence for the first flight. Thus, previous experience with the test item was balanced across subjects.

Subjects made three approaches per condition. The first approach was a warm-up for each condition. The last two approaches (trials) per condition were used for collecting data.

For each approach, the dependent variables listed in Table 4 were recorded on magnetic tape. Subjective data was also collected.

TABLE 5. SEQUENCE OF APPROACHES

Subject No.	Flight 1	Flight 2	Flight 3	Flight 4
1	ABCDEF	AAA/BBB	CCC/DDD	EEE/FFF
2	ABCDEF	FFF/EEE	DDD/CCC	BBB/AAA
3	ABCDEF	CCC/DDD	EEE/FFF	AAA/BBB
4	ABCDEF	DDD/CCC	BBB/AAA	FFF/EEE
5	ABCDEF	EEE/FFF	AAA/BBB	CCC/DDD
6	ABCDEF	FFF/EEE	BBB/AAA	DDD/CCC
7	ABCDEF	AAA/FFF	EEE/CCC	DDD/BBB
8	ABCDEF	EEE/AAA	CCC/FFF	BBB/DDD

Instrumentation

1. Objective
   A magnetic tape recorder and asssociated signal conditioning units provided recording of the dependent variables. The analog magnetic tape was digitized in order to produce a computer-compatible tape. The digital tape was then used for data processing and analysis.

2. Subjective
   The order of presentation for the questionnaires is presented in Table 6.

TABLE 6. ORDER OF PRESENTING QUESTIONNAIRES

QUESTIONNAIRE	TIME ADMINISTERED
Opinionnaire	Prior to first flight
Daily Experimental Flight Log (Cooper Rating and bipolar adjective rating)	After each data flight
Opinionnaire and Flight Questionnaire	After the last data flight

On the Opinionnaire, each subject was required to indicate on a scale from -3 to +3 his opinion of the following test mode characteristics:

glide slope acquisition accuracy
glide slope tracking accuracy
glide slope acquisition work load
glide slope tracking work load
localizer acquisition accuracy
localizer tracking accuracy
localizer acquisition work load
localizer tracking work load
go-around accuracy
go-around work load
profile accuracy
profile work load

Administering the Opinionnaire before all flights was a technique designed to reveal baseline opinions which subjects might have had regarding the test item or concept.

In the Daily Experimental Flight Log, each subject assigned a Cooper rating number to each mode. Each mode was also assigned -3 to +3 on the bipolar adjective scale for each of the following dimensions:

demanding - undemanding
confusing - clear
undesirable - desirable
sluggish - sensitive
rough - smooth
burdening - unburdening
complex - simple

After completing all missions, every subject was required to fill out (1) a Flight Questionnaire, which asked specific questions about the performance of each test mode, and (2) another Opinionnaire, which assessed any attitude changes which could have occurred after flying all modes.

Data Collection Procedures

After completion of the Pilot Personal Data Questionnaire, subjects were briefed on the flight test project. Then they filled out the opinionnaire for the first time.

Prior to each data flight, the subject received procedure sheets for the particular conditions flown on a given day. The experimenter completed a check list of procedures to insure proper operation of the instrumentation system.

Subjects flew in the left seat and wore an instrument hood for all approaches. The copilot flew in the right seat and did not wear an instrument hood. The subject was directed to act, to the greatest extent possible, as pilot in command. He called for all check lists and made all decisions that the aircraft commander normally makes. At glide slope intercept, he set the flaps at 17 degrees and lowered the landing gear.

Immediately following each of his data flights, the subject filled out the Daily Experimental Flight Log. Following his last flight, each subject completed another Opinionnaire and the Flight Questionnaire.

Data Reduction and Analysis

The objective data was segmented into four parts corresponding to the following profile divisions:

(1) from localizer capture to glide slope capture
(2) from glide slope capture to 100 feet AGL (or flare initiation)
(3) from 100 feet AGL to 50 feet AGL (or simulated touchdown)
(4) from simulated touchdown through 30 seconds of go-around

The data from both trials was combined and the following statistics were calculated for each parameter:

1. arithmetic mean -- determines the size and direction of deviations from the reference or zero error value

2. absolute mean -- determines the relative size of deviations without regard to direction from the reference or zero error value

3. standard deviation -- senses large, possibly infrequent, deviations without regard to direction; a measure of variability.

These statistics were then subjected to an analysis of variance (ANOVA) to determine if significant differences existed among the modes and subjects, or if there were significant interactions between modes and subjects. A complete description of the statistics and the ANOVA is presented in Appendix B.

Subjective data were graphed and are presented in the Results Section.

Hazards and Precautions Due to Nature of Test

The following were the potential hazards which existed as a result of the installations of the test systems:

1. The cockpit contained equipment not standard on a JC-131B aircraft. Hence, the subjects familiarized themselves with the equipment and its arrangement in the cockpit. They were provided with a set of

detailed operating instructions including photographs of control panels, pictures of instrument panel layouts, etc. Test aircrews received extensive briefings on the use of the equipment as well as detailed mission briefings prior to each flight.

2. Autopilot malfunctions could have occurred during automatic, semiautomatic, or work load sharing approaches. Hence, the pilot monitored the autopilot trim indicator on the instrument panel during such approaches. If a malfunction had occurred, the pilot would have used the autopilot disengage switch on his control wheel to revert back to the standard aircraft control system.

SECTION III

RESULTS

Subjective Results

1. Pilot's comments on Flight Questionnaire:
   The complete responses of the pilots are presented in Appendix A while this section contains only summaries. In general, all pilots felt that one training flight plus one practice approach for each mode was adequate to perform the mission.

   (a) Manual ILS Approach (Mode A):
   The Flight Questionnaire did not contain any questions concerning Mode A since comments would have concerned the basic aircraft which was not being evaluated, but rather served as a reference for the other modes.

   (b) Manual Approach with Flight Director System (Mode B):
   Pilots believed that this system's performance was very good. Many comments included terms such as "smooth" and "precise". Only normal corrections were necessary for keeping the flight director bars centered.

   (c) Semiautomatic Approach (Mode C):
   Pilots rated this mode as good. The sensitivities of the FWS sensors were judged satisfactory although the control breakout forces might have been a bit stiff, especially for the rudder. Although no major difficulties were encountered in keeping the flight director bars centered, pilots did report that the steering bars were more sensitive than they would like. Pilots did not comment on their performance with this mode.

   (d) Work Load Sharing (Modes D and E):
   Pilots felt that they would perform their share of the control task more effectively and that the work load for the particular axis(es) flown was reduced by not having to control the other axis(es). However, only one subject in the present investigation reported that he liked this concept.

The problems mentioned by the pilots included:

(1) subject's monitoring a control input over which he had no control,

(2) lack of trust in other pilot,

(3) worrying about engine gages, radios, etc., which the copilot usually takes care of,

(4) lack of total responsibility for making decisions, narrowed span of attention caused by the monitoring of only one axis, and

(5) a tendency for pilot and copilot to "fight" each other, which produced fatigue, according to some subjects. A recurring suggestion for improving the work load sharing concept was to more throughly isolate the two axes (assumed to mean mechanical isolation).

(e) Automatic Approach Mode (F):

Performance was described as "very good". Subjects did not want to improve or to modify the system steering bar centering performance by using the aircraft controls. Most subjects never used the force wheel during the approach.

(f) Modified Panel:

Comments from the pilots concerning the modified panel indicated that the AVRI and ADI took "one" to "several" flights to get used to. No other significant comments were made.

2. Bipolar Adjective Ratings from Daily Experimental Flight Log:

Bipolar Adjective Ratings are shown in Figure 4. Mode rankings were made by the experimenter on the basis of bipolar adjective ratings and are presented in Table 7.

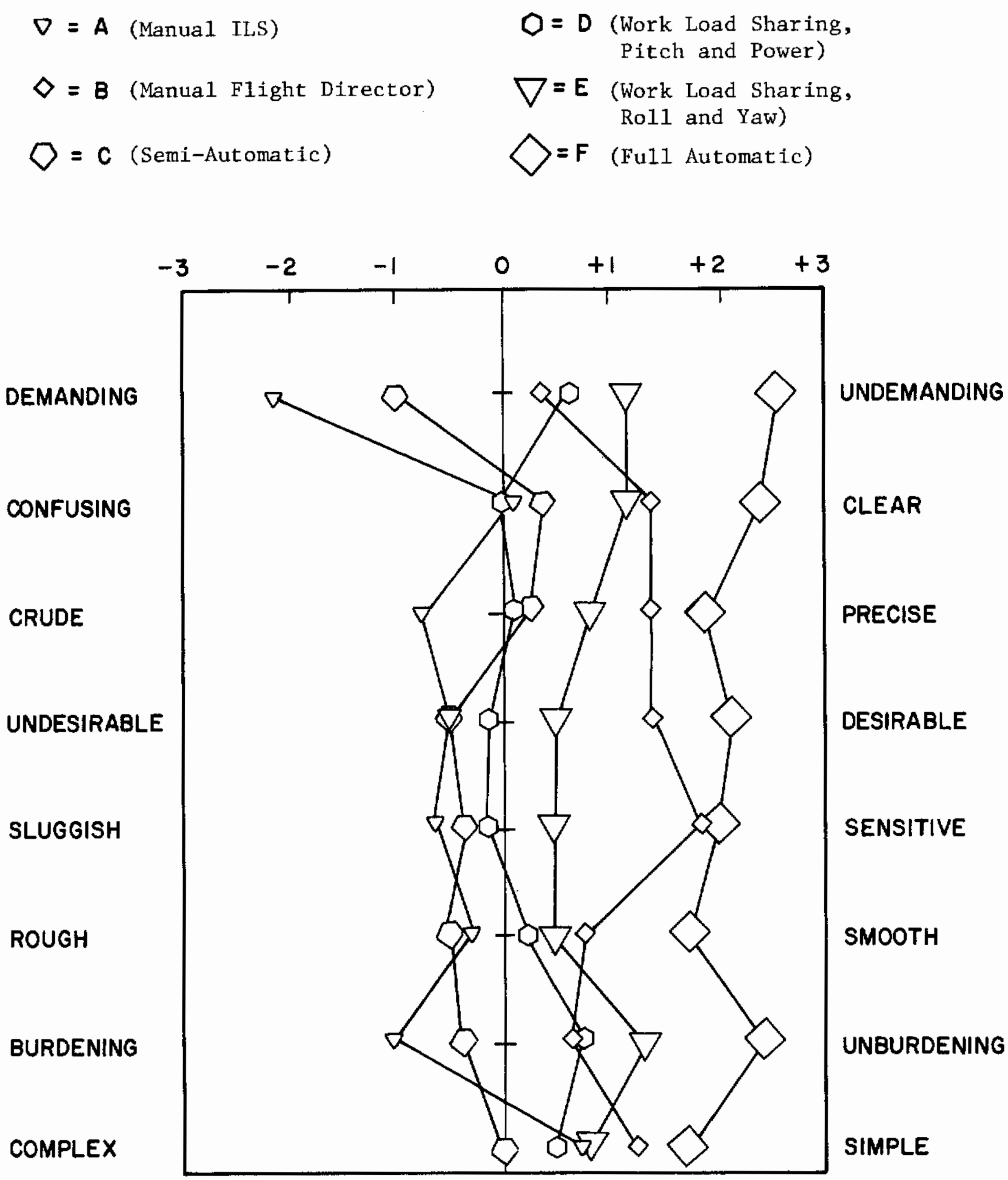

Figure 4. Bipolar Adjective Ratings Across Subjects

TABLE 7. RANKING OF TEST MODES BY BIPOLAR ADJECTIVE RATINGS

1. Mode F (automatic approach) - best
2. Mode B (manual approach with flight director)
3. Mode E (work load sharing with pilot controlling roll and yaw axes)
4. Mode D (work load sharing with pilot controlling pitch and power)
5. Mode C (semiautomatic approach)
6. Mode A (manual ILS approach) - worst

3. Cooper Ratings from Daily Experimental Flight Log:

Cooper Ratings of each mode are presented as frequency distributions in Figure 5. The modes were ranked by the experimenter from best to worst as presented in Table 8.

TABLE 8. RANKING OF TEST MODES BY COOPER RATINGS

Best	1.	Mode F (automatic approach)
	2.	Mode B (manual approach with flight director) Mode E (work load sharing with pilot controlling roll and yaw axes)
	3.	Mode A (manual ILS approach) Mode D (work load sharing with pilot controlling pitch and power)
Worst	4.	Mode C (semiautomatic approach)

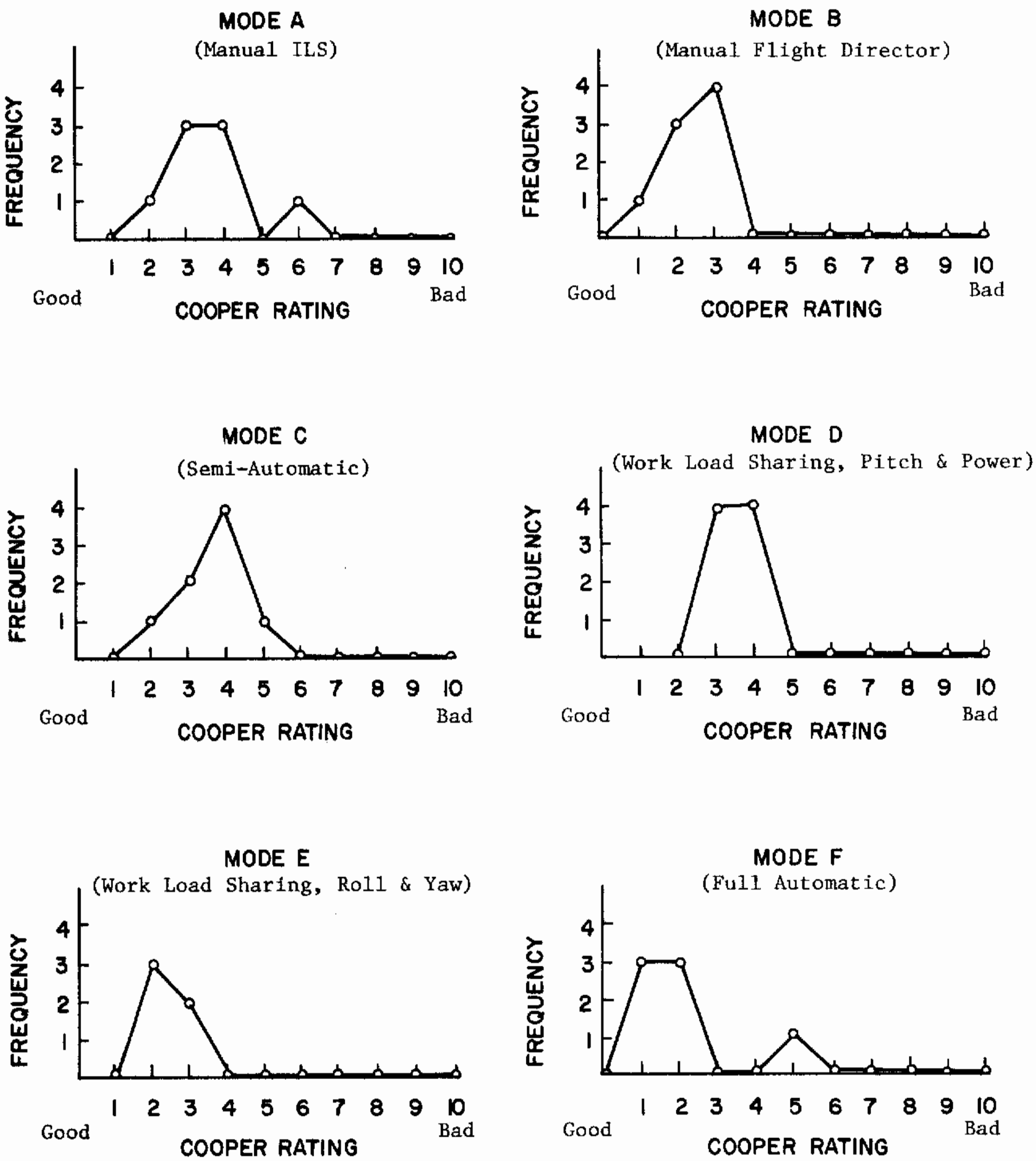

Figure 5. Cooper Ratings of Each Mode.

4. "Pre- and Post-flight" Ratings from Opinionnaire:

Changes in subjects' opinions which occurred between pre- and post-flight questionnaire are presented in Figures 6 and 7. There was a general change to a lower opinion of most modes upon completion of all flights, except Mode F which was rated slightly higher.

Mode rankings by the experimenter were based on postflight average accuracy ratings and are presented in Table 9.

TABLE 9. RANKING OF TEST MODES FOR ACCURACY FROM OPINIONNAIRE

1.	Mode F (automatic approach) - best
2.	Mode D (work load sharing with pilot controlling pitch and power)
3.	Mode E (work load sharing with pilot controlling roll and yaw axes)
4.	Mode B (manual approach with flight director)
5.	Mode A (manual ILS approach)
6.	Mode C (semiautomatic approach) - worst

Mode rankings based on post-flight average work load ratings are presented in Table 10.

TABLE 10. RANKING OF TEST MODES FOR WORK LOAD FROM OPINIONNAIRE

1.	Mode F (automatic approach) - best
2.	Mode B (manual approach with flight director) Mode E (work load sharing with pilot controlling roll and yaw axes)
3.	Mode D (work load sharing with pilot controlling pitch and power)
4.	Mode C (semiautomatic approach) Mode A (manual ILS approach) - worst

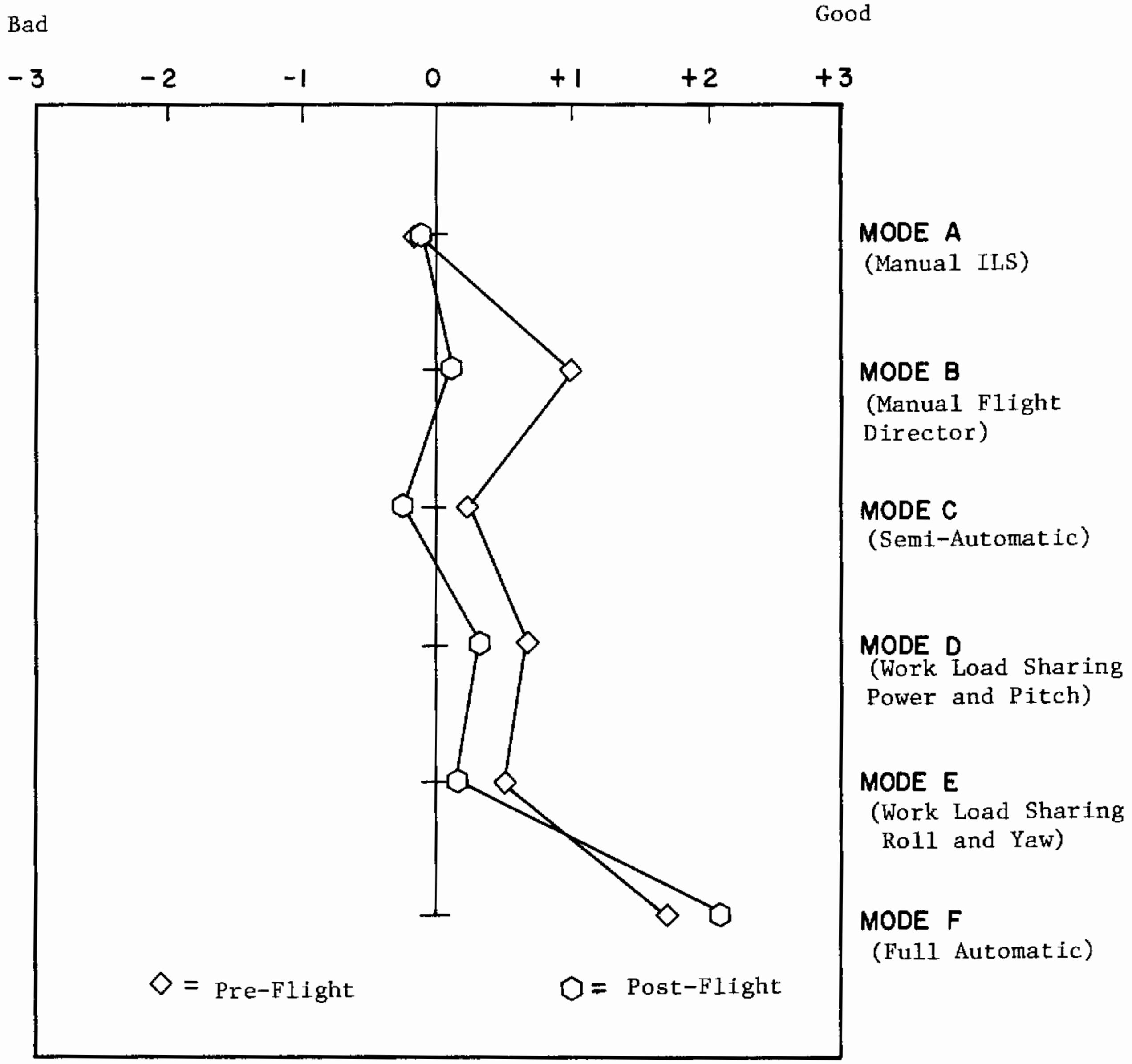

Figure 6. Averaged Accuracy Ratings.

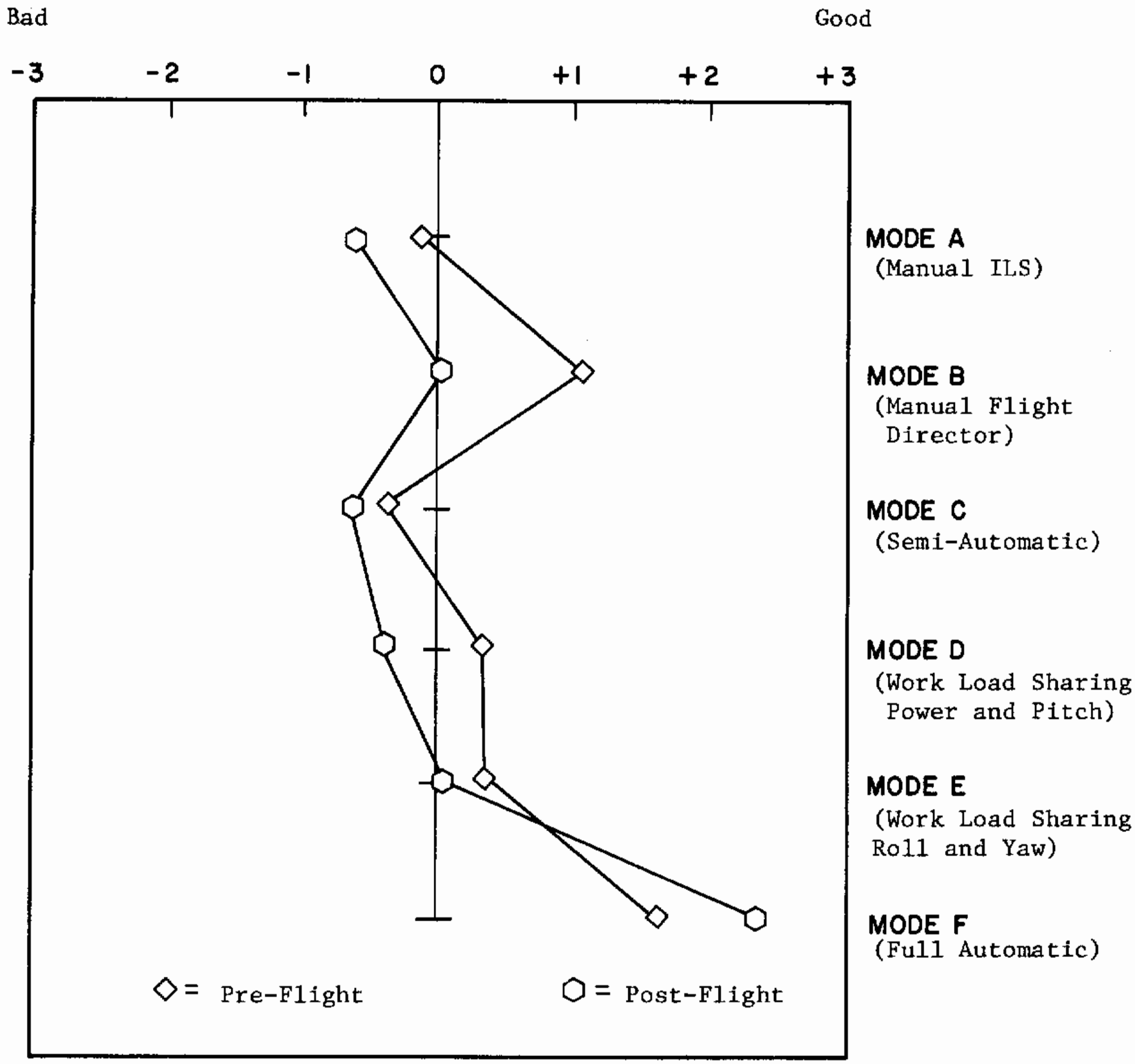

Figure 7. Averaged Work Load Ratings.

Objective Results

The objective data and a description of the analysis of variance (ANOVA) can be found in Appendix B. Differences among modes were considered statistically significant if the probability of obtaining the observed difference by chance alone was less than 5 times out of 100 ($p < .05$).

Statistically significant subject/mode interactions and a significant subject factor appeared in each segment for various parameters. A statistically significant interaction means that a significant amount of data variability was not attributable to the mode alone or to the subjects alone, but rather to some combination of these factors. However, the significant interactions and subject factor did not occur for all parameters, segments, and statistics. Pilots varied greatly across parameters, segments, and statistics (AE, AAE, S.D.). Consequently, no performance or work load patterns developed from the interactions and the subject factor due to the lack of uniformity. However, a pattern of results for the mode effect did develop which permitted a comparison of the various mode configurations. Those results are presented graphically in Figures 8 through 21 and in Appendix B. The significance level for the mean and the standard deviation of each figure is given in Table 11. It should be noted that those modes contributing to small but statistically significant differences were not determined because the low probability of operational significance did not warrant performing post-ANOVA tests. Large scale differences were obvious by "quick-looking" the analyses.

1. Segment 1

   All modes provided good localizer performance (Figure 8). Figures 9 and 10 indicate that modes D (work load sharing, pitch and power) and F (full automatic) had the least variable (but not necessarily the lowest mean) bank and rudder force inputs.

2. Segment 2

   Figure 11 shows that localizer performance was comparable in all modes except A (manual ILS) which had the largest average error and variability. Figure 12 shows fairly comparable glide slope performance for all modes except that mode A had greater variability. As indicated in Figure 13, less variable bank force inputs resulted for modes D and F. Figure 14 shows that in mode F pilots made the lowest and least variable pitch force inputs.

TABLE 11. SIGNIFICANCE OF DIFFERENCES BETWEEN MODE AT THE .05 PROBABILITY LEVEL

FIGURE	STATISTIC	
	Mean	Standard Deviation
8	* $p < .05$	$p > .05$
9	* $p < .05$	* $p < .05$
10	* $p < .05$	* $p < .05$
11	* $p < .05$	* $p < .05$
12	$p > .05$	* $p < .05$
13	$p > .05$	* $p < .05$
14	$p > .05$	* $p < .05$
15	$p > .05$	* $p < .05$
16	$p > .05$	* $p < .05$
17	* $p < .05$	* $p < .05$
18	$p > .05$	* $p < .05$
19	* $p < .05$	* $p < .05$
20	$p > .05$	* $p < .05$
21	* $p < .05$	* $p < .05$

* Statistically significant at the .05 level or better

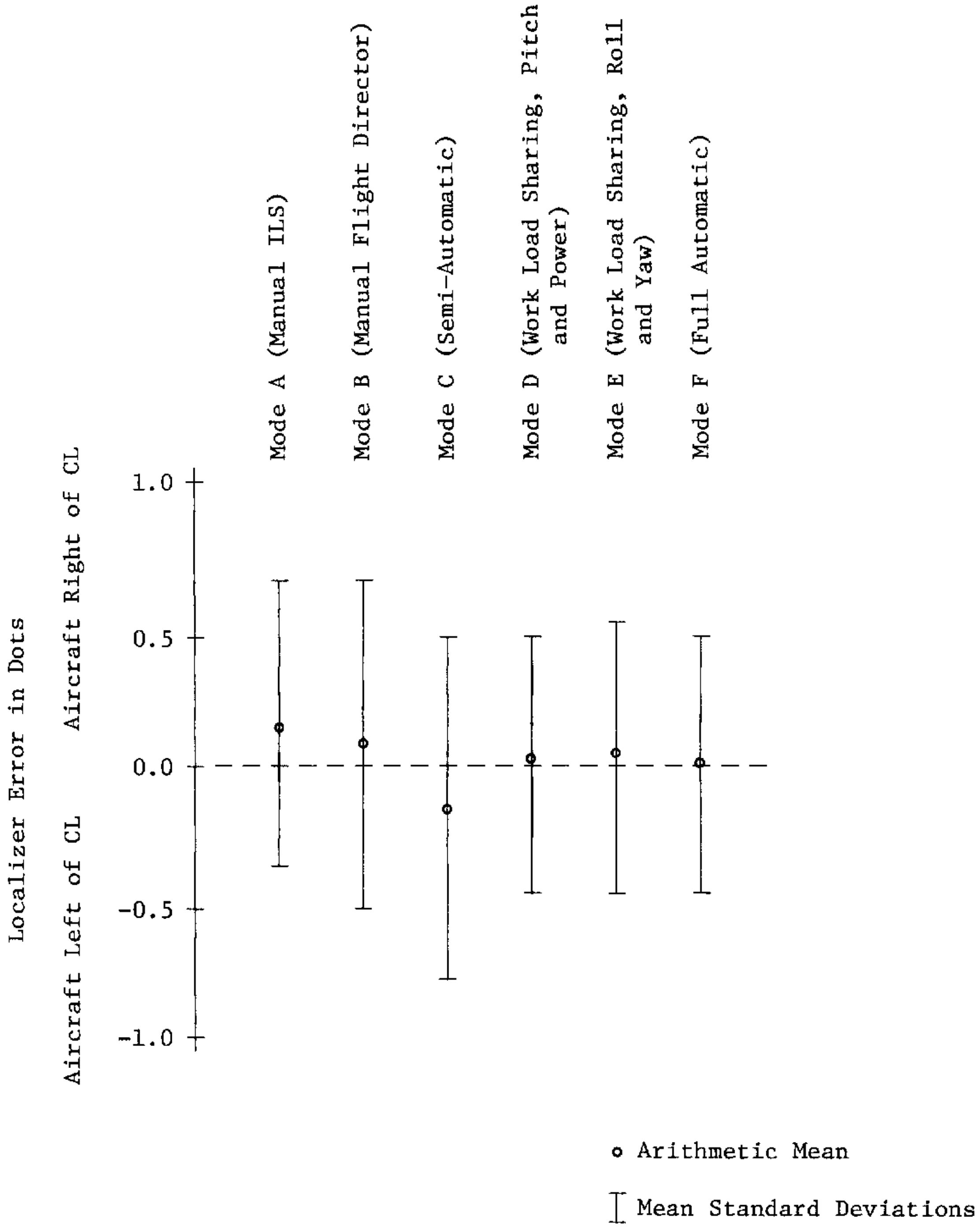

Figure 8. Localizer Error Arithmetic Mean and Mean Standard Deviations for Profile Segment 1.

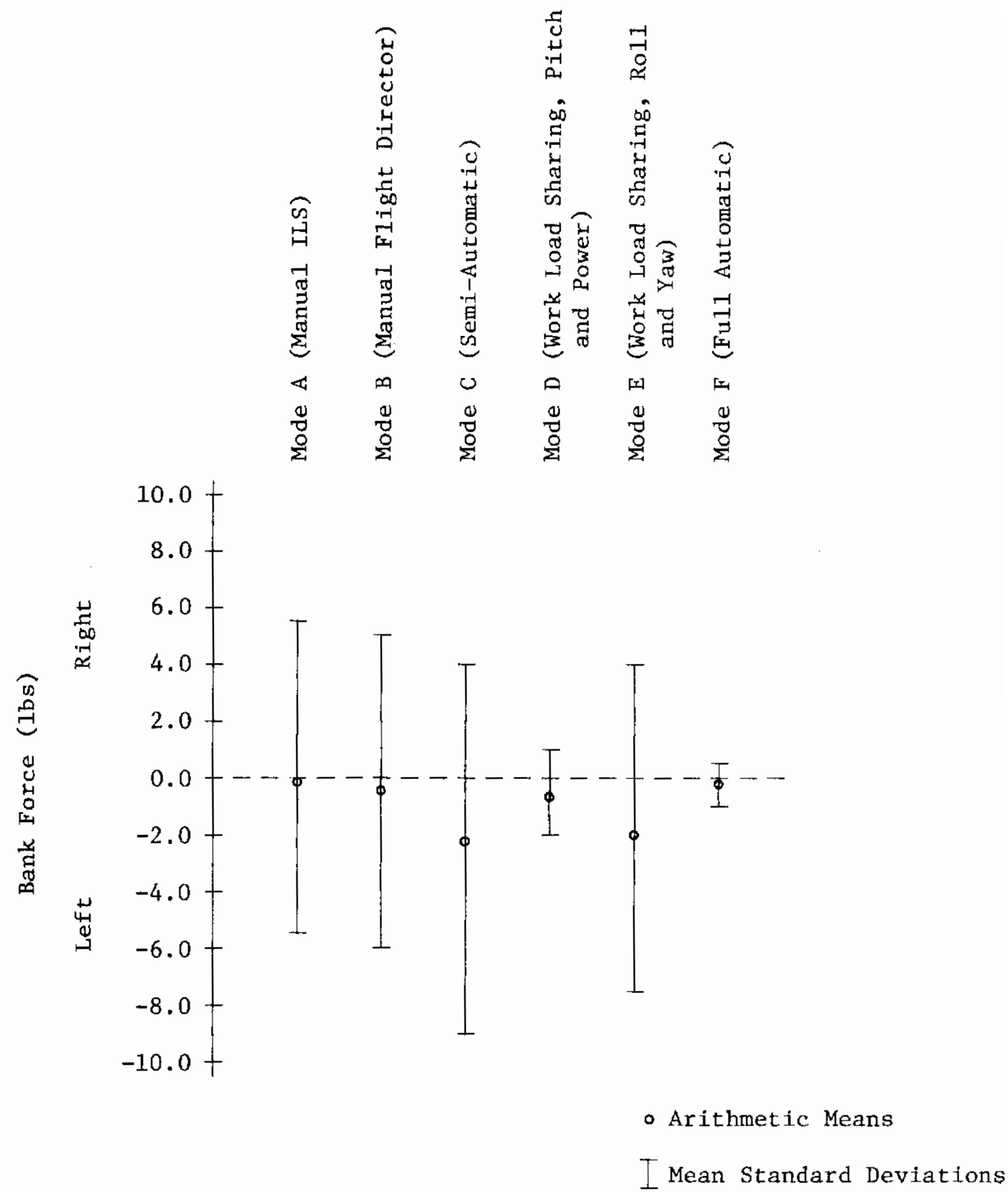

Figure 9. Bank Force Arithmetic Means and Mean Standard Deviations for Profile Segment 1.

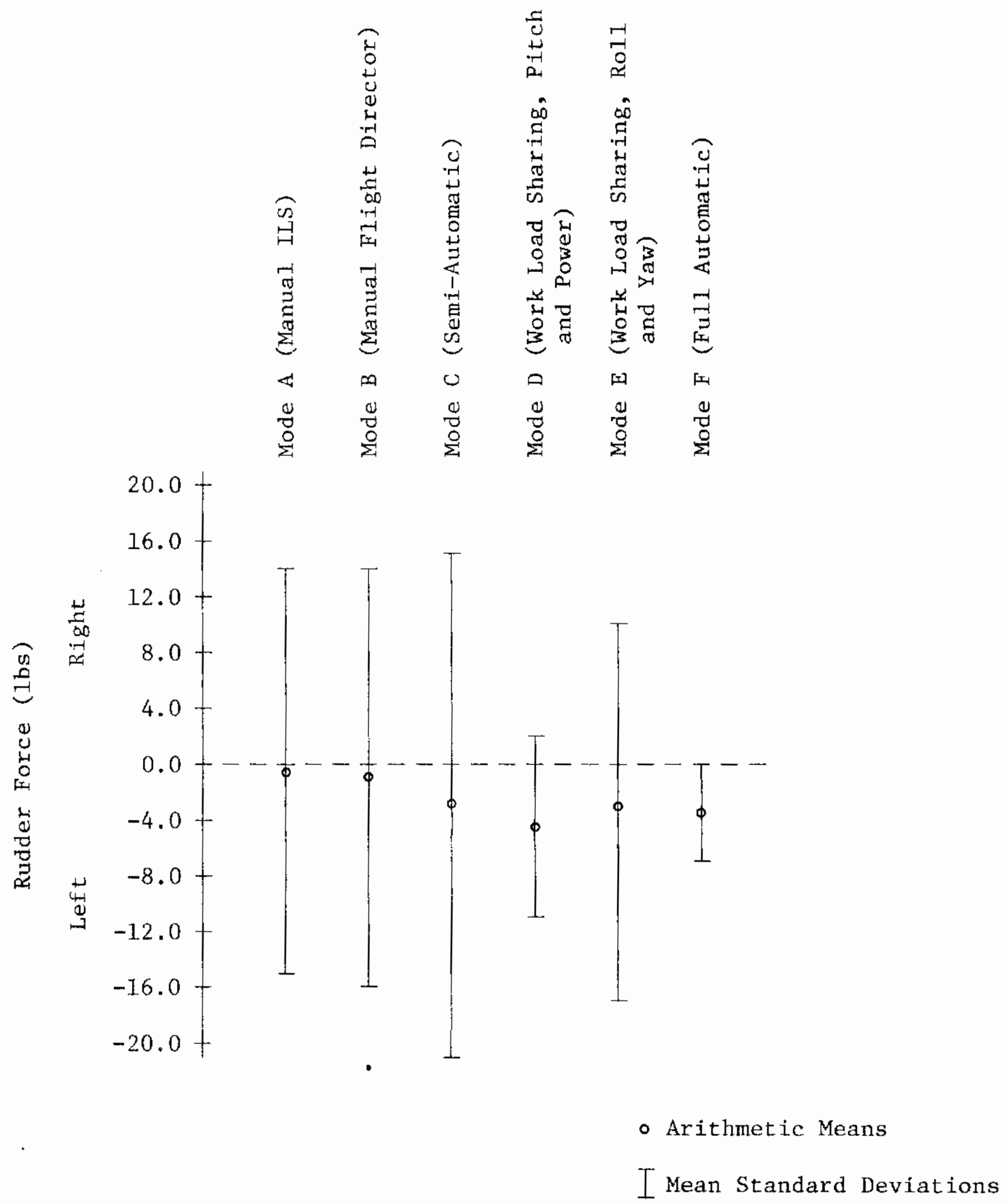

Figure 10. Rudder Force Arithmetic Means and Mean Standard Deviations for Profile Segment 1.

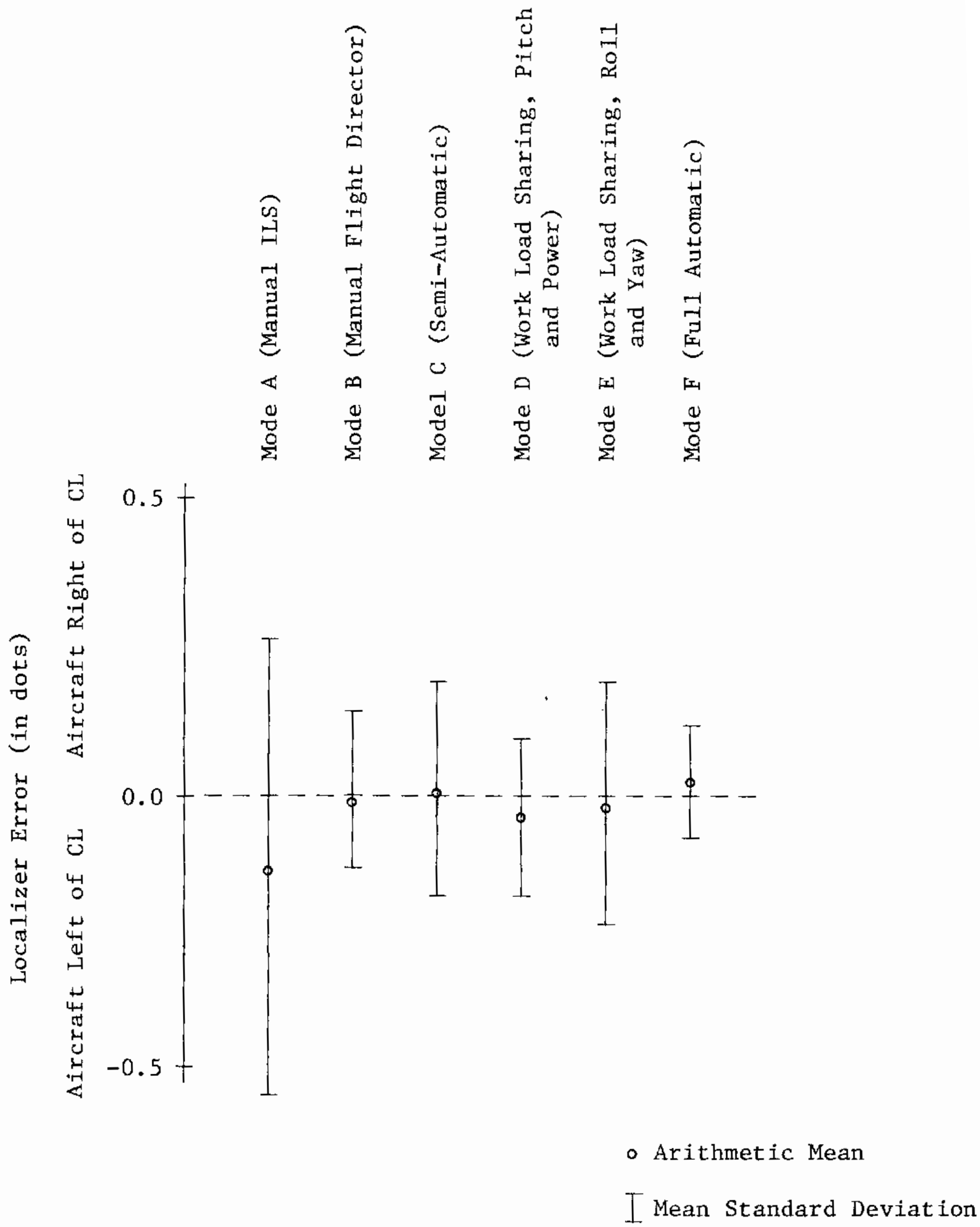

Figure 11. Localizer Error Arithmetic Means and Mean Standard Deviations for Profile Segment 2.

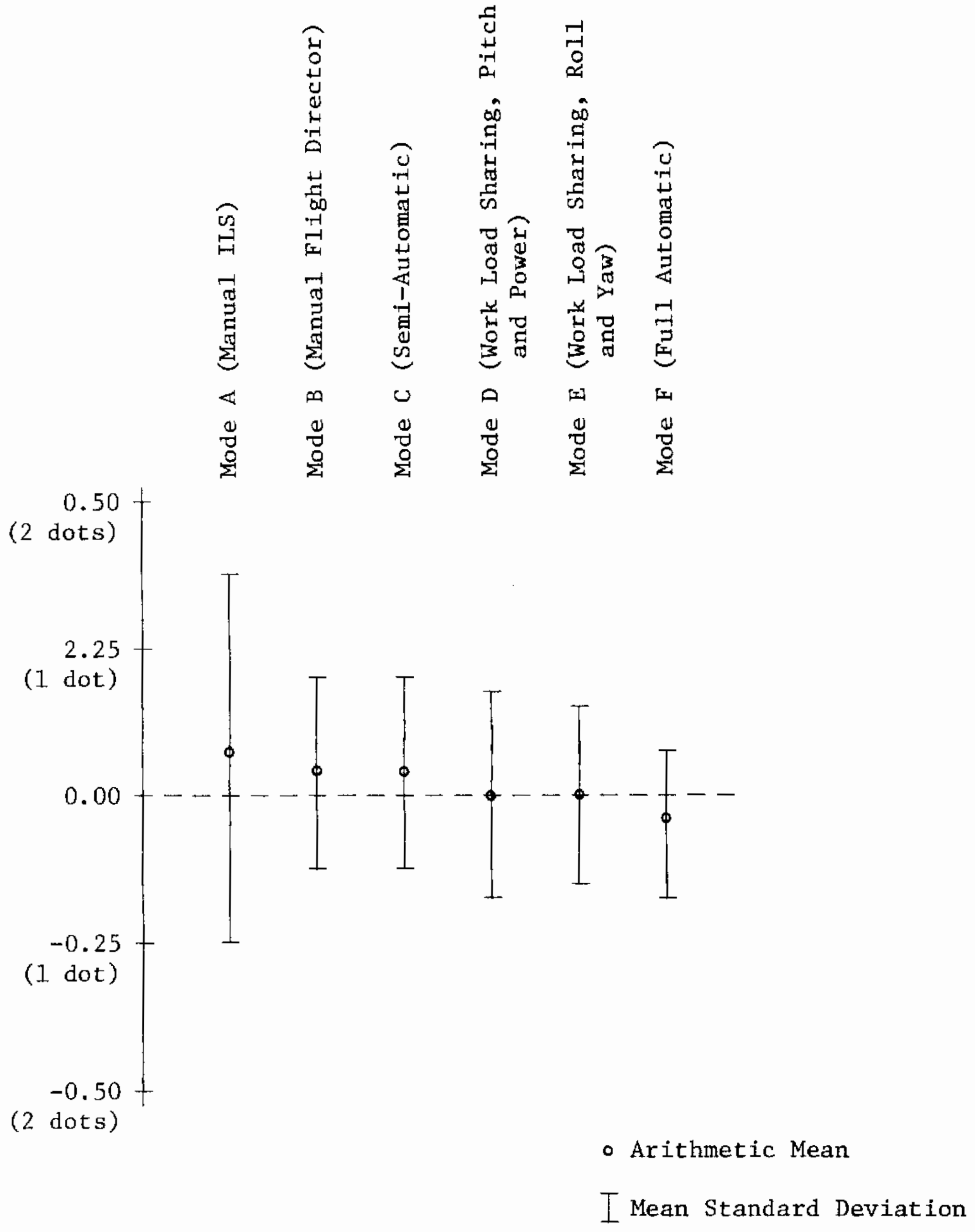

Figure 12. Glide Slope Error Arithmetic Means and Mean Standard Deviations for Profile Segment 2.

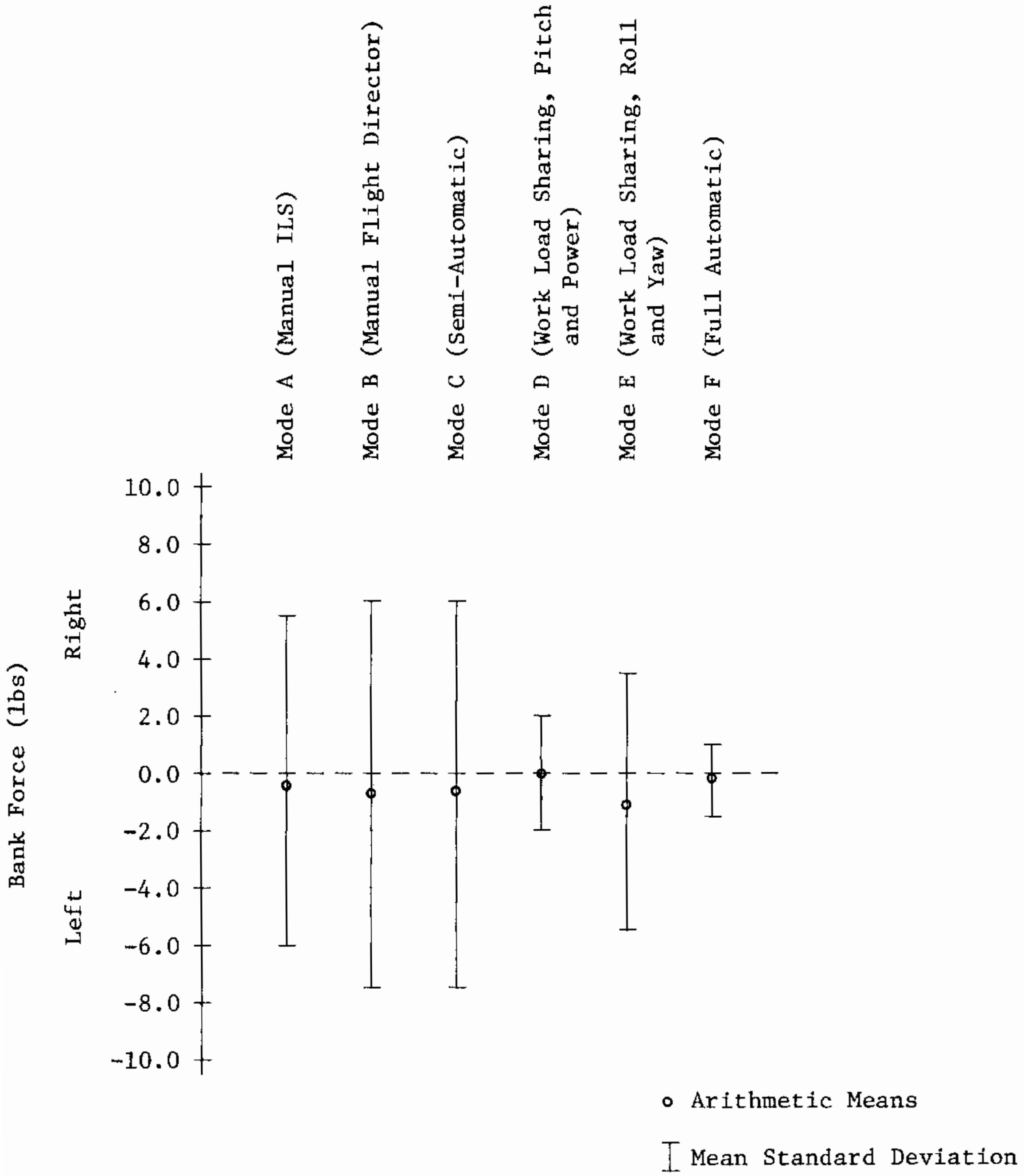

Figure 13. Bank Force Arithmetic Means and Mean Standard Deviation for Profile Segment 2.

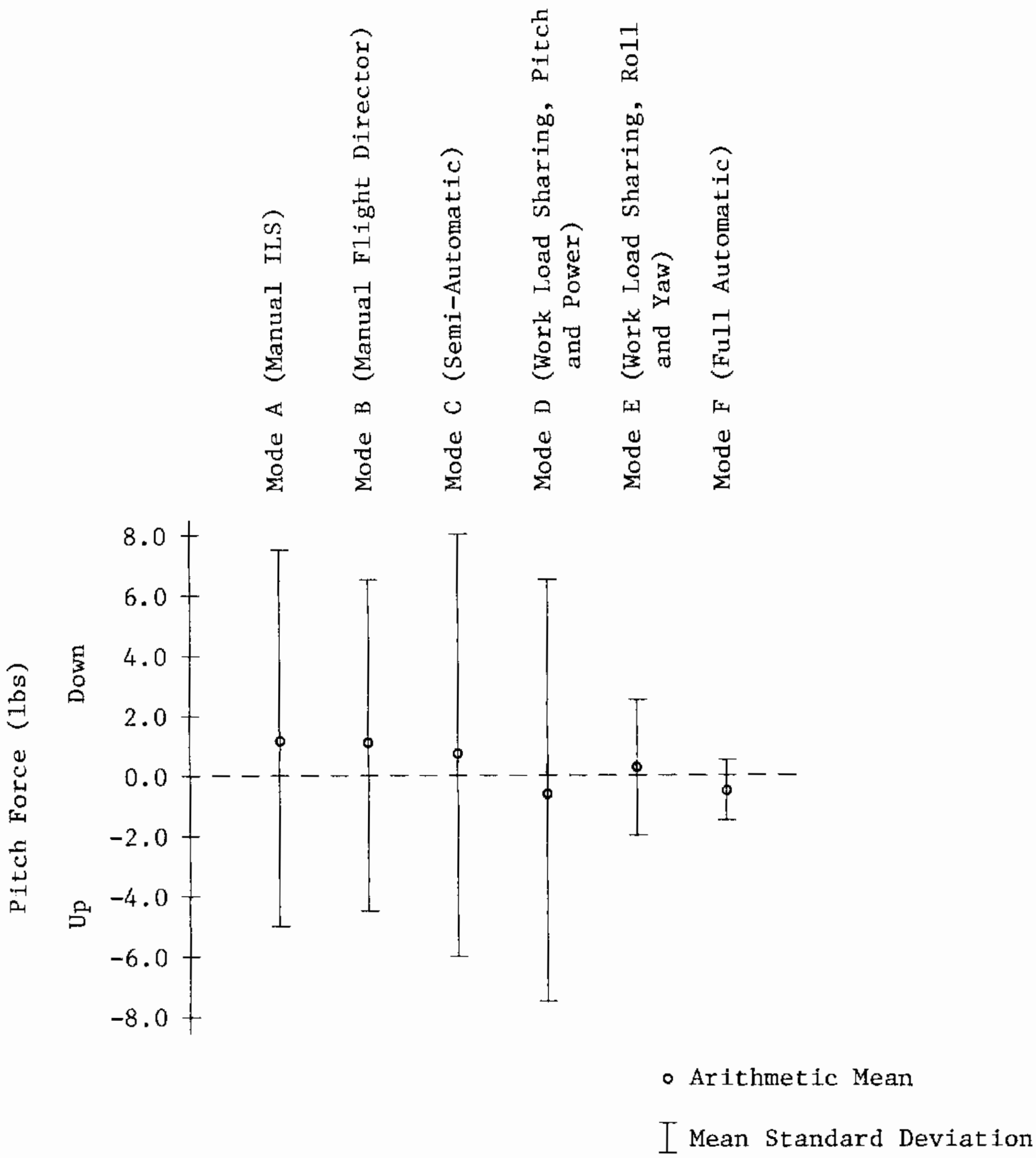

Figure 14. Pitch Force Arithmetic Means and Mean Standard Deviations for Profile Segment 2.

Segment 3

Localizer error (Figure 15) was very low with little variability in Modes B (manual flight director), D (work load sharing, pitch and power) and F (full automatic). Bank steering bar deflection (Figure 16) was least variable in Mode F; bank force (Figure 17) was low and less variable in Modes D and F. Figure 18 indicates that rudder force was less variable for Modes D and F while Figure 19 shows that pitch force was least variable in Mode F.

Segment 4

Figure 20 shows that bank steering bar deflection was slightly less variable in Modes F (full automatic) and D (work load sharing, pitch and power) but D had the lowest arithmetic mean. Figure 21 indicates that pitch steering bar deflection variability was greater in Modes E (work load sharing, roll and yaw) and F; Mode F's arithmetic mean was the lowest and Mode E's was the highest.

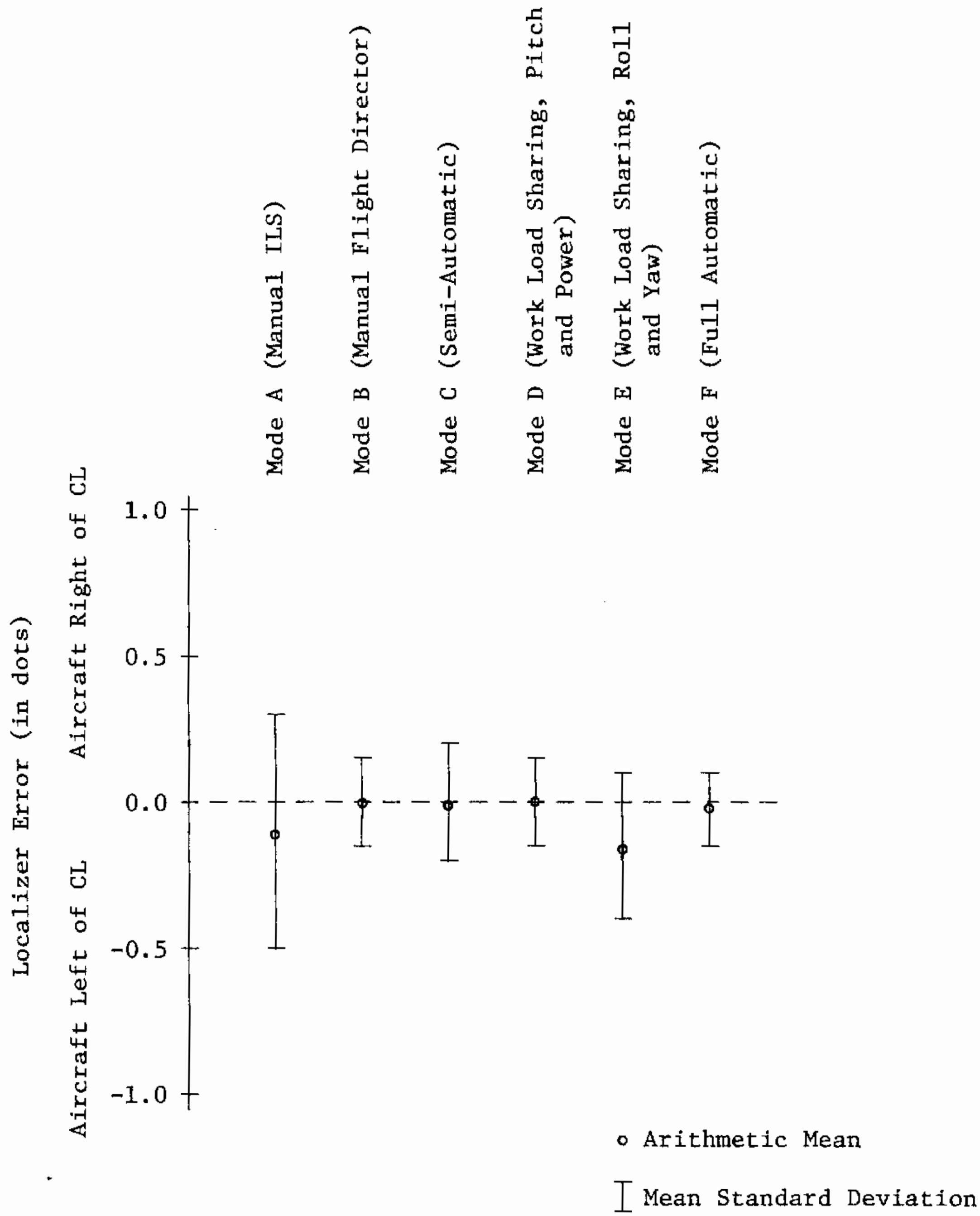

Figure 15. Localizer Error Arithmetic Means and Mean Standard Deviations for Profile Segment 3.

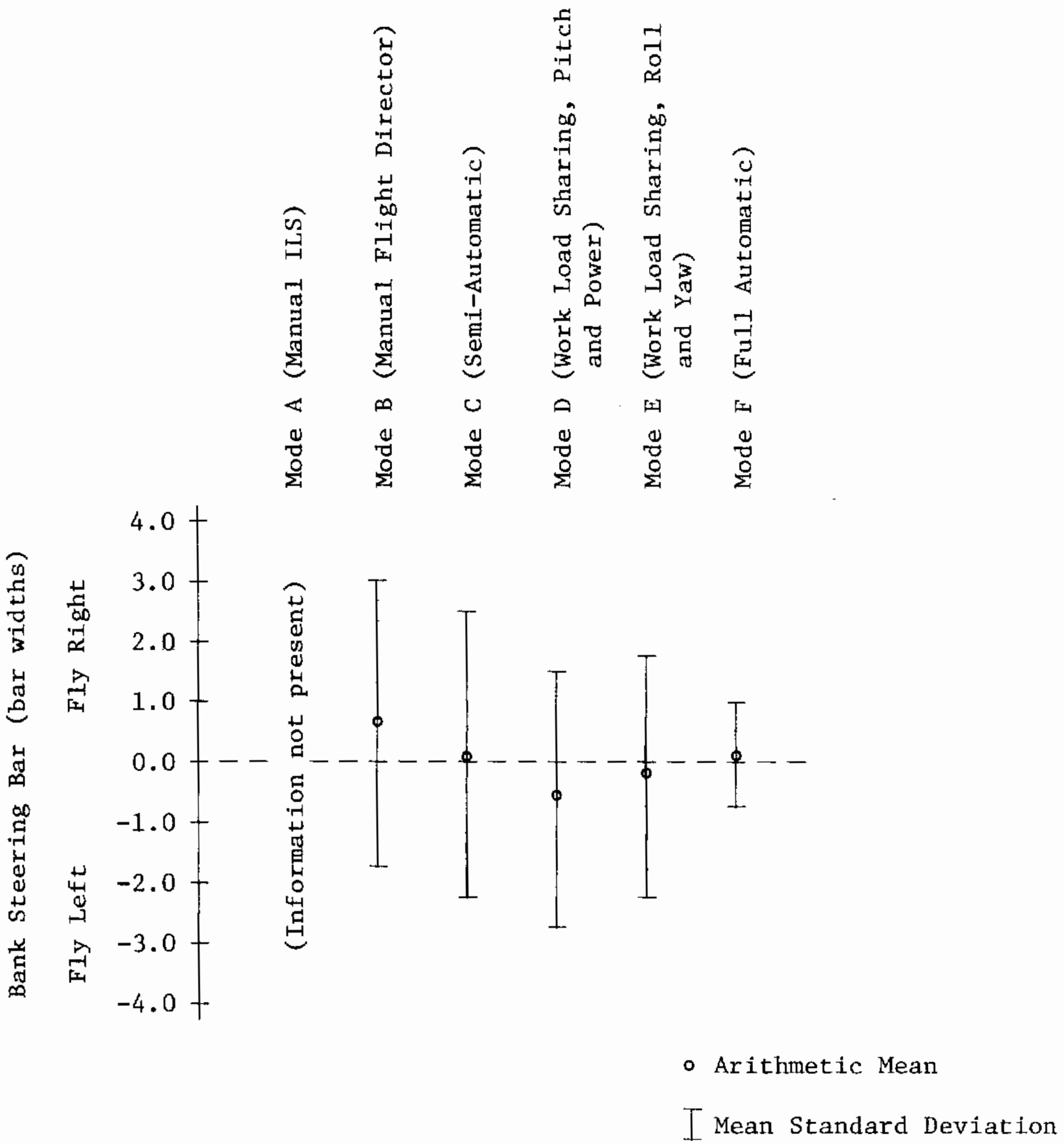

Figure 16. Bank Steering Bar Deflection Arithmetic Means Standard Deviations for Profile Segment 3.

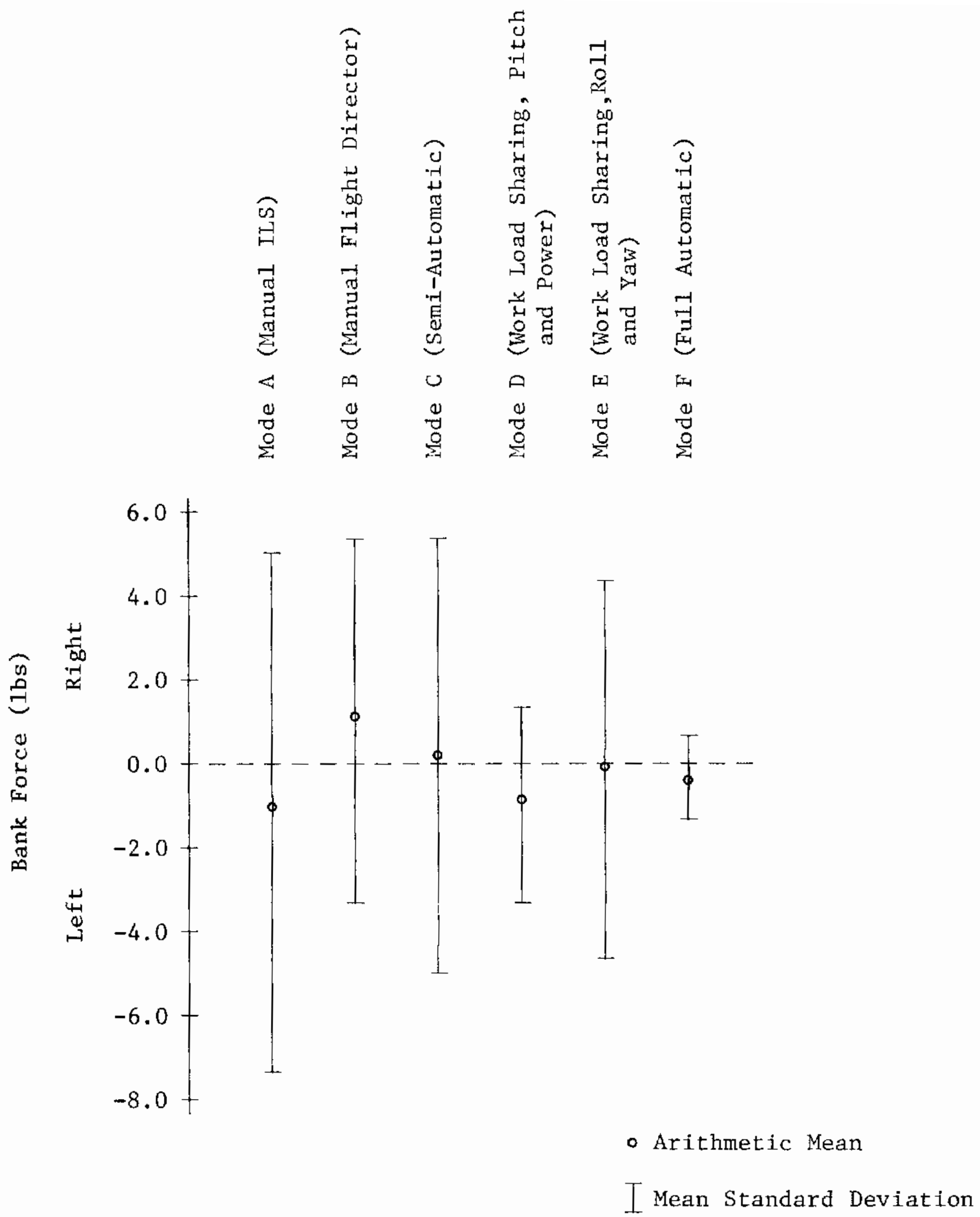

Figure 17. Bank Force Arithmetic Means and Mean Standard Deviations for Profile Segment 3.

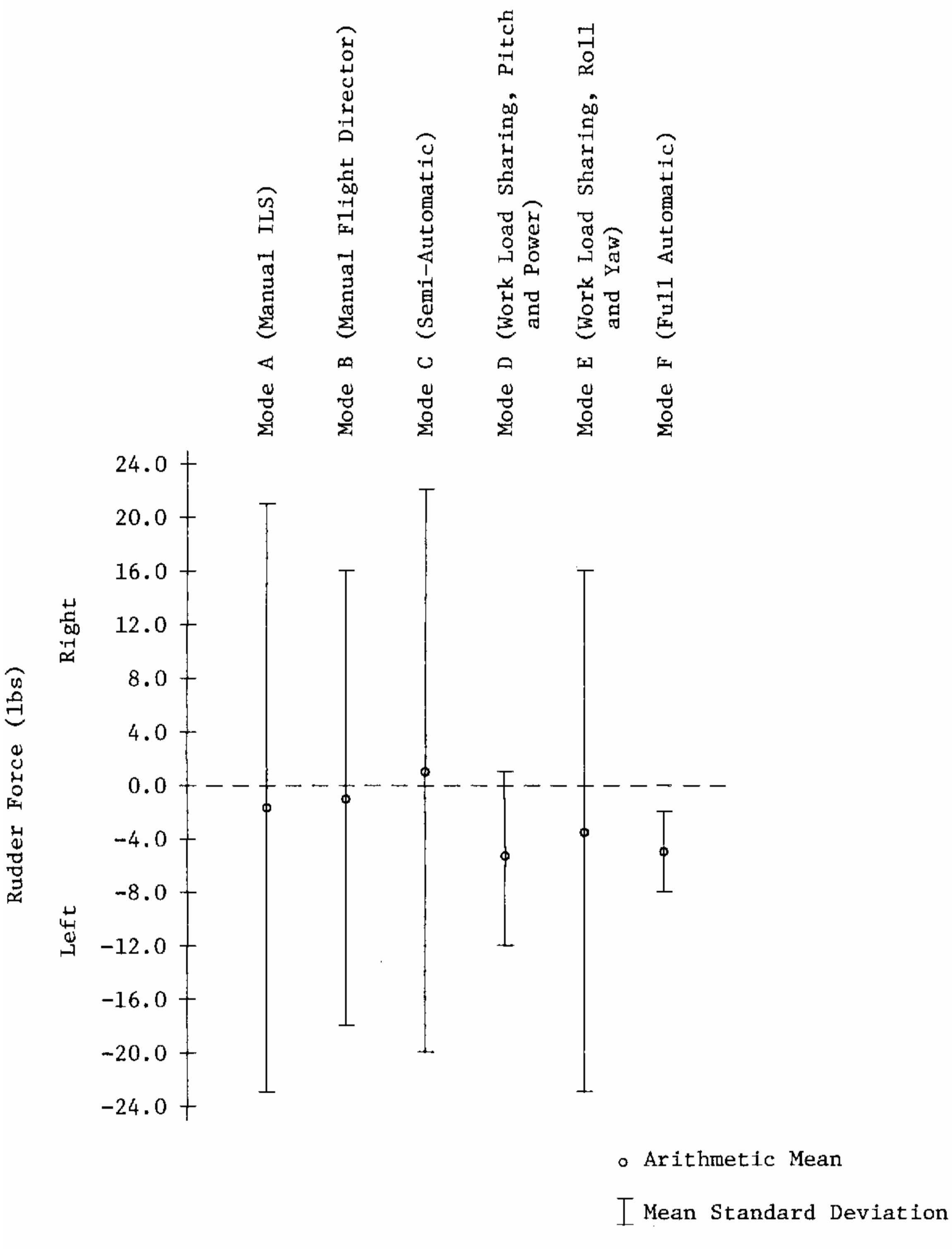

Figure 18. Rudder Force Arithmetic Means and Mean Standard Deviations for Profile Segment 3.

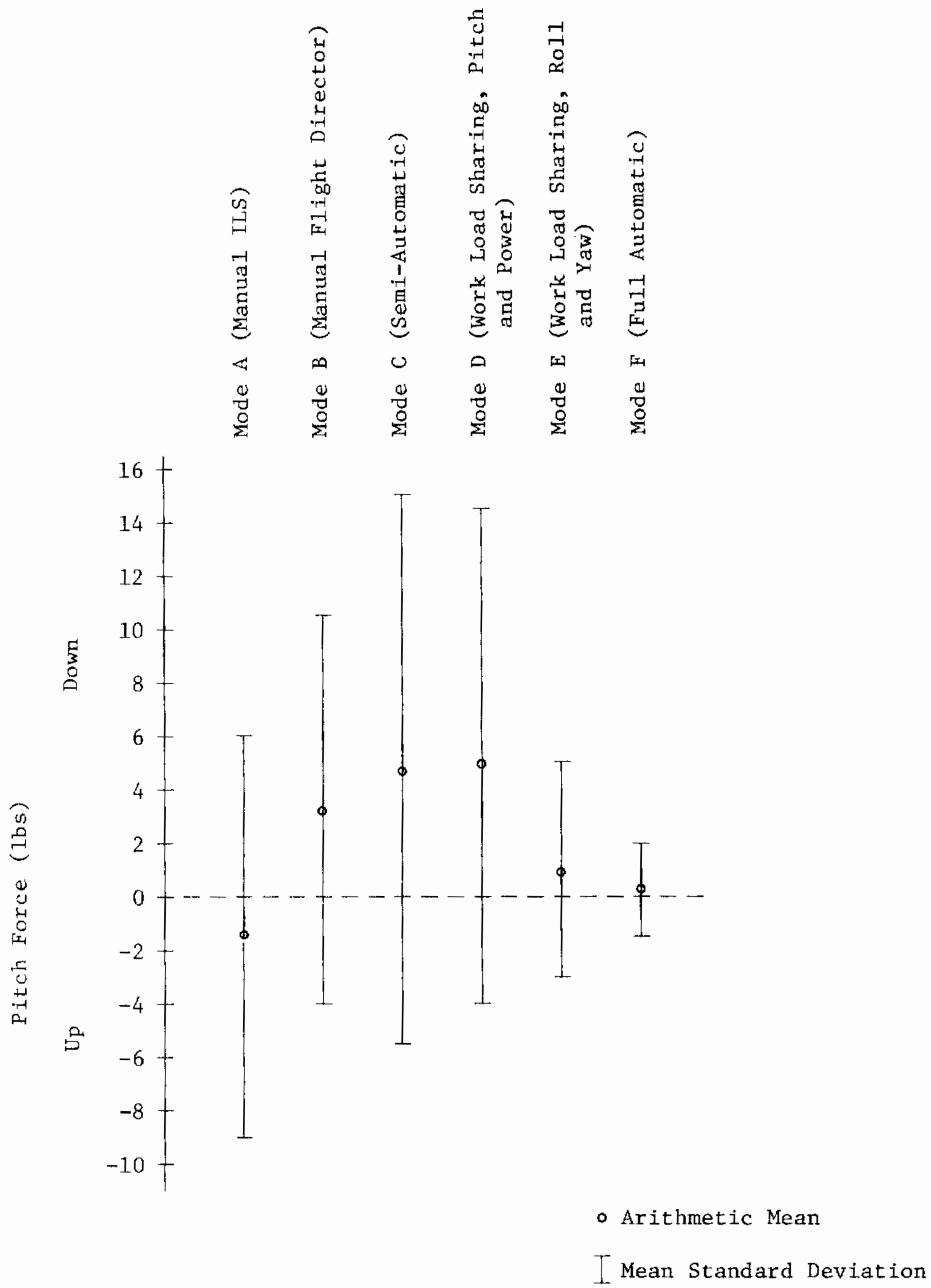

Figure 19. Pitch Force Arithmetic Means and Mean Standard Deviations for Profile Segment 3.

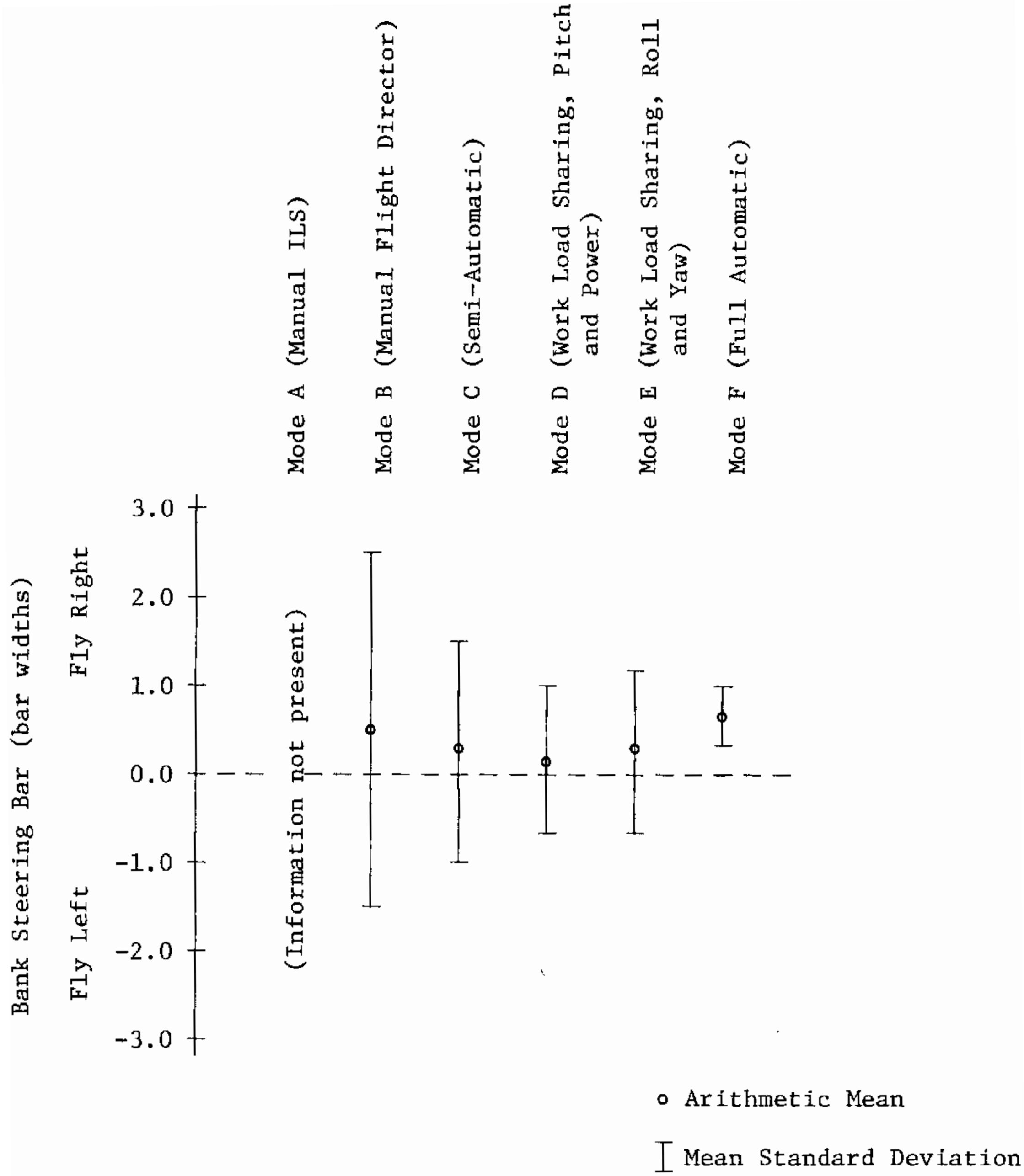

Figure 20. Bank Steering Bar Deflection Arithmetic Means and Mean Standard Deviations for Profile Segment 4.

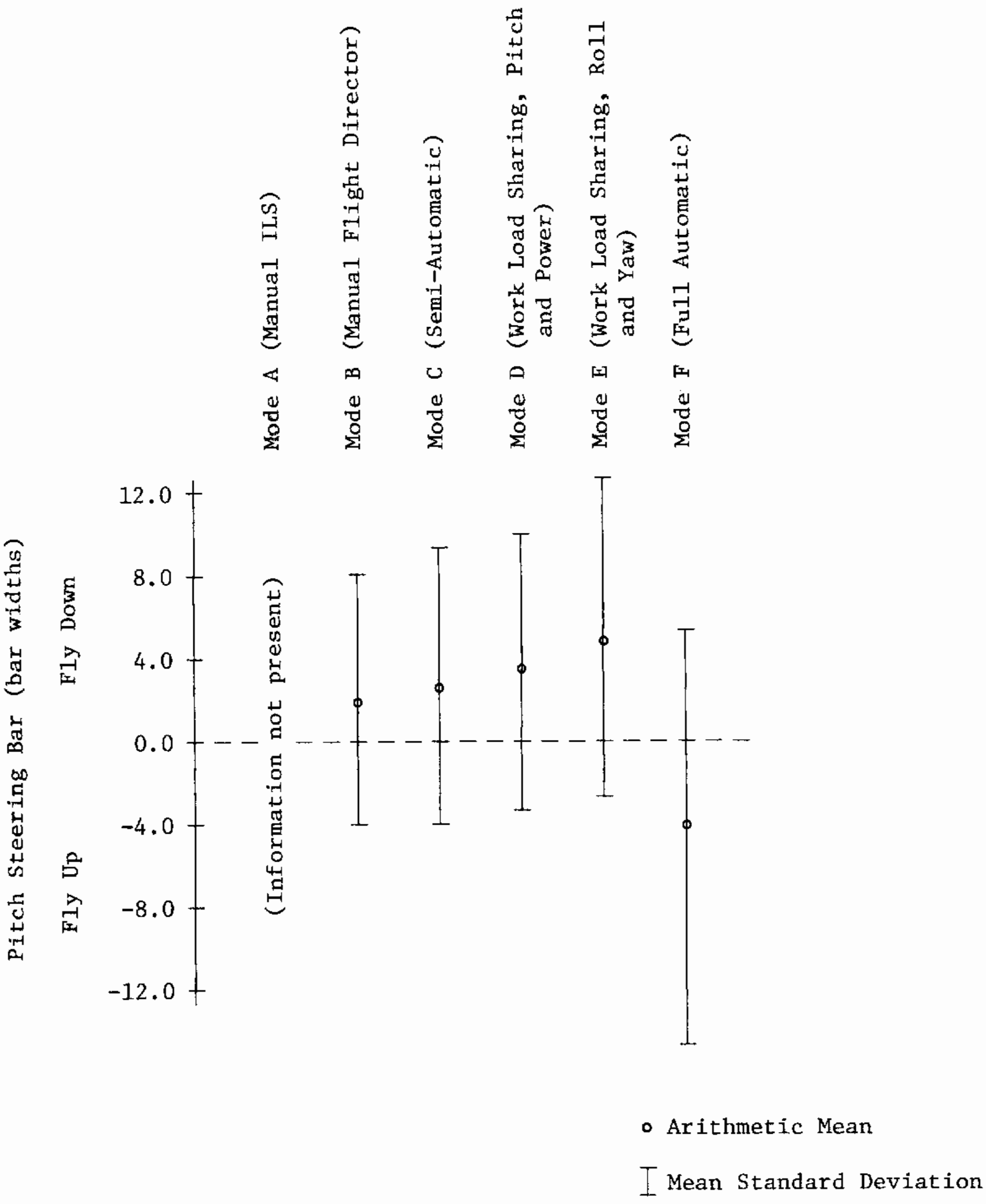

Figure 21. Pitch Steering Bar Deflection Arithmetic Means and Mean Standard Deviations for Profile Segment 4.

SECTION IV

DISCUSSION

This particular project investigated several control system configurations with primary interest in work load sharing and force wheel steering. Force wheel steering was considered alone and was also present for all work load sharing modes but work load sharing was not examined independently. This was due to the mechanical complexities involved and also the interest generated by previous research for implementing the two ideas simultaneously. Any differences between previous research and the current project could be the result of different breakout forces and/or force gradients even though work load sharing and force wheel steering were present in both instances.

Previous research also dictated the various combinations of axes used here but it is reasonable to consider that different arrangements could be used based on pilot preference and/or mission requirements.

Any positive effects due to the new instrument panel must be kept in perspective. Some improvements were expected since the standard instrument panel was over 15 years old and developments such as the flight director and radar altimeter are considered almost basic by current standards.

The profile used was designed to simulate a real world approach to touchdown, within the constraints imposed by the flight test environment. Some of the differences between the simulated approach used here and the real world include:

(a) glide slope and localizer characteristics which change as a function of range such as noise and beam width,

(b) Stress factors for the subject pilot since he knows the safety pilot is "heads-up" and will not allow a dangerous situation to develop, and

(c) performance differences between the hooded subject pilot flying given axes versus the safety pilot flying the same axes "heads up".

The profile and procedures assumed a continuous control situation and did not investigate such things as rapid transition of control from autopilot to pilot due to a graceful/catastrophic equipment failure.

The experimental design used a counterbalanced sequence of control system configurations to compensate for potential practice, fatigue, and order effects. Use of counterbalancing in situations where there are suspicions of interactions between the independent variable (here, control system configuration) and order effects is generally unwise. However, there was no evidence to support such a suspicion for this project and hence the use of counterbalancing.

The instrumentation system gave priority to "performance" parameters rather than "control" parameters. Glide slope and localizer performance were believed to be more important than pitch rate and roll rate, for example, since the simulated task was to achieve a specified performance task rather than optimize control responses. Smoothness of pitch and roll rates alone will not accomplish such a task.

The subject pilots were asked to complete several forms during their participation and the quantity of these might explain some of the similarities expressed in the subjective data. If there were more detailed questions and fine choices asked of the subjects than they were able to discriminate, the accuracy of the subjective data might suffer. For this reason, it is believed that only the larger differences should be considered reliable; small differences might fall within the subjects' variability and would not necessarily be indicative of true differences based on the independent variable alone.

A somewhat parallel situation occurred with the quantity of objective data. It was possible, based on chance alone considering the number of statistical tests, to obtain significant differences. For this reason there was an interest in patterns rather than isolated effects. The flight test effort described here, with numerous possible combinations of independent and dependent variables, lends data which might suitably be analyzed by more sophisticated techniques than the analysis of variance. This does not mean that the current techniques were necessarily wrong but it was possible that some experimental effects went unnoticed. The constraints of the project did not permit analysis of the data with additional statistical techniques.

Now that some of the limitations of the project have been advanced, it is appropriate to discuss the results themselves.

The information obtained from the Pilot Personal Data Sheets did not bear any observable relationship to the subjective or objective data because the pilots, regardless of the background, usually showed close agreement in their ratings of the various modes. However, the pilots did not show close agreement in performance from segment to segment and parameter to parameter.

Comments on the Flight Questionnaire indicated that the amount of time needed to adapt to the test item was adequate except for unfamiliar instruments which required additional concentration. This fact suggests that ratings and performance of the various modes were not artifacts of how familiar each pilot was with particular modes, but were in fact the results of flying each mode. It is still possible that familiarization with certain modes of flying could have contributed some small amount to the fairly high ratings of those modes. For example, Mode B (manual flight director) was considered very good, although no comments were offered for comparing it with other flight directors which the subjects had flown. It is possible that this high rating was the result of familiarization since Modes A (Manual ILS) and B were the two most familiar to the subjects. (However, Cooper Ratings and Bipolar Adjective Ratings indicated that Mode B was slightly better than Mode A although they were equally familiar).

Mode F (full automatic) did not receive many comments, probably due to a lack of interaction between the pilot and the control system. Since the pilot was merely a monitor, he was not compelled to be an active participant. The "emergency" GO-AROUND mode was disliked by two pilots and it might be well to consider the utility of this mode. First, if the system were not operating properly for an approach it would not likely be trusted for a go-around. Second, if a go-around were initiated due to other reasons (traffic, directive from the control tower, etc.) the pilot would likely be trying a unique maneuver, e.g. turning onto a specific heading or altitude. Hence, the relatively "rigid" GO-AROUND mode may not even be necessary.

The bipolar adjective ratings were good for indicating the extreme of "good" and "bad" because only two modes were designated as being significantly different from average: Mode F (full automatic) was judged best and Mode A (manual ILS) was judged poorest. The rest of the modes were relatively close together within these extremes, and any differentiation must be based on the other data.

The Cooper ratings also showed Mode F (full automatic) as the best, but offered further discrimination of the other modes:

Second Best	Mode B (Manual FD) Mode E (Roll and Yaw)
Third Best	Mode A (Manual ILS) (Pitch and Power)
Fourth Best	Mode C (Semi-automatic FD)

As indications of aircraft handling characteristics, some of these ratings are unexpected. Mode A would have been expected to be poorest, followed closely by Mode C, because of the high magnitude of the breakout forces. Although Mode E required control of two axes, it received more favorable ratings than Mode D. This was unexpected because controlling power would not normally be as difficult as controlling an axis since fewer power inputs are normally required. These ratings seem to indicate that Modes D and E deserve some attention regarding the handling characteristics although serious problems did not exist.

The pre- and post-flight ratings indicated fairly small opinion changes, but most of them were in a negative direction; that is, the pilots' opinions of the various modes became less favorable after flying them. The two exceptions were: (1) Mode A (manual ILS) which showed little change, probably indicating that the pilot knew the basic aircraft fairly well; and (2) Mode F (full automatic) which received a more favorable rating after flying. An examination of the direction of the opinion changes did not reveal any additional pattern for specific tasks (e.g. glide slope capture, etc.). An overview of the post-flight ratings suggest Mode F is best, and the rest cluster together below it.

Using the objective data from which Figures 8 through 21 were derived, the experimenter ranked the modes within each segment as shown in Table 12.

TABLE 12. "RANKING" OF TEST MODES BY PROFILE SEGMENT USING QUICK-LOOK OBJECTIVE DATA

PERFORMANCE	WORK LOAD
Segment 1. (Localizer Intercept to Glide Slope Intercept)	
Mode F slightly better than the rest which clustered	Modes D and F best; the rest cluster
Segment 2. (Glide Slope Intercept to Flare Initiation)	
Mode F best; Modes BCDE cluster Mode A worst (all modes provided acceptable glide slope tracking, i.e. less than 1 dot).	Mode F best; then the rest cluster; within the cluster Mode D best in roll force, Mode E best in pitch force.
Segment 3. (Flare Initiation to Go-Around Initiation)	
Modes B,D,F, better for localizer error Mode F best for Roll Steering Bar (Localizer Error and Bank Steering Bar not correlated as expected)	Mode F best; the rest cluster with: Mode D best for roll force and rudder force; Mode E best for pitch force.
Segment 4. (Go-Around Initiation + 30 Seconds)	
For Roll Steering Bar, Mode F best For Pitch Steering Bar, Modes E and F poorest	Not considered

To summarize, Mode F for Segment 1 and 2 was the best overall. Modes D and E work load sharing) confirmed that work load is reduced in the roll and pitch axes, respectively, for the person who is not supposed to control these axes.

A large amount of subjective and objective data was collected for the purpose of investigating the various modes of the test item. Due to the number of unique characteristics of the objective data, it was difficult to integrate the various types of data. However, as stated previously, of prime importance were patterns of significance for the work load sharing modes of operation. With this guide, all of the data was examined to determine the main results of the flight test. Table 13 depicts the order of modes from best to worst, considering performance, work load, subjective and objective data, across subjects and profile segments.

TABLE 13. RANKING OF MODES BASED ON ALL DATA

	Rank	Mode
(best)	1	F - automatic
	2	D - pitch and power
	3	B - manual FD E - roll and yaw
	4	C - semiautomatic FD
(worst)	5	A - manual ILS

This ranking was not based on isolated comments but rather on general patterns. For example, most subjects considered the amount of training and the panel layout to be adequate, yet there were infrequent casual responses about dislikes for one or two displays. The overall conclusion would then be that the subjects were adequately familiarized with the test item.

This final ranking supports the expectations for the extremes of the scale. The fully automatic approach, where the subject merely acted as a monitor and controlled power, was expected to have at least the lowest physical work load. The subjective data indicated that work load was lowest here also. For the poorest condition, manual ILS, the subject had to control the entire aircraft without the benefit of steering commands, etc.; this accounted for the high work load with still the poorest performance. However, the other modes of operation were of more interest and deserve some elaboration.

Although the modes ranked as 2, 3, or 4 were of specific interest, the differences between 3 and 4 were fairly difficult to judge since they were not radically different for each type of data collected. The ranking of Mode C was believed due to the fact that the copilot had outside the cockpit cues which helped him control his respective axes. However, the pilot, flying hooded, had no command for the yaw axis as he did for pitch and roll. Controlling power is not thought to induce much additional work load since it requires only an occasional input.

Another interesting comparison is between Mode B (manual flight director), ranked third, versus Mode C (semiautomatic flight director), ranked fourth. There are two reasons which could cause such differences: First, the manual flight director mode permits continuous control by the pilot which not only requires him to be more alert but also gives a source of tactile feedback. Second, in the semiautomatic flight director mode the pilot must contend with the electrical dead band in addition to the mechanical breakout forces for each axis. Hence, it is possible he could have more difficulty making small, smooth inputs.

Mode C (semiautomatic) was described as good but with stiff or high breakout forces, particularly for the rudder. This could have produced commands which were described as "too sensitive" since high forces could be conducive to lags or over shoots. This was probably the basic reason why the mode was downrated since there were not consistent comments about the aircraft handling qualities.

The work load sharing modes in Modes D (work load sharing, pitch and power) and E work load sharing, roll and yaw) were described as having reduced work load but still needing more isolation between axes. The pilots reported that they had difficulty forgetting the copilot's axes and could have used more confidence about the copilot's performance. This could have been the result of the pilots' training and lack of familiarity with the copilot since they were trained to control all axes. It may therefore be desirable to give pilots sufficient training to overcome these difficulties. It is interesting to note that USAF Instrument Flight Center (IFC)[4] found that pilots actually favored the work load sharing modes. It is possible that their pilots had more extensive training and experience with one another and the concept of work load sharing. Hence, their pilots may have been able to overcome such potential problems as lack of mechanical isolation between pilot and copilot controls. In addition, the equipment used in the current study had some differences from that in previous research, e.g. higher force level for pitch axis dead band.

4. "Summary of the Allocation of Control Tasks Program", Gerald C. Armstrong, IFC-TR-74-1, January 1974, pg. 6.

SECTION V

CONCLUSIONS

Within the limitations of the flight test project, the following are believed to be the conclusions which can be drawn:

1. Regarding Performance Differences Between Modes:

   (a) Mode A (manual ILS) showed significantly poorer glide slope performance than the other modes.

   (b) The remaining performance differences were observed primarily in the lateral axis as indicated by localizer tracking.

      (i) Mode A (manual ILS) was noticeably poorest and Mode F (automatic) noticeably best (except for go-around mode).

      (ii) Mode B (manual flight director) and Mode D (pitch and power) were better than Mode A (manual ILS) but not as good as Mode F. Note that for Mode D, the localizer tracking was performed by the "heads up" safety pilot.

      (iii) Mode C (semiautomatic FD) and Mode E (roll and yaw) were better than Mode A (manual ILS), but not as good as Modes B and D. Note that for Mode E, the localizer tracking was performed by the "heads down" subject pilot.

2. Regarding Work Load Differences Between Modes:

   (a) Work load was noticeably lowest for Mode F (automatic).

   (b) When a given axis or axes were controlled by the copilot, the work load was reduced for the pilot in the same axis(es).

   (c) Sharing the work load with the autopilot for stability augmentation and using force wheel steering (Mode C) did not reduce the pilots' work load.

(d) A conclusion based on objective data alone could not be reached concerning work load sharing of itself or force wheel steering of itself. The reason is that whenever there was a work load sharing mode, whether with the autopilot for stability augmentation or with the other pilot, there was also the use of force wheel steering.

3. Relevance of Modes to Autopilot Failures:

(a) Whether the work load was shared between pilots, or between pilot and autopilot affording stability augmentation (Modes C, D, E), these work load sharing modes were considered acceptable substitutes for a partial autopilot failure (i.e. when the autopilot can not be coupled to the ILS but merely offers stability augmentation). This assumes that there are no serious effects due to the transitions itself when the autopilot experiences such a failure.

(b) Mode B (manual flight director) was believed to be an acceptable substitute for a partial or total autopilot failure. This assumes that there are no serious effects due to the transition into such a mode from such an autopilot failure.

4. Relevance to "Keeping the Pilot in the Loop":

(a) The work load sharing modes (C, D, and E) appear to be an acceptable way of keeping the pilot in the control loop with another pilot and/or autopilot affording stability augmentation.

(b) An inadequate amount of data was obtained concerning the pilot interaction with the autopilot when it was coupled to the ILS (Mode F).

5. Miscellaneous:

(a) There were no indications that any of the modes evaluated compromised safety.

(b) Axes were effectively isolated from one another, electrically, for the work load sharing modes. However, there was a minor problem due to the lack of mechanical isolation.

SECTION VI

RECOMMENDATIONS

1. Determine which performance/work load effects are attributable to force wheel steering itself and those which are attributable to work load sharing itself.

2. Implement more sophisticated statistical analysis techniques (e.g. multivariate analysis of variance) to detect added effects of the various control system configurations.

3. Investigate the control system configurations under real-world conditions with both pilots hooded, simulating a low visibility or zero-zero approach to touchdown.

4. Determine whether the pitch-power and roll-yaw combinations of axes are optimum or whether different combinations exhibit better performance and lower work load. An autothrottle should be considered a vital part of such an investigation.

5. Examine the characteristics of the work load sharing and force wheel steering concepts to serve as a backup for a graceful or total autopilot failure. Of particular concern is the time needed to recognize such failures and the time needed to assume control in one or more axes.

6. Investigate potential advantages of mechanical isolation of axes between pilot and copilot. This would prevent control movements for a given axis from distracting the pilot/copilot if they are not supposed to be controlling that axis during work load sharing.

7. Document the work load of pilot and copilot for each axes of the work load sharing modes to determine the total pilot/copilot work load.

8. Determine the usefulness of the automatic go-around and automatic take-off modes.

9. Quantify the amount of training required for each mode of operation and determine differences between low-time pilots and highly experienced pilots.

10. Determine mental work load for the modes of interest.

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USAF Instrument Pilot Instructor School, Aircraft control task allocation: Phase I - feasibility. CDG Project 64-1A, Randolph Air Force Base, Texas, November 1965.

USAF Instrument Flight Center, Summary of the Allocation of Control Tasks Program. IFC-TR-74-1, Randolph Air Force Base, Texas, January 1974.

APPENDIX A

PILOT STATEMENTS FROM FLIGHT QUESTIONNAIRE

FORMAT:

Question

Response from Subject 1

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.
.
.

Response from Subject 8

FLIGHT QUESTIONNAIRE

JC-131B S/N 53/7789
AIRCRAFT CONTROL TASK ALLOCATION

1. Do you feel that the training flight plus one practice approach on each condition was adequate for you to perform the mission? If not, why? How much more training would you recommend?

    1. One practice on each approach is adequate. Any more practice would be a waste of flying time.
    2. Adequate
    3. Definitely adequate if experienced in Convairs and Flight Director.
    4.
    5. Yes
    6. Yes
    7. I had the advantage of having flown this system before, however, I think a minimum of three practice rides would be required for cockpit orientation and to rid the confusion on crew duties.
    8. Yes

2. How long did it take you to adapt to the new instrument? The AVRI and the flight path angle tape on the ADI?

    1. The flight path angle was somewhat confusing still at the end of the first mission. The AVRI is an easily understood useful instrument.
    2. I never accepted the AVRI information as reliable. I found the VVI information too sensitive. I liked the flight path angle tape and used it quite a bit.
    3. One approach
    4.
    5. Several flights
    6. Two flights
    7. Two approaches, but I had flown a flight director system before which helped in the learning curve. The tape was always confusing to me because it oscillated and because 100 was 50 ft and it seemed to me it ought to go from top down instead of bottom up.
    8. FPA - Quick
       AVRI - Very slow--numbers did not relate to anything familiar.

3. Comment on the system's performance when you were flying a manual approach with the Flight Director System.

    1. Good, much better and easier than any round dial approach. The system is an aide to the ease of Flight Director flying.
    2. I found the alt. hold command info useful. The command bars obstruct my view of the ADI for small corrections to attitude.
    3. Excellent
    4.
    5. I think it's a very good system - precise, smooth response.
    6. Good
    7. Sensitive, but adequate
    8. Good

3a. What, if any, difficulties were encountered in keeping the flight director bars centered?

    1. The suddenness of movement on final course interception and again on interception of the glide path.
    2. Obstructed view to ADI for minute attitude corrections, scalloped ILS glide slope, forced constant power changes affecting trim, etc.
    3. None, except for normal corrections.
    4.
    5. Rollout command when intercepting localizer begins too early and then is so slow as to give the effect of a non-constant rate turn.
    6. None. Using the system became much easier with each flight.
    7. Adequate, but tiring due to the control pressures.
    8. Normal.

4. Comment on the system's performance during the semi-automatic approach.

1. Very good. First approach was somewhat confusing in that control inputs had to be held in.
2. I found it fairly smooth and very accurate; however, monitoring it takes too much concentration on command bars breaking down crosscheck.
3. System's performance was okay.
4.
5. Did not like this much, because of the kickback through the controls and the artificiality of the feel of the airplane (like a poorly maintained simulator).
6. Flight Director steering bars seemed to be slightly more sensitive.
7. Adequate, but tiring due to the control pressures.
8. Good

4a. Was it easy to adapt to this method of flying an approach?

1. Yes
2. Yes
3. Not easy
4.
5. No
6. No. Required much more concentration and a much faster crosscheck.
7. Yes
8. Yes

4b. Were the sensitivities of the force sensors satisfactory?

1. They were set very well.
2. Yes
3. Yes
4.
5. Seemed too sluggish when first applied, then too sensitive after breakout force overcome.
6. Yes
7. Tiring
8. Usually

4c. Were the control breakout forces satisfactory?

1. Never had to breakout of my assigned axis and never had any trouble accidently getting into the wrong axis. So they were set good.
2. I don't remember.
3. Yes
4.
5. Too stiff.
6. No--required much more pressure than I felt was desirable.
7. Yes
8. Yes

4d. Were the aircraft's maneuvering characteristics satisfactory using this mode? (e.g. use of rudder for heading control)

1. Yes
2. Satisfactory
3. No--in making turns and corrections it was like a continuous isometric exercise down final.
4.
5. No--rudder had to be a conscious input beyond that which is natural for normal coordination; therefore, a mechanical response rather than instictive.
6. No--more pressures were needed than was desirable.
7. Yes
8. Yes

4e. What, if any, difficulties were encountered in keeping the flight director bars centered?

1. Easier than in manual.
2. None
3. None
4.
5. Tended to over control on heading changes when close to minimums and pitch trim changes caused heavy control forces, especially on go-around.
6. The steering.
7. See paragraph 2a.
8. Normal

5. Comment on system's performance during the automatic approach.

1. Very good.
2. Scalloped glide slope cause abrupt attitude changes.
3. Excellent
4.
5. Worked very well.
6. Automatic approach was highly satisfactory. I found it to be a very enjoyable system to fly and monitor.
7. Easy
8. Good

5a. Did the autopilot adequately fly the aircraft keeping the flight director bars centered?

1. It did a good job.
2. Yes
3. Yes
4.
5. Yes
6. Yes
7. Yes
8. Yes

5b. Did you at any time during the automatic approach want to improve or modify system steering bar centering performance by using the aircraft controls?

1. No
2. No
3. No
4.
5. Yes--on go-around. No need to have a severe pitch change unless some emergency, and then I'd want manual control.
6. No
7. No
8. Yes

5c. Did you actually use the force wheels during the approach? If so, why?

1. No
2. On short final twice to avoid a dangerous nose-down attitude.
3. No
4.
5. No
6. No
7. No, not intentially anyway.
8. Yes, to correct to localizer and glide slope.

6. What is your opinion of this work load sharing flight control concept as used during the approach?

1. I liked it.
2. It takes just as much work as the single pilot concept. I found myself monitoring the other pilot's work more than my own task.
3. Low
4.
5. Only one pilot should be on the controls - and have the responsibility for the airplane during an approach and landing.
6. Has some desirable aspects. Biggest plus being the fact that both pilots monitor each other out of necessity.
7. Confusing and tiring as it seemed to me that the pilot and copilot were fighting each other on the controls unconsciously.
8. Mixed emotions.

6a. During the approach, do you feel that the work load was reduced by not having to control the aircraft's longitudinal (or directional) axis?

1. Yes
2. No, it's fairly easy for an experienced pilot to keep the bars safely centered.
3. Yes
4.
5. Yes
6. Yes
7. See 6 (confusing and tiring as it seemed to me that the pilot and copilot were fighting each other on the controls unconsciously.)
8. Not appreciably.

6b. During the approach, were you able to "forget" the control not being flown by you?

1. No, not completely but I didn't have to think about it as much as if I were flying it.
2. No, I don't trust anyone else.
3. Yes
4.
5. No
6. Not really.
7. No, see 6.(confusing and tiring as it seemed to me that the pilot and co-pilot were fighting each other on the controls unconsciously).
8. No!

6c. Did you feel that the work load sharing concept permitted you to perform your share of the overall control task more effectively?

1. Yes
2. No--spent more time watching other pilot.
3. Yes
4.
5. Allowed slightly more precision in following a steering bar, but tended to narrow span of attention, which is all right for the copilot perhaps, but bad for pilot.
6. Yes
7. No, see 6. (confusing and tiring as it seemed to me that the pilot and co-pilot were fighting each other on the controls unconsciously).
8. Ailerons - Yes
   Pitch - No, about the same.

6d. What new cockpit problems, if any, did the work load sharing concept introduce?

1. None except maybe monitoring a control input that I had no personal control over.
2. Didn't trust other pilot. Worried about the engine gages, radios, nav aides, outside, etc., that other pilot usually takes care of while I fly.
3. Who makes decisions?
4.
5. Narrowed span of attention and reduced sense of total responsibility.
6. No problems.
7. See 6. (confusing and tiring as it seemed to me that the pilot and co-pilot were fighting each other on the controls unconsciously).
8.

6e. In flying the work load sharing mode, were you consciously monitoring the performance of the other pilot?

1. Yes, I monitored it but it wasn't distracting.
2. Yes
3. Yes
4.
5. Yes
6. No; however, unconsciously I monitored the other pilot. On several occasions I found myself checking his axis.
7. Yes and see 6. (confusing and tiring as it seemed to me that the pilot and co-pilot were fighting each other on the controls unconsciously)
8. Yes

6f. What suggestions would you make to improve the work load sharing concept?

1. None. The worst part is overcoming the pilot liking to think he can do it all himself.
2. Let one man fly and the other take care of all other details.
3. Dispense with it. My personal feelings are that two people cannot be flying the aircraft that close to the ground in event of emergency.
4.
5. Not to use it.
6. Try to isolate the axis a little more. It's relatively easy to get into the other pilot's axis and this causes some minor deviation in the precision of the approach.
7. Not have it.
8. Remove alternate indications from instruments; e.g., have either pitch or bank steering bar zeroed out when alternate is being flown - this would reduce tendency to attempt to fly both axes.

7. Please comment on following display factors relative to any of the instruments on the experimental flight panel: (refer to pictures of panel or wall of the briefing room)

The following pages contain comments on these factors:

a. Scaling
b. Interpretability
c. Method of Information Presentation
d. Integration
e. Accuracy
f. Use of colors
g. Rates
h. Visibility

7a. Scaling

1. Good, AVRI has too short of scale.
2. O.K.
3. O.K.
4.
5. Altitude tape scale should not require interpretation. Scale divisions all right.
6. Good
7. Adequate except for the tape.
8. O.K.

7b. Interpretability

1. Easy
2. No problem.
3. No problem.
4.
5. Altitude tape scale should not require interpretation. Scale divisions all right.
6. Good
7. Easy, except for the tape.
8. Good except AVRI.

7c. Method of information presentation

1. Good
2. Good
3. O.K.
4.
5. Good
6. Good
7. Nice, but I think the tape could be eliminated and position the radar compass to a closer vicinity of the ADI.
8. Good

7d. Integration

1. Good
2. Good
3. O.K.
4.
5. Good
6. Good
7. O.K.
8. Good

7e. Accuracy

1. Very good.
2. AVRI VVI information too sensitive.
3. O.K.
4.
5. Good
6. Good
7. Sensitive but good.
8. Bank steering too sensitive to minute heading changes.

7f. Use of colors

1. Good
2. O.K.
3. Good
4.
5. Good
6. Good
7. Adequate
8. Good for daylight - not flown at night - night flights should be included to evaluate.

7g. Rates

1. AVRI has too much movement
2. See 7e.
3. Good
4.
5. Rate of change of flight path angle indication too rapid to use for making adjustments to FPA. Had to adjust on attitude indicator pitch marks and check FPA when it stabilized.
6. Good
7. Sensitive
8. Good

7h. Visibility

1. Good
2. HSI was difficult to see over yolk.
3. Good
4.
5. Tower instruments in poor place but can't do much about it in a C-131 with such a massive control column.
6. Good; except glide slope, nav, and out off trim lights are sometimes obscured from view by the control column.
7. As good as you can get in a C-131.
8. Good - See 7f.

8. How useful or beneficial do you consider the AVRI?

1. Very useful in low vis approaches; tended not to consider it very reliable.
2. Radar altimeter good for roundout. VVI useless.
3. Very useful.
4.
5. Very useful.
6. Quite beneficial, especially at low altitudes.
7. Not beneficial at all - a hinderance.
8. Not very.

9. How useful or beneficial was the display of flight path angle?

1. Pretty useful but hard to get use to using it. Was easily deleted from the cross check.
2. Very good; helpful.
3. I rarely used it.
4.
5. Good instrument except as noted in 7g.
6. Seemed to be easy to use.
7. Good
8. Extremely

10a. Did the mode of flying affect your cross check of the flight director with HSI, glide slope indicators and AVRI? IF so, how?

1. No. The hood got in the way.
2. My cross check fell down because I was concentrating on command steering bars too much.
3. No
4.
5. Yes; because of the need to concentrate on different things.
6. No
7. Yes, see comments on the AVRI.
8. No

10b. During which mode of flying was your cross check best?

1. Semi-automatic. After a control input was made then I could relax until I noticed a new discrepancy.
2. Manual flight director. Semiautomatic. Familiarity.
3. Manual flight director because the bar movement would catch your eye better than movement on the ADI.
4.
5. Manual flight director - requires use of most instruments.
6. Manual flight director - it demanded a good cross check without being burdensome. Automatic approach was also very desirable and allowed for an easy cross check with the system.
7. Automatic, of course - could concentrate on the instruments and didn't have to contend with control pressures and trim.
8. Normal ILS - Naturally requires the best cross check.

11. In an evaluation of the total test program, rate the following types of approaches one through six in order of increasing work load and add any verbal comparisons between them: (1 lowest)

Work Load Sharing Approach (Elevators and Power)

1. 3
2. 6
3. 4
4.
5. 2
6. 3
7. 5
8. 5

11. Work Load Sharing Approach (Ailerons and Rudder)

1. 2
2. 5
3. 5
4.
5. 3
6. 4
7. 6
8. 1

11. Normal ILS Approach Without Flight Director System

1. 6
2. 4
3. 3
4.
5. 6
6. 5
7. 4
8. 6

11. Semiautomatic Approach

1. 4
2. 2
3. 6
4.
5. 4
6. 6
7. 3
8. 3

11. Automatic Approach

1. 1
2. 1
3. 1
4.
5. 1
6. 1
7. 1
8. 2

11. Manual Flight Director Approach

1. 5
2. 3
3. 2
4.
5. 5
6. 2
7. 2
8. 4

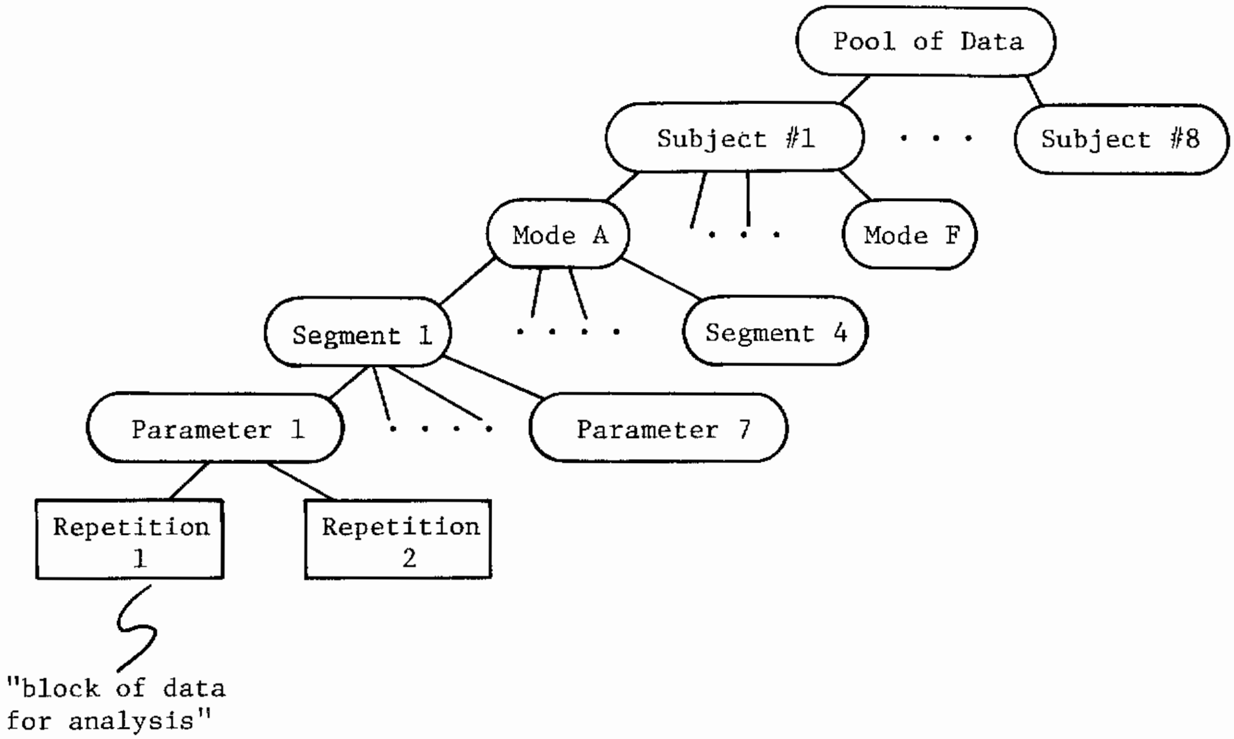
12. List any additional comments and recommendations:

1. No comments.
2. I don't like the displacement force wheel sensors. I believe I would prefer the rate type although I have never used them. The displacement system required too much concentration on command steering bars and attitude breaking down a good cross check.
3. No comments.
4.
5. No comments.
6. No comments.
7. Two suggestions: 1. Eliminate the AVRI and use the radar compas
   2. Incorporate a pleasant audio signal for flare point.
8. No comments.

Appendix B

OBJECTIVE DATA AND DESCRIPTION OF ANOVA

In order to assess performance and work load, it was necessary to compute measures of central tendency (average scores and absolute average scores) and a measure of variability (standard deviation) for the various dependent variables. These measures were computed for "blocks" of data as shown below:



The general form for computing the various description measures was:

$$\text{Average Score} = \frac{\text{Sum of the values of the data points}}{\text{Number of data points}}$$

$$\text{Absolute Average Score} = \frac{\text{Sum of the absolute values of the data points}}{\text{Number of data points}}$$

$$\text{Standard Deviation} = \sqrt{\frac{\text{Sum of the square of the data points from the mean}}{\text{Number of data points}}}$$

These computations then yielded numbers which were indicative of performance or work load. In order to determine whether or not there were differences between modes or subjects, it was necessary to see if groups of these numbers were different for the various modes and subjects. The groups of numbers were tested to see if the differences were large enough to be attributed to the independent variables (control system configuration) or so small as to be the result of chance alone. Numerous F ratios were computed to test the differences between groups. Following is a generalized scheme which was adapted for the flight test data.

Source	SS	d.f.	MS (variance est.)	F
Rows	SS Rows	R - 1	$\frac{\text{SS Rows}}{R - 1}$	$\frac{\text{MS Rows}}{\text{MS Error}}$
Columns	SS Columns	C - 1	$\frac{\text{SS Columns}}{C - 1}$	$\frac{\text{MS Columns}}{\text{MS Error}}$
Interaction	SS Interaction	(R - 1)(C - 1)	$\frac{\text{SS Interaction}}{(R - 1)(C - 1)}$	$\frac{\text{MS Interaction}}{\text{MS Error}}$
Error (within cells)	SS Error	RC(n - 1)	$\frac{\text{SS error}}{RC(n - 1)}$	--
Totals	SS Total	RC(n - 1)	--	--

General Form of Analysis of Variance for Two Factors (Independent Variables) where

Rows and columns refer to the main factors, i.e., the independent variables of subjects and control system configuration.

Interaction refers to the effect due to unique combinations of the main factors--subjects and control system configuration.

Error refers to the effect due to subject variability under given conditions rather than variability due to the main effects alone.

R ≈ number of rows or values of a given factor (number of subjects, 8)

C ≈ number of columns or values of the other factor (number of control system configuration, 6)

i or n ≈ repetition number or number of cell entries. (In this case 2, since two data approaches were used.)

SS ≈ sum of squares

MS ≈ mean square

j ≈ column number

G ≈ row number

N ≈ total number of observations

d.f. ≈ refers to degrees of freedom

$$SS_{Rows} = \frac{\sum_k \left(\sum_j \sum_i Y_{ijk} \right)^2}{C_n} - \frac{\left(\sum_j \sum_k \sum_i Y_{ijk} \right)^2}{N}$$

$$SS_{Columns} = \frac{\sum_j \left(\sum_k \sum_i Y_{ijk} \right)^2}{R_n} - \frac{\left(\sum_j \sum_k \sum_i Y_{ijk} \right)^2}{N}$$

$$SS_{Interaction} = \frac{\sum_j \sum_k \left(\sum_i Y_{ijk}\right)^2}{n} - \frac{\sum_k \left(\sum_j \sum_i Y_{ijk}\right)^2}{C_n} - \frac{\sum_j \left(\sum_k \sum_i Y_{ijk}\right)^2}{R_n} + \frac{\left(\sum_j \sum_k \sum_i Y_{ijk}\right)^2}{N}$$

$$SS_{Error} = \sum_j \sum_k \sum_i Y_{ijk}^2 - \left[\frac{\sum_j \sum_k \left(\sum_i Y_{ijk}\right)^2}{n}\right]$$

$$SS_{Totals} = \sum_j \sum_k \sum_i Y_{ijk}^2 - \frac{\left(\sum_j \sum_k \sum_i Y_{ijk}\right)^2}{N}$$

When the various F ratios were computed, they were compared with table values of F for the same degrees of freedom at a given chance level (e.g., 0.05). If the computed F value were equal to or larger than the tabled value, then statistical significance was said to exist at the given probability or chance level. This was interpreted by saying, for example, that there were 5 or less chances out of 100 that the differences were atrributable to chance rather than the independent variable.

The following sheets present the tables which summarize the analyses of variance. NOTE:

1. Some cells are empty due to the lack of data due to the nature of the flight test. For example, glideslope was not available for the first segment which was defined as being before glideslope capture.

2. Table values represent the average of the data values which were cell entries (for given modes/subjects) in the analysis of variance.

GLIDE SLOPE ERROR

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
SEGMENT 1												
Arithmetic Mean												
Absolute Mean												
Mean Standard Deviation												
SEGMENT 2												
Arithmetic Mean	0.05	0.05	0.55	0.17	0.74	0.74	0.00	0.07	7	48	2.09	p>.05
Absolute Mean	0.09	0.16	0.13	0.14	0.11	0.15	0.12	0.12	7	48	3.95	p<.05
Mean Standard Deviation	0.10	0.20	0.16	0.19	0.13	0.19	0.15	0.15	7	48	4.31	p<.05
SEGMENT 3												
Arithmetic Mean	-0.28	0.18	-0.02	0.00	0.08	-0.13	-0.15	-0.06	7	48	1.13	p>.05
Absolute Mean	0.23	0.38	0.39	0.32	0.16	0.45	0.43	0.30	7	48	4.15	p<.05
Mean Standard Deviation	0.27	0.43	0.44	0.37	0.18	0.49	0.49	0.33	7	48	4.97	p<.05
SEGMENT 4												
Arithmetic Mean												
Absolute Mean												
Mean Standard Deviation												

GLIDE SLOPE ERROR

SEGMENT 1

	MODE						Degrees of Freedom		F Ratio	Probability
	A	B	C	D	E	F	Mode	Error		
Arithmetic Mean										
Absolute Mean										
Mean Standard Deviation										

SEGMENT 2

Arithmetic Mean	0.06	0.05	0.05	0.05	0.04	0.01	5	48	1.22	p>.05
Absolute Mean	0.23	0.11	0.14	0.12	0.10	0.08	5	48	26.68	p<.05
Mean Standard Deviation	0.30	0.14	0.17	0.14	0.12	0.10	5	48	29.75	p<.05

SEGMENT 3

Arithmetic Mean	0.02	0.05	0.11	-0.09	-0.17	-0.03	5	48	1.36	p>.05
Absolute Mean	0.48	0.24	0.34	0.34	0.30	0.31	5	48	3.51	p<.05
Mean Standard Deviation	0.52	0.26	0.37	0.39	0.35	0.36	5	48	3.79	p<.05

SEGMENT 4

Arithmetic Mean										
Absolute Mean										
Mean Standard Deviation										

GLIDE SLOPE ERROR

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean				
Absolute Mean				
Mean Standard Deviation				

SEGMENT 2

Arithmetic Mean	35	48	1.51	$p>.05$
Absolute Mean	35	48	1.94	$p<.05$
Mean Standard Deviation	35	48	2.17	$p<.05$

SEGMENT 3

Arithmetic Mean	35	48	1.24	$p>.05$
Absolute Mean	35	48	1.19	$p>.05$
Mean Standard Deviation	35	48	1.16	$p>.05$

SEGMENT 4

Arithmetic Mean				
Absolute Mean				
Mean Standard Deviation				

PITCH STEERING BAR

SEGMENT 1

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
Arithmetic Mean	0.75	0.17	0.10	0.02	0.55	3.62	0.47	0.49	7	40	5.46	$p<.05$
Absolute Mean	1.99	1.96	1.22	1.16	1.67	1.80	1.54	1.46	7	40	2.94	$p<.05$
Mean Standard Deviation	2.61	2.78	1.70	1.53	2.37	2.53	2.17	2.18	7	40	2.77	$p<.05$

SEGMENT 2

Arithmetic Mean	0.44	0.85	0.49	0.55	0.69	0.11	0.43	0.92	7	40	2.40	$p<.05$
Absolute Mean	1.46	2.16	1.74	1.96	1.74	2.68	2.27	2.30	7	40	5.18	$p<.05$
Mean Standard Deviation	1.79	2.61	2.18	2.48	2.12	3.36	2.74	2.75	7	40	5.21	$p<.05$

SEGMENT 3

Arithmetic Mean	0.22	6.74	0.75	3.27	2.56	0.55	3.01	3.48	7	40	2.29	$p<.05$
Absolute Mean	4.07	7.86	4.27	6.75	4.03	5.01	7.38	4.86	7	40	3.15	$p<.05$
Mean Standard Deviation	4.70	8.64	5.05	7.52	4.65	5.79	8.41	5.50	7	40	3.95	$p<.05$

SEGMENT 4

Arithmetic Mean	2.45	1.37	2.11	2.12	2.59	1.63	2.20	2.44	7	40	0.96	$p>.05$
Absolute Mean	4.95	4.95	5.29	5.12	5.61	5.63	4.47	5.49	7	40	1.18	$p>.05$
Mean Standard Deviation	6.58	6.46	6.52	6.55	7.17	7.06	5.80	7.04	7	40	1.34	$p>.05$

PITCH STEERING BAR

	Mode						Degrees of Freedom		F Ratio	Proba-bility
	A	B	C	D	E	F		Error		
SEGMENT 1										
Arithmetic Mean		1.23	0.24	0.42	0.30	-0.82	4	40	36.52	$p < .05$
Absolute Mean		2.68	1.67	1.39	1.22	1.04	4	40	20.10	$p < .05$
Mean Standard Deviation		3.54	2.37	2.15	1.78	1.33	4	40	15.84	$p < .05$
SEGMENT 2										
Arithmetic Mean		0.74	1.29	0.82	0.36	-0.35	4	40	6.89	$p < .05$
Absolute Mean		2.36	2.76	2.02	2.21	0.84	4	40	28.25	$p < .05$
Mean Standard Deviation		2.88	3.38	2.53	2.70	1.03	4	40	27.92	$p < .05$
SEGMENT 3										
Arithmetic Mean		4.19	3.37	1.91	2.06	1.33	4	40	1.10	$p \ngtr .05$
Absolute Mean		6.51	6.48	5.66	4.62	4.38	4	40	2.09	$p < .05$
Mean Standard Deviation		7.25	7.32	6.77	5.17	4.91	4	40	3.11	$p < .05$
SEGMENT 4										
Arithmetic Mean		2.50	2.88	3.41	5.74	-3.96	4	40	114.16	$p < .05$
Absolute Mean		4.01	4.54	4.16	6.20	6.96	4	40	20.68	$p < .05$
Mean Standard Deviation		5.40	5.78	5.58	7.32	9.16	4	40	27.78	$p < .05$

PITCH STEERING BAR

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean	28	40	3.64	p<.05
Absolute Mean	28	40	3.10	p<.05
Mean Standard Deviation	28	40	3.14	p<.05

SEGMENT 2

Arithmetic Mean	28	40	1.85	p<.05
Absolute Mean	28	40	2.64	p<.05
Mean Standard Deviation	28	40	2.42	p<.05

SEGMENT 3

Arithmetic Mean	28	40	1.19	p>.05
Absolute Mean	28	40	1.89	p<.05
Mean Standard Deviation	28	40	2.15	p<.05

SEGMENT 4

Arithmetic Mean	28	40	2.52	p<.05
Absolute Mean	28	40	3.07	p<.05
Mean Standard Deviation	28	40	2.84	p<.05

PITCH FORCE

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
SEGMENT 1												
Arithmetic Mean	0.48	0.23	0.88	-0.05	0.25	1.15	-0.03	0.02	7	48	2.19	p>.05
Absolute Mean	2.20	2.32	2.35	1.86	1.84	2.78	1.96	2.04	7	48	4.96	p<.05
Mean Standard Deviation	3.07	3.18	3.44	2.46	2.64	3.51	2.77	2.70	7	48	4.92	p<.05
SEGMENT 2												
Arithmetic Mean	1.23	-0.86	1.70	-0.12	0.61	2.18	0.74	0.69	7	48	3.71	p<.05
Absolute Mean	3.32	4.21	4.73	4.11	2.97	4.23	3.61	2.98	7	48	6.46	p<.05
Mean Standard Deviation	3.94	5.19	5.76	4.95	3.68	5.02	4.43	3.64	7	48	6.25	p<.05
SEGMENT 3												
Arithmetic Mean	2.84	0.32	2.39	0.72	2.23	3.72	4.35	2.25	7	48	1.64	p<.05
Absolute Mean	4.77	5.72	5.68	5.82	4.12	5.64	8.35	4.49	7	48	4.77	p<.05
Mean Standard Deviation	5.87	6.52	6.68	6.60	4.81	6.58	9.47	5.24	7	48	4.79	p<.05
SEGMENT 4												
Arithmetic Mean	0.71	0.42	3.37	-2.13	-0.09	1.82	1.97	1.37	7	48	8.41	p<.05
Absolute Mean	5.79	4.60	5.92	6.60	6.01	4.82	6.21	6.97	7	48	11.82	p<.05
Mean Standard Deviation	6.91	5.72	7.25	7.84	7.16	5.81	7.52	8.11	7	48	11.00	p<.05

PITCH FORCE

SEGMENT 1

	Mode						Degrees of Freedom		F Ratio	Probability
	A	B	C	D	F	F	Mode	Error		
Arithmetic Mean	1.23	1.14	0.24	0.83	0.55	-0.16	5	48	9.07	p<.05
Absolute Mean	2.56	3.27	3.33	1.84	1.75	0.25	5	48	88.99	p<.05
Mean Standard Deviation	3.21	4.08	4.53	3.53	2.14	3.06	5	48	103.20	p<.05

SEGMENT 2

Arithmetic Mean	1.51	1.61	0.90	0.26	0.59	-0.23	5	48	2.71	p<.05
Absolute Mean	4.61	4.45	5.64	5.58	1.99	3.41	5	48	93.96	p<.05
Mean Standard Deviation	5.68	5.37	6.83	6.77	2.41	0.40	5	48	93.88	p<.05

SEGMENT 3

Arithmetic Mean	-1.42	3.05	5.65	5.63	1.03	0.17	5	48	10.13	p<.05
Absolute Mean	6.02	6.19	9.00	8.01	3.38	8.41	5	48	34.55	p<.05
Mean Standard Deviation	7.02	7.32	10.20	9.35	3.85	1.09	5	48	38.56	p<.05

SEGMENT 4

Arithmetic Mean	-2.72	-4.53	6.00	6.31	0.47	0.04	5	48	82.80	p<.05
Absolute Mean	6.81	8.68	8.46	8.05	2.68	0.51	5	48	283.23	p<.05
Mean Standard Deviation	8.32	10.37	10.11	9.47	3.27	6.82	5	48	317.21	p<.05

PITCH FORCE

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
SEGMENT 1				
Arithmetic Mean	35	48	1.09	p>.05
Absolute Mean	35	48	5.41	p<.05
Mean Standard Deviation	35	48	4.65	p<.05
SEGMENT 2				
Arithmetic Mean	35	48	1.35	p>.05
Absolute Mean	35	48	1.97	p<.05
Mean Standard Deviation	35	48	1.97	p<.05
SEGMENT 3				
Arithmetic Mean	35	48	1.47	p>.05
Absolute Mean	35	48	1.83	p<.05
Mean Standard Deviation	35	48	1.90	p<.05
SEGMENT 4				
Arithmetic Mean	35	48	4.54	p<.05
Absolute Mean	35	48	3.15	p<.05
Mean Standard Deviation	35	48	3.10	p<.05

LOCALIZER ERROR

SEGMENT 1

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
Arithmetic Mean	-0.01	0.03	0.19	0.12	-0.03	0.05	0.06	0.15	7	48	3.32	$p<.05$
Absolute Mean	0.28	0.33	0.33	0.29	0.46	0.33	0.29	0.29	7	48	1.98	$p>.05$
Mean Standard Deviation	0.48	0.52	0.58	0.48	0.69	0.53	0.47	0.48	7	48	1.76	$p>.05$

SEGMENT 2

Arithmetic Mean	-0.13	0.02	-0.01	0.00	0.04	-0.10	-0.03	-0.06	7	48	4.33	$p<.05$
Absolute Mean	0.19	0.12	0.11	0.18	0.15	0.21	0.13	0.16	7	48	3.33	$p<.05$
Mean Standard Deviation	0.22	0.14	0.13	0.21	0.17	0.25	0.15	0.18	7	48	3.91	$p<.05$

SEGMENT 3

Arithmetic Mean	-0.10	0.02	-0.05	-0.09	0.06	-0.01	-0.13	-0.06	7	48	0.75	$p>.05$
Absolute Mean	0.17	0.16	0.11	0.28	0.14	0.24	0.24	0.18	7	48	1.59	$p>.05$
Mean Standard Deviation	0.17	0.17	0.12	0.29	0.15	0.25	0.24	0.18	7	48	1.29	$p>.05$

SEGMENT 4

Arithmetic Mean												
Absolute Mean												
Mean Standard Deviation												

LOCALIZER ERROR

SEGMENT 1

	Mode						Degrees of Freedom		F Ratio	Proba-bility
	A	B	C	D	E	F	Mode	Error		
Arithmetic Mean	0.19	0.10	-0.09	0.04	0.10	0.07	5	48	3.32	p<.05
Absolute Mean	0.33	0.37	0.41	0.27	0.33	0.26	5	48	2.32	p>.05
Mean Standard Deviation	0.50	0.60	0.60	0.48	0.52	0.47	5	48	1.40	p>.05

SEGMENT 2

Arithmetic Mean	-0.15	0.01	0.00	-0.05	-0.02	-0.01	5	48	4.33	p<.05
Absolute Mean	0.36	0.13	0.13	0.01	0.16	0.08	5	48	37.01	p<.05
Mean Standard Deviation	0.42	0.16	0.16	0.11	0.19	0.01	5	48	44.78	p<.05

SEGMENT 3

Arithmetic Mean	-0.09	-0.02	-0.03	0.01	-0.12	-0.01	5	48	0.75	p>.05
Absolute Mean	0.41	0.12	0.21	0.10	0.21	0.08	5	48	10.02	p<.05
Mean Standard Deviation	0.42	0.13	0.21	0.10	0.22	0.08	5	48	10.65	p<.05

SEGMENT 4

Arithmetic Mean										
Absolute Mean										
Mean Standard Deviation										

LOCALIZER ERROR

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean	35	48	1.61	p>.05
Absolute Mean	35	48	1.19	p>.05
Mean Standard Deviation	35	48	1.15	p>.05

SEGMENT 2

Arithmetic Mean	35	48	2.47	p<.05
Absolute Mean	35	48	3.71	p<.05
Mean Standard Deviation	35	48	4.43	p<.05

SEGMENT 3

Arithmetic Mean	35	48	1.79	p<.05
Absolute Mean	35	48	1.24	p>.05
Mean Standard Deviation	35	48	1.29	p>.05

SEGMENT 4

Arithmetic Mean				
Absolute Mean				
Mean Standard Deviation				

BANK STEERING BAR

SEGMENT 1

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
Arithmetic Mean	0.15	0.00	0.19	0.08	-0.26	-0.08	0.00	0.22	7	40	2.01	p>.05
Absolute Mean	1.48	1.59	1.40	1.94	1.85	1.58	1.76	1.65	7	40	3.89	p<.05
Mean Standard Deviation	2.44	2.42	2.15	3.31	3.20	2.47	2.79	2.88	7	40	6.44	p<.05

SEGMENT 2

Arithmetic Mean	0.25	0.56	0.24	-0.21	0.53	0.01	0.12	0.25	7	40	1.96	p>.05
Absolute Mean	1.18	1.27	0.98	1.82	1.61	1.22	1.29	1.07	7	40	9.57	p<.05
Mean Standard Deviation	1.48	1.58	1.22	2.23	1.96	1.46	1.58	1.33	7	40	9.24	p<.05

SEGMENT 3

Arithmetic Mean	0.66	0.73	-0.92	-0.34	0.66	0.39	0.77	0.48	7	40	0.77	p>.05
Absolute Mean	1.68	1.54	1.37	3.27	1.27	1.51	1.81	1.00	7	40	3.07	p<.05
Mean Standard Deviation	1.87	1.73	1.56	4.17	1.46	1.76	2.01	1.15	7	40	3.03	p<.05

SEGMENT 4

Arithmetic Mean	0.24	0.49	0.48	0.28	0.60	0.44	0.51	0.51	7	40	0.96	p>.05
Absolute Mean	0.74	0.95	0.91	0.99	0.96	1.09	1.17	0.80	7	40	4.27	p<.05
Mean Standard Deviation	0.93	1.18	1.14	1.59	1.18	1.34	1.43	1.00	7	40	7.16	p<.05

BANK STEERING BAR

SEGMENT 1

	MODE						Degrees of Freedom		F Ratio	Probability
	A	B	C	D	E	F	Mode	Error		
Arithmetic Mean		0.18	0.06	-0.27	0.06	0.18	4	40	4.21	p<.05
Absolute Mean		1.98	1.82	1.87	1.66	0.94	4	40	31.62	p<.05
Mean Standard Deviation		3.14	2.77	3.14	2.76	1.72	4	40	21.13	p<.05

SEGMENT 2

Arithmetic Mean		0.49	0.40	-0.29	0.26	0.27	4	40	4.17	p<.05
Absolute Mean		1.56	1.44	1.37	1.46	0.71	4	40	22.33	p<.05
Mean Standard Deviation		1.93	1.76	1.64	1.79	0.91	4	40	21.52	p<.05

SEGMENT 3

Arithmetic Mean		0.88	0.56	-0.41	0.22	0.28	4	40	0.76	p>.05
Absolute Mean		1.95	2.25	1.84	1.72	0.64	4	40	3.91	p<.05
Mean Standard Deviation		2.56	2.51	2.04	1.98	0.74	4	40	3.04	p<.05

SEGMENT 4

Arithmetic Mean		0.61	0.44	0.26	0.39	0.51	4	40	1.71	p>.05
Absolute Mean		1.23	1.06	0.92	0.90	0.66	4	40	14.79	p<.05
Mean Standard Deviation		1.72	1.31	1.13	1.15	0.82	4	40	25.56	p<.05

BANK STEERING BAR

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean	28	40	5.82	p<.05
Absolute Mean	28	40	3.06	p<.05
Mean Standard Deviation	28	40	2.57	p<.05

SEGMENT 2

Arithmetic Mean	28	40	2.15	p<.05
Absolute Mean	28	40	2.35	p<.05
Mean Standard Deviation	28	40	2.15	p<.05

SEGMENT 3

Arithmetic Mean	28	40	0.68	p>.05
Absolute Mean	28	40	1.05	p>.05
Mean Standard Deviation	28	40	0.76	p>.05

SEGMENT 4

Arithmetic Mean	28	40	2.21	p<.05
Absolute Mean	28	40	5.61	p<.05
Mean Standard Deviation	28	40	8.44	p<.05

BANK FORCE

SEGMENT 1

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
Arithmetic Mean	-0.99	-0.69	-1.62	-0.51	-1.45	-0.41	-1.21	-1.86	7	48	15.01	$p<.05$
Absolute Mean	3.18	3.58	3.42	2.51	3.05	3.03	2.31	3.17	7	48	11.05	$p<.05$
Mean Standard Deviation	4.46	4.77	4.69	3.39	4.27	4.10	3.25	4.23	7	48	12.84	$p<.05$

SEGMENT 2

Arithmetic Mean	-0.47	1.30	-0.79	-0.82	-0.51	-0.68	-0.76	-1.35	7	48	8.03	$p<.05$
Absolute Mean	3.14	3.02	4.02	3.24	2.93	3.41	2.17	3.34	7	48	8.20	$p<.05$
Mean Standard Deviation	4.14	3.92	5.37	4.14	3.86	4.50	2.81	4.16	7	48	11.56	$p<.05$

SEGMENT 3

Arithmetic Mean	-0.39	1.29	-1.84	-0.39	-0.99	1.07	-0.98	-1.99	7	48	2.91	$p<.05$
Absolute Mean	3.01	3.03	3.97	2.43	2.82	3.25	2.30	2.62	7	48	1.39	$p>.05$
Mean Standard Deviation	3.82	3.77	5.15	3.12	3.59	4.02	2.88	3.14	7	48	1.71	$p>.05$

SEGMENT 4

Arithmetic Mean	-0.51	0.38	0.06	0.23	0.11	0.61	0.22	-1.64	7	48	5.65	$p<.05$
Absolute Mean	2.28	2.59	2.93	2.75	2.81	2.77	2.64	3.65	7	48	3.39	$p<.05$
Mean Standard Deviation	3.11	3.54	4.00	3.67	3.88	3.63	3.55	4.64	7	48	2.96	$p<.05$

BANK FORCE

SEGMENT 1

	MODE						Degrees of Freedom		F Ratio	Probability
	A	B	C	D	E	F	Mode	Error		
Arithmetic Mean	-0.16	-0.48	-2.43	-0.65	-2.25	-0.58	5	48	67.48	p<.05
Absolute Mean	3.76	4.04	4.80	0.88	4.07	0.63	5	48	258.89	p<.05
Mean Standard Deviation	5.46	5.62	6.62	1.06	5.45	0.66	5	48	368.48	p<.05

SEGMENT 2

	A	B	C	D	E	F	Mode	Error	F Ratio	Probability
Arithmetic Mean	-0.25	-0.39	-0.53	-0.24	-1.06	-0.60	5	48	1.61	p>.05
Absolute Mean	4.06	4.77	4.67	1.37	3.41	0.67	5	48	122.54	p<.05
Mean Standard Deviation	5.68	6.19	5.95	1.70	4.44	0.70	5	48	170.01	p<.05

SEGMENT 3

	A	B	C	D	E	F	Mode	Error	F Ratio	Probability
Arithmetic Mean	-1.23	0.65	0.14	-0.24	-2.04	-0.43	5	48	2.52	p<.05
Absolute Mean	4.41	3.38	3.82	1.62	3.58	0.77	5	48	13.33	p<.05
Mean Standard Deviation	5.72	4.38	4.76	2.04	4.36	0.84	5	48	15.25	p<.05

SEGMENT 4

	A	B	C	D	E	F	Mode	Error	F Ratio	Probability
Arithmetic Mean	0.06	0.09	0.31	-0.24	-0.17	-0.44	5	48	1.08	p>.05
Absolute Mean	4.73	3.54	3.43	2.10	2.31	0.70	5	48	56.98	p<.05
Mean Standard Deviation	6.61	4.99	4.53	2.65	2.99	0.76	5	48	84.14	p<.05

BANK FORCE

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean	35	48	4.70	$p<.05$
Absolute Mean	35	48	4.93	$p<.05$
Mean Standard Deviation	35	48	5.93	$p<.05$

SEGMENT 2

Arithmetic Mean	35	48	1.84	$p<.05$
Absolute Mean	35	48	3.11	$p<.05$
Mean Standard Deviation	35	48	3.69	$p<.05$

SEGMENT 3

Arithmetic Mean	35	48	1.03	$p>.05$
Absolute Mean	35	48	1.16	$p>.05$
Mean Standard Deviation	35	48	1.07	$p>.05$

SEGMENT 4

Arithmetic Mean	35	48	3.56	$p<.05$
Absolute Mean	35	48	2.08	$p<.05$
Mean Standard Deviation	35	48	2.26	$p<.05$

RUDDER FORCE

SEGMENT 1

	Subject								Degrees of Freedom		F Ratio	Probability
	1	2	3	4	5	6	7	8	Subject	Error		
Arithmetic Mean	-4.76	-5.15	-2.34	-2.90	-3.43	-1.75	0.07	-5.46	7	48	13.80	p<.05
Absolute Mean	6.53	11.24	8.83	12.90	10.43	12.98	11.25	7.60	7	48	19.78	p<.05
Mean Standard Deviation	8.11	13.02	10.37	15.14	11.75	14.76	12.92	9.57	7	48	13.04	p<.05

SEGMENT 2

Arithmetic Mean	3.73	-5.36	3.47	-2.04	-2.89	-0.58	0.39	-4.95	7	48	9.78	p<.05
Absolute Mean	6.29	11.91	11.17	13.97	12.76	13.86	17.93	10.68	7	48	42.55	p<.05
Mean Standard Deviation	6.63	14.08	13.34	16.39	14.19	16.06	20.23	12.11	7	48	37.82	p<.05

SEGMENT 3

Arithmetic Mean	-5.32	-4.70	2.25	-1.90	-4.74	5.10	-1.03	-4.56	7	48	2.00	p>.05
Absolute Mean	7.03	12.76	12.93	14.74	13.96	15.12	17.54	11.37	7	48	3.67	p<.05
Mean Standard Deviation	7.40	13.98	14.50	16.58	15.57	16.59	20.00	12.36	7	48	3.96	p<.05

SEGMENT 4

Arithmetic Mean	-4.60	-1.36	6.28	-0.87	-2.34	3.88	2.80	-3.17	7	48	8.09	p<.05
Absolute Mean	5.59	10.91	11.69	13.79	13.71	11.85	17.72	13.76	7	48	30.86	p<.05
Mean Standard Deviation	5.91	12.65	13.34	15.90	15.37	13.18	19.81	15.41	7	48	30.72	p<.05

RUDDER FORCE

	MODE						Degrees of Freedom		F Ratio	Probability
	A	B	C	D	E	F	MODE	Error		
SEGMENT 1										
Arithmetic Mean	-1.68	-1.87	-3.82	-4.12	-4.19	-3.61	5	48	6.63	p<.05
Absolute Mean	11.98	12.42	15.59	4.55	13.03	3.73	5	48	111.69	p<.05
Mean Standard Deviation	14.41	14.70	18.64	4.84	15.36	3.79	5	48	121.87	p<.05
SEGMENT 2										
Arithmetic Mean	0.61	-2.23	-0.60	-4.28	-1.57	-3.68	5	48	5.06	p<.05
Absolute Mean	15.79	14.90	19.39	4.80	15.69	3.75	5	48	218.62	p<.05
Mean Standard Deviation	18.54	16.76	22.29	5.18	18.18	3.82	5	48	194.98	p<.05
SEGMENT 3										
Arithmetic Mean	0.41	-1.48	1.68	-5.74	-2.39	-3.66	5	48	1.33	p>.05
Absolute Mean	19.53	14.95	18.32	5.93	16.61	3.77	5	48	22.71	p<.05
Mean Standard Deviation	21.74	16.48	20.93	6.22	18.54	3.84	5	48	23.03	p<.05
SEGMENT 4										
Arithmetic Mean	1.64	2.84	3.84	-5.06	0.79	-3.57	5	48	9.57	p<.05
Absolute Mean	18.59	15.74	17.69	5.26	13.31	3.67	5	48	142.12	p<.05
Mean Standard Deviation	21.53	17.72	20.03	5.61	15.09	3.71	5	48	148.90	p<.05

RUDDER FORCE

SEGMENT 1

	Degrees of Freedom		F Ratio	Probability
	Interaction	Error		
Arithmetic Mean	35	48	4.96	p<.05
Absolute Mean	35	48	5.96	p<.05
Mean Standard Deviation	35	48	5.97	p<.05

SEGMENT 2

Arithmetic Mean	35	48	5.12	p<.05
Absolute Mean	35	48	16.73	p<.05
Mean Standard Deviation	35	48	15.12	p<.05

SEGMENT 3

Arithmetic Mean	35	48	2.25	p<.05
Absolute Mean	35	48	2.77	p<.05
Mean Standard Deviation	35	48	2.69	p<.05

SEGMENT 4

Arithmetic Mean	35	48	2.63	p<.05
Absolute Mean	35	48	10.26	p<.05
Mean Standard Deviation	35	48	9.96	p<.05

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