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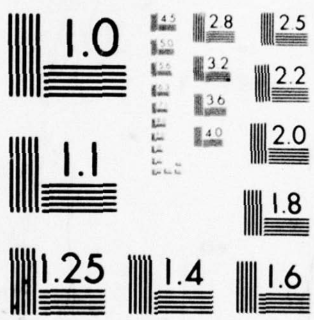

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EFFECTS OF DIRECT SIDE FORCE CONTROL ON PILOT TRACKING PERFORMANCE

AEROSPACE MEDICAL RESEARCH LABORATORY

DECEMBER 1976

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NOTICES

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 80-33.

FOR THE COMMANDER

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An experiment was conducted to determine the effects of direct side force motion on a pilot's tracking performance in a simulated air-to-air engagement. Two degrees of control, pitch and lateral velocity, could be commanded by the pilot. Forty-five second runs at various normal G profiles were made with and without dynamic lateral motion, using four subjects. The results showed some degradation of performance at low normal G levels with side motion, but the subjects demonstrated they could easily maintain effective tracking control with +2 Gs of dynamic lateral acceleration.

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PREFACE

The experiment reported herein was performed by the Aerospace Medical Research Laboratory, Environmental Medicine Division, in 1975 as a study of pilot tracking performance in an aircraft incorporating direct side force control. It was conducted in support of a joint Technology Need AFFDL-0602-74-3, Pilot Performance in Vectored Force Fighters. The work was accomplished as part of AMRL Project 7222, Task 10, Analysis and Dynamic Simulation of Combined Stress Environments.

This study was the result of the combined efforts of an experimental team consisting of members of the Environmental Medicine Division and their contractors. Particular thanks go to Mr. Walter C. Summers for statistical design and analysis, Mr. William Broach and Ms. Sharon Ward of Systems Research Laboratory, Inc., for data processing and analysis, Dr. George Potor, Jr. for software design and implementation, Capt Arthur K. West for technical advice, Major John S. Kirkland and Major James A. Kennealy for medical monitoring, Mr. John W. Frazier and SMSgt Thomas G. Shriver for scheduling the subjects and managing the centrifuge operating crew, and Mr. Edward Mersereau of Raytheon Corp. for managing centrifuge operation and maintenance.

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INTRODUCTION

The past and present generations of fixed wing aircraft have not been designed to translate in lateral (side) motion independent of other motions associated with conventional maneuvering. However, a new Air Force concept for fighter aircraft, called the Vectored Force Fighter or VFF, will incorporate this and other new types of controlled motion. Along with the proposition of greater mobility comes the attendant prospect of a pilot's undergoing radically different acceleration stresses from those with which he must normally contend.

In 1974, the Air Force Flight Dynamics Laboratory (AFFDL) developed a Technology Need, AFFDL-0602-74-3, which requested that the Aerospace Medical Research Laboratory (AMRL) undertake a research program to investigate the impact of vectored force maneuvering on manned weapon system performance. Although extensive studies of vectored force technology had shown that such an aircraft was feasible, no systematic investigation of pilot factors affected by such designs had been performed. Neither the mechanical effects of the unconventional acceleration stresses nor the effects of increased mental work load, resulting in unconventional visual cues or additional degrees of control freedom, were known. Extensive fixed base simulation had been performed, but there had been no motion simulations of the actual acceleration environment.

The AMRL motion studies of the VFF environment began with a study of direct side force (DSF) and its effects upon pilot performance of an air-to-air gunnery tracking task. The objectives of the study were to answer the following questions concerning DSF:

(1) What amount of DSF can a pilot profitably use?

(2) What are the effects of DSF upon a pilot's performance of a simulated air-to-air tracking task?

(3) How do the effects of DSF compare at various normal G levels?

(4) How do the effects of DSF compare during level flight and during a dive?

(5) How effective is a conventional cockpit seat and restraint system in allowing a pilot to perform while using DSF?

(6) How realistically and effectively can a centrifuge with three degrees of freedom simulate the acceleration stresses encountered while using side force in a VFF?

The answers to the above questions would provide data on the man-machine aspects of DSF and serve as guides for the future AMRL experiments.

METHOD

The AMRL Dynamic Environment Simulator (DES) was the motion simulator used in these experiments. This centrifuge has three axes of motion and can apply up to 20 G acceleration. The cab was configured to represent an advanced fighter aircraft with a standard cockpit seat (20° seat back angle) and restraint system and an isometric sidearm controller for pilot commands. The visual tracking display was a 23-inch TV monitor, which presented a gunsight reticle and a target aircraft as shown in Figure 1. The size and dynamics of the display were scaled so as to represent a target aircraft with a wing span of 50 feet at a range of 1500 feet. The subject's lateral stick inputs commanded proportional lateral velocity up to 70 feet per second with a maximum acceleration of 1 Gy from straight ahead flight.

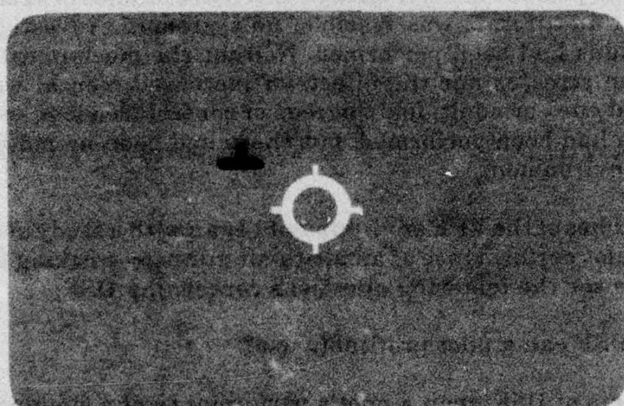

Figure 1. Display Layout

The output of the sidestick was fed into an Ambilog 200 digital computer, programmed to respond as a VFF and return to the display the visual perspective of the relative positions of the two aircraft. Only two degrees of control freedom were represented, pitch and lateral translation. The aircraft dynamics were supplied by AFFDL, taken from McDonnell Douglas Report MDC A2333. They represented the direct force mode of that VFF design. A block diagram of the computer setup is shown in Figure 2.

The method of generating DSF to represent lateral motion was to rotate the DES cab to produce an off-normal G component, simulating aircraft DSF.

EXPERIMENTAL DESIGN

Figures 3 and 4 present the simulation overview. The tracking task was designed to simulate an air-to-air environment with a target aircraft (also a VFF) undergoing various evasive actions, represented by a hard Gz pull-up with associated pseudo-random lateral motions. The lateral maneuvers were actually the sum of 12 sine waves at various amplitudes and frequencies, chosen to facilitate a Fourier analysis of the human operator model.

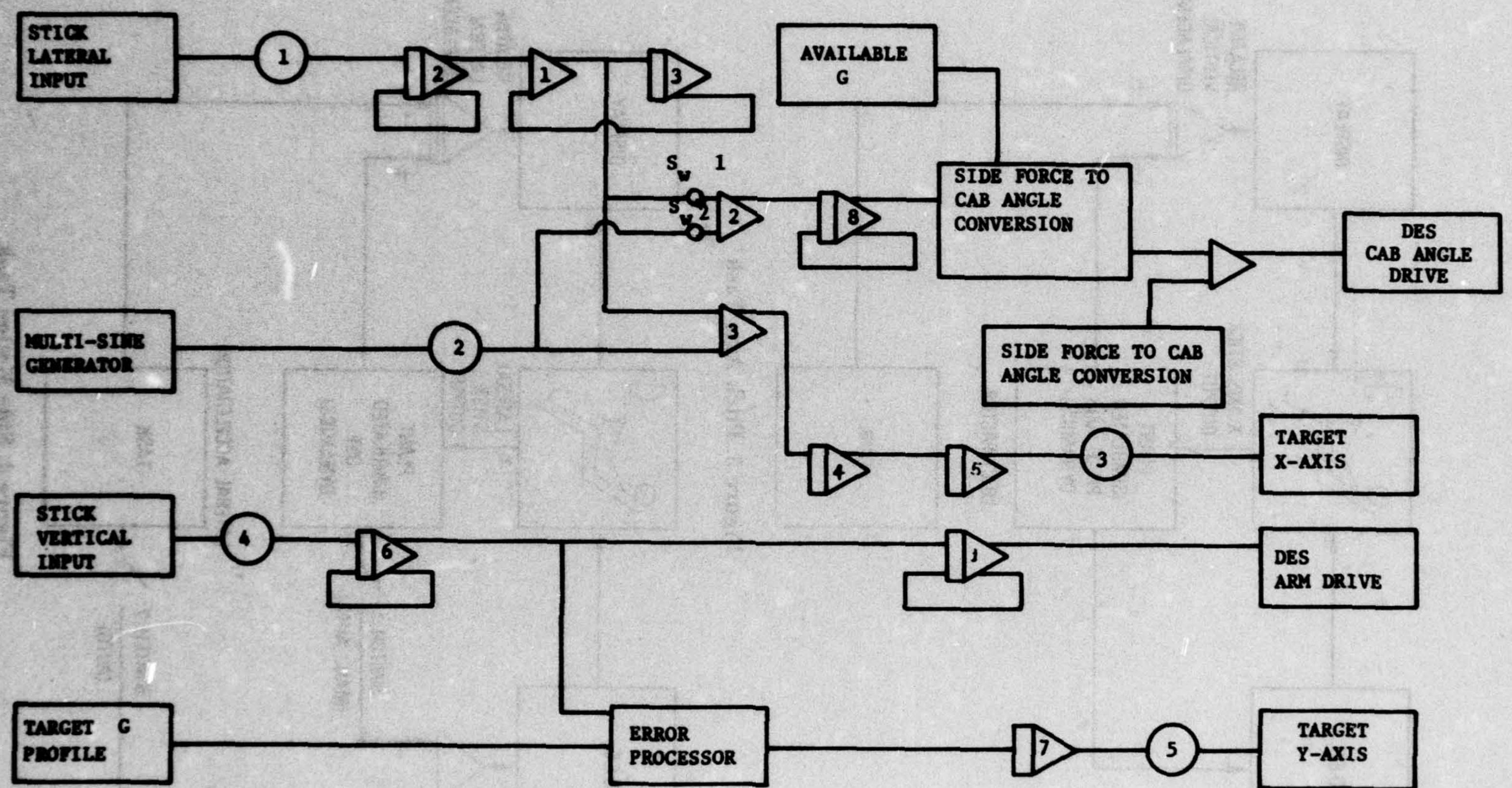

Figure 2. Simulation Block Diagram

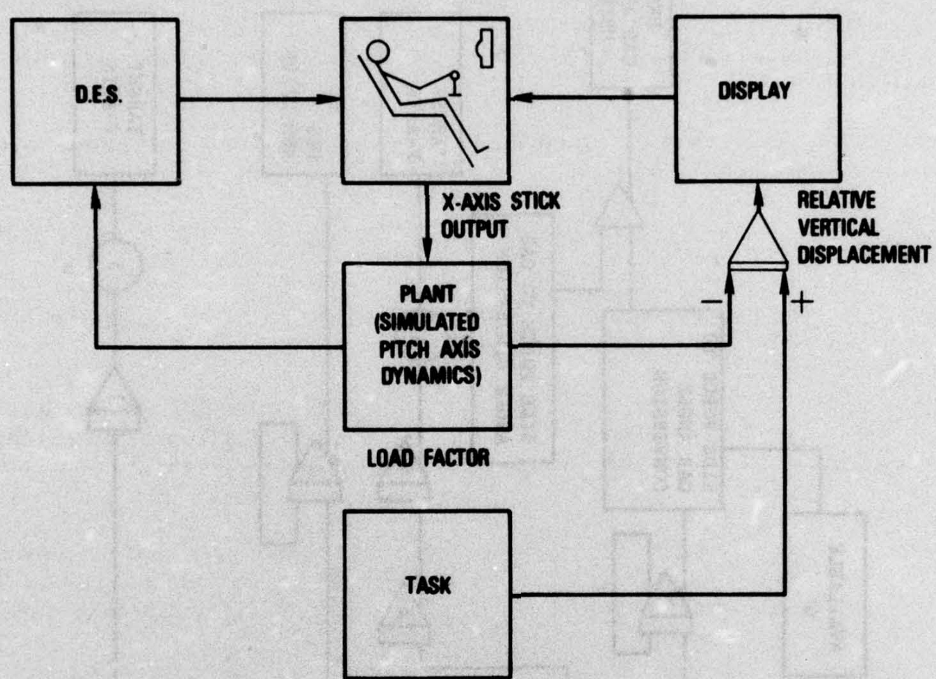

Figure 3. Pitch Axis Task

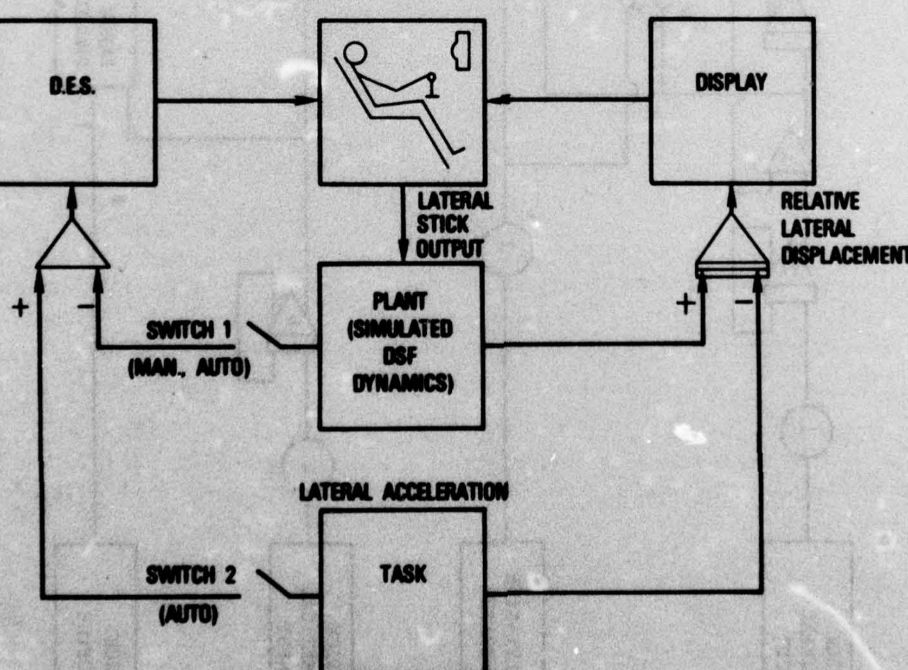

Figure 4. Side Motion Task

The pitch pull-up maneuver by the target was programmed at 1.6, 3, or 5 G; it was one of the independent variables in the study. In addition, a fourth flight maneuver was included, a 60° dive at 1.6 G. This condition allowed an investigation into the use of DSF at very low Gz levels where the pilot was supported primarily by his harness restraint system, intuitively a difficult situation for such control.

The second independent variable was called mode and was related to the lateral motion experienced by the subject pilot as follows:

Mode 1 — *base line* where the subject's lateral stick inputs produced a visual aircraft response with no actual physical accelerations.

Mode 2 — *manual*, where the side motion responses of the cab simulated those of the real aircraft in conjunction with the apparent visual motions.

Mode 3 — *automatic*, where the motion felt by the subject was the result of his own inputs, as in Mode 2; however, the subject's cab, rather than the target, was disturbed from a straight flight path by the forcing function. His task, then, was to respond to and overcome those disturbances and maintain target tracking as though he were being buffeted by wind gusts, etc.

The matrix of treatments consisted of four flight conditions of three modes each for a total of twelve. Each of the twelve treatments was presented to a subject once during a day's run. The order was random. Each treatment exposure lasted 45 seconds, during which data were recorded for analysis and subject feedback scores.

Four subjects participated in the experiment, all making five repetitions of each data run, for a total of 20 replicates of the experimental data. For statistical analysis, the independent variables were mode (1, 2, or 3), Gz level (1.6, 3, or 5), and dive angle (0° or 60°).

SUBJECTS

The subjects for the experiment were military volunteers of the AMRL hazardous duty panel. Although all were nonrated, two subjects possessed civilian private pilot licenses. For the experiment, standard USAF personal flight equipment was used, including flight helmet, gloves, and anti-G suit, inflated according to the standard G filling schedule.

In addition to the four panel members, a civilian test pilot (a contractor project pilot for advanced vectored force fighters with extensive fixed base simulator time flying with DSF) participated in the evaluation of the validity of the simulation and side force mechanization. Although his objective data were not included in the statistical analysis because he made so few runs, his subjective observations and recommendations are included in this report.

TRAINING

Each subject was given five days of static training on the simulator task of 30 minutes duration each and five days of dynamic training consisting of actual sequences of run profiles. Data records were kept so that the day-to-day performance of each subject could be observed during training.

FLIGHT PROFILE

The experimental run each day began by securing the subject in the cockpit and bringing the DES up to 1.4 Gz by remote control. At that time, control was turned over to the subject. The subject indicated when the run was to begin; and immediately the target aircraft began an evasive maneuver consisting of a hard pull-up and pseudo-random lateral motions with lateral acceleration limited to 1 Gy. The lateral motion felt by the subject during this tracking period was dependent on the mode of side force simulation selected by the computer for that experimental run. After 45 seconds of tracking, the target aircraft returned to 1.4 Gz with no lateral motion; and DES control was removed from the subject. Twelve such runs per subject per day were made, separated by 30-second rest periods. A typical flight profile of one run is shown in Figure 5.

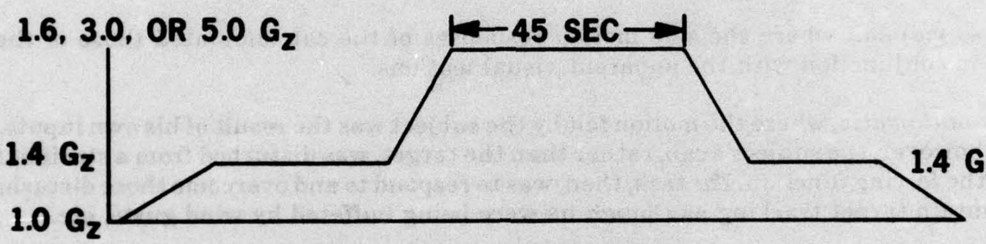

Figure 5. Typical Flight G Profile

After each profile, the subject was presented a display of the number corresponding to the inverse of his total RMS tracking error during the profile for feedback and motivation. In addition, he was informed of the experimental conditions for the next profile; i.e., Gz level, dive condition, and mode of cab motion.

DATA COLLECTION AND ANALYSIS

During each run, data were collected at a rate of 25 samples per second and recorded on digital magnetic tape for computer processing. Each profile was labeled for identification. The data recorded are listed below.

1. Profile segment
2. Cab angle
3. Fork (Dive) angle
4. Total arm accelerometer
5. Lateral stick output
6. Lateral acceleration — plant output
7. Target lateral acceleration
8. Lateral tracking error
9. Shaped pitch stick output
10. Main arm RPM command
11. Target normal acceleration
12. Vertical tracking error rate
13. Vertical tracking error
14. Lateral tracking error rate
15. Lateral Gy command to DES
16. Gx accelerometer
17. Gy accelerometer
18. Gz accelerometer
19. Cardiotachometer
20. Ear oximeter
21. Cab angle drive command
22. Raw pitch stick output

In addition, subjective response questionnaires were administered after the runs each day. The questionnaire is included in Appendix A.

The objective data were analyzed by computer to produce the following outputs as functions of the independent variables: RMS azimuth error, RMS elevation error, and total RMS error. The computer then performed two analyses of variance of the major effects to determine the statistical significance and possible interactions of the data. One analysis examined all of the level flight scores and determined the effects of mode and load factor. A second analysis examined all of the 1.6 Gz scores and determined the effects of mode and dive position.

Computer processing also produced histograms showing the percentage of time spent within certain levels of Gy for each condition of the study.

The postrun questionnaires were summarized and the ratings tabulated to obtain insight into the subjective factors which might have influenced the performance data and to compare the subjective and objective results.

MEDICAL SAFETY

In compliance with Air Force requirements, all centrifuge runs were monitored by a physician. The physician monitored electrocardiogram, instantaneous pulse rate, a close-up closed-circuit TV picture of the subject's face, and voice communication with the subject. The subject could terminate the run at any time by activating an emergency button.

RESULTS

PERFORMANCE

The analyses of variance (ANOVA) resulted in statistically significant performance differences in the two major variables of Gz and mode with an F ratio of .01. There were no significant differences due to dive angle at the .05 level. There were no significant interactions between the major variables at the .05 level. The performance RMS errors are given in Figures 6-8. Time spent commanding and receiving Gy between certain levels for the various experimental conditions are shown in Figures 9 and 10. These are indicative of the actual stress levels commanded and encountered by the subjects during tracking.

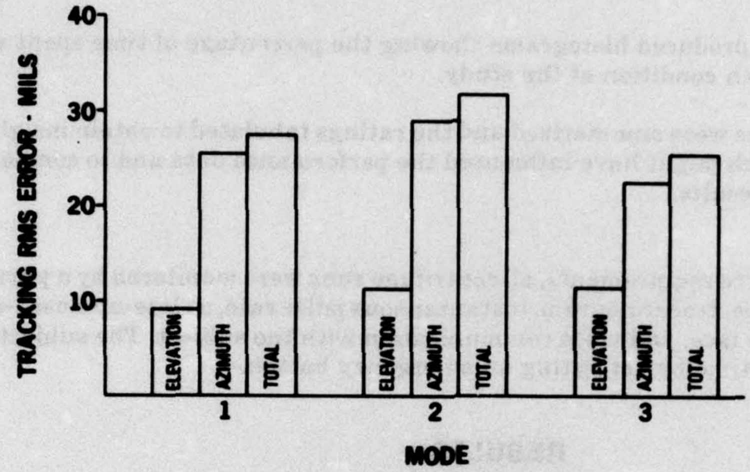

Figure 6. Tracking Error versus Mode

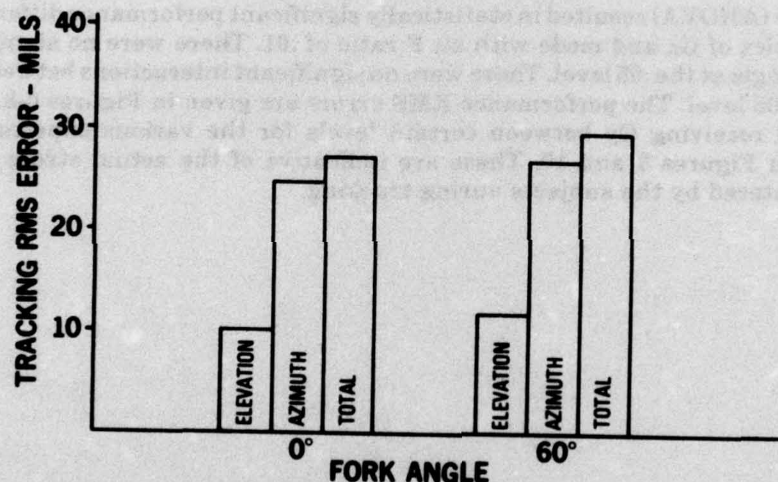

Figure 7. Tracking Error versus Dive Angle

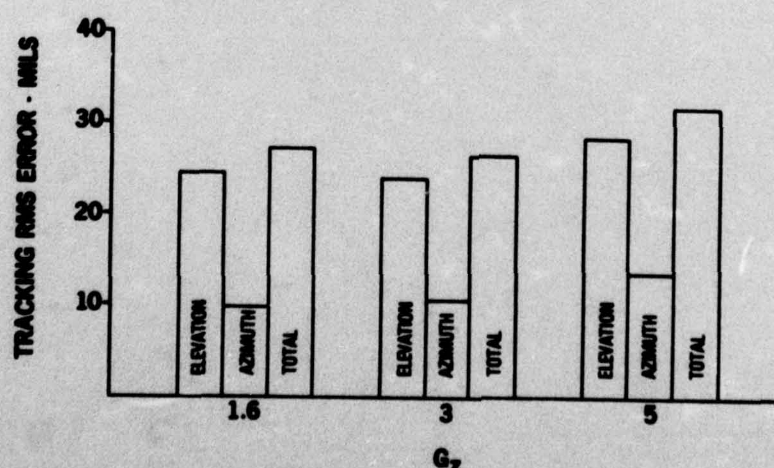

Figure 8. Tracking Error versus Load Factor

Computer processing also produced histograms showing the percentage of time spent within certain levels of Gy for each condition of the study.

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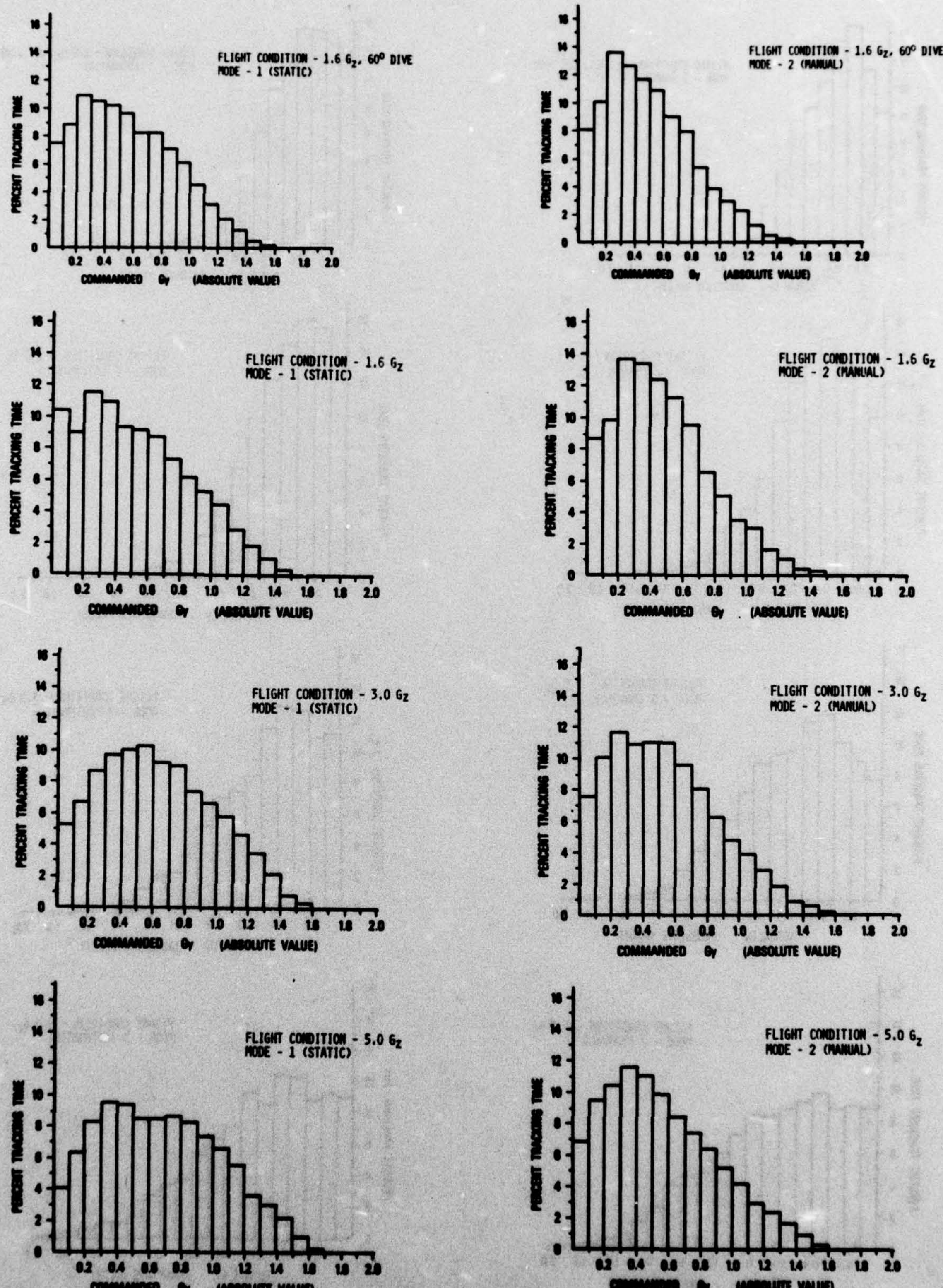

Figure 9. Command Gy Histograms

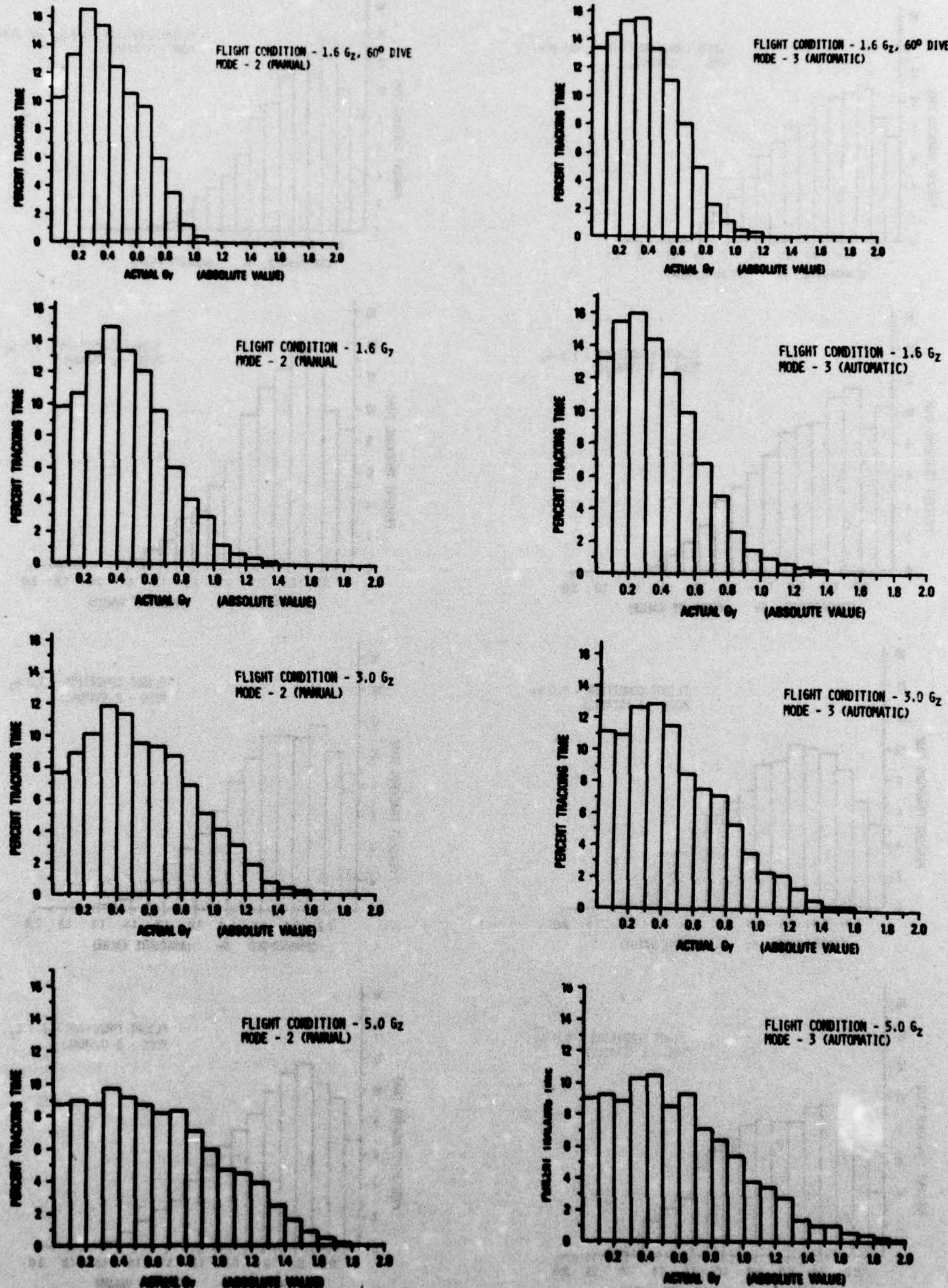

Figure 10. Actual Gy Histograms

QUESTIONNAIRES AND RATING SCALES

The responses to the postrun questionnaires are detailed in Appendix A. The responses are summarized as follows:

1. **The subjects did not feel that the direct side forces were bothersome or hard to handle nor did they appear to induce vertigo or nausea.**

2. **The restraint system (lap belt and shoulder harness) was felt to be adequate to allow a pilot to use DSF, but the upper torso motion was somewhat disturbing and fatiguing.**

3. **The method of simulating DSF (by rotating the DES cab) was felt to be a realistic one, particularly at the higher Gz levels (3 and 5). At 1.6 Gz, the sensation of rotation, in addition to lateral acceleration, was prominent.**

4. **The isometric sidestick controller was felt to be rather unsuitable for DSF control, because of the lack of displacement feedback and the amount of motion-induced extraneous inputs.**

5. **The DSF motion was felt to be of value in flying the task because of the additional feedback information it provided. However, the overall DSF task was considered more difficult than flying a conventional aircraft.**

The subjective rating scales of tracking work load and accuracy and side force versus rotational sensations were in accordance with the performance data and the questionnaire responses. Appendix B contains a tabulation of the subjective ratings of accuracy, workload, and motion sensation for various flight conditions.

DISCUSSION

Several questions were thought to be pertinent in interpreting the results of the experiment.

"How much direct side force could a pilot use when subjected to the resulting stresses?" — At least all of the capability provided in this study was usable. The subject's simulated aircraft plant had a ±1 G acceleration capability from straight ahead flight. This meant that up to ±2 G side force could actually be commanded when going from full left to full right velocity, or vice versa, because the output of the plant was proportional velocity. The G time histograms showed that the subjects actually experienced up to ±1.8 G in some instances, yet maintained control of the plant.

"How did experiencing direct side force affect the subject's performance on his tracking task?" — Three different control modes were designed to vary the application of direct side force to the subjects while keeping the tracking task and the visual cues constant. Performance differences between modes were statistically significant in both the level and dive conditions and the Gz (normal G) analyses of variance. The difference between Modes 1 and 2 was that Mode 1 was devoid of physical lateral acceleration feedback, while Mode 2 conveyed the pilot's commanded dynamic maneuver back to him by cab motion. This factor caused the mean tracking error to increase by 20% as shown in Figure 6. Mode 3, on the other hand, was configured so that the subject felt, in addition to his own impact, the complement of the relative target aircraft motion as though his own aircraft were being perturbed laterally. As shown, also in Figure 6 the Mode 3 tracking errors returned to the approximate level of Mode 1. This performance could have resulted because in Mode 3 better tracking performance provided a smoother ride, while in Mode 2 the reverse was true. However, the Gy histograms for Mode 2 and Mode 3 were very similar, showing the subjects to be receiving about the same amount of jolting in either mode. It is more likely then that this performance improvement was due to the additional anticipatory cue of target motion that Mode 3 side force provided. The subjective responses rated the Mode 1, normal G only, and no side force, to be the easiest mode to fly, correlating with the objective performance measures.

"How would side force affect pilot performance under less than 1 G normal conditions as in a 60° dive?" — The analysis of variance of the diving versus level performance revealed no statistically significant difference. The only noteworthy difference in the Gy histograms was the smaller percentage of time in which the subjects experienced high Gy in the dive runs; because, while the fork was tilted 60°, a given cab excursion commanded by the plant produced less GY. Notice that there was essentially no difference in the *commanded* Gy histograms, showing no change in strategy between level flight and dive. The diving position did, however, require some subjective acclimatization. The subject's main support was his harness; as one subject commented, even with the shoulder straps pulled as tightly as possible, there was nothing to brace against to insure smooth control. The subjects judged their own tracking performance to be the poorest and their work load the greatest while in the dive condition. The overall results, nevertheless, showed no great performance problems in going from the level to the 60° dive condition.

"How would task performance change with increasing normal G?" — The analysis of variance comparing the effects of various load factor levels on task performance revealed a significant increase in tracking error at higher levels of Gz. This result is not as predictable as it would first appear to be. During static training on the tracking task, two of the subjects commented that tracking was easier on the 5-G profiles. The constant back pressure on the isometric stick required to track in the pitch axis made fine control of the stick easier in the lateral axis. During the actual runs, all subjects thought they could handle more side force at higher G levels because they were better anchored in their seat. Indeed, the Gy histograms reveal a direct correlation between the percentage of time spent at higher side force levels and load factor. Nevertheless, fatigue became the limiting factor at 5 Gz. All subjects commented that it was hard to simultaneously concentrate on the tracking task and on the straining maneuvers necessary to maintain vision. Even the contractor test pilot commented that performing the tracking task at the higher G levels while receiving direct side force required "more than the average amount of flying." He recommended use of a reclined seat of at least 45 degrees.

For a first experience with direct side force, the base line cockpit configuration was chosen to be that of conventional aircraft, including a standard upright seat with a head rest but with no special lateral support, a standard four-strap harness, an isometric sidearm controller, and standard protective clothing (flight suit, G suit, and helmet) (Figure 11). Another pertinent question, therefore, was, **"How effective was this configuration in allowing the pilot to perform using direct side force?"**.

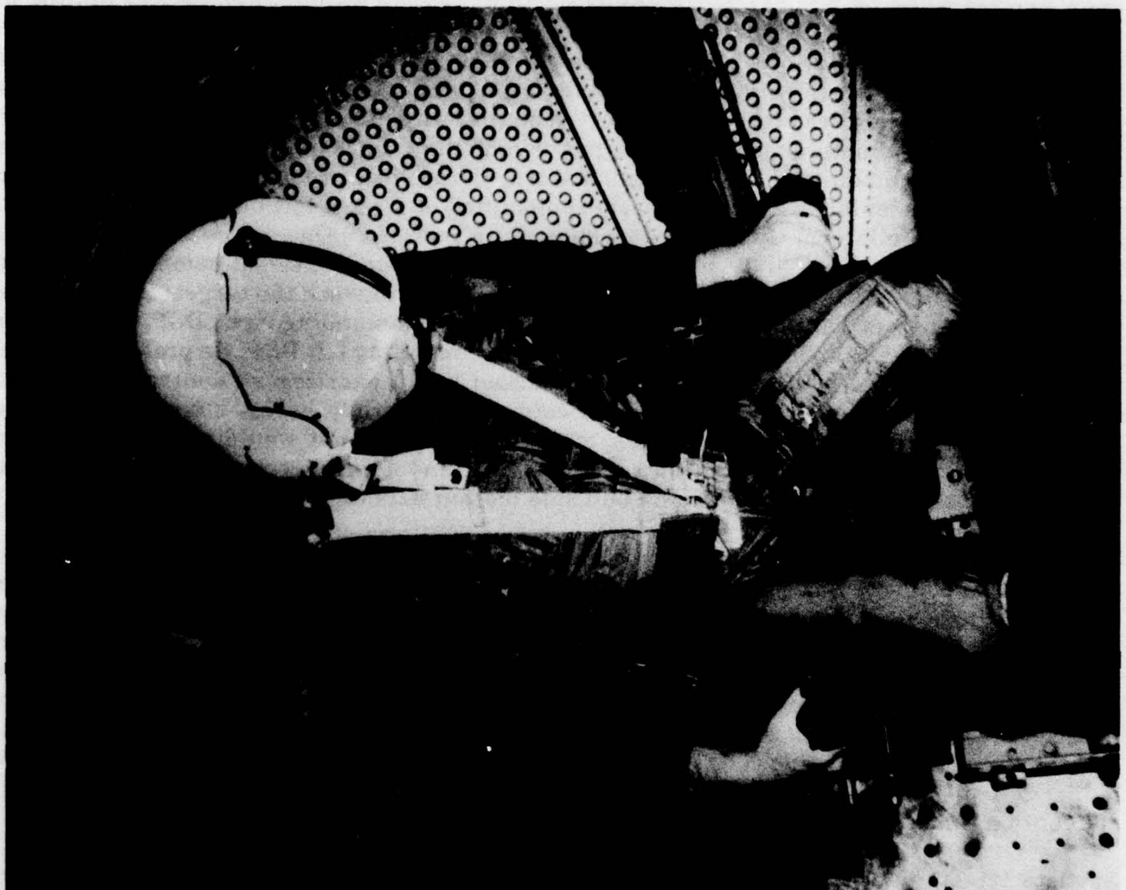

Figure 11. Seat and Restraint System

The effects of direct side force were measured on both side motion and pitch axis tracking tasks. The data show the tracking tasks in the side motion and in the pitch axis to be affected almost equally by direct side force, implying only negligible effects of mechanical coupling between side force and the lateral controller at these levels of Gy.

The most frequent criticism of the cockpit configuration from the subject was the lack of good lateral support; hips, trunk, shoulders, and head were all mentioned. Several subjects commented that they found it helpful to brace their helmet back against the headrest to help prevent head movement. The head still moved, however, and one subject complained that in this position his head was too far back to be comfortable. A partial head support allowing head rotation but not head translation was recommended. Sliding back and forth in the seat was particularly discomforting in the dive position where support from seat friction was minimal. In the questionnaire, only one subject responded that improvement in side restraints would not be a major factor in improving his tracking performance.

The second most frequent criticism of the cockpit configuration was about using an isometric sidearm controller (Figure 12). All subjects mentioned at least two problems. First, there was no direct feedback to the subject of what he was commanding through the controller. He did not know exactly when he was exceeding the maximum stick input nor when he was nulling his stick input in either axis. He could only obtain indirect feedback of his commands through the visual display and the side forces he felt. Since the display provided only displacement cues and the centrifuge gave acceleration cues, this feedback was difficult to assimilate. The second problem was with the stick cross-coupling between the two control axes. It was extremely hard to input a pure side motion on a pure load factor command. Lack of direct feedback about the stick commands compounded this problem. A third, more subtle probiem arose in using a force stick for lateral commands. Three subjects complained of a right-left disparity in the lateral task even though bilateral Gy histograms showed no such bias. One subject complained that more direct side force was felt when left inputs were made; a second complained he was constantly having to input large forces to the right in order to track the target; a third subject perceptively observed that his thumb knuckle, used for commanding right DSF, was a poorer pressure transducer than his whole hand, used for commanding left DSF. He preferred to use a more symmetrical gearshift-type grip with a locked wrist, exerting all control through his forearm. Unfortunately, he was unable to continue the study so his suggestion was not adequately tested. All of these controller problems are ones that would also appear during conventional maneuvering and are not specific to tasks involving direct side force. This is to be expected from the preceding pitch axis and side motion axis task comparison.

The sidearm controller did have one particularly good design characteristic for a direct side force task. It could be easily manipulated by one hand while the supporting arm was braced firmly on the seat. This becomes very important when the subject is trying to prevent two dimensions of large amplitude body movement (instead of just one) from inadvertently feeding back into his stick. The resultant body movements of this study were much larger than ever observed in conventional maneuvering studies. The minimal effects of this motion on performance were probably because a firmly braced arm with a sidearm controller prevented mechanical coupling. The importance of arm support in this study is evidenced by the fact that three subjects requested a height adjustment of their elbow support. That has never been critical in conventional maneuvering studies.

Statistical tests showed that there was no net learning effect during each subject's five days of data runs. This implies that the subjects were adequately trained on the tracking task in the new motion environment before data were taken. Before achieving this level of training, however, all of the subjects made two major adjustments. First, they acclimated to the wide differences in response of the plant between the pitch axis and the side motion. The dynamics of both had been derived to be representative of a modern aircraft with a ± 1 Gy capability. The pitch axis response by the plant was much quicker than the side motion response. Second, when training, statistically all subjects at first found that the easiest tracking strategy was to input short pulses into the system. When switched to dynamic training, they found that this control strategy resulted in an extremely rough ride; and they had to relearn to track using very smooth inputs.

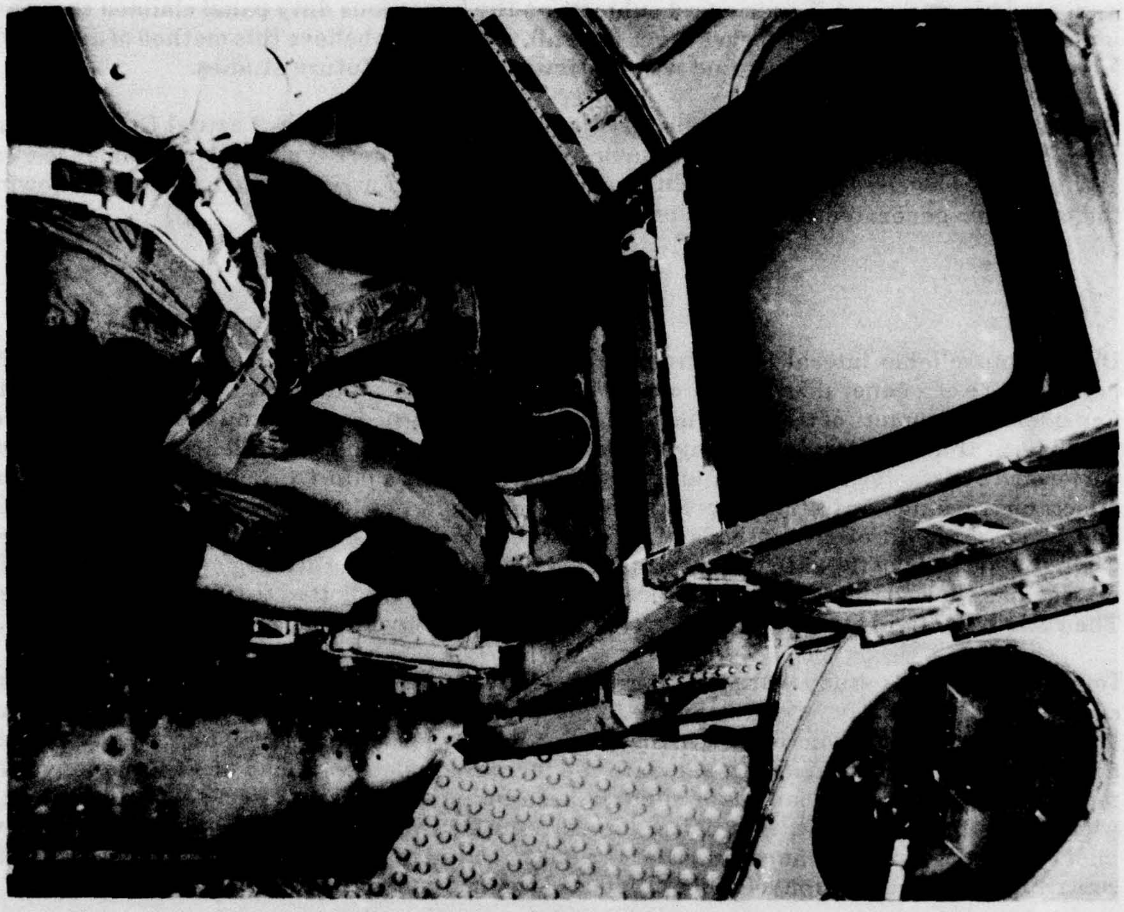

Figure 12. Pilot Controls and TV Display

Finally, how realistic was our simulation of direct side force on the centrifuge? Because we were constrained to three degrees of freedom of motion in simulating an aircraft capable of six, there would have to be some artifacts in the simulation. In addition to the usual Coriolis forces present whenever the centrifuge is operated, the actual method of producing side force also produced angular acceleration that is not present in actual direct side force. Also, in this method of simulation, there is a decrease in load factor as side force is applied. After much consideration, the authors concluded that the only way of measuring the importance of the artifacts was subjective evaluation. All subjects said the illusion of side force was real at 3 and 5 Gz.

None felt that the rotation itself was a major factor in affecting their test performance; the lateral acceleration was the key variable. The contractor test pilot, who was not an experienced rider on the centrifuge, commented that the usual Coriolis forces (not the side force rotation) increased his work load. Experienced subjects on the hazardous duty panel claimed that they could adapt so well that they forgot them. Overall, the authors believe this method of direct side force simulation to be of value and will continue to use it in future studies.

Comparison of the Mode 2 commanded Gy histograms with the Mode 2 actual Gy histograms reveals that, except in the dive condition described earlier, there is close correspondence even at the high Gy levels. This implied that the dynamics of the centrifuge had no trouble following the computer generated commands of the plant and task.

CONCLUSIONS

Direct, controllable lateral translation of a fighter aircraft was shown to be usable in the performance of a generalized two-dimensional tracking task under all conditions of this study. Considerable amounts of training and acclimatization were necessary; and the task was harder to perform than similar ones using conventional maneuvering. Once learned, the subjects performed satisfactorily with no undue disorientation or discomfort. Significant, but not major, effects on tracking strategy and performance were found when load factor was varied up to 5 Gz and when three different methods of closing the side force control loop were implemented. Changing from level flight to a dive position did not alter tracking strategy or performance. Gy histograms showed that the entire direct side force capability allotted to the subjects was used. The cockpit configuration, representative of a modern conventional fighter, was adequate.

Implications of this study were that larger amounts of direct side force than the ±1 Gy peak capability of this study (straight ahead flight to maximum lateral velocity) might be useful; that fixed base simulations of VFF maneuvering would yield optimistic results; that automatic flight control modes designed to alleviate the increased pilot work load of VFF maneuvering might be beneficial; that load factor might be a major limiting factor in VFF performance as it is with conventional aircraft; that better lateral support and a better controller would improve pilot comfort and performance; and that the method used to simulate direct side force with the centrifuge, although it unavoidably produces some motion artifacts, was basically valid.

APPENDIX A

QUESTIONNAIRE RESPONSES

Q. Did the side forces make you uncomfortable?

A.
- **(1) Early in the study but not toward end.**
- **(2) No.**
- **(3) A little, only during 1.6 Gz runs.**
- **(4) No, only a little during the last run.**
- **(P) Not as long as I concentrated on the task. If I concentrated on DSF feedback there was a disconcerting period of adaption.**

Q. Were the body restraints adequate? If not, how not?

A.
- **(1) To help keep my head steady I must lean back against the seat. That's too far back to be comfortable and my head still tilts sideways. On day 2 the torso motion interfered with holding the pitch steady.**
- **(2) Yes, but I felt on days 1 — 3 that side boards on the upper seat might help, particularly during the dive runs.**
- **(3) Yes, but I felt like I was falling sideways off the seat and I stabilized my body with my left hand. Perhaps a contoured seat would help.**
- **(4) Yes, but on days 1 and 2 there was lots of sliding back and forth so I needed shoulder and hip support. On day 1 I submarined during the dive.**
- **(P) Lower body OK (waist down). Upper torso (chest and shoulders) motion did cause some tiring toward end of run.**

Q. Comment on number of repetitions, fatigue, and rest periods.

A.
- **(1) None.**
- **(2) No problem.**
- **(3) Day 1 — general fatigue existed a few hours after the run. In general, 5 Gz runs are strenuous, particularly with two of them back to back.**
- **(4) No, except a little on day 3. Day 2 I felt exceptionally well.**
- **(P) Coriolis force was a little disconcerting on deceleration to baseline Gz.**

Q. Did you feel nauseous, disoriented, or dizzy?

A.
- **(1) On days 1, 2 and 5 I needed a couple of seconds to adjust to the dive position; otherwise, no.**
- **(2) Day 1 — very slight dizziness; day 2 — slight visual graying on start of 5 Gz runs; days 3, 4, 5 — no.**
- **(3) No.**
- **(4) Day 1 — slight disorientation when returning from dive to level; days 2 through 5 — no.**
- **(P) Yes. After several stops on initial orientation. I would recommend no food for previous 4 hours on future orientation runs.**

Q. Would better side restraints help performance?

A.
- **(1) I need some head restraint, particularly at low Gy, and something to hold the upper body still.**
- **(2) A little perhaps, but it's not a major factor.**
- **(3) Yes.**
- **(4) Day 1 — Marginally, primarily at 1.6 G level; day 2 — No, but it would add confidence; day 3 — No; day 4 — not as much as at first; day 5 — yes, for shoulders, hips, right forearm.**
- **(P) Yes.**

Q. Do you feel that the side force simulation was realistic?

A. (1), (2), (3), (4) Yes, at 3 and 5 Gz; at 1.6 Gz, the feeling of rotation dominated.

(P) Didn't really notice whether DSF or rotation prevailed, but the simulation was the most realistic at 5 Gz.

Q. What is your feeling regarding the use of a force stick, like the one we used, for side force control?

A. (1) Inadequate feedback. I'm not sure of what I'm putting in; I have no reference for when no force or movement is taking place. Perhaps some displacement would help.

(2) OK.

(3) Day 1 — seems effective, but sometimes it takes a good bit of pressure to home in; day 2 — too sensitive for the amount of pressure required for the cab to respond; day 3 — sometimes when performing in two axes it's difficult to find the neutral position in one. In general, pitch control is too sensitive; day 4 — I'm still convinced that this isn't the best system but I still have no suggestions.

(4) I dislike the cross coupling due to stick axis alignment. Pitch input spills into lateral commands; I don't like it.

(P) Too much cross coupling between pitch and lateral. No indication of maximum command signal in either axis, which causes a loss of harmony and degrades tracking at maximum rate commands.

Q. Other comments?

A. (1, 2, 3, 4) It seemed more force was felt when left inputs were made. It's hard to simultaneously concentrate on both straining maneuvers and tracking properly at 5 Gz.

The rapid return to baseline Gz in disconcerting.

Mode 3 seemed inconsistent; sometimes the seat would predict the motion; at other times the target moved before the seat would. Dives were hardest. There was nothing to brace against, yet the strap was as tight as possible.

It was easier to track with the helmet back against the headrest. It was hard to correlate target motion with displacement on the visual display.

The foot angle in the cab is uncomfortable.

The stick was uncomfortable. It should be titled more forward and have a molded grip. I can't track laterally without coupling into the vertical.

Modes 2 and 3 were more uncomfortable, but I felt I had better capability to track the target with the motion feedback.

(P) I particularly liked the Mode 2 feedback; it helped me to lead better.

Our workload is probably greater than that of a real airplane due to rotation and Coriolis effects. I partially accommodated to it.

I would like to use the reclined seat, at least 45°. This would enable me to take more task leading.

I believe DSF will be beneficial, but it will take some training to learn to use.

APPENDIX B

SUBJECTIVE RATINGS OF ACCURACY, WORKLOAD AND MOTION SENSATIONS FOR THE VARIOUS FLIGHT CONDITIONS

TRACKING ACCURACY

		Low Accuracy 1	2	3	4	5	6	High Accuracy 7
STATIC MODE 1	1.5 G Dive	0	1	6	3	4	1	4
	1.5 G Turn	0	1	3	5	3	6	1
	3 G Turn	0	1	1	6	5	6	1
	5G Turn	0	0	6	8	5	1	0
MANUAL MODE 2	1.5 G Dive	2	7	4	3	1	1	1
	1.5 G Turn	1	1	7	6	1	3	0
	3 G Turn	0	1	0	10	5	3	1
	5 G Turn	0	0	6	9	3	2	0
AUTOMATIC MODE 3	1.5 G Dive	2	6	7	2	0	1	1
	1.5 G Turn	1	4	8	3	1	2	0
	3 G Turn	0	1	1	12	5	1	0
	5 G Turn	0	1	6	11	2	0	0

TRACKING WORKLOAD

		Low Effort 1	2	3	4	5	6	High Effort 7
STATIC MODE 1	1.5 G Dive	2	4	7	4	3	0	0
	1.5 G Turn	3	5	7	5	0	0	0
	3 G Turn	1	5	9	4	2	0	0
	5G Turn	0	2	5	4	6	2	2
MANUAL MODE 2	1.5 G Dive	0	1	5	1	10	2	1
	1.5 G Turn	0	2	6	2	8	1	1
	3 G Turn	0	1	7	9	3	1	0
	5 G Turn	0	1	1	4	7	5	3
AUTOMATIC MODE 3	1.5 G Dive	0	2	2	1	5	5	5
	1.5 G Turn	1	1	2	4	4	7	1
	3 G Turn	0	1	3	9	6	2	0
	5 G Turn	0	0	2	3	9	2	5

MANUAL MODE 2

1.5 G Dive

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
5	0	5	2	2	7	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	1	3	7	4	5

1.5 G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
2	3	6	0	3	7	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	3	3	6	5	3

3 G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	1	10	6	4	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
3	11	7	1	0	0	0

5G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	5	3	2	5	6

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
13	8	1	0	0	0	0

AUTOMATIC MODE 3

1.5 G Dive

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
5	0	4	1	5	6	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	1	5	8	1	5

1.5 G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
2	3	5	1	3	7	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	4	4	5	4	3

3 G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	1	4	8	6	3	0

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
1	12	7	2	0	0	0

5G Turn

SIDE FORCE SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
0	3	4	2	4	4	5

TURNING/TUMBLING SENSATION

WEAK 1	2	3	4	5	6	STRONG 7
11	9	2	0	0	0	0

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