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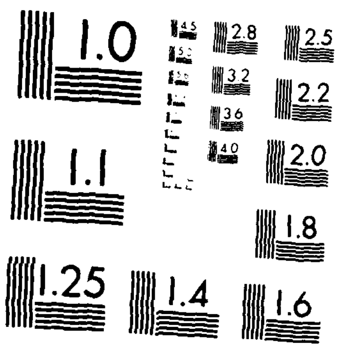

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PILOT PERFORMANCE IN SUSTAINED AND OSCILLATING LATERAL ACCELERATION — AFTI/F-16 RUDDER TRACKING

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AFAMRL-TR-82-85

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

HENNING E. VON GIERKE, Dr Ing
Director
Biodynamics and Bioengineering Division
Air Force Aerospace Medical Research Laboratory

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A group of AFTI/F-16 Project Test Pilots was exposed to a series of lateral acceleration exposures of 40 seconds duration. The acceleration was either a sustained + or -2 Gy, or oscillating ±2 Gy. The pilots were required to perform a multidimensional tracking task while tracking a target moving randomly in the ±Y axis. Performance in this stress and workload environment was examined with two different restraint systems. The first was a conventional lap and shoulder harness array; the second was the same harness system augmented by shoulder restraint pads of a design proposed by the airframe manufacturer for

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20. ABSTRACT (cont)

the AFTI/F-16. With or without shoulder pads, the sustained acceleration exposures were shown to degrade performance. Less degradation was observed in the oscillating environment. It was recommended that the design of the shoulder restraint pads continue pending a decision on likely tactical use of sustained and oscillating Gy. Rudder tracking in this environment was shown to be a viable implementation but was seen to be workload and fatigue susceptible. Consideration of pitch and roll stabilization during lateral acceleration was suggested. Pilot maintenance of adequate line-of-sight with the head-up display (HUD) was shown to be difficult without shoulder pads. Some measurements of pilot upper body displacement were made during the exposures. Tests with a production HUD were recommended. Fatigue as a consideration in pilot performance exhibited itself after a total exposure of approximately 300 seconds. Helmet weight was cited by pilots as a major contributing factor. Pilot comments on the restraints and lateral acceleration are included in Appendix B.

SUMMARY

A group of AFTI/F-16 Project Test Pilots was exposed to a series of lateral acceleration exposures of 40 seconds duration. The acceleration was either a sustained + or -2 Gy, or oscillating ±2 Gy. The pilots were required to perform a multidimensional tracking task while tracking a target moving randomly in the ±Y axis.

Performance in this stress and workload environment was examined with two different restraint systems. The first was a conventional lap and shoulder harness array; the second was the same harness system augmented by shoulder restraint pads of a design proposed by the airframe manufacturer for the AFTI/F-16.

With or without shoulder pads, the sustained acceleration exposures were shown to degrade performance. Less degradation was observed in the oscillating environment. It was recommended that the design of the shoulder restraint pads continue pending a decision on likely tactical use of sustained and oscillating Gy.

Rudder tracking in this environment was shown to be a viable implementation but was seen to be workload and fatigue susceptible. Consideration of pitch and roll stabilization during lateral acceleration was suggested.

Pilot maintenance of adequate line-of-sight with the head-up display (HUD) was shown to be difficult without shoulder pads. Some measurements of pilot upper body displacement were made during the exposures. Tests with a production HUD were recommended.

Fatigue as a consideration in pilot performance exhibited itself after a total exposure of approximately 300 seconds. Helmet weight was cited by pilots as a major contributing factor.

Pilot comments on the restraints and lateral acceleration are included in Appendix B.

PREFACE

The research reported herein was conducted by the Air Force Aerospace Medical Research Laboratory, and jointly sponsored by the Air Force Wright Aeronautical Laboratory under the terms of a Memorandum of Agreement, dated 14 November 1979.

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Section 1

INTRODUCTION

The initial experiment conducted under this Memorandum Of Agreement was concerned with the evaluation of experimental shoulder restraints which had been proposed by the airframe contractor, General Dynamics Fort Worth, as a solution to the problem of pilot body displacement by the Lateral (±Gy) accelerations which the AFTI F-16 is expected to develop. The results of this restraint evaluation experiment were conclusive in that the video tapes taken during the lateral acceleration exposures clearly demonstrated the extreme torso bending which is produced by the ±2 Gy acceleration employed. Pilot response to the use of the shoulder pads was predominantly favorable, and the decision was taken to proceed with the design of the shoulder restraints. On the basis of serious reservations concerning the impact of the shoulder restraints on pilot mobility ("checking 6") and access to cockpit side panels, the decision to go ahead with the installation of the shoulder pads was delayed pending further evaluation.

The primary objective of the research described in this report was that of obtaining data which would allow evaluation of pilot capability to perform a tracking task using the rudder pedals to control and command the lateral acceleration. As events developed, the experiment yielded an unexpectedly large amount of information on this question as well as on a variety of other questions which are of crucial interest to the military aviators who will fly aircraft of this type in the future.

Section 2

METHODS

COCKPIT FURNISHMENTS

The subjects were seated in an experimental High Acceleration Cockpit prototype seat which was designed by McDonnell-Douglas and already in place in the AFAMRL human centrifuge, the Dynamic Environment Simulator (DES). This seat incorporates a back angle displaced 20 degrees from the vertical and is, accordingly, somewhat more upright than the standard F-16 seat. The seated subjects were placed directly in front of a 21-inch video monitor located at a distance of a nominal 24 inches from the individual eye. On the left armrest of the seat was provided a throttle assembly connected through appropriate simulation circuitry to the left hand vertical airspeed scale of a simulated head-up display (HUD) also displayed on the video monitor. Airspeed was set a 500 knots for each trial, and full deflection of the throttle would result in changes in airspeed in accordance with a 1/S+1 exponential to simulate engine spool-up. The right hand armrest of the McDonnell-Douglas seat was replaced with the preproduction elbow and wrist support which was provided by the AFTI/F-16 Advanced Development Project Office. A force stick, manufactured by Measurement Systems, Inc., was provided for the pilot's control inputs to the other HUD displays. The simulation gains were set so that full pitch force on the sidestick controller would produce changes in altitude equivalent to climb/dive of 10,000 feet/minute. The roll axis gains were set so that full roll force on the stick would produce a roll rate of 180 degrees/second. The altitude changes were displayed on the vertical right hand scale of the simulated HUD and the nominal altitude at the beginning of each trial was 10,000 feet. Climb/dive information was provided by a pitch ladder, each rung of the latter representing a change of 5 degrees. Roll information was provided by roll tabs located on the center reticle of the simulated HUD. The nominal appearance of the target and HUD displays are shown in Figure 1. A set of preproduction F-16 rudder pedals were provided which, although not correctly located with respect to the seat reference point (SRP), were adjustable fore and aft. Yaw inputs to the tracking task were commanded by the pilot's use of the rudder pedals, the display being simulated so that right rudder commands "steered" the reticle to the target when it was displacing to the right, and vice versa. The target display was driven in an oscillatory fashion in the Y axis by a forcing function described under the following section. No forcing functions were applied to any of the other tasks; accordingly, disturbances in these displays were either the result of pilot inputs or inertial effects on the controllers resulting from the acceleration field.

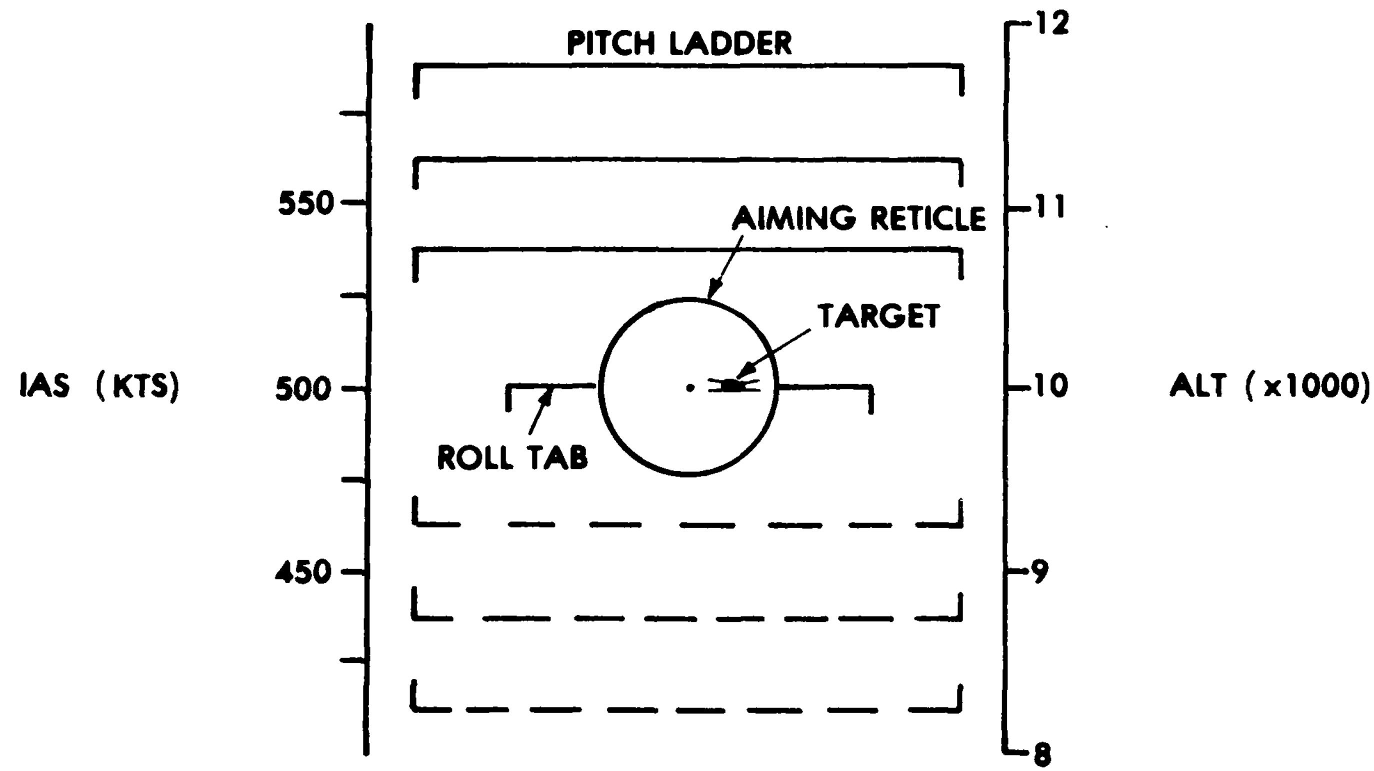


Figure 1. Appearance of Simulated HUD

A question was raised by the AFTI F-16 ADPO regarding pilot ability to maintain the proper point of regard for the HUD because of the narrow field of view (FOV) of the F-16 HUD. In the time available, it was not possible to implement a hard structure to represent the HUD, primarily because of the subject rescue removal and treatment constraints imposed by the Laboratory Human Use Review Committee. In this context a HUD unit would have interfered with access to the subject and subsequent removal from the gondola of the centrifuge. The solution to the problem was based upon calculations derived from the diameter and focal length of the optical element in the F-16 HUD and the resultant ray tracing geometry. A piece of Foamcore painted flat black was taped over the face of the video monitor. This element had a rectangular aperture in it the same size as the F-16 HUD frame. This aperture was surrounded by a rectangular "shadowbox" with the width and height the same as the aperture on the screen, and a depth of 7.4 inch. The open end of this structure faced the pilots and was equipped with a thin sheet of clear plastic with an opening 2.6 inches in diameter cut in. This opening was surrounded by a translucent red ring of pen dye 3/16 inch wide. Using this device, the pilots were asked to report when any portion of the red ring touched (visually) any edge of the opening on the face of the video screen. In such a case, it would be highly probable that the pilot would be unable to use the HUD. The essential features of this portion of the simulation are shown in Figure 2. The video HUD display was centered on the viewing axis of this device.

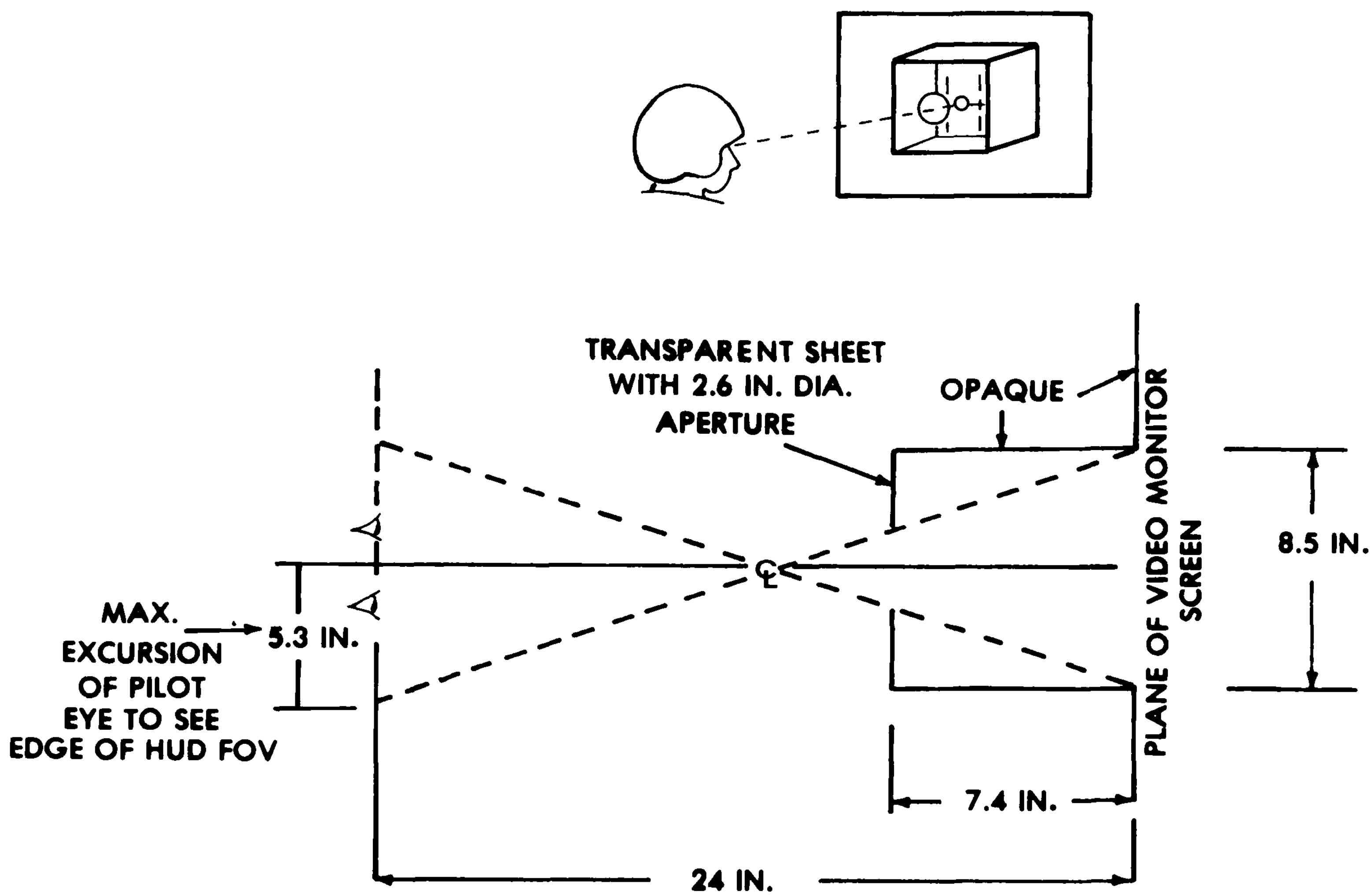


Figure 2. Geometry of HUD Field of View Apparatus

RESTRAINTS

Two sets of restraints were employed in addition to the left and right arm supports described below. The first of these consisted of a standard four point lap and shoulder harness array which was not equipped with an inertia reel, and which each pilot tightened in accordance with personal preference. The second arrangement of these pads may be seen in Figure 3.

Figure 3. Experimental Shoulder Restraints

PERFORMANCE TASKS

During the initial restraint evaluation experiments, means were employed, without the pilot's knowledge, to determine their responses to sustained lateral acceleration. The results of that experiment clearly showed that they were using the rudder pedals as braces. The simulated HUD and its associated control elements were incorporated in this experiment in order to prevent the pilots from using any control element as a brace in a manner which would not be possible in a real aircraft, and to provide a task and workload situation with some relevance to that which will be found in flight. No attempt was made to incorporate display and control dynamics which were necessarily "airplane like." As noted above, no disturbing functions were fed into the HUD element aside from hose fed in by the pilots or by inertial forces resulting from the acceleration. During the individual pilot inbriefing, each was instructed to attempt to maintain zero pitch angle, 500 knots IAS, 10,000 feet altitude, and zero roll angle, all while tracking the dynamic target motion through rudder commands to the aiming reticle.

The primary performance task embodied a target nominally representing a stern on view of an A-10. This target appeared in the center of the aiming reticle at the beginning of each engagement. Thereafter, it was perturbed in the ±Y direction by a disturbing function of the form:

$$f(t) = A_i \sin(\omega i t + \phi_i)$$

where ϕ_i is a randomly varied phase angle which, during the fade in of the target display, was equal to zero for the first 3 seconds of each trial. Table 1 documents the values used for the forcing function of the first and second days of the experiment.

TABLE 1. FORCING FUNCTION VALUES

Frequency ω_i rad/sec	A_i (Day 1)	A_i (Day 2)
W_1 =	.6938	.82008
W_2 =	.7021	.7021
W_3 =	.5907	.5907
W_4 =	.3884	.2000
W_5 =	.2495	.1000
W_6 =	.1409	.0100
W_7 =	.0753	.0010
W_8 =	.0431	.0010
W_9 =	.0238	.0010
W_{10} =	.0130	.0004
W_{11} =	.0074	.0004

NOTE: The Day 1 power in Forcing Function = Day 2 Power in Forcing Function, i.e.,

$$1/2 \sum_{i=1}^{11} A_i \;{}^{\text{Day 1}}\, 2/2 = 1/2 \sum_{i=1}^{11} A_i \;{}^{\text{Day 2}}\, 2/2$$

That is, both forcing functions produce equal dispersion on the CRT.

When the pilots responded to the target motion with rudder motion, the output from the rudder pedals was in the form of a position command signal which drive the cab dynamics in the closed loop mode, during which exposures the subject was tracking the target and simultaneously vectoring the gondola in the main arm acceleration vector to produce ±Gy. In the open loop mode, the rudder commands drove an analog simulation of the cab dynamics instead of actually vectoring the cab. In this mode, the subject experienced either a sustained + or - Gy field. In both the open and closed modes, the rudder commands "steered" the aiming reticle in the direction commanded by the pilot.

During the first day of experimentation, the characteristics of the forcing function were as is indicated in Table 1. These characteristics were judged by the pilots to be too fast to be realistic; and on the second day, the forcing function was modified as indicated in Table 1 so as to reduce the high frequency content of the signal. The resulting forcing function was judged to be far more realistic. Henceforth, this forcing function will be used in AFTI/F-16 experiments.

EXPERIMENTAL CONDITIONS

All pilots were exposed to the following sequence of experimental conditions. In some cases the number of replications of each exposure varied in accordance with pilot requests.

Experimental Condition	**No. of Replications**
Static (no motion tracking for familiarization with the task and controls	ad lib
Sustained +2 Gz, open loop	3
Sustained +2 Gy, open loop	3
Sustained —2 Gy, open loop	3
Full dynamic ±2 Gy, closed loop	3
Poststress static tracking	3

The relationship between the acceleration profile and presentation of the tracking task is shown in Figure 4.

ANALYSIS OF DATA

Rudder and Hud Tracking Performance

The following observations result from statistical analysis of the ensemble means and standard deviations of the data used for Figures 5 and 6. The data were subjected to t-test analysis for correlated data where data pairs are not independent. Confidence level for these observations is 0.05.

1. Training effects are evident on the basis of both the pre- and post- stress static data for both the rudder tracking and HUD tracking tasks.

2. The performance impact of the sustained +2 Gy stress is always worse than the +2 Gz stress for both tracking tasks.

3. The performance impact of the sustained —2 Gy stress is always worse than for the sustained +2 Gy for HUD tracking tasks.

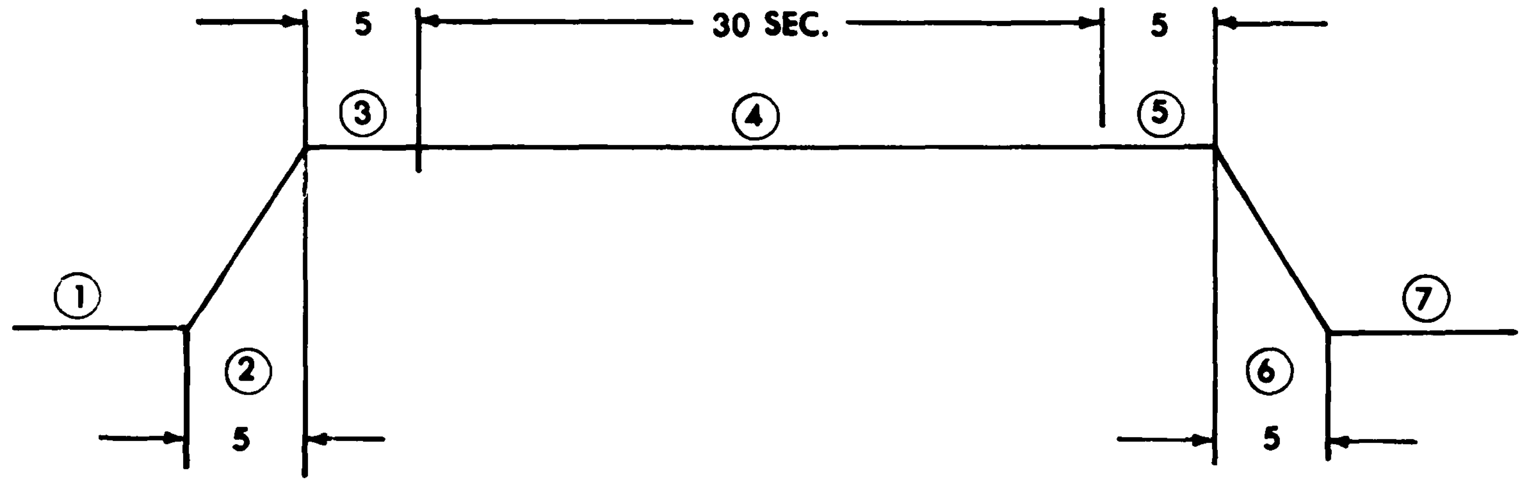
4. Rudder tracking scores under the fully dynamic ±2 Gy closed loop conditions are better than those seen under the sustained +2 Gy stress.

5. Both rudder tracking and HUD scores under the full dynamic ±2 Gy closed loop conditions are better than those seen under the sustained —2 Gy stress.

6. HUD tracking performance is less precise without the shoulder restraints in both the sustained +2 Gy and —2 stress conditions.

7. HUD performance scores are better without the shoulder restraints under the full dynamic ±2 Gy closed loop conditions of stress.

8. Shoulder restraints are helpful in improving performance under sustained Gy conditions, and especially so in +2 Gy, with respect to rudder tracking scores.



(1) BASELINE: +2Gz, NO DISPLAY
(2) ONSET: 0.4 Gy/SEC., NO DISPLAY
(3) HUD DISPLAY APPEARS ON VIDEO MONITOR, CAB VECTORS TO Gy
(4) TARGET APPEARS IN DISPLAY (G=+2Gy, −2Gy, OR ±2Gy)
(5) TARGET DISAPPEARS, HUD REMAINS, CAB VECTORS TO Gz
(6) OFFSET: 0.4Gy/SEC., HUD DISPLAY DISAPPEARS
(7) BASELINE: +2Gz, NO DISPLAY

Figure 4. Acceleration Profiles versus Task Presentation

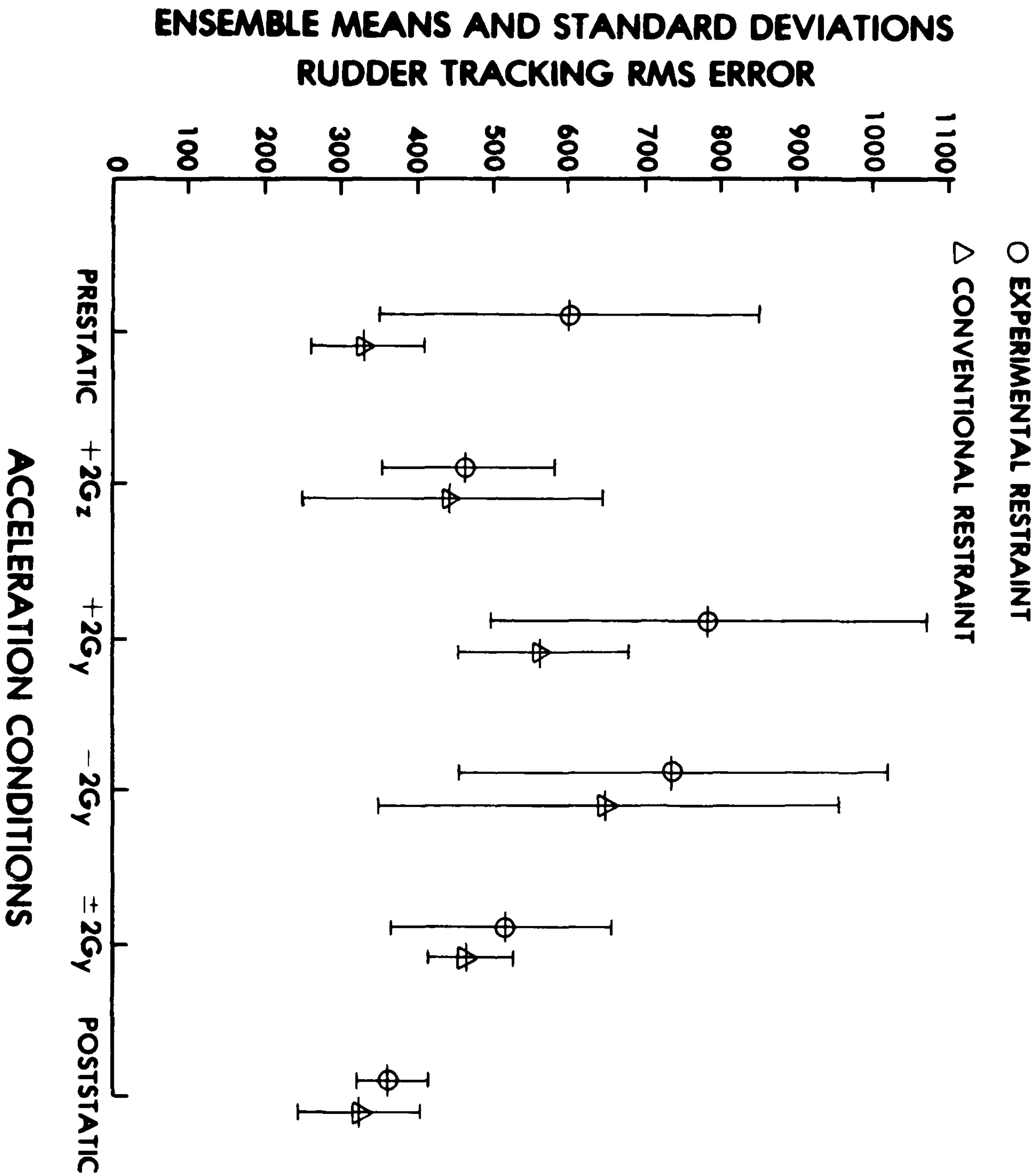


Figure 5. Rudder Tracking Performance

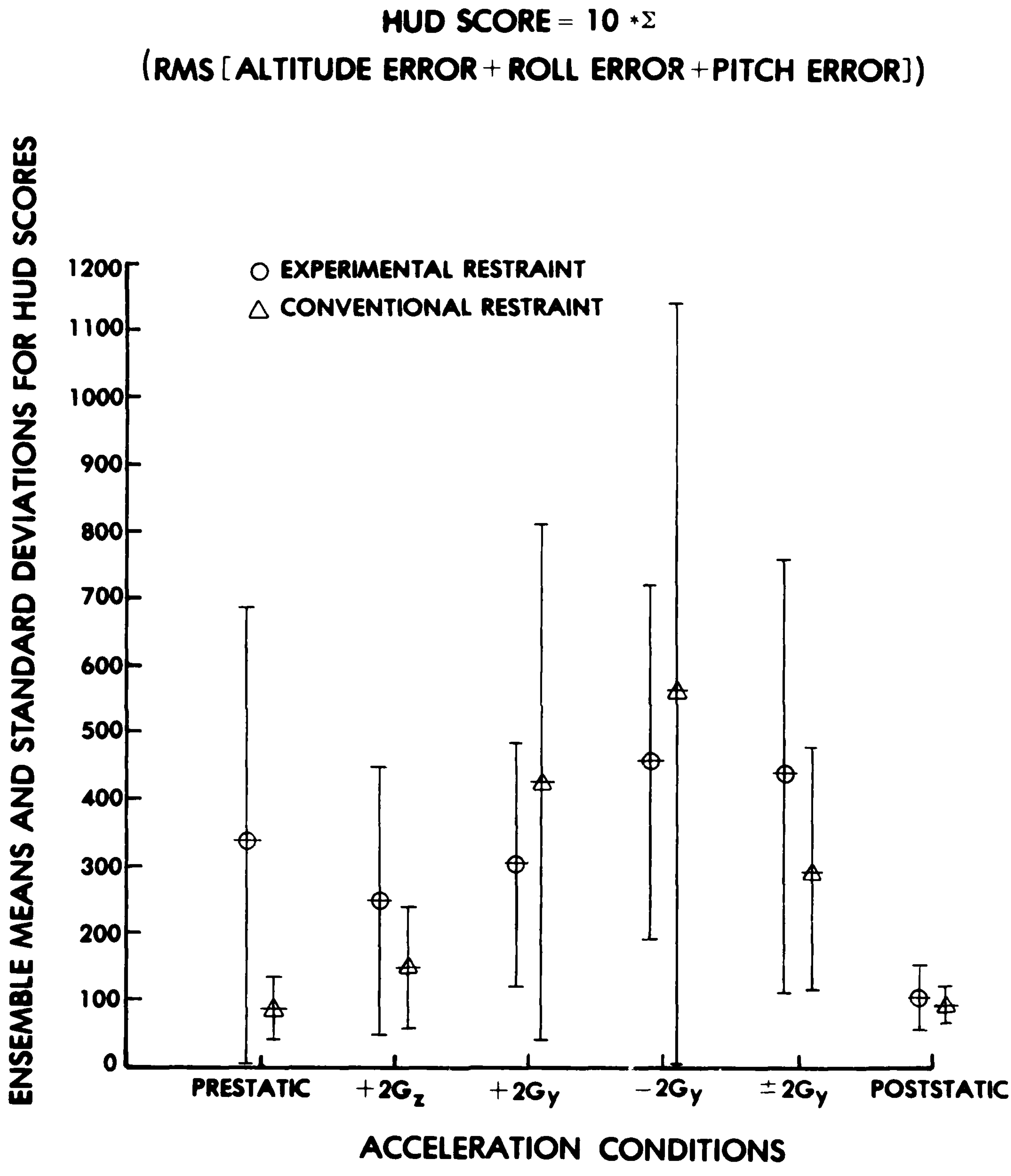


Figure 6. HUD Tracking Performance

AEROMEDICAL FINDINGS

Evaluations of the evidence available from the video tapes has not been completed at time of writing. In the interest of the quickest possible reporting of the biodynamic and performance aspects of this experiment, this report will document only the most superficial aspects of this topic.

In summary, there is now evidence of transient visual disturbances during the various stress conditions. It is highly probable that these are caused by the motion artifacts which are an unavoidable adjunct of centrifugation. Owing to the low overall acceleration levels being used, it is necessary to vector the centrifuge gondola through large angles. This fact, combined with the main arm motion, probably causes a brief vestibular disturbance accompanied by nystagmus. This phenomenon would not, of course, occur in a real aircraft.

At this point, there are some indications of not necessarily adverse pulmonary or cardiopulmonary effects. Coughing and throat clearing were commonly seen across all subjects following exposure to the lateral accelerations. There were also indications of difficulty in breathing as evidenced by apnea, grunting, and oral commentary. In no case did these symptoms appear to be more than superficial and transient. Nevertheless, the physiology involved is complex and deserves study. Any significant findings will be reported separately.

FATIGUE

Fatigue was a universal complaint. Remarks concerning this issue began after approximately ten exposures and helmet oxygen mask loads on the neck and head were cited as the primary problem. See Appendices A and B.

WORKLOAD

Discounting the unairplane-like aspects of the multidimensional tasks involved in this experiment, the data and the pilot comments make it clear that under both sustained and dynamic conditions of lateral acceleration, the rudder tracking task is a difficult one. The workload effect is clearly a function of fatigue as well as multidimensionality. The pilot comments on fatigue and inability to cope with airspeed, altitude, pitch, and roll seem to run parallel. See Appendices A and B.

HUD POINT OF REGARD

Measurements were taken from the video tapes made during the sustained portions of the acceleration exposures. The results of these measurements are presented in Table 2. The displacements listed in this .able are approximations of the displacement of the bridge of the nose of each subject.

Based upon the information provided to AFAMRL/BBS as shown in Figure 2, any motion which moves the eye more than 5.6 inches from the centerline of the HUD will produce adverse visual conditions for the use of the HUD. As the table indicates, the displacements under sustained +2 Gy and sustained —2 Gy are of large enough magnitude to be suspect. The large displacements are additionally exacerbated by the head tilt angles the subjects were forced to assume as they attempted to maintain point of regard. The transcripts of the video tape audio portions incorporated in Appendix B indicate that this was a complicating factor for the subjects in addition to the gross displacement problem.

TABLE 2. ENSEMBLE MEANS AND STANDARD DEVIATIONS FOR EACH CONDITION OF RESTRAINT AND ACCELERATION

+1 1/2 Gy - w/o Shoulder Pads	Displacement from center: 4.73 ± 0.46 inch
-1 1/2 Gy - w/o Shoulder Pads	Displacement from center: 4.80 ± 0.14 inch
+2 Gy - w/o Shoulder Pads	Displacement from center: 5.07 ± 1.22 inch
-2 Gy - w/o Shoulder Pads	Displacement from center: 5.63 ± 1.41 inch
+2 Gy - With Both Shoulder Pads	Displacement from center: 3.10 ± 1.78 inch
-2 Gy - With Both Shoulder Pads	Displacement from center: 4.39 ± 2.95 inch
+1 1/2 Gy - With Both Shoulder Pads	Displacement from center: 2.61 ± 1.22 inch
-1 1/2 Gy - With Both Shoulder Pads	Displacement from center: 2.93 ± 1.00 inch

Measurements were not attempted for the displacements occurring during the dynamic ±2 Gy conditions because of the difficulty of making reliable measurements, and the low magnitude of head and torso movement which is typical under dynamic conditions.

Section 3

CONCLUSIONS AND RECOMMENDATIONS

SHOULDER RESTRAINTS

This issue cannot be decided without reference to the **operational** use of the AFTI/F-16. If tactics dictate that **sustained** lateral accelerations of 2 Gy will be necessary, there are now robust indications that is significant fraction of the pilot population will require additional restraint. The judgment on the use of the shoulder restraints will further be influenced by the number of successive uses of sustained lateral acceleration, since it is clear that the cumulative effects are far greater than the single or occasional use of the Gy acceleration. This aspect is overwhelmingly a function of fatigue and is complicated by the head and neck loads imposed by the helmets and oxygen masks.

On the other hand, the results of these experiments indicate that if operational considerations and tactics dictate the use of primarily dynamic ±Gy in an oscillating fashion, then the shoulder restraints would probably not be as crucial as they will undoubtedly be for sustained accelerations. All of these considerations must be integrated into the structure of airframe capabilities, tactics, engagement structure, sortie rates, pilot head and torso mobility, pilot anthropomorphics, and cockpit layout.

Accordingly, it is recommended that the design of the shoulder restraint system be allowed to proceed until such time as the necessary information on operational and tactical issues enables a final decision. In a more global context, it should be noted that six degree of freedom aircraft in generations beyond the AFTI/F-16 should be provided with an integrated ejection seat/restraint system specifically designed for these challenging new flight regimes.

RUDDER TRACKING AND WORKLOAD

These experiments have shown that rudder tracking is a viable control implementation for the AFTI/F-16 in either the sustained or dynamic Gy environment. It has also been demonstrated that with repeated exposures and mounting fatigue, it becomes increasingly more difficult for pilots to cope with other control tasks. It is, therefore, recommended that pitch and roll stabilization be implemented when rudder tracking is being employed.

HUD POINT OF REGARD

There are indications that, during sustained periods of positive and negative 2 Gy without shoulder restraints, the pilots will have difficulty using the HUD. Accordingly, it is recommended that General Dynamics conduct a simple experiment with an actual F-16 HUD to determine whether the displacements which have been measured do, in fact, result in a compromise of HUD usability. If this proves to be the case, and if sustained lateral accelerations will form a significant part of the AFTI/F-16 tactics, then the use of shoulder restraints is strongly indicated.

FATIGUE

The pilots participating in this experiment commenced complaints of neck fatigue and discomfort after 10 to 12 exposures to the conditions of lateral acceleration. Detailed comments are documented in the appendices. It is recommended that these data be taken into account in the planning of tactics and in the consideration of special physical conditioning exercises of aviators assigned to the aircraft.

This information also lends further urgency to the effort for the development of a lightweight helmet for the F-16. during the week of 23 June 1980, representatives from the Life Support SPO were given a briefing on the findings of this experiment and were shown pertinent portions of the video-tapes.

Appendix A

TEST PILOT QUESTIONNAIRES

EXPERIMENTAL RESTRAINT

Subject 800005

With a four dimensional task, what was your impression of this restraint:

1. **Under sustained Gy conditions (+, -2 Gy):**
   The left restraint felt uncomfortable at sustained Gy. The right restraint was more comfortable than the left. I never felt so uncomfortable that I could not work on the tracking task.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   The oscillating condition appeared to be less of a problem (more comfortable) than the **sustained** condition. Because the comfort level was higher, I felt that I could concentrate on the tracking task a little more.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   I feel that it is significant that I did not notice lateral head position. If my eye position was out of the HUD FOV, I did not notice it.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   a. Wrist rest is not used.
   b. Armrest tilt angle is too flat. The support arm should be tilted inward.
   c. The left forearm rest is not noticed.

CONVENTIONAL RESTRAINT

Subject 800005

With a four dimensional task, what was your impression of this restraint:

1. **Under sustained Gy conditions (+, -2 Gy):**
   The lack of side restraint did not prevent accomplishment of the task. The lateral forces did make the weight of the helmet more of a fatigue factor than with the side restraint. **By far,** the weight of the helmet seems to be more significant than the presence or absence of the side restraint. I was much more aware of the strain on my neck without the restraints than I was when the side restraints were installed although there was an effect of cumulative fatigue. I found my ability to concentrate was decreased with the additive fatigue on my neck. Toward the end of the session, I noticed a definite decrease in concentration during any given run; the effect of neck fatigue was more significant as a cumulative factor than with effect of the magnitude of any single shot of side force.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   The oscillating Gy was less tiring than the steady Gy. There was a definite reluctance to aggressively pursue the target with full rudder command when the target was significantly away from the center of the HUD reference; that reluctance was caused by the additive fatigue effect.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint system?**
   On several runs the reference circle was at the edge of the box but it was always within limits.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   It appeared to be adequate because I did not think about it until after the session.

EXPERIMENTAL RESTRAINT

Subject 800006

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
It was a reasonably comfortable restraint. I had 3-4 inches of side travel between shoulder pads. The sense of lateral attitude control was unsatisfactory. Making the wrong sense input dominated more of my perceptions than G discomfort.

2. **Under oscillating (±2 Gy) closed loop conditions:**
The jerks that were associated with reversing direction were very distracting. The acceleration reversals that were associated with rudder pedal inputs were sufficiently disorienting to break what little concentration that I haa for tracking the TGT for 5-8 seconds after input.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
Satisfactory.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
I don't like the wrist constraint in the simulator or airplane.

CONVENTIONAL RESTRAINT

Subject 800006

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
   It was more uncomfortable to the left than the right. I received most of my support from the left shoulder strap when accelerating to the left. I was equally supported by shoulder strap and armrest when accelerating to the right.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   I was not very sensitive to the lateral accelerations by themselves. I was much more aware of the jerks of changing direction than G forces.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   I slid so far to one side that my reticle was completely below and to the side of the HUD field of view.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   The wrist support was extremely uncomfortable during positive accelerations.

EXPERIMENTAL RESTRAINT

Subject 800015

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
   Positive G: The restraint system was very helpful and as comfortable as possible. The general feeling was that of lying on your side. The pad was comfortable. The left seat brace was used also to stabilize the body. The pilot is restrained considerably, and it would be difficult to look behind.

   Negative G: There was a little pain in the right arm about 1.6 Gs. The task was much more difficult than under negative (sic) Gs.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   Oscillating Gs were more comfortable than the sustained Gs; however, it was more difficult to coordinate all the tasks.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   The HUD FOV was maintained during all runs. It was most difficult with the sustained negative G and easiest with the positive G. The circle was slightly offset to the right at a stabilized condition (1 G).

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system:**
   The armrest and wrist rest were very useful in maintaining minimum pressures on the stick. Neither item was used to support the pilot.

GENERAL

The rudder pedals would have been more comfortable had I been able to move them about 1 foot. This presented a very uncomfortable feeling while using the rudders.

The seat leg braces were very useful in stabilizing the pilot during sustained Gs.

The right shoulder pad caused slight pain at the bottom edge during the 2 G sustained maneuvers.

The helmet weight did not cause a problem but this is a very lightweight helmet specially built for the pilot.

There was a tendency to put in the wrong roll inputs and rudder inputs because there was a tendency to want to move the target and not move the aircraft to the target.

CONVENTIONAL RESTRAINT

Subject 800015

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
   Positive G: Without restraints I felt myself using the rudder pedals as a brace as well as the seat leg brace. It was very difficult to bring my head back to a centered position on the HUD. Tracking was difficult with all axes. I tended to concentrate on one task at a time. By using the rudder pedals as a brace, it was more difficult to use the rudder pedals because I was having to push against myself. It was difficult to breathe during these times. The workload was much higher without the restraints than with the restraints.

   Negative G: It seemed easier to raise head back to center position. Breathing was easier. Workload was less. The armrest was definitely used as a brace, and it was noticed that the arm was actually resting on the corner of the armrest.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   It was very difficult to coordinate all tasks during these oscillations. Actually, on occasion, I was totally ignorant of bank angle. The physical workload seemed to be less than with steady state G.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   It was more difficult than with the restraints. The head was never actually centered, but I was able to keep the target within the red circle.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   Armrest is definitely used as a brace.

The restraints were definitely an asset during all the tests. The restraints caused slight bruises but the straps also caused bruises on the shoulder and collarbone when used without the restraints.

EXPERIMENTAL RESTRAINT

Subject 800004

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
   a. The restraints are adequate, provide sufficient support, and do not interfere with the tasks presented.
   b. Free hand and wrist movement was possible at ±2 Gy. The preproduction wrist support is deeper than the production support; and during —2 Gy, my wrist could not make the small lateral shift with my right arm. The result was a disproportionate force on the wrist. —2 Gy was more comfortable without the wrist support. Recommend acquisition of production restraint.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   a. No new impressions under dynamic conditions. Arm pads were close enough that there was no tossing or bouncing back and forth.
   b. Mild neck fatigue noted after 10 runs.
   c. Tasks much improved.
   d. The installation of an F-16 seat with correct relationships of throttle, stick, and rudders should make the task even easier.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   I could maintain a centered eye position with minimal effort.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   See 1.2 above.

NOTE: I still have significant reservations reference the installation of these (shoulder) restraint devices in the cockpit. Please send a status report on this hardware to JFTO.

CONVENTIONAL RESTRAINT

Subject 800004

With a four dimensional task, what was your impression of this restraint?

1. **Under sustained Gy conditions (+, -2 Gy):**
   a. Marginal support is offered by the conventional straps. During sustained conditions, while "hanging" in the straps and with minimal lateral restraint from elbows/forearms, significant torso bending is required to maintain a "design eye" head position. This straining maneuver could be fatiguing over a period of time.
   b. +2 (actually +1 1/2) Gy is the wrose case due to free stick arm.

2. **Under oscillating (±2 Gy) closed loop conditions:**
   Restraints were generally acceptable during transitory conditions. Comfort level is far below that experienced with the pads.

3. **How well were you able to maintain your eye position in the HUD field of view with this restraint?**
   Well, but with great difficulty at +2 Gy, and some difficulty at 1 1/2 Gy.

4. **Do you have any comments on the F-16 right arm elbow and wrist supports with this restraint system?**
   Nothing new.

Appendix B

SEMI-VERBATIM COMMENTS OF PILOTS DURING EXPOSURES TO VARIOUS EXPERIMENTAL CONDITIONS

NOTE: In the following, the items enclosed in parentheses or brackets are remarks or comments made by the Principal Investigator. The items enclosed in quotation marks are comments made by the pilots.

CAVEAT: In assessing what follows in terms of workload, the reader should be aware that the roll task displayed to the pilots showed roll to left and right. The pilots noted that they would have preferred it to act as an attitude/direction indicator. Since it did not, they had somewhat more workload to contend with than they would in an actual airplane. This was made more difficult by the fact that the roll tabs were implemented so that when the roll exceeds a 180 degrees, it stopped. Thus, when the roll display was in that state, the pilots had no clue as to which way to go to correct it.

SUBJECT 800005, WITH PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run: (Clears throat after first exposure.) "Armrest (pad) may be too high." (Did not request it be changed.)
- 2nd run: [Stated he did not believe he was having any trouble with the head-up display (HUD) point of regard and that the restraints were doing a good job in that respect.]
- 3rd run: "Holding your head up is tough — forces on the neck awfully high." (Clears throat again after this exposure.)

SAME SUBJECT, WITH PADS, —2 GY SUSTAINED, OPEN LOOP

- 1st run: (Reports greater sensation of yaw in -Gy direction, probably due to greater cab vector angle required to produce -Gy. His breathing seems more labored.) "Seems more comfortable to the right, and I did not notice myself bracing on the armrest."
- 2nd and 3rd runs: (No germane comments.)

SAME SUBJECT, WITH PADS, ±2 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: "When I'm thinking about the rudder tracking and the motion, I get distracted from the HUD task." (Workload?)
- 2nd and 3rd runs: (No germane comments.)

SUBJECT 800005, WITHOUT PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run: (Body rides up to the left in the harness. Subject coughs.) "More significant than the side restraint is the helmet. I didn't pay that much attention to it the first time. The most uncomfortable thing is your head. I can kind of hang here in the straps and not feel too uncomfortable but holding my head in position is kind of tough. It becomes more significant when you don't have any restraint, if that makes any sense, because if I'm sliding off to the left I have to hold my head back to keep the circle (HUD) within the area that I need to do, so all of a sudden the side forces reference the weight of the helmet becomes more significant. So I think if we go without the restraints there's going to be an even bigger demand for a lighter helmet." (Clears throat.)
- 2nd run: "Oh, yeah ... I can really see that now. It's starting to manifest itself a lot more." [This comment was made during the +2 Gy and pilot's head was at about a 20 degree angle. Muscular (neck) straining tremors are evident.] (Clears throat after the run.)
- 3rd run: "Tendency to put in a roll command when you initially get the lateral G." (This is probably an inertial biodynamic effect of G load both on the forearm/hand, and on the stick.) (Breathing is labored, accompanied by grunting.)

SAME SUBJECT, WITHOUT PADS, —2 GY SUSTAINED, OPEN LOOP

- 1st run: "I think I had a little bit of fatigue on my neck from the earlier sessions. That's becoming additive, and that may be significant also. I can find myself sitting here thinking I'm kind of dreading three more of these things just because of the force on the neck. The body motion left and right doesn't bother me enough to even think about it. The biggest thing that's on my mind right now is the neck forces, the weight of the helmet." (These comments were made before the run began.)

  "Roll (adverse roll input) is in the opposite direction this time." (Following the run, pilot indicates in words and with hand motions that he felt a pitch up sensation as the cab vectored from -Gy back to baseline G.)

- 2nd run: (Breathing does not appear to be quite so labored to the right as it was to the left. The pilot grunts lightly.) "Just the fatigue on your neck causes a significant distraction in the tracking task. I find myself thinking, 'God, how long is this going to go on?' I think I'm bracing myself with my knees so there is not as much of a tendency for my feet to slide off the rudder pedals."

- 3rd run: "Man, that is tough on the old neck. (Clears throat.) **Tough** on the old neck. I was kind of joking about that before, but now that I am sort of into thinking about the helmet, I think it's something that I haven't spent enough time talking about or considering. A lot of discomfort in the movement has to do with the helmet itself. At this 2 G lateral, it really is a pain in the neck. It ends up being very distracting from the task, so its important."

SAME SUBJECT, WITHOUT PADS, ±GY FULL DYNAMIC, CLOSED LOOP

- 1st run: "You know, I am finding myself just fatigued. I find my concentration beginning to decrease on this tracking task, and its very much a result of the neck fatigue ... it really is. As soon as that target slips off to the side I find myself saying, 'Oh, s--t, I've got to get it!' I think a guy could take a couple of pops of the lateral forces and not have too much of a problem. If you were to, say, have a series of sustained engagements or drop 16 bombs off of the airplane individually where you have a lot of lateral, I think there would be some decrease in your ability to do the skill task just by the additive effects of the neck fatigue and the weight of the helmet. I am to the point now that I'm not even thinking about the lateral restraint."

- 2nd run: "Your mind does not take control over it. I find myself sliding back at the time but I didn't notice that pitch sensation." ("Yes you're too busy.") "It's too bad I'm in a centrifuge. What I'd like to do right now is just roll my head around." (Note: what the pilot is referring to in this exchange is the diminution of the perception of the motion artifacts involved in simulating air combat with a centrifuge. His last remark indicates his awareness that if he does roll his head around while he's in a moving centrifuge, he will become highly disoriented and nauseated.)

- 3rd run: (During the run) "Went the wrong direction that time." "Wrong direction again." "I find myself just not doing as well ... just can't concentrate." (This subject requested a fourth run.)

- 4th run: "I do find a little bit more crosstalk in the two commands without the restraint (shoulder pads) ... a tendency to put in roll commands when I really don't want to. There is a G effect, Bob, which we're going to have to correct in the airplane. That time when we started in, I tried not to have any input whatever and as I put in rudder I found the roll changing so there's either the weight of the sideslip itself or there's some crosstalk in the control."

SUBJECT 800006, WITH PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run, "At +2 Gy, the center reticle goes down to 1/2 inch or so of the clear plastic." [The meaning of this comment is not clear. It probably indicates subject was having some difficulty staying within HUD field of view (FOV).]

- 2nd run: (Does not straighten self in seat after this run; is well to his left in the seat.)

- 3rd run: (Subject was asked if he would like pads tighter, that they'd be too constraining otherwise.)

SAME SUBJECT, WITH PADS, —2 GY SUSTAINED, OPEN LOOP

(Subject centers self in seat prior to run)

- 1st run: (Appears to ride up in his harness to his right as the acceleration builds up. States that he does not make a strong correlation between the task and the acceleration.)

- 2nd run: (Definitely rides up in the harness to his right.) "I'm not having as much difficulty keeping within the HUD FOV as I did last winter." (This is a reference to the original restraint evaluation experiment.)

- 3rd run: Not on video tape.

SAME SUBJECT, WITH PADS, ±2 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: "It's a major distraction to have it reversing like that."

- 2nd run: (Appears to ride up to his left when inertial force is in that direction.) "Without the normal G, it's going to be hard for me to extrapolate what it would feel like." ("Okay, you're getting normal Earth gravity.") "I mean with a reasonable amount of G ... 3, 4, 5 G. Each time I get with the jerk, the lateral acceleration, I move back and forth across my seat."

- 3rd run: "Yeah ... I just kind of ignored the stick task." (Workload?)
  (Note: this data was not used in the calculation of ensemble means and standard deviations.)

SUBJECT 800006, WITHOUT PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run: (Subject commented on incorrect positioning of the simulated HUD framework.)

- 2nd run: "It's pretty hard for me to make any lateral inputs with the stick because your wrist support ... my wrist falls over to the left of the wrist support so I have to bend my wrist over and around and it ... let's see, when I need to make a right lateral (roll) input about halfway through the run I just give up because I really can't get my wrist around there."

- 3rd run: (Straining head tremors quite evident on this run.) "I don't know what to say about the restraint. I think I'm bracing myself mostly on my collarbone with the shoulder strap. That's about the only thing I feel right now. I slip so far to the side that the FOV ... I don't have a good reference point on that because the reticle slips so far to the left of the red ring. (This indicates that he would be having extreme difficulty using the HUD.) I'm bracing myself somewhat with my calf and my knee that it's hard to make small inputs (on the rudder). I'm really having to tighten up my buttocks to make the rudder inputs. The lateral inputs (presumably roll) I can't make."

SAME SUBJECT, WITHOUT PADS, —2 GY SUSTAINED, OPEN LOOP

- 1st run: "I feel I'm about to fall out on this one. It's not easy to make a right roll when I'm leaning so hard against my right elbow. That was only partly a subterfuge there to get out of doing it."

- 2nd run: (Coughs as G builds up. Comments on task roll axis ambiguity.)

- 3rd run: (Clears throat during the run.) "I think to the right I'm just about evenly divided between resting on my elbow or forearm and the shoulder strap. To the left, its almost entirely the strap."

SAME SUBJECT, WITHOUT PADS ±2 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: "I think I've got just about one more axis than I can keep track of. I was just about oblivious to the last 10 seconds, or so, what the pitch ladder was doing. Small perturbations are okay but once they get large, once I get one that's very far out off of what I have in mind ... the target ... I've got to start dropping them off. I think I'm just about saturated. Up to small perturbations, keeping the target within 10, 15 degrees of center. The bank attitude is the main thing for me."

- 2nd run: "I don't think I've looked at the airspeed scale in the last 3, 4 minutes. I couldn't tell you within a 100 knots where it was. ("It's a pretty busy job.") "Yeah, I'd say that on any weapon system that I'm familar with I'd try to organize things a little better so that I wouldn't have quite this much to do. There are just a few more monitoring tasks than I'm comfortable with. I usually have one or two, at the most three parameters that I try to keep control of. I'm many more times aware of the jerking around when I make rudder inputs than I am of the accelerations."

- 3rd run: No comments.

SUBJECT 80015, WITH PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run: "Able to keep my head nicely in the center, there ... but I'm using my neck muscles. I'm basically leaning on the restraint system. Once you (coughs) ... sort of leaning on the pad it felt very comfortable."

- 2nd run: "The same kind of comments ... I'm just laying on the strap there. After you do it a couple of times you get used to this.

- 3rd run: No comments.

SAME SUBJECT, WITH PADS, —2 GY SUSTAINED, OPEN LOOP

(Subject notes that the correct direction to push the rudder is hard to learn.) "I feel as if I keep wanting to bring it back to the nose." (Coughs.)

- 1st run: "... the right for some reason seem a lot harder. It may be because I'm looser in the straps than I was with the left side. Much more difficult task for me than when we had 2 G right. Lower part of the pad is digging into my arm. It seemed like to the left it was easier to just lay there and track. To the right, I start getting occupied with other problems besides."

- 2nd run: "I'm able to keep it inside the circle (indicates that he was not having any problem keeping his point of regard within the HUD FOV). There is pain on the right. My right foot is starting to slip off the rudder pedals a little bit. It might be wise to put some kind of a guard to keep your foot from slipping off, and I think the F-16 has a cavity there to protect you."

- 3rd run: (Subject was questioned by attending Flight Surgeon about the pain. Responded that it was from the pad. In the next run, he indicated that the pain begain between -1 and -2 Gy, increasing up to the maximum 2 Gy level.) "I am using the leg brace a little to help keep my foot on the rudder." (Presumably, here, the subject is referring to the high sides of the seat which was being used.)

  (Note: Upon postrun medical examination, this subject exhibited marked strap bruises from the shoulder harness and had petechiae in both axillae.)

SAME SUBJECT, WITH PADS, ±2 GY FULL DYNAMIC, OPEN LOOP

- 1st run: "That's a different story altogether. As far as keeping your body position, it doesn't feel near as bad (as in sustained G)."

- 2nd and 3rd runs: no germane comments.

SUBJECT 80015, WITHOUT PADS, +2 GY SUSTAINED, OPEN LOOP

- 1st run: "Yeah, its a lot more work without the restraints, I'll tell you. Okay ... it was very difficult to keep my head up, there ... I could see everything (presumably he means the HUD) ... really need something to lean on. I think the canopy bow in the real airplane, or the side of the airplane would be good. It's a real problem to keep your head back up there. I don't have any comments on the weight of the helmet. It doesn't seem to be a problem to me. Really is awkward ... I'm sliding more in the seat than I thought I would, and I had my restraints on about as tight as would be normal and allow me a little bit of motion."

- 2nd run: "Yeah, I'm bracing myself on the rudder a little (coughs). Boy, I'm really having to work at that. I'm sliding over to the side of the seat. Pretty hard for me to get my head back up to the center of the HUD FOV."

- 3rd run: "That is really hard work and I'm not having much effect on the roll ... I'd like a little longer time to rest ... when I get out there, and trying to work the roll and the pitch is very difficult, and the rudders ... I'm concentrating mainly on the rudders. Initially, once I get started, I'm able to keep my head up there; but as it goes on, its coming down. I suppose that's the weight of the helmet again, forcing the head down. (What the pilot means by "down" is that his head is being forced in the direction of the inertial force. Also note that this pilot earlier said he didn't consider the helmet weight a problem.) And I feel, frankly, that it's kind of hard to breathe when I'm over there and I don't know why. I didn't feel that this morning (with the shoulder pads) but I'm over on my side and I feel like I have to work harder to breathe than normal. I definitely, for this kind of maneuver, prefer the restraint system."

SAME SUBJECT, WITHOUT PADS, −2 GY SUSTAINED, OPEN LOOP

- 1st run: "As far as the breathing goes, this is a lot easier on this side, I'm having the same sort of trouble controlling the parameters but it feels a lot easier over here. The harness is digging into my collar, my shoulder bone. ("Do you think it's easier because you have the elbow and wrist support to lean on?") "I think that's probably a good call. Again, I slid over in the seat and that's kind of uncomfortable."

- 2nd run: "This time I can feel my leg helping quite a bit. Getting confused on the roll and I find my head ... not quite able to get it back to the center the way I'd like it to ... drifting off to the right. I can feel the armrest pressure on my forearm now so I think that subconsciously I'm using that quite a bit."

- 3rd run: "I'm definitely supporting myself with the rudder pedals. I can feel myself supporting on the wrist. What I am doing on that ... my arm is out of the little groove, resting on the top ... a little bit of a pain there ... my arm actually slipped out of the rest. There's a real tendency to hold onto the rudders."

SAME SUBJECT, WITHOUT PADS, ±2 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: "It's all I can do to work the rudders ... have absolutely no control of the altitude ... its very uncomfortable. (Coughs.) I imagine in a tight tracking situation if you were doing that a lot that would be very difficult in a real airplane. I think that was the hardest maneuver to control the roll attitude in for me ... working the rudders is my ... main concern."

- 2nd run: "What I'm sure I'm doing is pushing against myself because I'm bracing on the rudder pedals, opposite rudder. So I'm pushing harder than I have to. I didn't see a tendency for my feet to slip off the rudder pedals the way I did this morning (with shoulder pads)."

SUBJECT 800005, NO HELMET, RIGHT SHOULDER PAD ONLY, +2 GY SUSTAINED, OPEN LOOP

- "The same roll thing is there. I'm putting the wrong yaw command in. Significant decrease in the problem with my head. A world of difference on my neck." (Video tape ends here).

NOTE: Subject 800004 was run on the day following the runs for the other pilots. At the request of the other pilots, we agreed to run this subject at a maximum of ±1.5 Gz using a task with a lower bandwidth forcing function. This change was made in order to attempt to discover whether or not there is a significant difference between pilot reactions at 1.5 and 2 Gy. The frequency content of the tracking task was lowered because the pilots unanimously felt that it was unrealistically difficult.

SUBJECT 800004, WITH PADS, +1.5 GY SUSTAINED, OPEN LOOP

- 1st run: ("How does that feel?") "It felt alright ... I felt I had good support with the shoulder pads. The only distressing thing to me was the lack of correlation between the lateral acceleration and the roll axis. I was anxious to keep putting a roll input into the thing which is probably normal. I had no trouble controlling the stick very precisely but it was the disorientation feature of having the lateral acceleration and no cue of that on the HUD. Mild pressure on my left arm." ("Any vision or breathing problems?") "No."

- 2nd run: (As G comes on) "Like right here I feel I should have some roll input in the thing ... it's hard to divorce the tactile sensation from the visual." ("Would they ordinarily uncouple the roll axis in the AFTI when you're tracking with rudders?") "Yes, We can have direct (unintelligible) on the thing. We can do that for a straight side force but it would be for the duration of a firing pass. The objective is to point the weapon line of the airplane so if you did that you would want to be transitioning into a normal Nz soon (here he makes a roll-in motion with left hand) to track him. Would be just the firing solution that would have you there.

- 3rd run: "My principal bracing point is my shoulder and then my left knee ... I'm bracing a fair amount there. Both my left and right hands are really quite free. I'm not hanging onto anything there, and I'm not using the armrest to restrain myself." ("How about the HUD Line of sight? Do you have any problem with that?") "No, it's real easy."

SAME SUBJECT, WITH PADS, —1.5 GY SUSTAINED, OPEN LOOP

- 1st run: "I'm more uncomfortable with the lean on the right keeping my hand free. A little more uncomfortable on the right."

- 2nd run: "A little better, I guess. Got some pressure on my right wrist. Notice that I'm using that wrist support. It does help me a great deal. An interesting point; I don't fly with the wrist rest, normally."

- 3rd run: (Subject stows wrist rest and asks for a -Gy run.)

- 4th run: (No wrist rest. Clears throat.) "I guess I didn't notice too much difference. I think my hand was actually more comfortable without it in there. I noticed on the first three runs that I was keeping a fair amount of pressure on the wrist rest to the outside and pressure coming on my arm (indicates an area just behind and outside of his right wrist) so I don't think it hindered me any but I didn't have any trouble keeping a free arm or a free hand to track on the 4th run without it. "The neck fatigue I do notice but it's not terribly distracting. I think if you did this all day, you'd have a tired neck, I suppose."

SAME SUBJECT, WITH PADS, ±1.5 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: (Without wrist rest.) "That's a real thriller. The dynamics of the cab don't match the dynamics of the target very well." ("Do you feel its slower or faster?") "Slower, the cab is, which will actually help my tracking."

- 2nd run: "I got a little out of sync. Going from plus to minus is a little distressing in that it gets a little hard to read the pitch scales right at the transition." ("Because your head is moving around?") "No, just the change in acceleration kind of makes you blink a little. Is that a coriolis problem?" ("It could be. You might be getting a little nystagmus because of the coriolis input. Eyeball jitter.") "Yeah, it feels as if it's about to jitter. It doesn't last more than a second or so but it's a little annoying."

- 3rd run: (Subject notes awareness of changeover from minus to plus Gy as the cab vectors.) "Roll parameter is the one that wanders the most, transitioning back and forth." ("Yes. That could be a combination of just a straight inertial effect on the stick, it's polar moment of inertia and acceleration, and there's probably some component of the acceleration on your hand and forearm, too.") "Yeah, I feel like it's mostly my input."

NOTE: There is more material on this issue later on in the narrative. What is seen here is probably a pilot's instinctive reaction to the motion artifacts inherent in centrifugation.

- 4th run: "Yes, that was my input there. I really wanted it to roll. There's no need to do it, but I want to put in anyway. The restraint is perfectly adequate. I can wiggle my fingers on the stick, not holding onto it."

(Subject requests rerun of —1.5 Gy sustained open loop conditions)

- 4th run: "Yeah, I see what it is. My whole body is kind of shifted over there and the arm restraint can take the movement but the wrist restraint can't (he has previously unstowed the wrist restraint) so I'm getting some force on it."

  "You can see that when you look at the restraint. The wrist restraint, as deep as it is, that whereas the arm restraint, my arm can slide a little bit to accommodate the shift in my body, which isn't much, maybe an inch or so, whereas the wrist restraint can't accommodate that. I'm going to take the wrist restraint out now." (Subject requests an additional run.)

- 5th run: "See, I don't lose any precision on that. You see, I've got a very open hand here... its easy and light in both directions. But it really is more comfortable (without the wrist restraint). I'm going to make some pitch inputs. Those really are easy, too. (Subject requests an additional run.)

- 4th run: (+1.5 Gy): "OK. A little harder for gross corrections because you see my arm has come off of the arm (elbow) restraint a little bit which gives me a little freer arm on the stick which does make it a little tougher to be precise on the stick but that's probably why I enjoyed the wrist rest a little more on the +Ay. I think, all things considered, a shallower wrist rest is probably the solution."

SUBJECT 800004, WITHOUT PADS, +1.5 GY SUSTAINED, OPEN LOOP

- 1st run: (Extensive discussion between subject and investigator concerning adverse roll inputs which made it clear that these are an instinctive reaction to the complex acceleration vectors. they are not necessarily caused by the presence of Gy alone.)

- 2nd run: (States HUD FOV was not much trouble.) "I'll do the 3rd run here and then take the wrist rest off."

- 3rd run: "There was definitely more effort to maintain center of the FOV. You can see that, with my shoulder down, I've got to hold my neck up."

- 4th run, no pads, no wrist rest +1.5 Gy: "I noticed that my arm was riding up on the inside of the armrest on that also, but it didn't bother me and I'm not sure whether it was because I had the wrist rest or not. We'll see here." "Okay, the wrist rest I think is actually a help on the +Gy even though it bothered me on the minus. You can see my arm is almost off of... it is off the rest now... I'm not paying too much attention to the score ... but I've got my arm actually away from the rest there. Line of sight was okay on it (coughs). My torso is shifted enough that I'm not working on the rest, working just the edge of it here. (Burps.) I'm going to bring my shoulder harness down now and we'll do one more Gy plus. Okay, that's about as tight as I would normally wear it in combat."

- 5th +Gy run: "Okay, the tighter straps do help. I've got a little better arm position on the right. With large corrections and forces I've really got to bring my arm away from the rest to make them. The maintenance of the line of sight is not too much trouble. That's going to be a little tiring after awhile, I'm sure." "So, the biggest annoyance was without tucking an arm in down here (indicates an area by his side with his left elbow) to brace my torso. I end up with kind of a free arm on the right so the wrist rest really was to help because it did give me something near the stick when my arm would come away this way (indicates by moving, rotating, right elbow in toward his body) you see. So the wrist rest is really an advantage there.

SAME SUBJECT, NO PADS, WRIST REST IN PLACE, −1.5 GY SUSTAINED, OPEN LOOP

- 1st run: (Subject stops breathing as Gy comes on. Resumes after about 5 seconds.) "Okay, the same interference problem with the wrist that I had this morning. That really does drive my roll inputs when the lateral G comes on with the back of my arm coming off to the outside of the armrest (coughs) and the principal point of force for support becoming my wrist right in this area (again indicates outside of wrist), and it is driving an input into the stick in roll."

NOTE: This is apparently a pure inertia effect which has nothing to do with anything except the forces developed by lateral G.

"It's pretty annoying and I did find this morning that it was better without the wrist rest and the **wrist rest is stowed** for the next run.

- 2nd run: "I see another problem. I didn't notice it quite so much in the +Gy is that for me to monitor the HUD FOV I've got to, because of my torso being over, rather than holding everything up ..."

- 3rd run: "Ooops, wouldn't want to miss this for the world. I end up turning my head more. So the angle between my head, my eyes, and the visual scene, that angle is much, much greater than with the restraints and that complicates the tracking task because up-and-right don't have quite the correspondence, so when I'm like that for example (coughs) I would rather have the wings like this (holds up both hands indicating a tilted line) because just visually in that plane it's more comfortable for me so I have to keep sort of flying instruments sort of thing and forcing myself to ignore that tactile cue of which way is up. Another point, the task without the wrist rest (and without the shoulder pads) really is better. So we have a problem if we can't have shoulder restraints." ("Are you noticing any cumulative neck fatigue?") "Oh (rolls head around), I guess I do. It's work on your neck. That doesn't bother me too much. I guess more than anything thinking that this (the stress) is a transitory affair and if I had to fly anywhere for a long time at ±2 Gy I would just lay my head down. Yeah, I feel it. My neck doesn't hurt, or anything."

SAME SUBJECT, WITHOUT PADS, WRIST REST IN PLACE, ±1.5 GY FULL DYNAMIC, CLOSED LOOP

- 1st run: (Subject's oxygen mask pops loose.) "Okay, I got a little behind there. About the only comment was the (wrist) rest did bother me so **I've got it out** for the 2nd run."

- 2nd run: "Well, a little better. I felt as if I had much more precision without the wrist rest. The rapid transitions from side to side are not a bother physically, just a touch disorienting with the large swings. Probably more coriolis than anything."

- 3rd run: "The roll inputs that I make in here are as much a function of visual cues as anything. I'm not dragging the stick with me at all. I'm actually putting the input in because I have this cue that to stay upright, in the roll, I need to do that."

- 4th run: "when I've got +Gy, the wrist rest is kind of nice because I can kind of hook it and it helps me maintain upright a little bit and still make small adjustments with my hand. When I had the shoulder restraints on for gross maneuvers, even +Gy fair amount of force on the wrist which complicates the maneuver. But in either case with —Gy it really does hinder the job and particularly during the dynamic thing, which I think is a more reasonable thing in terms of the Ay, where there just isn't that much time spent in either direction, the maneuvers are a little more precise without it. The flatter (production) table sort of rest might help.

- 5th run: "I guess under these dynamic conditions the lack of the shoulder restraint is far less annoying than in the sustained, for the obvious reasons; and once you get the hang of that onset it's pretty comfortable, really."

- 6th run: "Little bit of a dynamic lag in the cab itself, but then we don't know what the airplane is going to have for lag either for the Ay onset, you know."

NOTE: Subsequently, this subject was advised of the differences between his exposures and those of the pilots of the previous day. He was then exposed to the following runs.

SAME SUBJECT, NO PADS, +2 GY SUSTAINED, OPEN LOOP

- "Well, that's about how I remembered it before ... really disagreeable. More torso movement obviously, a little more work to keep my head centered. No increase in the problem on the stick at all. My left shoulder was a little further left and changed the angle on the throttle a touch, not enough to make any difference. The tracking task is really deficient next to what we flew today — the damping is really far more realistic for a tracking task on what we flew earlier today. Bulk of the weight was taken on the strap and left elbow.

SAME SUBJECT, NO PADS, −2 GY SUSTAINED, OPEN LOOP

- "Basically, the same thing here. (Coughs.) On the −2 Gy again, basically in the strap with some weight on my arm in the armrest on the outside against the (elbow) bone. Was able to keep a free hand on the stick and it felt a little easier in control but a little more work to keep the weight off the arm than in +Gy. HUD FOV was similar to the 1.5 G runs."

SAME SUBJECT, NO PADS ±2 GY FULL DYNAMIC, CLOSED LOOP

- (Lost his mask again.) "The dynamics of the target with the cab lag makes that an annoying exercise."

- 2nd run: (Comments again on lag, loses task.) "It's amazing how your perception of the difficulty changes with that task."

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